AD-A119 559 ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT--ETC F/G 1/3
ADVANCED AVIONICS AND THE MILITARY AIRCRAFT MAN/MACHINE INTERFA--ETC(U)
JUL 82
UNCLASSIFIED AGARD-CP-329 NL

1 OF 4
ADA
119559

AGARD-CP-329

AGARD-CP-329

AD A119559

DTIC FILE COPY

AGARD

ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

7 RUE ANCELLE 92200 NEUILLY SUR SEINE FRANCE

AGARD CONFERENCE PROCEEDINGS No. 329

Advanced Avionics and the Military Aircraft Man/Machine Interface

DTIC
ELECTE
SEP 24 1982
S D
A

NORTH ATLANTIC TREATY ORGANIZATION

DISTRIBUTION AND AVAILABILITY
ON BACK COVER

82 09 24 125

AGARD-CP-329

NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARD Conference Proceedings No.329

ADVANCED AVIONICS AND THE MILITARY AIRCRAFT MAN/MACHINE INTERFACE

Copies of papers and discussions presented at the Meeting of the Avionics Panel
held in Blackpool, UK, 26–29 April, 1982.

THE MISSION OF AGARD

The mission of AGARD is to bring together the leading personalities of the NATO nations in the fields of science and technology relating to aerospace for the following purposes:

- Exchanging of scientific and technical information;
- Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;
- Improving the co-operation among member nations in aerospace research and development;
- Providing scientific and technical advice and assistance to the North Atlantic Military Committee in the field of aerospace research and development;
- Rendering scientific and technical assistance, as requested, to other NATO bodies and to member nations in connection with research and development problems in the aerospace field;
- Providing assistance to member nations for the purpose of increasing their scientific and technical potential;
- Recommending effective ways for the member nations to use their research and development capabilities for the common benefit of the NATO community.

The highest authority within AGARD is the National Delegates Board consisting of officially appointed senior representatives from each member nation. The mission of AGARD is carried out through the Panels which are composed of experts appointed by the National Delegates, the Consultant and Exchange Programme and the Aerospace Applications Studies Programme. The results of AGARD work are reported to the member nations and the NATO Authorities through the AGARD series of publications of which this is one.

Participation in AGARD activities is by invitation only and is normally limited to citizens of the NATO nations.

The content of this publication has been reproduced
directly from material supplied by AGARD or the authors.

Published July 1982

ISBN 92-835-0315-4

Printed by Technical Editing and Reproduction Ltd
5–11 Mortimer Street, London, W1N 7RH

THEME

Avionics equipment and systems are in a period of very rapid change. Within the next few years their incorporation into new military aircraft designs should increase the aircraft's combat capability and efficiency while reducing aircrew workload. This improved capability will be increasingly required, particularly for single-seat aircraft, because of the demands created by the mission scenarios now being forecast. To obtain the maximum benefit from advanced avionics requires that the most careful consideration be given to the interface between avionics systems and aircrew.

The aim of this Avionics Symposium was to explore in depth several topics of particular importance in interfacing the aircrew of modern military aircraft with the advanced avionics equipment and systems which are now becoming available. These subjects comprised:

I. The provision and use of new advanced displays in aircraft, including multicolour displays, displays incorporating new optical techniques, and more reliable display systems.

II. The use of voice input and output systems for man/machine interface, including speech synthesis.

III. Management of complex avionics systems.

IV. Tactile controls and their use.

PROGRAM AND MEETING OFFICIALS

TECHNICAL PROGRAM COMMITTEE

Chairman:	Dr G.H.Hunt, UK
Members:	Prof. Ir. D.Bosman, NE Mr Y.Brault, FR Prof. W.Hollister, US Mr V.Schmit, UK Mr T.Sueta, US

HOST NATION COORDINATOR

Mr R.D.Hillary
Ministry of Defence, P.E.
Room 2115, Main Bldg., Whitehall
London SW1A 2HB
United Kingdom

AVIONICS PANEL

Chairman:	Mr Y.Brault Thomson CSF Division Equipements Avioniques et Spatiaux 178 Bld Gabriel Péri 92240 Malakoff, FR	Deputy Chairman:	Dr F.Diamond Chief Scientist, RADC/CA Rome Air Development Center Griffiss AFB., N.Y.13440

PANEL EXECUTIVE

Lt. Col. J.B.Catiller
AGARD/NATO
7, rue Ancelle
92200 Neuilly-sur-Seine
France

CONTENTS

SESSION 1 – INTRODUCTORY PAPERS

SESSION 2 – COLOUR DISPLAY SYSTEMS

SESSION 3 – VOICE INPUT AND OUTPUT SYSTEMS

SESSION 4 – AIRCREW INTERACTION WITH COMPLEX SYSTEMS

SESSION 5 – DISPLAY TECHNOLOGY

TECHNICAL EVALUATION REPORT

by

R A Chorley
Head of Advanced Displays Studies
Smiths Industries Aerospace and Defence Systems Company
Bishops Cleeve, Cheltenham, Glos GL52 4SF, England

1. INTRODUCTION

The 43rd Symposium of the Avionics Panel was held at the Imperial Hotel, Blackpool, England, 26-29 April, 1982. The programme chairman for the meeting was Dr. G H Hunt, of the Royal Aircraft Establishment, Farnborough, England. The full text of the papers presented at the meeting is published in the Conference Proceedings CP 329.

2. THEME AND OBJECTIVES

The increasingly rapid rate of development in technology in general, and electronics and associated areas in particular, has had and continues to have a profound effect on avionic equipment and systems. It is generally accepted that proper application of the new technology should lead to the development of military aircraft capable of much higher combat capability and effectiveness than their predecessors, and should enable their crew members to operate with high efficiency and at reduced levels of workload. In view of the current trend towards the use of single seat aircraft for a wide variety of missions, and considering the operational environment in which these missions are likely to be carried out, it is clearly essential that these potential advantages of properly applied technology should be realised to the fullest possible extent.

In particular, the interface between the pilot and his aircraft and its systems must be made more efficient. It is pointless to build aircraft with superb performance, and to man them with highly intelligent, highly trained pilots, if restrictions on the rate of flow of information from the machine to the man, and on the rate at which the man can make inputs to the machine, are the limiting factors in the performance of the overall man/machine systems. In parallel with improvements in the man/machine interface, attention must be given to improving reliability and maintainability of equipment.

The objectives of the symposium were to study in depth the impact of modern technology on the pilot/aircraft interface, with particular reference to:

(i) new display techniques, including multicolour electro-optic displays, displays incorporating new optical techniques, and means of improving display reliability;

(ii) the use of speech recognition and speech synthesis systems for data transmission from pilot to aircraft and vice versa;

(iii) the overall management of complex avionic systems;

(iv) the use of tactile controls.

Coverage of these topics was organised in six sessions:

I	Introductory papers
II	Colour display systems
III	Voice input and output systems
IV	Aircrew interaction with complex systems
V	Display technology
VI	*Round table discussion*

3. TECHNICAL EVALUATION

3.1 Opening Speeches

The scene for the whole symposium was set during the opening speeches, in which attention was drawn to the rapid rate of evolution of avionic devices and systems, and to the consequent need for continuing study of the man/machine interface. The point was made that increasing automation in the cockpit necessitates more rather than less study of the part which the pilot has to play.

For newcomers to AGARD, the Panel Chairman's outline of the organisation and activities of the group formed a useful introduction to the meeting.

In his overview of the week's papers, the Programme Chairman summarised the change that has occurred in aircraft systems in the past forty years. In World War 2, aircraft had separate equipments and systems, and could be said to have a low level of intelligence. Modern aircraft have intelligent systems which can communicate with each other, but although machine-to-machine communications are now easy, as those from man-to-man have always been, man-to-machine communication still poses problems. Attention is being given to the use of speech as a means of communication between man and machines; this may be a valuable addition to the traditional forms of interface, but in the interests of minimizing training problems and probabilities of errors, speech between man and machine should be modelled on that normally used between men. In all interface studies consideration must be given to data rate requirements, the balance between multi-function and dedicated controls, and the all-important capability for modification. In conclusion, the general point was made that in many cases, the technologies being used may have applications outside aircraft.

3.2 Session I - Introductory Papers

Two of the three papers in this session reviewed the position of the pilot in the complex environment in which he works. This subject has been treated many times before, but because of the changes and potential changes in the technological environment, new aspects of the problem are continually emerging. Advances in the micro-electronics industry place at the disposal of the avionics designer the means for making ever more powerful (and therefore probably more complex) systems, and it is essential that the capability of the pilot for comprehending and operating these systems is understood. Again, the fundamental differences between the capabilities of the man and the machine in the overall system must be stressed - both man and machine can be considered as complex systems with great, but not infinite, intelligence; the control performance of the machine is fast and repeatable, that of the man is slow and variable; both are liable to malfunction under stress; the man's decision-making capability is slow-acting but flexible, the machine's response is rapid but limited by the extent of the program it can hold. Of the developments related to communication between the pilot and the aircraft, speech systems are currently arousing the most interest. Speech comes naturally to man, keyboard operation does not, but there is evidence that speech activity may impose as much load on the pilot as keyboard activity, and this requires further investigation. However, since in a given situation a speech command is likely to be transmitted in a shorter time than a keyboard command, attention will be diverted from other tasks, such as flight control, for a shorter period of time.

Much useful information about pilot performance has emerged from studies of incidents and accidents. These tend to confirm the sequential nature of the processing of data by the human being, and also the variation in output which can be achieved under conditions of varying workload: increase in the load can be met by increase in performance, but only up to some limiting level at which the system saturates and the man ceases to function rationally. Over-simplification and over-automation of the pilot's task can lead to boredom and resentment, and this should be taken into account in overall system studies.

A further point emerging from the studies is that under conditions of stress, pilots exhibit a recognisable load-shedding mechanism: above a certain level of workload communication ceases, and at still higher levels attention to navigation wanes, all effort being concentrated on the basic flying task. As the workload decreases, the whereabouts of the aircraft becomes of concern, and finally, communication recommences.

The third paper in the session was a review of the papers and discussions at the 32nd Guidance and Control Panel Symposium, held a year previously, which covered an area somewhat similar to that of the present meeting, though from a systems rather than a technological view point. This link between two meetings with similar themes was valuable, and the same arrangement should be recommended for the programme of future meetings when related subjects are due for discussion.

3.3 Session II - Colour Display Systems

Although much work on colour displays has been done in recent years, and many papers presented on the subject, it was clear from the five contributions to this session that ideas on the proper use of colour in airborne displays are still very flexible, and much work remains to be done.

An excellent introduction was given in a paper which combined a description of the psycho-physiological effects of colour with an outline of the problems involved in defining and specifying colour. Many non-specialists in the audience found this particularly valuable as background to the succeeding papers.

The two principal uses of colour in displays are for coding information, and for providing enhanced contrast between different component parts. Care must be taken in using colour, because of the effects on the observer's sensation caused by ambient illumination, previous exposure to colour inputs, background colours and other factors. Although detailed studies of colour vision have enabled many of these effects to be explained in physiological terms, it is not always clear where the thresholds lie, and how many of the known effects are relevant to practical displays.

One of the well-known effects which can be demonstrated in colour displays is chromo-stereopsis, in which an area of one colour (say red) appears to be in a different plane from another background colour (say blue). It was suggested that this effect might be applied usefully to airborne displays, but this is clearly another area in which more work must be done. Potential problems in the use of colour were listed, including fatigue due to the need for varying accommodation according to the colour of the part of the display being fixated, variation of acuity with colour, and the subjective change in colour over the wide range of luminance required to cover day and night flight.

Attempts have been made to quantify the effect of combining chrominance contrast with luminance contrast, as a means of measuring the discriminability of adjacent components of colour displays, and the Index of Discrimination defined by Galves and Brun has been proposed as one method of achieving this.

The application of computer generated imagery (CGI) technology to airborne displays gives rise to various interesting possibilities. One example quoted was a synthetic view of the outside world, with the apparent viewing direction of the display capable of being moved anywhere between directly forward and directly downward. Various means of incorporating threat information in such a display were described. It is also possible to use CGI techniques to produce detailed weapons and systems displays, which could give sequential pictorial representations of emergency situations and corrective actions. It was thought likely that best results would be produced by a combination of pictorial and text information, and it was reported that experiments in this area are continuing.

The result of one investigation was reported, which seemed to be in opposition to the general view that the use of colour appears to enhance virtually any display. This was a report of an experimental assessment of the use of colour in Lofargram displays, in which the spectral content of a signal is displayed in terms of intensity modulated dots representing particular frequencies, at defined time intervals. Under the experimental conditions used, no improvement in performance could be measured with any of the large number of colours used.

The session concluded with a description of a complex display, the successful operation of which in simulator trials could probably be attributed to the use of colour. This was a display designed to enable pilots to fly complex approach trajectories based on MLS guidance, and it incorporated both forward-looking and downward-looking pictorial elements, as well as a number of scales. Although no comparison was carried out between the display used, which had four colours, and a similar one in monochrome, the view was expressed in discussion that the successful performance by all the pilots involved in the trial was at least partially due to the use of colour, since work done some years ago with a similar display on a monochrome CRT indicated confusion between different elements of the display.

3.4 Session III - Voice Input & Output Systems

It was apparent from informal conversation after this session that a number of members of the audience who had no prior knowledge of voice systems would have benefitted from an introduction to the basic principles involved, similar to that on colour definition and measurement given at the beginning of the preceding session. Much of the necessary information was in fact included in the text of the printed papers, but unfortunately was not included in the verbal presentations.

The overall impression given by the papers in this session was that whereas in the case of colour displays more is known about the technology of the subject than about the best way of applying it, in the case of speech systems there is still a great deal to be learned about both technology and application.

There was fairly general agreement that a voice input system which is speaker-independent (that is, does not have to be trained by the particular operator who is going to use it) and can recognise connected speech with 100% accuracy under all cockpit conditions, will find ready application in avionic systems. The majority of currently available systems, however, are speaker-dependent and only capable of recognising isolated words or short groups of words, and that with an accuracy which is questionable under real operating conditions. Despite these limitations, it was clear from the papers presented and from the discussions that there is much interest in this area.

The first paper of the session provided a comprehensive review of the current state of development of speech systems, including reference to various NATO activities, and gave an indication of possible areas where the emergent technology might be applied. This paper includes a lengthy list of references, and will form an excellent introduction for newcomers to the subject of speech systems for airborne use. Subsequent papers covered the physiology and psychology of speech processes in the human being, as well as the technology of speech recognition and synthesis equipment. Several speakers emphasized the changes in the characteristics of speech which occur under stress, acceleration forces, and other environmental aspects of the normal military operation, and pointed out that speech recognition systems must be able to accommodate these changes. Whilst extraneous inputs to the microphone, from breathing, oxygen control valve clicks and other sources, are commonly taken as the primary effects of background noise, it was pointed out that noise at the pilot's headphones also has an effect on the speech signal, since it causes him to tend to shout and to raise the pitch of his utterances.

One of the principal advantages of direct voice input systems should be the ease with which pilots will be able to use them; since speech is a natural process, training problems should be minimized. The somewhat formalised communication procedures already learned for radio telephony will assist in the use of speech recognition equipment. It is important to remember that in a real system the pilot will quickly adapt his speech to the requirements of the system, and for this reason, tests of systems carried out by using recordings of pilots' voices (often used in the study of the effects of unfavourable environments) are likely to give misleading results. The use of tapes may also mask other practical problems, such as the effect on the system of involuntary utterances and of lapses from the system's learned vocabulary when the pilot is under stress.

Considerable attention was given to the potential effects of speech systems on pilots' information handling capacity. It was suggested that, whilst the use of multi-modal inputs (for example, visual and audio) may have advantages over mono-modal systems from the point of view of the rapidity of sampling of the data sources which can be carried out by the operator, his central processing system works serially. This means that incoming data requiring a high level of processing can only be dealt with from one source at a time. A parallel was drawn with the use of car radios - when following a well-known road, the driver can listen to a news bulletin and can absorb its information content, but when faced with conflicting traffic at a busy junction, will continue to hear the output from the radio, but will cease to process the data, which is therefore lost.

Whilst one of the principal advantages foreseen for the use of speech systems is their theoretical capability for providing information transfer without the use of the pilot's hands or eyes, it was pointed out that in practice it is necessary to have some form of switch to activate the direct voice input system, so that it only operates on speech intended for it. There is also need for feedback to confirm that the message has been recognised correctly; whilst this feedback could be provided by synthesised speech, most speakers felt that a visual display is likely to be preferable. Having confirmed that the message has been recognised correctly, a further switching action is necessary to tell the system to act on the information; it was suggested that this could be effected by another speech command such as "enter". The need for proper integration of a direct voice input system with reversionary controls was stressed by several speakers.

One of the problems in discussing the performance of speech systems is that there is at present no agreed way of defining and specifying their performance. Error rate is sometimes taken as being the percentage of misrecognitions, and at other times the percentage of rejections and misrecognitions together; there is no agreement on what level of performance is necessary for a real-life system.

Recognition of the need to minimize the effect of the harsh cockpit environment on speech systems has led to the investigation of means of applying noise reduction techniques to speech signals, and one paper described a programme of work on speech enhancement which started in the context of ground communication systems, and is now being extended to cover cockpit applications as well.

Most of the interest in speech synthesis appeared from the references in the symposium to lie in the area of voice warning systems. In general, speech synthesis systems have reached a higher stage of development than recognition systems, as is indicated by the introduction of this type of equipment already in commercial applications such as automobiles. There is still much work to be done on the application of the technology to airborne systems, and doubts were still being expressed at this meeting about the advisability of introducing voice warning systems in aircraft, since some of the experimental work which was described showed no reduction in the reaction time to the warning when speech was added to existing audio and visual warnings.

In support of voice warnings, it was reported that there is evidence that recall from short term memory is better for an auditory than for a visual input. Against this however, is evidence that the auditory channel is easily overloaded.

Overall, it was clear that many investigations into voice warning systems are being carried out, and that most experimenters feel that a system limited to a small number of top-priority warnings (say, four or five) may offer considerable benefits.

3.5 Session IV - Aircrew Interaction with Complex Systems

This session dealt primarily with systems and controls which are already available, and in some cases due to go into service in the near future, rather than the less well defined concepts of speech systems discussed in the previous session. At least one speaker expressed the view that practical speech input systems for military aircraft will not be available for a long time, and stated that the control concepts he was proposing would require appreciable modification to incorporate speech input.

Each of the papers pursued particular aspects of the effect that recently available components (such as microprocessors, CRT displays, and push-buttons with integral, changeable legends) together with comprehensive digital data transmission systems (for example, MIL STD 1553B or DEF STD 00-18) can have on reducing the number of separate controls needed in the cockpit.

The first paper of the session dealt specifically with the problem of the radio controllers in a small helicopter, and proposed a single unit providing all the necessary controls in a panel area only 35% of that of the separate controllers. Such a unit can be designed to operate in ambients varying from full sunlight to night conditions involving the use of night vision goggles. Problems may be encountered with such a multimode control unit when the pilot is wearing NBC or other glove assemblies, and this consideration places a limit on how far the miniaturisation of such controllers can be carried.

The high level of current interest in push-button and keyboard controls led to the production of another paper presented in this session which provides a survey of existing standards and summarises much human factors information not covered by the provisions of these standards. The paper also describes the results of experiments designed to investigate the problems of operating keyboards when wearing gloves. Together with its extensive list of references, this paper provides a very comprehensive and useful source of data on push-buttons.

The flexibility of a control and display system based on a digital data distribution system gives rise to a number of problems discussed in other papers in this session. Such a system does not obviate the need for scanning between different displays, for both cross-referencing and cross-monitoring purposes, and more extreme scanning may be required in reversionary modes of operation following equipment failure. An experimental investigation was reported, which indicates that, because of adverse effects on overall performance, cross-referencing and cross-monitoring requirements should be minimized, and necessary scan angles should be kept as small as possible; also, primary and secondary flight information sources should have similar scan patterns and coding.

The need in a modern military cockpit for the pilot to spend the maximum possible time looking outside, and to minimize the requirement for him to stretch forward to reach controls, particularly under high g conditions, gives rise to the concept of "head-up, hands-back" control, described in another paper. Such a system can be implemented using a digital data bus and intelligent sub-system controllers, and it can be designed with panels relating to single subsystems, arranged by order of priority of control function and frequency of use.

The point was made by several speakers that in any system including multi-function controls, careful study of the control tasks must be carried out in order to minimize the number of steps which must be taken to achieve the desired result. In many cases better results can be obtained by basing the logic on the probability of particular functions being required in particular flight phases, rather than basing it on the steps involved in using conventional dedicated controls.

3.6 Session V - Display Technology

This final session of presented papers was introduced by a description of an ergonomic study of the images produced by flat panel matrix displays and their relationship with the human visual system. These images are considerably different from those generated by CRTs (which have been researched extensively in the past) in that they are generated from discrete picture elements formed by the reticulation of the light emitting or modulating display surface, and the light emitted by (or reflected from) each element is approximately uniform in distribution. It is characteristic of displays of this type that they contain more unwanted high spatial frequency components than CRT displays. The results of the study indicate that a picture element density of approximately 50 per mm^2 is desirable for displays viewed at a distance of 70 cm, to provide a fully acceptable display usable over the whole range of ambient light experienced in a cockpit. The study also indicates the results of using a less-than-optimum display resolution.

Several programmes relating to specific display devices were described in other papers in this session. Among these was an account of the development of a cockpit lighting system capable of providing sufficient illumination for one crew member using natural vision, without dazzling another crew member using night vision goggles. A satisfactory result was obtained by a combination of optical means, involving the use of electroluminescent lighting and colour filters to keep the waveband of the instrument lighting as remote as possible from that accepted by the goggles, together with mechanical means consisting of directional filters. An environmental problem remains, in that currently available directional filter material will not withstand high temperatures; it is hoped that further developments in the material will solve this problem.

Another programme investigated a helmet mounted display system in which data generated on a remote CRT are transmitted to the helmet-mounted collimating optics by means of a coherent fibre optic bundle. The capability of a fibre optic bundle to provide sufficient resolution for typical head-up display symbology has been established, but it appears that one of the major drawbacks to this system which was found when similar experiments were tried somes years ago still exists; this is the problem of breakage of fibres in the bundle, which gives rise to black spots in the display.

The last of the papers on specific displays described the optical system of the F-18 combined map and CRT display. Reasons for the choice of components and configuration for this system were given in some detail, together with performance data. It was stated in discussion that it would be feasible, using available technology, to build a display system comprising a single multi-colour CRT providing a map display from a video signal generated by a television camera scanning a remote film projection system, and also providing symbology, but such a map display would in no way have the resolution and brightness which can be achieved by the use of optical projection.

Optical topics were pursued in two further papers which related to diffractive optical components and their use in wide-angle head-up display (HUD) systems. The first of these was another educational paper, of great value to the considerable number of people in the audience who had heard about (and in many cases talked about) diffractive, or holographic, HUDs without having any real knowledge of the fundamental optical principles involved. The paper gives a clear presentation of these principles, and explains the reasons for the high photometric efficiency which can be achieved in HUDs using diffractive optics, and also the wide fields of view they can be designed to have.

The second optical paper summarised the field of view properties of conventional HUDs and indicated the practical constraints which prevent the achievement of wide fields of view with these units. The development of projected-porthole (or pupil-forming) optical configurations has been shown to provide advantages both in increased field of view and in enabling much more of the display to be viewed with both eyes simultaneously. The implementation into practical display units of various optical systems of this type has been made feasible by the use of diffractive elements, and several different configurations were described. It was pointed out that these wide angle displays are at present larger, heavier and more costly than conventional HUDs, and their introduction into service must depend on a satisfactory trade-off between these factors and the improved operational capability they provide. This capability centres on the greater facility provided for off-axis target and way-point tracking, and for the use of raster displays of data derived from imaging sensors such as infra-red or low light television.

The remaining presentation in this session was concerned with overall systems architecture for future combat aircraft. The paper is based on the assumption that such an aircraft will need to have both air defence and ground attack capability (with all that this means in the way of sensors and equipment), that it will be single-seat, and that it will use a MIL STD 1553B dual multiplex data bus as the main data transmission system. The conclusion drawn from the study is that the traffic loading on the avionics bus constitutes a major problem; the problem could be reduced by assuming that a simpler system would meet the operational requirements, or that a data bus with a greater capacity than MIL STD 1553B was available. The adoption of a fully federated systems architecture, in which subsystems are each controlled by a processor which is the only interface with the avionics bus, helps to reduce bus traffic. It is also apparent that a large proportion of the total data on the bus is concerned with the display system, and it is suggested that a ruthless assessment of the amount of information that is really useful in a single-seat cockpit should be made.

3.7 Session VI - Round Table Discussion

It was apparent from the final session that of the topics discussed during the symposium, voice input and output systems had aroused the most interest, with colour displays lagging some way behind.

A recurring theme in the discussion on voice systems was the need to retain existing control devices as a reversionary mode of selection, and the problem of designing adequate compatibility between systems. Feedback problems were discussed, and voice feedback was advocated, though with the proviso that this could present short term recall problems.

The suggestion was made that the only way to design the right mix of voice and other input systems would be by study of detailed behavioural models of pilots in various phases of operations. It was believed that such models could be developed, but only by means of very lengthy simulator and flight tests with extensive recording of all pilot actions, and that such tests would be vastly expensive.

The transitory nature of speech signals was compared unfavourably with the permanence of visual indications for warnings and status indications. It was pointed out that in the F-18 visual verification of selected communication channels, IFF, etc. is only available for a short period after selection, and is then occulted, and this has proved acceptable to the pilots. However, it is possible in this case to recall the information on demand.

In some situations correct operation of the DVI system could be immediately apparent from the observed response; this could be the case when using it to call up particular display formats, or for selecting transmission to another aircraft, the reply from which would indicate successful communication. The question was raised as to what accuracy could be expected from existing speech recognition systems, and what performance measures could be introduced. It was pointed out that most of the equipment available at present was designed for use in situations where a good signal-to-noise ratio could be achieved, and that this is unlikely to be the case in airborne applications. Experience with existing systems shows that an error rate of 1% to 2% in the laboratory can rise initially to 10% to 20% in the field. It was claimed, however, that properly designed equipment with a motivated speaker could maintain a 2% error rate under operational conditions. Speaker motivation implies a willingness on the part of the speaker to adapt his speech to match the requirements of the system.

The final point in this part of the discussion was that attention should be given to speech sensors; the microphones in common use in aircraft are analogue devices working in noise, and it was suggested that a different type of sensor might provide a better signal for recognition purposes.

Turning to colour displays, reference was made to the view expressed at the 1981 GCP symposium that colour could not be rated as necessary in airborne CRT displays, and the question was asked whether this was the view of the present meeting. From the various responses it was clear that many speakers disagreed with the earlier verdict, and believed that colour is essential, or, at least, highly desirable. Various examples were cited, including the use of colour for warning information, for map displays to differentiate between ground above and below safety height, and for radar displays to differentiate between returns from friendly and hostile aircraft. Surprise was expressed that there should any doubt about the desirability of using colour in CRT displays, in view of the long history of the use of colour coding in conventional instruments.

It was suggested that, whilst the use of colour in displays may not produce any measurable improvement in performance, it may make displays easier to use, and therefore more attractive from the pilot's point of view. Reference was made to experimental work which seems to indicate that the use of colour in a management type of display allows some degree of parallel processing to be carried out by the operator, with a possible 20% improvement in performance; it is hoped that this improvement may apply to other types of display, such as maps, but this has not yet been investigated.

In response to a question on how many colours can be usefully employed in an airborne display it was stated that there is no simple answer, since the number will depend on ambient light levels and other variables, but that the maximum for symbology displays is about 5 to 7, whilst a greater number can be used to advantage in map displays.

As a tailpiece to the discussion on colour, it was remarked that the present symposium had come no nearer to providing definite proof that colour is necessary for airborne CRT displays than had the GCP symposium a year previously.

The Programme Chairman's summing up made the point that there are no simple and neat solutions to the problems which were debated during the meeting, and that a common theme running through many of the discussions was the fundamental adaptability of aircrew - a fact that has always made difficult the task of gaining an accurate assessment of the utility of new systems and equipment. It was pointed out that, to some extent, fashion plays a part in dictating the direction new developments will take. Many topics were discussed during the symposium, and much interesting and useful information was presented, but there are still many questions waiting to be answered.

4. SYMPOSIUM ORGANISATION

With one or two exceptions, the practical arrangements for the symposium met with general approval. Whilst the venue lacked the glamour of some of the other meeting places used by AGARD, the Victorian splendour of the Imperial Hotel, Blackpool was impressive. It was generally felt that the conference room itself was not up to standard; the seating was very cramped when fully occupied, as it was for most of the sessions; the undulating silver foil background to the stage might be suitable for a glamorous singer or a rock group, but did little for the average AGARD chairman or speaker, and was a positive distraction when visual aids were being used; the electronic cuckoo which seemed to have nested in the sound amplification system was also distracting (although at times appropriate).

The general standard of presentation was adequate, and in some cases excellent, but there were still too many slides and viewgraphs which in no way complied with the clear instructions given by AGARD to all authors. Any author should realise that nothing dis-interests his audience quicker than the remark "I know you won't be able to read this slide, but...." In cases where it is quite impossible for a diagram or a numerical table to be simplified, the speaker will do much better to ask for the lights to be put on and to ask the audience to turn to the appropriate page of the printed paper. One further plea relating to illustrations - authors should endeavour to ensure that all slides used in their presentation are reproduced in the printed paper, except perhaps for photographs which will not reproduce satisfactorily. It is disappointing, after a well-illustrated presentation, to turn to the printed paper for confirmation of details and find only a fraction of the diagrams used in the lecture.

Finally, there is the question of video-taped presentations, of which there were two in this symposium. This is perhaps a legitimate technique for a speaker prevented by a genuine emergency from attending a meeting, and is better than leaving a gap in the programme. One would be sorry to see the tendency grow, since although a good presentation can result, it is impersonal and discussion is unlikely to be very effective, even if a colleague of the author is present. Also it could be the first step towards a not-so-brave new world in which we all stay at home and play video-tapes of papers, and hold our discussions by video-conference-phone.

5. RECOMMENDATIONS

(i) There is uncertainty at present whether the full colour range shadow mask CRTs coming into service in display units in commercial transport aircraft will be capable of meeting the full environmental requirements for combat aircraft, or whether colour displays for military use will have to be based on the limited colour range penetration phosphor CRT. When this question is resolved, further discussion of human factors and operational aspects of the use of colour should be arranged.

(ii) Voice technology is at an early stage of development, where only a relatively small number of people understand what is involved in speech recognition and synthesis, and therefore understand the likely scope for application of this technology. Further coverage should be given to this subject in a future symposium.

(iii) Video tape presentations of complete papers should be discouraged except in extreme emergency.

(iv) Authors should be further encouraged to apply the recommendations on the preparation of visual aids which are supplied to them by AGARD.

HUMAN FACTORS IMPLICATIONS OF NEW AVIONIC TECHNIQUES

by

F. G. Cumming
J. Laycock
Royal Aircraft Establishment
Farnborough
Hampshire, UK.

SUMMARY

Advances in technology particularly in the micro-electronics industry have created a situation where the avionics systems designer has at his disposal a greater number of design options than he has ever had before, giving him the capability of constructing systems that are more complex than any previously envisaged.

In the past not every new system was received with total operator enthusiasm for the simple reason that the system was often given priority over the more fundamental requirements of the pilot.

It is considered that the new techniques available should not only improve on already existing systems but new ideas can be precisely tailored to the pilot's requirements in a way which has not been possible up till now.

THE MAN MACHINE INTERFACE

Before considering specific pieces of hardware and their related problems it is pertinent to ask some fundamental questions about "*the man/machine*", or in this context "*pilot/aircraft*" interface. If the subtleties of this interface are to be discussed some simple, workable definition for the two major components of the interface should first be formulated. An aircraft may be considered as an extremely complex control system based on very advanced technology but having only a limited intelligence. This intelligence is provided during the design and construction phases. Similarly, the pilot is a sophisticated control system but both his control capability and limited intelligence have been acquired by a much more flexible and variable development and training programme. As the two major components of the system, the man and the machine may be similarly defined, this poses the question "*Is optimum control of the aircraft achieved by the presence of a man in the cockpit or should control be totally automatic?*".

For basic control, the fast, repeatable performance of the machine is far superior to the slow, variable performance of the man. Although both types of controller are unreliable under environmental stress, the machine solution can often withstand more severe temperature, vibration and g effects than the man. Also it is not subject to the additional stress imposed by human emotions. *Why do these differences arise?* Whereas a machine may exhibit a parallel processing capability or may be multiplexed to permit high speed sequential operation, the man possesses only very limited parallel processing. The majority of human activities are achieved by low speed sequential operation. The reason why this is so may be best understood by referring to a simple model of human information processing (Fig 1).

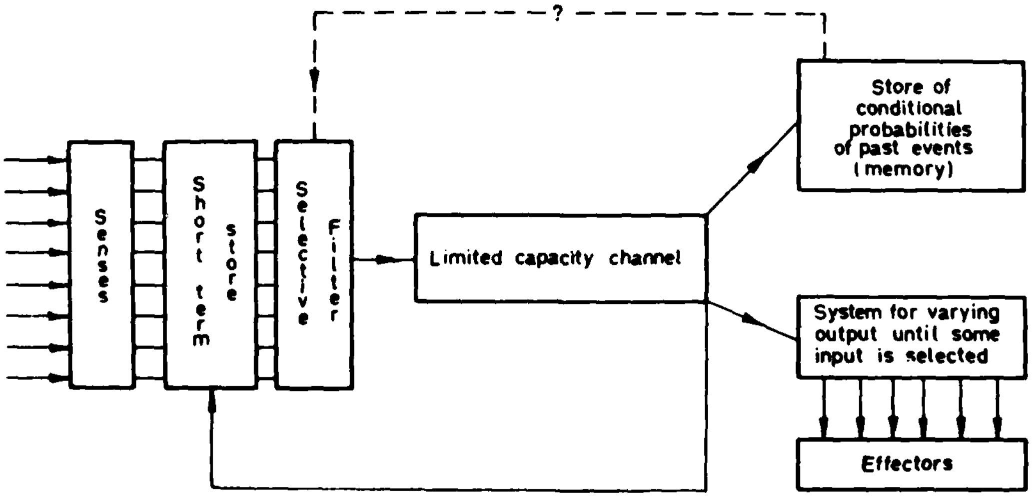


Fig 1. A diagram of the flow of information within the nervous system, as conceived by Broadbent (1958).

To the left sensory stimuli impinging upon the man are represented by the numerous small arrows. As further along the system there is a limited capacity channel only a few of these sensory inputs can be allowed to pass through the selective filter. These selected inputs pass along the system to operate on stored information and influence either the intake of further information or cause interaction with the outside world. This interaction is achieved via limb movement or speech, represented by the effector box. Such interaction with the outside world will in turn cause a change to the sensory input.

As the man's limited capacity channel restricts him to relatively low speed sequential operation, this raises the question which is often voiced, "*Why have a pilot?*". Although for basic operations the man must be considered inferior to a machine, it is in the areas of perception and decision making that he has more to offer than a machine. Whilst the machine can make very rapid responses to preprogrammed options, during design and assembly it is not possible to cater for all possible options. As a result of this, when novel situations arise the machine can achieve only a limited response. The man, on the other hand, is slow to respond to preprogrammed options but he has the capability to produce new solutions to novel situations which were not envisaged during designing the system. This decision making ability plus the ability of the human visual system to outperform any electro-optical target detection and pattern recognition system are the two major reasons for retaining a pilot in the aircraft. It could be argued that the development of more secure data transmission links may favour the introduction of remotely piloted vehicles which are smaller and can pull more g forces than any piloted vehicle. However, at present, the electro-optical sensors incorporated in such vehicles cannot compete with the eye brain combination when data must be extracted from a complex visual scene, using subtle interpolations and recognition based on memorized information.

From this simple comparison of man and machine it becomes obvious that both possess features which are highly advantageous whereas other features are less desirable. The aim should be to combine the two components in a way which maximises the advantages that each has to offer, whilst at the same time not utilising those attributes which may lead to slow, unreliable performance.

With the present division of activity *how efficiently has the labour been divided between man and machine?* The machine manipulates computational algorithms in the form of hardware and software. These operate on limited, selected data bases which are stored in the computer or arrive at the computer from many transducers carried in the airframe. The man utilises machine displayed information derived from such algorithms combining it with new information arriving from the outside world to make decisions about future flight path and tactics. Although in existing aircraft the man and machine may together be performing these roles, when current technologies and the way in which they are integrated into the cockpit are appraised the division of labour is not quite so clear cut. The current level of capital and effort being expended on the development of avionic systems specifically designed to bridge the man/machine interface would suggest that the optimum man/machine balance has not yet been achieved and expectations are that new avionic techniques will allow significant improvements to be made in this balance.

If there is agreement that an imbalance does exist and that there is a need to improve the situation *what is the optimum strategy to adopt when developing new avionic systems?* When the model of human information processing is considered (Fig 1) it is apparent that the efficiency of the man could be maximised by providing him with a reduced number of partially processed sensory inputs. This would result in reduced demands on his central processing and involve the minimum number of outputs. Unfortunately, there is a need to extend the man's inherent capabilities to allow him to fly closer to the ground, to a precise location where he is required to detect a target prior to weapon delivery, whilst avoiding weapon threats from both air and ground. Because of this requirement it has become necessary to augment his sensory inputs by providing him with the outputs from numerous transducers. Thus rather than reducing the demands on the pilot the introduction of avionic systems may make the situation worse.

INFORMATION DISPLAY

Up until recently individual transducers have provided inputs to discrete instruments spatially distributed over the cockpit panel area, frequently separated from their associated control knobs and switches. The introduction of increased computing capacity and cathode ray tube displays has allowed the input to the man from basic transducer systems to be reduced by collating data prior to presentation. This collation procedure not only significantly reduces the time spent by the pilot visually searching around the panel but also substantially reduces the processing he is required to perform to correctly interpret the displayed information. The introduction of colour may further improve the pilot's ability to assimilate data, but care must be taken to use it correctly. With such devices the maintenance of attitude and heading becomes considerably simplified, but it is necessary to assess whether any significant penalties have been incurred to arrive at this solution.

The transition to the electronic displays viewed by the pilot has not been easy due to two major factors:

(1) It has been difficult to provide an emissive display device which can be adequately perceived under the extreme range of environmental illuminations experienced in the airborne environment. Neither has it been easy to provide sufficient resolution and field of view.

(2) A display/transducer system which combines data in a complex manner must be reliable, as any insidious failures become difficult for the pilot to detect and may mislead him, sometimes with disastrous consequences.

When designed in a quiet, comfortable office and further tested in the simulator it is difficult to see how such displays can be misinterpreted, but reality is somewhat more hostile.

ELECTRO-OPTICAL SENSORS AND RELATED DISPLAYS

The presence of the cathode ray tube in the cockpit has stimulated interest in extending the pilot's operating capability under reduced visibility conditions. Several sensor options have been considered to augment the visual capabilities of the pilot's eyes. Although each has its own unique characteristics it is ultimately dependent upon one of a number of possible display options to transmit the output to the pilot. Currently, an attractive option which reduces visual search activity involves the superimposition of computer generated symbology on a sensor derived image of the outside world. Using this approach a low light television or forward looking infra-red sensor can provide an image adequate for flight. Both types of sensor are selective in the detection and transmission of data to the pilot and care must be taken to select the correct option for the role envisaged. In low level flight a low light television adequately provides data to the pilot about the trees which obstruct his path, whilst the same scene viewed by an infra-red sensor detects the potential targets in the wood and provides an horizon for improved navigation. Which should be used? Ideally the advantages of both are desirable, but it is unlikely that the space or the money can be afforded to allow both sensors to be installed. Consequently, whichever solution is chosen it is to a certain extent suboptimal.

Having selected the sensor type it is necessary to specify an optimal field of view. This in itself becomes a severe problem. If the sensor output is viewed on a head-up or head-down display arranged to provide unity magnification with the outside world the limited forward field of view offered by the display may seriously affect the pilot's flying performance by depriving him or peripheral cues required for accurate manoeuvre and navigation. Also, the inferior resolution of the display makes target detection more difficult and weapons must be launched at reduced ranges.

Numerous solutions have been devised to overcome these limitations but a totally adequate option has not yet been provided. This situation is likely to remain relatively unchanged in the near future. Increasing the field of view of the sensor produces an unnatural relationship between actual forward airspeed and perceived airspeed. Also, there is a reduction in the number of small cues available for accurate judgment of height and detection of potential targets. This conflict between the wide field of view required for manoeuvre and the narrow field of view required for weapon delivery is partially resolved in dual field of view sensors but the pattern recognition problems experienced by the pilot whilst cross-comparing the two images are far from trivial. A second possible solution which retains unity magnification between sensor and outside world increases the visual field by providing a display with larget instantaneous field of view. This has been impracticable until now due to optical limitations. Recent developments in holographic optics now make this solution feasible. A third solution involves mounting the display on the helmet and directly coupling it to the sensor, so that by moving the head different portions of the outside world may be seen. The night vision goggle does this in a reasonably efficient manner but again at a cost:- loss of resolution; incompatibility with existing cockpit instrument lighting, and relatively unsatisfactory ergonomics causing increased muscular fatigue and potential ejection difficulties. The helmet mounted display operates using similar principles and consequently may be subjected to the same criticisms.

DATA STORAGE

So far only that aspect of the flying task which involves the pilot processing sensory inputs derived from the outside world has been considered. To make maximum use of this sensory information the pilot utilises stored information in his memory. Storage within the aircraft can be used to free human memory for other activities. For example, tedious checklists can be stored and presented when required. Map information stored on film and driven by the inertial navigation system has done much to relieve the pilot of both the mental and manual load required to calculate and plot positions on a paper hand-held map. Although invaluable in their present form it is conceivable that digital mapping techniques may provide even more versatility allowing the pilot to request alternative formats and scales. More advanced algorithms may even provide steering information showing threat zones.

CONTROL SYSTEMS

Moving on to investigate how the aircraft deals with the output from the man. When flying, conventional aircraft process the limited control outputs produced by the pilot to provide multiple inputs to the aerodynamic control surfaces. Currently, hydraulic feedback systems provide artificial feel at the column which varies according to airspeed and altitude. This facilitates optimum control by the pilot and partially guards the system from excessive demands. The desire for smaller more manoeuvrable aircraft with accompanying small cockpits has given rise to active control technology. Using on-board computing an airframe of limited stability and hence great manoeuvrability can be maintained in a stable configuration. This could not be achieved by pilot control alone.

Such well proven technology is likely to have a major impact on the cockpit of the near future. Rigid force operated devices provide a compact means of controlling current and future aircraft. When side mounted they allow displays in the centre of the panel to be more easily seen. Also, the computing power behind such a device may be programmed to make more use of the pilot's inherent control capability. Direct-lift and direct-side force techniques allow the aircraft to manoeuvre in a manner which was previously impossible. However, despite this optimism it is likely to be the pilot that eventually limits the usefulness of such facilities as it is *he* who has to decide which type of manoeuvre he would like to perform and *he* has to manipulate the hardware which allows him to select and control the desired option.

During weapon delivery intelligent weapon systems greatly assist the pilot but mechanical limitations within the aiming controller may ultimately determine the final accuracy achieved. Such limitations become critical during air to air engagements when the pilot needs to have access to essential flight, engine and weapon controls without moving his hands off the throttle and stick.

The helmet mounted sight and display were conceived as devices allowing rapid target acquisition using man's inherent capability to correctly orientate the head. However, the accuracy with which sight alignment can take place is perhaps not as high as one might imagine, especially in a turbulent low level environment where severe involuntary head motions may occur.

DATA INSERTION

This leaves the discussion to deal with the portion of the control loop which requires the pilot to interact with the display suite to insert or select data by limited "keying" activity. This is a particularly difficult interface as excessive time can be spent with the head down in the cockpit, drawing vital attention away from the flying task. Advanced avionic suites have placed more and more information at the pilot's disposal but he is still required to perform the basic operation of data selection by using his effectors to change the sensory input. Over the last decade we have seen the movement away from keys with discrete functions to the multifunction keyboard. Because of difficulties experienced whilst operating keyboards with complex hierarchial decision networks behind them a retraction to an intermediate position can now be observed, where some keys retain discrete functions whilst others, usually positioned around a CRT, may have various functions. This type of arrangement still requires extensive keying and often severely restricts the type of format that can be displayed.

Complex tabular formats, which are difficult to search and assimilate, are gradually being replaced by formats where information is presented ready processed. This allows rapid, simple decisions to be made. In several proposed formats the pilot is no longer required to know the positioning of weapons on the airframe, nor is it necessary for him to go through protracted arming procedures. A single decision and minimal keying provides him with a complete package. Alternative methods of presentation remove alpha numeric information by means of a simple pictorial representation. If this latter option is used, how best could the pilot interact with the display? Simplification of the sensory input to the man may produce an increase in the control outputs he is required to make. A touch sensitive display enables rapid interaction to occur with this type of format, giving immediate visual feedback of change of state. Although these devices operate adequately under vibration conditions it has yet to be proven that they are operable in high g manoeuvres and that the absence of substantial tactile feedback is not detrimental to performance.

What then for the future? There appears to be a basic need to facilitate the transference of commands to and from the computer. The current extensive interest in speech recognition perhaps reflects the feeling that an acoustic interface is more effective than a visual/manual interface. It may be argued that speaking and listening are highly efficient, well developed skills possessed by every pilot, whereas keying is an unnatural skill which has to be developed by training. However, it must be realised that auditory and vocal actions involve sensory and motor activities dependent upon the limited capacity channel, just as do visual and manual activities. Thus the premise that the pilot can talk and listen to the computer whilst still monitoring the outside world is perhaps incorrect. Tests indicate that the act of speaking involves just as much central load on the pilot as does using a manual keyboard. Thus an equivalent rate of deviation from flight path results when using either device. However, as speech entry is more rapid and fewer errors arise, the overall deviations produced are less with a speech system. Also, demands on the pilot are less.

Speech generation systems offer exciting possibilities for acoustic feedback. This is not a particularly new area as voice warning systems have been in existence for some time. However, auditory feedback does not always provide the benefits expected and requires a well structured decision tree within the computer to assign priority when multiple messages need to be simultaneously conveyed to the pilot.

CONCLUSIONS

There can be little doubt that the pilot will be retained in aircraft of the future because of his unique ability to make decisions in unanticipated situations and for his visual systems capacity to search, detect and recognise visual information present in the outside world. In order to maximise his efficiency the avionic systems of the future should be used to reduce the demands placed on his peripheral senses, allowing unambiguous signals to be passed through his limited capacity channel to produce the minimum number of motor control actions at the output.

This may be achieved by:

(1) Reducing the number of times he is required to close the display/control loop by providing an improved flight control system and a better correlation between the instruments and the outside world.

(2) Reducing the number of selections of data sources that are required throughout the sortie by introducing automated procedures to take care of plant failures, and providing a more easily operable interface to allow essential interaction with the various systems to be made both fast and accurately.

These improvements should assist the pilot to more readily deal with the essential task of responding to new information from external sources.

OVERVIEW OF THE 32nd GCP SYMPOSIUM

by

Prof.em. Dr.-Ing. K.H. Doetsch

Techn. University Braunschweig
3300 Braunschweig
Germany

1. Introduction

The 32nd GCP Symposium on the Impact of New Guidance and Control Systems on Military Aircraft Cockpit Design was held in Stuttgart from 5 - 8th May last year (CP-312 and CP-312 (Supp., Classified)).It covered - though from a different point of view - much of the ground of the present symposium. Therefore a short review of its findings might be useful for the discussion during the next few days. As the author of the TER of last year's symposium I have been invited to give this overview.

The difference in perspective of the two symposia is essentially that the present symposium sets out to explore several new technology developments and to stimulate their application, whereas the GCP-symposium introduced, as it turned out, a sense of restraint in their application: that symposium was cautious not to accept new technologies until it is established that they actually reduce crew workload. Furthermore, the GCP-symposium emphasized the need to integrate cockpit equipment.

2. Cockpit Equipment Integration

From a Guidance and Control aspect the cockpit is the vital interface between the human operator and the highly complex systems which, on the one hand, provide him with information and, on the other hand, require attention and enable manipulation. Thus the conference considered all three facets of the cockpit design problem, the human operator, the provision of information and the actuation although the important definition of the human operator's capabilities and limitations was given only implicitly, mainly in the discussions.

The conference naturally also put emphasis on the more recent technology developments. The serious problem of proliferation which dominated many of the discussions of the conference had, paradoxically, arisen out of such a development. The technical means have become progressively "avionic" with consequent opportunities for miniaturisation, for vastly increased capabilities and for flexibility. This has permitted and encouraged a multiplication of human interface channels that ran wild. It was shown in the conference that some fighter aircraft accumulated up to 320 switches and more than 70 displays around a single crew member. This must cause concern because of the implications for training needs, for maintenance etc. Fortunately, a drastic change in this trend was demonstrated by examples of the latest cockpit developments for fighter aircraft (F-18 Hornet) and helicopters (ADAS) with far fewer interface channels.

Many papers of the conference addressed individual aspects of the total interface, showing modern ways of rationalising the systems and their operation, thus achieving impressive relief in cockpit clutter and pilot's workload.

The most obvious tools providing information in an improved way are multifunction CRT displays, which permit the suppression of information in which the pilot is not currently interested from the displays; he need no longer filter out this unwanted information mentally. They are also able to integrate in a most logical way information from different sources such as e.g. route and weather data. The transfer of information to the human brain can be enhanced by a great choice of symbol shape, prominence and, if desirable, colour.

For the "reverse flow through the interface", i.e. for the selection and control activities of the pilot, great benefits have been derived from a careful application of interconnected switching, so that the pilot's actions are moved to a higher hierarchical level with fewer operations necessary. And, of course, automatic control is applied wherever and whenever the task to be performed is fully predictable, e.g. feed-back regulation of disturbances and stabilisation of flight path, again permitting the pilot to operate on a less busy higher hierarchical level, where his intelligence rather than routine skill is required. Furthermore, very good examples were shown of logically integrated management blocks, e.g. for CNI tasks, fuel and engine management, weapons etc. Keyboards are introduced, combined with mode or address selectors, to operate through a single multifunction input system what hitherto had been done through hundreds of dedicated switches. Caution, however, is indicated because the keyboard operation sequences can take longer than the operation of a dedicated switch.

It was concluded that the complex integration process of cockpit systems for information displays, CNI facilities, function selection and control will, with increasing use of distributed microprocessors, continue to change cockpit design at a swift pace.

3. A Caution and a Plea for Simplicity

A cautious note with respect to new developments was first struck by the Keynote speaker of the symposium, Group Captain Robinson from the International Military Staff of NATO. This experienced member of the military user community introduced early in the proceedings a damping effect on undue enthusiasm for "new technology". He warned against misusing a fighter cockpit to show off how much can be packed into it in the way of displays, switches, controls, selecting devices and warning systems. He introduced the valid concept of the "Raw Guy", the less experienced and less well conditioned pilot for whom the cockpit has to be designed as opposed to a finger artist and mnemonist. Thereafter this "Raw Guy" notion kept recurring in the subsequent discussions. Two further points, relevant to the aircraft users, are worth quoting:

(i) "mission abort due to minor battle damage cannot be tolerated",
(ii) "fingers cannot be used to operate densely arrayed kayboards in battering low level flight".

In this discussion other military speakers explained their reservations regarding automation because in the past too many promises were only partly fulfilled. Too often something had been "just round the corner" but the corner was never reached. They are concerned that training requirements would go up with new and additional capabilities, and training is very expensive. One contributor from the military procurement side went so far as to suggest that for every single piece of information the cockpit builder offers on a display, he himself should carry the burden of proof that it is absolutely needed. Even the technical people, the researchers and designers, although occasionally blamed for excessive enthusiasm for technological novelties and sophistication, repeatedly endorsed the pleas of "Keep it simple" and "Have the courage to omit things that are not proved to be vital". I think that such warnings might usefully be kept in mind during this conference.

Turning from the consideration of overall philosophy to individual topics I intend using the sequential arrangement of this present symposium rather than reporting chronologically on the run of last year's GCP-symposium.

4. Colour Displays

Mr. H.L. Waruszewski of Wright-Patterson AFB gave a thorough treatment of the factors to be considered in the development and use of colour displays. In addition to CRT-technology he covered the characteristics and abnormalities of human colour perception, e.g. its variation with viewing angle. For practical applications he concluded that:

(i) Colour is not helpful when brightness contrast is great; it is beneficial at very small brightness contrast between target and surround.
(ii) The addition of colour provides a visually pleasant experience; pilot's performance, however, does not significantly improve statistically.
(iii) The appropriate use of colour coding can lead to substantial performance improvements; the inappropriate use of colour coding can increase the workload and cause confusion.

Although subsequent papers and discussions expressed differing views the general consensus was that colour appears more helpful with the less vigorous manoeuvering of large transport aircraft, whereas its usefulness in fighter cockpits was contested. As an example of the former the new Airbus transport was quoted where an electronic display arrangement with 6 colour-CRTs helped to establish the feasibility of operating such aircraft with a two-man crew. An undisputed example of the latter was the F-18 Hornet cockpit which obviously does very well without colour.

The question of colour *coding* was raised on several occasions. It was confirmed that even when restricted to sparse colour coding, more harm than good can be done by inadequate design. Standardisation of colour coding was strongly advocated. In the transport aircraft this was attempted by using green for fixed scales, magenta for selection inputs, white for present indication and red for warnings or limits. With respect to warnings it was suggested that red and amber should not be continuously present in the display but should be brought on when actual warning is due, to avoid diminishing attention. It was also proposed to use amber colouring for warning, progressively changing to red when alerting is required. The point was made that red print has poor readability and might better be replaced by a red rim around black (or white) print.

On the status of technology it was said that colour tubes are now available that give three times the resolution of ordinary TV tubes. These rugged shadow-mask tubes give low reflectivity to ambient light and therefore good contrast of display. If necessary, this may be further enhanced by externally mounted filters.

5. Voice Interactive Systems

A paper based on the findings of an NADC conference early in 1981 discussed voice controlled avionics as an alternative or additional communication channel between man and machine.
It started from the premiss that even multifunction controls do not always reduce workload and that these are still just as dependent "on already saturated visual/manual information channels". I fear one could conclude that the workload is reduced through voice control; in fact it is merely transferred from one channel to another, and the bottleneck

still remains within the human brain with its limited independent access channel capacity, whether visual or aural. Nevertheless, an aural channel has distinct advantages when sharing attention with a visual-input/manual-output channel. If sparingly used it catches attention more readily than the visual channel through its "arousing" effect, as utilized in voice warning systems. It also interferes less with manual aircraft stabilisation and trim than additional switch or control manipulations by hand would do.

The discussion brought out probable limitations that might persist even after some further development of a voice interactive system, e.g. in high stress situations and under high-g conditions. Noise poses a minor problem, e.g. breathing noise when using an oxygen mask. A breadboard system for tests in an FD-16 aircraft was started in Jan. 81.

A comprehensive French research program was described by M. Costed who is going to address us again tomorrow, I understand. One of his conclusions is that a voice control system always needs "personalisation", i.e. adjustment to the individual user's speech characteristics, to obtain good speech recognition performance. This personalisation is achieved by means of personal sonagrams, taken on tape (personal cassette) beforehand. The recognition of a word or command by comparison with this sonagram needs 100 to 400 milliseconds time. Tests gave 99% success in speech recognition in the absence of noise disturbance, and 98% when using an oxygen mask. In the discussion a military operator stressed that he would not wish to look at the recognition rate in terms of 98% success but rather at the remaining error rate of 2% which he and others would find unacceptable.

Further discussion emphasized the danger of mixups between similar sounding words. Standardisation of a vocabulary of about 100 carefully selected words and selected syntax are good tools against this. The recognition time delay must be further investigated to assess its effect on airborne tasks. 400 milliseconds appear unacceptable but 200 to 250 might be tolerated.

6. Keyboard Design

A recurring theme of the conference discussions was the proper design of keyboards as multifunction input devices. Two questions caused concern:

(i) should the key arrangement follow the "telephone-norm" or the usual "computer and business machine standard"; the general consensus was in favour of the telephone standard, and

(ii) how to ensure accurate operation of keys in high-g, low-level flight or in the presence of vibrations as in helicopters.

Some further human factors research, especially on push distance and push force was advocated. The F-18 Hornet arrangement was commended because it permits safe operation of pressbuttons under vibration by the simple means of having the keyboard project about 4" so that the operating hand can be steadied against its side.

The point was made that too many pressbutton operations when changing targets or weapons during attack, or even simply switching radio frequencies either take too long for the time available or increase crew workload unacceptably. One way of alleviating this problem in fighter aircraft was demonstrated in the HOTAS concept (Hands on Throttle and Stick operation) as applied to the F-18 Hornet.

It was also suggested that touch sensing displays might permit larger errors in correct finger placement than pressbuttons.

7. Head-Up and Helmet-Mounted Displays

Head-up display technology has, in most respects, reached maturity. The introduction of off-boresight weapons, for instance air to air missiles with ± 60^o lock-on angle, however, emphasized the need for an increased width of the field of view, up to 30^o or 35^o. Smaller increases, as occasionally offered, would in this case be meaningless. The alternative solution to this problem, the helmet-mounted display is gaining acceptance. Systematic flight investigations of such a device for helicopter low level operation at night or in poor visibility gave good results. The HMD was used in conjunction with a slaved infrared camera (Mini-FLIR). This (or any other low light level camera) is mounted on a gimballed platform underneath the helicopter and provides outside visual information for terrestrial navigation, which, after mixing with symbols for instrument derived information, is fed to the HMD.

The discussion on the difference between this sophisticated system and the less expensive use of night goggles brought out the important advantage that the HMD can be used with a variety of image producing sensors or their combination. Nevertheless, the alternative use of goggles during certain phases of flight is not precluded. With goggles, normal cockpit instrumentation can be read by looking unterneath the lower goggle rim.

The suggestion was made to let one member of the crew use the HMD for target acquisition whilst a second member used goggles and HDD for safe navigation in low ceiling conditions.

A different approach to feeding extra information into the HMD was demonstrated in which a matrix of light-emitting diodes is used as an image source. It was intended to transmit energy-manoeuvrability information in combat situations. So far pilot's reaction is cautious. The helmet is considered to be too unwieldy in operational aircraft and HUD is preferred. Thus doubts as to the final outcome still exist.

An apparently successful method for the comparative inflight evaluation of different HUD concepts was described in a paper from NATC, Patuxent River. The investigation used the "secondary task performance" method by presenting an item recognition task in the form of letter combinations in the centre viewing field of a HUD, which can easily be achieved in actual flight with software modifications to the HUD picture generation system. The flying task, viz. standard instrument approach, had to be chosen such that it was not noticeably affected by the secondary task. The results were remarkably consistent and informative.

8. Summing Up

In the Final Discussion the moderator, Mr. McFarlane summarised the conference findings as follows.

The operators want: more military effectiveness from each aircraft,
more availability, even in hostile weather,
less vulnerability, in increasingly hostile environments,
increased integrity, no increase in peace time training loss rate,
improved maintainability, as part of keeping cost of ownership low.

Solutions indicated during the meeting are:

(i) miniaturised equipment using less cockpit area,
(ii) multifunction displays and controls to permit a time multiplex use of more information, different weapons or flying modes,

(iii) automation for pilot relief "in the hopeful knowledge that the things he is not looking at are being taken care of", and

(iv) perhaps for future use, new information transmission means like colour displays and voice interaction.

Compromises will have to be made in each cockpit design, to fit the operational task, the inexperienced "Raw Guy" (because of training costs), the economic limits etc. Care has to be taken not to use sophisticated solutions in the wrong area.

Addressing the operators, the moderator unterstood their reluctance to accept keyboards, MFDs and automation which they do not yet feel they can trust, but they should realise that "Raw Guys" of tomorrow have grown up with calculators and playing Star Wars, and therefore would be quite willing to accept more sophisticated technology. Furthermore, he thought that more automation in the cockpit could well reduce the amount of information the pilot needs access to.

Addressing the *designers* in the field, he pointed to their practice of meeting integrity and availability demands by duplication and triplication of equipments which inevitably increases cost of ownership at every level. He asked if this trend is indeed irreversible. If it were, it might lead to ever increasing cost per aircraft, fewer and fewer aircraft in the front line inventory, and hence pressure to make each one do more, thus increasing the workload on the pilot, provoking new attempts to introduce additional expensive equipment to alleviate this, a truly vicious circle.

The conference thought that some questions were not fully resolved and I will quote them for the consideration of this Symposium:

When is colour necessary in displays; what can and should be standardised in colour coding, i.e. which colour for which parameter?

Which standard key arrangement should be made mandatory for military aircraft cockpits (telephone or calculator norm)?

Can HOTAS (Hands On Throttle And Stick) -operation of display, function selection and controls be standardised?

Will voice interaction become necessary? Can existing combat stress effects, elocution, noise interference be mastered?

LE FACTEUR HUMAIN DANS LE PILOTAGE DES SYSTEMES

par

Gen. J-C.Wanner
Ingénieur Géneral de l'Armement
Directeur adjoint de la Direction
des Recherches Etudes et Techniques
Délégation Générale pour l'Armement
DRET
4 Ave de le Porte d'Issy
Paris 75996

Les règles qui permettent d'améliorer la sécurité des systèmes pilotés lorsqu'entre en jeu le facteur humain sont également utiles pour améliorer les performances de l'ensemble du système homme-machine. Ces règles de sécurité misesau point à l'occasion de la certification de Concorde sont passées en revue après étude du comportement de l'homme intervenant dans les boucles de pilotage du système.

La philosophie de conception des systèmes de conduite des grands processus industriels est en train de subir une révolution déchirante.

Les accidents ou incidents graves survenus récemment, la panne d'électricité nationale française de fin 1978, l'échouage de l'Amoco-Cadix, l'accident de la centrale nucléaire américaine d'Harrisburg, la collision de deux Jumbo-Jets à Tenerife, ont mis en évidence l'effet prépondérant de ce que l'on appelle généralement le facteur humain, l'erreur humaine et souvent abusivement la faute humaine (rappelons que la notion de faute traduit la transgression volontaire des règles alors que l'erreur n'en est qu'une transgression involontaire n'impliquant donc pas culpabilité).

La conception des systèmes de présentation d'information et de commande des grands systèmes, bien qu'elle intéresse des systèmes aussi différents qu'un navire pétrolier, une centrale nucléaire, une unité de distillation, une unité de coulée continue etc..., doit tenir compte des possibilités d'adaptation de l'opérateur humain qui semblent à première vue très larges et qui sont en réalité très étroites.

Le premier type de système pour lequel des études approfondies ont été menées est le système de pilotage des avions. Historiquement, l'avion a été en effet le premier système pour lequel l'erreur de conduite "en temps réel" conduisait à la catastrophe.

C'est essentiellement au moment de la conception de Concorde, au début de la décennie 60-70 que le problème est apparu dans toute son ampleur.

L'augmentation du domaine de vol (Concorde vole deux fois plus haut et près de trois fois plus vite que les avions de transport classique), l'apparition de systèmes nouveaux dont le bon fonctionnement est indispensable à la sécurité (sur les avions de transport classiques le seul système critique est le système de propulsion) ont conduit les responsables de la sécurité à revoir les règles de certification.

Les règles empiriques classiques élaborées pour le Douglas DC3 et extrapolées prudemment jusqu'à être applicables à la Caravelle, aux Boeing 707 et 747, se sont révélées inadaptées, sans intérêt, voire même dangereuses pour Concorde.

L'établissement du règlement de certification Concorde a donc exigé une longue étude des conditions conduisant à l'accident, étude dont la philosophie est connue maintenant dans le domaine aéronautique sous le sigle ESAU*.

Une fois cette étude menée et le règlement de certification Concorde établi, il a été facile de s'apercevoir que sa philosophie s'appliquait, à des nuances près, à tous les systèmes contrôlés par l'opérateur humain (nous employons ici volontairement le mot "contrôle" dans son acception anglo-saxonne car les traductions possibles de "control" par "pilotage" "conduite" ou "gestion" ont un sens trop particulier en français ; nous utiliserons justement plus loin chacun de ces termes pour préciser les divers aspects du "contrôle de processus").

C'est cette philosophie que nous voulons exposer ici en l'illustrant d'exemples bien connus mais en laissant aux spécialistes de chaque type de système, le soin de l'adapter à son cas particulier.

QU'ENTEND-ON PAR ACCIDENT ?

Un système est en général un ensemble de sous-systèmes et d'éléments dont le fonctionnement de chacun peut être caractérisé par un ou plusieurs paramètres : température et pression de l'huile de graissage, régime de rotation d'un alternateur, braquage des roues d'un véhicule terrestre, vitesse du véhicule lui-même, distance de la voiture au bas côté de la route, angle d'incidence de l'aile, etc...

Le domaine de variation de chacun de ces paramètres de fonctionnement est en général limité. Les limites du domaine autorisé sont bien souvent floues ; en toute rigueur il faut admettre qu'au milieu du domaine autorisé, la probabilité d'accident est négligeable et qu'elle varie rapidement au voisinage des limites pour être voisine de l'unité à l'extérieur des limites.

Dépasser de quelques centimètres la bande blanche qui symbolise le bas côté droit de la route est sans grande conséquence, bien que peu recommandé ; la probabilité d'accident varie peu autour de la limite. Si, par contre, le bas côté est en bordure de précipice, le franchissement de la limite est rapidement catastrophique !

Il est néanmoins commode de parler de limite de domaine autorisé pour chaque paramètre de fonctionnement tout en gardant à l'esprit l'aspect probabiliste du concept.

Il est ainsi possible de représenter le fonctionnement d'un système par un "point de fonctionnement" dans un espace à n dimensions, chaque dimension étant consacrée à l'un des paramètres de fonctionnement.

Nous dirons alors qu'il y a accident lorsqu'à la suite d'une succession d'incidents, le point de fonctionnement du véhicule a franchi l'une des limites du domaine autorisé.

---

* ESAU : Etude de la Sécurité des Aéronefs en Utilisation (traduit en Anglais par ISAAC - Investigation on Safety of Aircraft And Crews).

En général, le franchissement d'une limite est dû à une succession d'incidents dont aucun ne joue un rôle prépondérant. Aussi est-il vain de chercher à définir "la cause" d'un accident ; chaque incident a joué un rôle et il aurait suffi qu'un seul d'entre eux, peu importe lequel, n'ait pas eu lieu pour que l'accident ait été évité.

Dans le cas des accidents évités de justesse (le "near miss" des anglo-saxons), on remarque bien souvent qu'il eut suffi de la coïncidence d'un seul autre incident pour provoquer la catastrophe ; mais cet incident n'en aurait pas été pour autant "la cause".

LES TROIS TYPES D'INCIDENTS

Les différents incidents dont la succession conduit à l'accident peuvent être répartis en trois classes, et trois seulement :

- incidents de pilotabilité,
- incidents de sensibilité aux perturbations,
- incidents de manoeuvrabilité.

Pour le premier type d'incident, l'opérateur dipose des commandes nécessaires pour maintenir le point de fonctionnement dans le domaine autorisé, mais le travail se révèle trop difficile à exécuter (rapidité et nombre d'interventions trop élevées, informations insuffisantes sur la position relative du point et des limites) ; l'opérateur laisse donc le point de fonctionnement se rapprocher d'une limite ou même la dépasser.

Le deuxième type d'incident, dit de "sensibilité aux perturbations" peut se décrire de la façon suivente. Sous l'effet de perturbations externes (rafales, ondulations de la route, houle, surtension du secteur, etc...) ou internes (pannes, y compris le feu), le point de fonctionnement approche ou dépasse une limite, soit parce qu'il s'est lui-même déplacé (augmentation de l'incidence de l'aile sous l'effet d'une rafale, augmentation d'une contrainte dans la structure sous l'effet de l'ondulation de la route ou sous l'effet de la houle, perte d'altitude ou augmentation de l'angle de dérapage d'un avion sous l'effet d'une panne moteur), soit parce que la limite elle-même a été changée (diminution de l'incidence de décrochage sur rupture de volet hypersustentateur, baisse de résistance d'un élément de structure sous l'effet du feu, diminution de la limite de dérapage sur crevaison d'un pneumatique, etc...).

Il faut bien noter que les incidents de sensibilité aux perturbations internes ne font intervenir que la réponse transitoire du système à l'apparition d'une panne. Une fois la panne établie on se trouve en présence d'un nouveau système ayant ses caractéristiques et ses performances propres et qu'il convient d'étudier tel quel vis-à-vis des incidents des trois types.

Enfin, pour suivre un programme donné (modification de la trajectoire de l'avion, du navire ou du véhicule routier, augmentation de fourniture d'énergie d'une centrale électrique pour faire face à la demande) ou, pour ramener le point de fonctionnement à la valeur nominale à la suite d'un écart dû à des incidents des deux premiers types, l'opérateur doit effectuer une "manoeuvre" qui en général amène le point de fonctionnement à se déplacer et quelquefois à se rapprocher des limites ; ce déplacement constitue une incident dit de "manoeuvrabilité".

En conséquence, à la suite d'une série d'incidents des trois types précédents, le point de fonctionnement se rapproche des limites de telle sorte qu'un dernier événement, toujours de l'un des trois types, conduit le point de fonctionnement à franchir une limite.

Ainsi, au cours de l'approche sans visibilité d'un avion en atmosphère turbulente, le pilote par suite d'une panne des systèmes d'aide au pilotage, laisse la vitesse chuter de 15 kt et vole 50 ft au-dessous du plan de descente (pilotabilité). Notant l'écart d'altitude, il effectue une manoeuvre de tangage pour le corriger (manoeuvrabilité). Enfin, une rafale vient s'ajouter aux deux augmentations d'incidence, dues à la diminution de vitesse et à la manoeuvre pour faire décrocher l'avion (sensibilité aux perturbations).

LES REGLES DE SECURITE

Les conditions menant à l'accident étant ainsi établies, les règles de sécurité auront pour but de diminuer les probabilités d'apparition des incidents des trois types.

Nous allons donner ici quelques idées générales des différentes règles applicables à chaque type d'incident mais il est bien évident qu'elles doivent être soigneusement étudiées suivant le type de processus contrôlé. Il est par ailleurs très difficile de juger a priori de la validité d'une règle et seule l'expérience peut fournir la réponse ; mais il faut savoir que l'observation des résultats est délicate car les accidents sont rares et l'estimation statistique de variations faibles de probabilités elles-mêmes faibles, demande beaucoup de précautions.

Les règles générales de pilotabilité peuvent se résumer en quelques points fondamentaux sur lesquels nous reviendrons plus longuement ultérieurement.

- Fournir des informations sur le point de fonctionnement et sa position relative par rapport aux limites.
- Ne pas fournir trop d'informations, c'est-à-dire certaines informations inutiles parce qu'elles sont redondantes ou sans rapport avec le fonctionnement.

- Fournir toutes les informations utiles ; cette règle semble évidente mais bien des fois oubliée ; lorsque l'on aborde un virage on ne connaît généralement pas la vitesse maximale autorisée dépendant du rayon de virage, de l'angle de dévers de la route et de la limite d'adhérence des pneumatiques (dépendant elle-même de l'état de surface de la route : gravillons, pluie, verglas, etc...).
- Fournir des informations faciles à interpréter (les opérations mentales d'interprétations occupent le cerveau de l'opérateur qui peut alors laisser échapper une autre information utile ou ne pas avoir le temps d'exécuter le actions nécessaires sur les commandes).
- Ne pas exiger un trop grand nombre d'acions sur les commandes et faire en sorte que ces actions soient sans ambiguité, faciles à concevoir et à exécuter.
- Laisser à l'opérateur la possibilité de fonctionner "en boucle", c'est-à-dire de corriger ses actions en suivant l'évolution des paramètres à corriger. Le fonctionnement en "boucle ouverte" correspond à ce que les règlements de certification aéronautique nomment "actions exigeant une habileté exceptionnelle de la part du pilote".

En définitive l'objectif des règles de pilotabilité est essentiellement de réduire la charge de travail de l'opérateur, cette charge de travail pouvant être définie comme la somme des quantités d'informations "absorbées", "traitées" et "fournies au système" par l'opérateur. Nous verrons plus loin que d'autres règles sont à ajouter pour traiter les cas de charge de travail trop faible.

Les règles de "sensibilité aux perturbations" et de "manoeuvrabilité" sont beaucoup plus faciles à établir car elles ne font pas intervenir l'opérateur humain et n'exigent qu'une analyse approfondie du système, du milieu dans lequel il évolue et de sa mission. Il n'est pas évident qu'une étude exhaustive du problème soit possible avec les moyens de calculs actuels mais elle ne relève que des lois connues de la physique alors que les règles de pilotabilité font intervenir le comportement psychosociologique de l'opérateur qui ne relève pas, pour le moment du moins, des sciences dites exactes.

Nous ne nous étendrons pas sur ces règles pour nous concentrer uniquement sur le problème du facteur humain.

COMMENT L'OPERATEUR HUMAIN SE COMPORTE-T-IL ?

L'opérateur humain peut être caractérisé par trois propriétés essentielles.

1) Il effectue sont ravail en séquence ; autrement dit les opérations de lecture d'instrument, d'interprétation des lectures, d'élaboration des stratégies et des tactiques, d'actions sur les commandes ect... se font successivement et non parallèlement, contrairement à ce que l'on croit généralement.
   Pour battre en brèche cette affirmation, on fait par exemple observer que l'homme est capable de prendre des notes tout en écoutant un exposé. En réalité, le discours oral est très redondant ; de nombreux mots et à l'intérieur des mots, des syllabes, sont inutiles à la seule compréhension ; il est donc possible au cerveau de fonctionner en "temps partagé" et de consacrer une partie du temps, non à l'écoute ("lecture des données"), mais à leur interprétation et à leur transcription sur le papier. Il faut noter aussi qu'une fois l'ordre d'écriture d'un mot envoyé par le cerveau, une partie de l'opération se fait en action que nous qualifierons de "réflexe", ce qui laisse le cerveau disponible pour d'autres opérations de "lecture de donnée". Cet exemple nous suggère deux remarques :

   a) la "lecture" d'une donnée par l'oeil, l'oreille ou tout autre capteur humain (contact, pression, effort, accélération, captés par les mains, les canaux semi-circulaires, les membres, l'ensemble du corps, etc...) est un acte volontaire, sauf si cette information se présente sous l'effet d'une alarme intense. Une donnée ne "pénètre" dans le cerveau que sur appel volontaire de celui-ci ; bien souvent d'ailleurs, les alarmes, flashes, bruits, vibrations, accélérations, chocs n'ont pas de signification en soi, mais font abandonner au cerveau ses tâches de routine pour ordonner à tous les capteurs de balayer toutes les données disponibles afin d'identifier l'incident. On notera donc qu'il ne suffit pas de metre un instrument sous le "nez" de l'opérateur pour que l'information qu'il fournit soit "lue" par l'opérateur (bien entendu c'est l'oeil qui est le capteur, le nez étant fort peu utilisé dans le contrôle de processus sauf comme système d'alarme pour les odeurs anormales) ;

   b) un certain nombre d'opérations s'effectue sous forme "réflexe", c'est-à-dire en laissant le cerveau de l'opérateur libre pour d'autres opérations de lecture, interprétation, élaboration, action sur les commandes.
   L'exemple même de ces opérations réflexes est celui du maintien de l'équilibre du corps en position debout ou assise ; ces opérations réflexes résultent d'un entraînement acquis plus ou moins tôt dans l'existence ; citons encore le maintien de la voiture à distance raisonnable du bas côté droit de la route ou le maintien des "ailes horizontales" sur avion en vol à vue. Les actes réflexes n'interviennent pas dans la charge de travail ; ils sont néanmoins très importants à identifier car il ne faut pas que des changements de dispositif de contrôle de processus ne viennent à les interdire.
   C'est en effet pendant ces périodes "réflexes" que le cerveau peut se reposer ou être disponible pour d'autres tâches. Ceci est particulièrement frappant dans le cas de la conduite automobile qui se fait en très grande partie en réflexe. Chacun a pu remarquer que bien souvent on ne se souvient plus si l'on est déjà passé ou non en tel point caractéristique du parcours. C'est grâce à ce type de pilotage que l'on est

en mesure de conduire pendant six à huit heures (alors que les débutants qui n'ont pas acquis ce type de conduite par manque d'entraînement sont souvent incapables de faire plus de cent kilomètres sans être épuisés).
C'est également grâce à ce type de pilotage que l'on peut écouter les informations à la radio, tout en conduisant ; mais on notera que le pilotage réflexe cède le pas au pilotage vigilant dès qu'un incident de parcours a été décelé. Qui n'a pas raté une information, intéressante et attendue, à la radio, parce qu'il est repassé en pilotage vigilant, ce qui a obligé le cerveau à se consacrer en entier à l'opération de contrôle de la voiture et à abandonner l'information auditive ?

2) La deuxième caractéristique de l'opérateur humain est son besoin d'information et sa capacité de prévision.

Le cerveau ressent en général douloureusement l'absence d'information et cherche à en recueillir par tous ses capteurs disponibles.
C'est la raison pour laquelle la mise au secret est si péniblement supportée par le prisonnier ; chacun, dans des circonstances moins dramatiques, a pu connaître l'impression de malaise ressentie lorsque l'on reste plus de quelques instants dans une chambre sourde.
Le besoin de capter de l'information à tout prix a également été observé par chacun dans le métro où l'on ne peut s'empêcher de lire tout ce qui tombe sous l'oeil, les titres du journal du voisin, les avertissements que l'on connaît pourtant par coeur et les panneaux publicitaires (les publicistes savent d'ailleurs combien le passager du métro est réceptif !).
Qui peut résister à l'attrait d'une image télévisée ? (même si le son est coupé et si l'image n'a aucune signification !) ; il faut un effort de volonté pour détourner les yeux !
Chacun a pu également constater qu'il était incapable de fixer plus de cinq secondes un feu rouge le bloquant à un carrefour ; le feu rouge fournit en effet une information nulle ! Aussi le regard a-t-il tendance à chercher de l'information tout autour, information inutile d'ailleurs, mais information. C'est seulement lorsque l'on a capté le passage du vert à l'orange sur l'autre voie que l'on accepte de reprendre la surveillance du feu rouge car l'on est alors en mesure de faire de la prévision ; l'on sait que dans moins de dix secondes le feu repassera au vert et l'attent de l'événement prévisible rend alors l'absence d'information supportable ; mais pour peu que le retard soit différend de la prévision, l'oeil s'égare à nouveau à la recherche d'autres informations.

Cet exemple pris parmi beaucoup d'autres possibles met en lumière la notion de prévision. Cette faculté de l'opérateur humain d'extrapoler la situation actuelle à deux conséquences :

a) une conséquence positive en ce sens qu'elle permet à l'opérateur de consacrer une partie de son attention à la surveillance d'autres paramètres lorsqu'il a constaté que l'un d'entre eux après contrôle, était en train d'évoluer favorablement. Le raisonnement, qui n'est jamais formulé de façon consciente, est le suivant : j'ai effectué une manoeuvre de correction tendant à diminuer un écart et j'ai constaté le début de diminution de l'écart ; j'ai donc quelques loisirs pour surveiller et éventuellement corriger les autres paramètres ; je peux également consacrer ces "loisirs" à quelque tâche auxiliaire (transmission radio par exemple sur avion).

b) une deuxième conséquence, fâcheuse celle-là, consiste à extrapoler audacieusement une situation stationnaire et à croire, par conséquent, qu'il ne se passera rien de plus dans les heures qui suivront.

   Pour peu que cette situation s'accompagne d'une absence d'information (si la situation est stationnaire, les paramètres sont constants et donc l'information fournie par les instruments ou le monde extérieur est nulle), l'opérateur en conclut à une absence d'incident possible et pour remédier au manque d'information, s'en crée artificiellement en pensant à autre chose : il se déroule un film intérieur le séparant totalement du processus à surveiller ; c'est ce que l'on appelle généralement la perte de vigilance.

3) La troisième caractéristique de l'opérateur humain est sa possibilité de compenser l'augmentation de difficulté d'une tâche par une augmentation de charge de travail fourni.

Il est à noter, et cette remarque est d'une importance capitale, qu'en conséquence l'augmentation de difficulté d'une tâche ne se traduit pas par une diminution de performance de l'opérateur. Autrement dit la précision avec laquelle la tâche est accomplie est maintenue indépendante de sa difficulté, l'opérateur augmentant la fréquence des opérations de contrôle donc augmentant la charge de travail au fur et à mesure que croît la difficulté.

Bien entendu, la charge de travail fournie par l'opérateur ne peut croître indéfiniment. Il existe une valeur maximale, dépendant de l'opérateur par ce que nous appellerons son état physique et mental, valeur maximale au-delà de laquelle l'opérateur ne peut plus compenser les augmentations de difficulté ; c'est alors qu'apparaît brutalement une dégradation des performances, l'un au moins des paramètres de fonctionnement n'étant plus maintenu à sa valeur nominale.

Ce type d'expérience est très facile à vérifier sur simulateur : on demande par exemple à l'opérateur de poursuivre sur écran cathodique une cible dont le mouvement est plus ou moins aléatoire et rapide, les fonctions de transfert entre les commandes et le "viseur" sur l'écran étant plus ou moins compliquées. La performance peut être mesurée par la somme des carrés des écarts cible-viseur prélevés à une fréquence fixe. On peut observer, après une période de familiarisation et d'entraînement, que l'on peut augmenter la difficulté de la tâche (augmentation de la "turbulence" de la cible par exemple) sans observer de variation significative de performance ; mais au-delà d'un certain niveau de turbulence, variable avec les opérateurs et avec la fatigue d'un même opérateur, celui-ci "craque" et la performance s'effondre brutalement.

Ces remarques ont une double conséquence :

a) toute augmentation de difficulté de la tâche se traduit par une augmentation de la charge de travail donc par une augmentation de la probabilité de dépasser le seuil au-delà duquel l'opérateur ne peut plus compenser.

Ceci justifie la règle consistant à réduire au maximum la charge de travail des opérateurs pour les tâches de tous les jours et de n'accepter des augmentations de charge que pour des temps courts à faible probabilité. Dans ces conditions le produit "probabilité de se trouver dans telle condition conduisant à un niveau N de charge de travail" par "probabilité, dans ces conditions, de dépasser la charge maximale que peut fournir l'opérateur" peut se trouver raisonnablement faible.

Réduire la charge de travail ne veut pas dire tomber à un niveau tel qu'aucune information n'est fournie à l'opérateur car on peut buter dans ce cas sur l'écueil de la chute de vigilance comme nous l'avons montré plus haut.

b) Une seconde conséquence des remarques précédentes est qu'il est impossible d'estimer la difficulté d'une tâche et corrélativement la charge de travail correspondante nécessaire par simple mesure des performances de l'opérateur.

Ceci est dramatique car bien souvent le fait d'avoir constaté au cours d'essais qu'un opérateur, en général trié sur le volet, reposé, parfaitement informé, est capable de piloter le système, en fait conclure que celui-ci peut être mis entre les mains de tous dans n'importe quelles conditions.

Or il est pratiquement possible avec un bon entraînement de faire accomplir n'importe quelle tâche à un opérateur. Mais ce n'est pas parce qu'un opérateur particulier arrive à accomplir sa tâche dans les conditions toujours artificielles de démonstration, que l'on peut en déduire quoi que ce soit quant à la charge de travail nécessaire.

C'est ainsi que l'on voit proposer sur le marché, des engins dont la conduite nécessite un long entraînement, pour la seule raison que l'on n'a pas réfléchi aux moyens parfois simples, de réduire la charge de travail. Lorsque l'erreur est commise par l'opérateur, tout le monde s'indigne, ne comprenant pas pourquoi cette erreur a pu survenir : c'est de la "faute" de l'opérateur qui n'a pas suivi, sous-entendu volontairement, les consignes.

Une difficulté supplémentaire pour lutter contre ce phénomène vient bien souvent des opérateurs eux-mêmes. Simplifier leur tâche conduit à leur faire perdre une qualification chèrement acquise au prix d'un long entraînement. Cet état d'esprit n'est pas toujours conscient mais il se rencontre trop souvent.

Pour résumer donc les caractéristiques de l'opérateur humain, nous dirons que celui-ci

a) opère en séquence : la charge de travail augmente avec le nombre d'opération à effectuer ;
b) ne supporte pas l'absence d'information, ce qui conduit au problème de la vigilance ;
c) compense les variations de difficulté de tâche par une augmentation de charge de travail sans variation de performances.

LES CAPTEURS HUMAINS

Pour compléter le tableau de présentation de l'opérateur humain il serait nécessaire de décrire les caractéristiques de fonctionnement des divers capteurs humains. Une telle présentation dépasserait le cadre nécessairement restreint de cet exposé.

Rappelons uniquement que les capteurs humains sont les suivants :

l'oeil (vision centrale), l'oeil (vision périphérique), l'oreille externe (captation des sons), l'oreille interne (capteur triaxial d'accélération de rotation et capteur de direction de la verticale apparente), la peau (capteur de contact et d'effort de contact ; permet en particulier de repérer la direction de la résultante des actions de contact du monde extérieur sur le corps, ce qui donne une deuxième information sur la verticale apparente), enfin, sans que l'on sache clairement les identifier, les capteurs d'efforts au niveau des membres (effort de serrage de la main, effort dans les bras et les avant-bras, etc...)

La qualité d'information fournie par le capteur à chaque prélèvement (volontaire, rappelons-le) est élevée pour la vision centrale de l'oeil, plus faible pour l'oreille externe et la vision périphérique et peu précise pour les autres capteurs ; ces derniers ne sont utilisés en général que comme des compléments d'information ou des alarmes, la captation principale étant assurée par l'oeil et l'oreille externe.

LE MODELE DE REPRESENTATION DU PROCESSUS

Au cours de son instruction et en particulier au cours des séances d'entraînement, l'opérateur bâtit progressivement un modèle de comportement du système qu'il a à contrôler. Ce modèle en général schématise très grossièrement le modèle mathématique complet du système. Il réduit les relations (en général différentielles) entre les commandes (entrées du système) et le point de fonctionnement (sorties du système) à des relations entre chaque commande et un paramètre de fonctionnement (ou ses dérivées premières ou secondes) en négligeant les interactions.

C'est à l'aide de ce modèle que l'opérateur, après avoir établi l'analyse de la situation obtenue par observation des divers paramètres de fonctionnement, prévoit l'évolution du système, choisit les commandes permettant de contrôler cette évolution et détermine l'amplitude des actions à entreprendre.

Il y a intérêt, chaque fois que l'on bâtit un nouveau système, à étudier les différents modèles qu'imaginent les opérateurs ; il n'est pas évident en effet que chaque opérateur arrive au même modèle (surtout lorsque plusieurs des paramètres de fonctionnement dépendent de façon plus ou moins complexe de plusieurs commandes). Cette étude doit permettre, d'une part, de déterminer le modèle le plus simple et le plus efficace afin de pouvoir le recommander aux opérateurs au cours des séances d'instruction, d'autre part de modifier si nécessaire le mode d'action de certaines commandes ou de choisir des combinaisons de paramètres de fonctionnement plus directement liées à chaque commande, afin de simplifier le modèle, et donc de réduire la charge de travail.

A titre d'exemple, les commandes agissant par double intégration sont à rejeter : l'expérience montre que l'opérateur humain sait piloter très facilement un paramètre lorsque la commande agit directement sur la valeur du paramètre (commande en position) ou sur sa vitesse de variation (commande en vitesse). La commande en accélération est par contre très difficile à utiliser car il faut agir avec avance de phase pour pouvoir annuler la vitesse lorsque leparamètre atteint la valeur désirée (il faut noter que toutes les commandes directes de force, les plus naturelles à imaginer, sont des commandes à double intégration, sauf lorsque des forces d'amortissement apparaissent).

RETOUR SUR LES REGLES DE PILOTABILITE

Cette analyse rapide du comportement de l'opérateur humain permet alors de dresser une lite, non exhaustive, de règles de pilotabilité destinées à diminuer les risques d'incidents de ce type.

1) Fournir des informations réellement utiles, c'est-à-dire en rapport direct avec la situation réelle du point de fonctionnement par rapport aux limites.

   Cette règle peut sembler évidente ; elle est en réalité bien souvent transgressée.

   L'accident de la centrale nucléaire d'Harrisburg en est l'exemple le plus spectaculaire. Le tableau de contrôle de la centrale comportait un voyant indiquant non pas la position de la vanne de décharge du circuit de refroidissement mais l'ordre de fermeture envoyé par le système de surveillance de la pression du circuit. A la suite d'une défaillance du circuit secondaire, le refroidissement du circuit primaire fut arrêté d'où augmentation de température et de pression dans ce circuit. Le système de sécurité fonctionnant normalement déclencha l'arrêt du réacteur (chute des barres de sécurité), ouvrit la vanne de décharge pour absorber le transitoire de pression et envoya l'ordre de fermeture de cette même vanne une fois le transitoire passé (12 secondes). C'est cet ordre de fermeture qui fut signalé ; or la vanne resta en réalité ouverte ce qui conduisit à la dépressurisation progressive du circuit primaire avec perte d'eau jusqu'à dégager le coeur du réacteur causant les dégâts que l'on sait.

   L'opérateur interpréta la signalisation de vanne comme une signalisation de position fermée et son interprétation de la situation qui a suivi a reposé sur cette hypothèse, évidente pour lui, de vanne fermée

   Les leçons à tirer de l'accident d'Harrisburg méritent un exposé à lui seul ; il ne peut être question de les développer ici. Nous retiendrons seulement qu'une information doit avoir une signification non ambigüe et qu'à partir du moment où un opérateur a interprété de travers une situation, il sera très difficile de faire en sorte qu'il revienne sur ses hypothèses.

2) Ne pas fournir des informations difficiles à interpréter, autrement dit ne pas obliger l'opérateur à effectuer des opérations mentales compliquées pour en déduire la marge par rapport aux limites.

   Un exemple bien souvent rencontré est celui de la présentation d'un paramètre de fonctionnement sous forme digitale et de sa limite sous forme analogique. Qui n'a pas été pris de panique en voyant affiché son train à 18h 52 et en lisant l'heure sur une horloge indiquant sept heures moins dix (en analogique) : la transposition d'un sytème à l'autre demande une charge de travail inutile et les erreurs d'interprétation sont probables.

Par ailleurs, la présentation digitale est néfaste pour le pilotage d'un paramètre car il est très difficile d'en déduire la grandeur de l'écart par rapport à la valeur nominale, le sens de l'écart et le sens de la vitesse de variation de l'écart (alors que tous ces paramètres sont évidents en présentation analogique).

3) Fournir toutes les informations utiles et éliminer soigneusement toutes les informations inutiles.

Là encore cette remarque est évidente mais combien de fois oubliée. Il est en effet néfaste d'augmenter la charge de travail par la lecture de paramètresinutiles, mais la tentation est grande d'ajouter sur le tableau de contrôle tel paramètre sous prétexte qu'il est facilement mesurable et qu'il "peut toujours servir". On peut en effet espérer augmenter ainsi l'information en permettant à l'opérateur de vérifier la cohérence des divers paramètres : cet espoir est en général irréalisé car l'opération de contrôle de cohérence augmente énormément la charge mentale et est très souvent abandonné par l'opérateur. Dans le cas d'Harrisburg, l'opérateur disposait de 19 autres paramètres lui permettant de conclure que la vanne de décharge n'était pas fermée ; il a d'une part interprété de travers quelques uns de ces paramètres pour justifier son hypothèse de vanne fermée, et d'autre part il n'a pas pensé à consulter les autres (cette consultation ne lui est même pas venue à l'esprit : pourquoi vérifier une hypothèse déjà largement confirmée !).

S'il est inutile de présenter les paramètres redondants, il n'est pas contre pas inutile de s'en servir pour un contrôle automatique de la cohérence des informations, et ne présenter à l'opérateur que le résultat de ce contrôle, sous la forme d'un seul paramètre permettant une interprétation facile de la situation.

4) Fournir des informations permettant la prévision.

Les informations de ce type sont les informations sur l'état du système à contrôler et sur le sens et l'amplitude de ses variations. Disposant de ces observations, l'opérateur peut alors prévoir l'évolution du système à l'aide de son modèle interne de représentation.

Il est évident que les opérations mentales de prévision nécessitent une certaine charge de travail de recueil de données, d'interprétation de la situation présente et d'extrapolation dans le temps.

On a quelquefois cherché à réduire cette charge de travail en présentant à l'opérateur, non la situation, mais la position des commandes permettant de corriger les écarts par rapport à la situation nominale. Incontestablement on supprime ainsi toute charge de travail d'interprétation de la situation et de choix des commandes, mais l'on supprime par la même occasion toute possibilité de prévision de l'opérateur ; celui-ci est dès lors obligé de capter en permanence les indications d'ordre de position de commande car il ne peut prévoir l'évolution de ces ordres. On remplace ainsi la charge de travail intelligente d'interprétation par une charge de travail stupide de captation continue d'informations, l'opérateur se trouvant ramené au niveau d'un servomécanisme pur.

C'est là l'occasion de faire la différence, dans les opérations de "contrôle" de processus entre ce que nous appellerons les opérations de pilotage et les opérations de conduite.

Nous appellerons pilotage toutes les actions qui, relevant d'une tactique à court terme, permettent de maintenir ou de faire évoluer un paramètre de fonctionnement, par exemple maintenir les "ailes horizontales" en dépit de la turbulence, maintenir la voiture à distance donnée du bas côté, etc....

Les opérations de conduite relèvent d'une stratégie à plus long terme permettant de gérer le processus. Elles reposent sur les prévisions d'évolutions du processus et relèvent de la comparaison entre prévision et observation.

Les opérations de pilotage peuvent être très facilement automatisées parce qu'elles relèvent d'algorithmes de décision très simple. Dans un contrôle de processus il y a toujours intérêt à soulager l'opérateur des opérations de pilotage en le remplaçant par des automatismes tout en lui laissant le travail noble de conduite pour lequel les algorithmes dedécision sont beaucoup plus délicats ; en effet, il n'est pas facile en général de prévoir toutes les situations possibles, donc de prévoir toutes les réponses nécessaires. A titre d'exemple, il est facile de guider automatiquement un missile sur un objectif militaire, mais décider d'interrompre le tir car le véhicule arbore une croix rouge, puis décider de le reprendre parce que les occupants du véhicule se révèlent être des combattants et non des blessés, ne peut être confié à un automatisme ! Par contre il importe de supprimer à l'opérateur toutes les tâches subalternes de pilotage pour lui laisser l'esprit libre pour l'analyse de la situation et le choix des stratégies.

5) Fournir de l'information

Nous avons déjà insisté sur cette caractéristique de l'opérateur humain qui ne peut supporter l'absence d'information.

Or, bien souvent l'automatisation des processus conduit l'opérateur à constater que l'état nominal du système est correctement maintenu ; l'ensemble des paramètres de contrôle est figé ; il ne se passe rien. Mais l'on compte sur l'opérateur pour intervenir au cas où une panne surviendrait.

Or, il est illusoire de compter sur une intervention possible de l'opérateur si la panne est rare et ceci en raison de deux des caractéristiques de l'opérateur humain.

L'absence d'information le conduit à "penser à autre chose", d'où une perte de vigilance. Par ailleurs, le constat de permanence de l'état du système l'amène à prévoir abusivement le maintien de l'état : il ne croit plus à la possibilité d'une panne. L'apparition de celle-ci risque donc de ne pas être perçue, parce que l'opérateur pense à autre chose et qu'il n'y croit pas !

Fournir de l'information lorsque le processus est stable demande de l'imagination.

A titre d'exemple, lors des approches automatiques des avions, l'ensemble des paramètres de contrôle classiques du vol : vitesse, assiettes, écarts par rapport à la trajectoire nominale etc... est figé et n'apporte qu'une information nulle au pilote. Un écran cathodique couleur présentant l'horizon, la piste (perspective calculée à partir de la position et des assiettes de l'avion) et la trace au sol du vecteur vitesse, fournit par contre une information qui retient l'attention du pilote par attrait d'une image qui évolue dans le temps (la piste "grossit" au cours de l'approche) ; l'absence de cohérence entre les informations indépendantes de position de l'avion, se traduisant par une dislocation du schéma représentant la piste, ne peut plus échapper au pilote qui peut alors commander la remise de gaz (la position de l'avion doit être mesurée par deux systèmes indépendants, chaque système étant à l'origine du tracé de parties complémentaires du schéma de piste). Le déplacement de la trace au sol du vecteur vitesse, hors du seuil de piste, est de son côté, signe de panne du système de guidage et ne peut passer inaperçu du pilote qui reprend alors le contrôle manuel de l'approche alors qu'il est déjà en possession de l'analyse de la situation (l'apparition d'une alarme avec une présentation classique nécessite une analyse préalable de la situation, retardant d'autant la reprise en pilotage manuel).

6) Fournir des alarmes qui ne passent pas inaperçues de l'opérateur.

Il faut distinguer deux types d'alarmes ; celles qui indiquent un fonctionnement anormal ou une panne d'un système et celles qui indiquent l'approche d'une limite pour l'un des paramètres de fonctionnement.

Les premières ne sont utiles que dans la mesure où elles conduisent l'opérateur à une prise de décision ou une action de sa part. Les secondes sont destinées à réduire les probabilités d'incidents de pilotabilité dans la mesure où elles complètent l'information de l'opérateur sur la proximité d'une limite.

L'expérience montre que plus la charge de travail de l'opérateur est élevée plus le niveau des alarmes doit être intense pour être perçu et interprété comme une alarme. C'est l'histoire classique, mais très caractéristique, du pilote qui prévient la tour de contrôle qu'un signal sonore intense rend inaudible la réception radio alors que le contrôleur essaye en vain de l'avertir que le train d'atterrissage n'est pas sorti (d'où le déclenchement de l'avertisseur sonore !).

La philosophie d'établissement d'un système d'alarme est très délicate à établir. Les quelques règles suivantes peuvent néanmoins servir de guide :

a) Limiter soigneusement le nombre d'alarmes au strict nécessaire car une alarme doit être rapidement perçue et interprétée (le panneau d'alarmes lumineuses ne doit pas prendre l'aspect d'un "arbre de Noël").

b) Choisir judicieusement le seuil de déclenchement d'une alarme de proximité de limite. Une alarme qui se déclenche trop tôt à l'approche d'une limite risque de fonctionner trop souvent et perdre par là son caractère de gravité ; par contre, déclenchée trop tard elle perd de son efficacité, car elle ne laisse plus à l'opérateur le temps de réagir. Chaque fois que la technologie le permet il est intéressant de remplacer un système d'alarme par un système automatique d'interdiction de franchissement de la limite (comme nous l'avons vu un tel système est utile pour diminuer les risques de pilotabilité mais est inefficace pour les risques de manoeuvrabilité).

c) Plutôt que de venir sous forme d'une information supplémentaire, une alarme peut se présenter comme la suppression d'une information essentielle (à condition que cette information puisse être rétablie rapidement par une action volontaire de l'opérateur). Par exemple, plutôt que de signaler un train d'atterrissage non sorti par une alarme lumineuse ou sonore qui peut ne pas être perçue car elle s'ajoute à une quantité d'informations déjà trop grande, il peut être judicieux de cacher l'indicateur de vitesse, instrument que le pilote ne peut ignorer lors d'une approche.

7) Limiter le nombre d'actions et faciliter l'élaboration des tactiques et des tratégies.

La limitation du nombre d'actions peut s'obtenir, comme nous l'avons vu, en automatisant toutes les actions tactiques simples où l'opérateur n'aurait qu'un rôle de servomécanisme et en lui laissant les opérations de conduite, qui en général, ne nécessitent que peut d'actions sur les commandes.

L'élaboration des tactiques et des stratégies passe par une compréhension de l'état du système et de son évolution. La compréhension rapide d'un état ne peut se faire, en général, pour les systèmes un peu complexes, qu'à partir de représentations analogiques, la représentation digitale étant réservée à une analyse précise, n'exigeant pas d'action rapide.

Avec l'introduction massive de l'informatique dans les contrôles de processus, on a vu apparaître des présentations d'informations sous forme d'états tabulés ; ces états permettent a posteriori de suivre de façon très précise l'évolution passée de l'état du système, mais ils ne permettent en aucun cas de suivre son évolution instantanée et d'avoir une idée globale et rapide de l'évolution passée. L'imprimante, périphérique classique, doit être éloignée de la zone de contrôle, car elle ne peut servir que de "mouchard" et doit être remplacée par des écrans cathodiques fournissant l'évolution dans le temps des paramètres de fonctionnement à contrôler et des limites correspondantes (sous forme de courbes et non sous forme digitale) ; l'opérateur doit disposer de claviers de commande permettant également de faire varier la présentation (échelles, paramètres regroupés, fonctions de paramètres, rappel de données datant de quelques heures etc...).

C'est ce type de présentation d'informations qui devrait par ailleurs résoudre le problème de manque de vigilance par absence d'informations.

8) Etudier soigneusement le sens d'action et le mode d'action des commandes.

Ces remarques relèvent du pur bon sens. Il ne faut toutefois pas oublier que l'amélioration d'une commande, c'est-à-dire la simplification de la relation entre commande et paramètre commandé exige parfois des modifications technologiques coûteuses dont l'intérêt ne paraît pas toujours évident au moment de la conception (celà coûte trop cher, l'opérateur n'aura qu'à s'entraîner et à faire attention !) ; c'est ainsi que les commandes des grues se réduisent à une forêt de leviers identiques dont chacun a une action différente et non évidente sur le déplacement de la charge !

Il faut se rappeler enfin que le choix d'une commande ne peut se faire uniquement sur une planche à dessin ; il est impératif de faire l'essai des solutions possibles, de préférence sur simulateur ou sur des machines prototypes, car seule l'expérience réelle avec un opérateur averti du problème peut fournir la réponse (attention aux opérateurs qui cherchent à mettre leur virtuosité en évidence en élaborant un système de commandes qu'ils sont seuls à maîtriser !).

La conception des commandes relève d'une branche de l'ergonomie que nous appèlerons l'ergonomie mécanique et qui traite des formes, tailles et positions des commandes compatibles avec les dimensions et les possibilités de déplacement des membres ; cette discipline est très utile mais ne constitue pas à elle toute seule l'ensemble de l'ergonomie, ainsi qu'on a bien souvent tendance à le croire ; l'ergonomie mentale dont nous avons abondamment parlé jusqu'ici est tout aussi importante.

LES SIMULATEURS

Nous avons remarqué que seule est valable l'expérimentation "vraie grandeur" des systèmes de présentation et de commande sur des systèmes réels ou des simulateurs, ce qui nous amène à évoquer le problème de la conception des simulateurs et des méthodes d'essais permettant de juger de la charge de travail de l'opérateur.

Pour qu'une simulation soit parfaite, il faut que la tâche imposée à l'opérateur soit identique à la tâche réelle, qu'il dispose des mêmes moyens d'action sur le système à "contrôler" (commandes) et des mêmes informations sur l'état du système et de son évolution.

On constate rapidement que le meilleur simulateur est le système lui-même ; néanmoins la simuation s'impose d'une part pour réduire les coûts (même un calculateur très "sophistiqué" coûte moins cher qu'un Airbus, une centrale nucléaire ou un navire pétrolier), pour réduire les risques d'expérimentation (un crash à l'atterrissage ou un échouage sont plus confortables au simulateur), pour augmenter le nombre possible d'expérimentation (le calculateur peut ramener l'avion en moins d'une seconde à la position de début d'approche, prêt pour un nouvel essai, alors que la même manoeuvre réelle demande une dizaine de minutes pour être exécutée), pour permettre l'expérimentation dans des conditions extrêmes, identifiables et reproductibles (les turbulences fortes sont rares et si l'on veut comparer plusieurs systèmes de commandes, on n'est jamais sûr que les états de l'atmosphère étaient identiques).

Pour des raisons de coût et quelquefois, nous le verrons plus loin, pour des questions de principe, il n'est pas toujours possible de satisfaire les trois critères d'identité de tâche, d'identité de commande, d'identité d'information. Les quelques réflexions qui suivent peuvent aider à valider les approximations nécessaires.

Il peut sembler que le premier critère d'identité de la tâche soit le plus facile à satisfaire : il suffit de demander à l'opérateur d'effectuer la "même chose" ! En réalité le problème se complique du fait que l'opérateur a bien souvent du mal à oublier qu'il travaille sur simulateur et que dans ces conditions les incidents les plus graves sont sans conséquence. Pour résoudre ce problème psychologique, il faut :

a) rendre l'environnement de l'opérateur aussi réaliste que possible : l'absence de certains détails que l'on ne pense pas toujours à reproduire, comme une légère vibration, un bruit de conditionnement d'air, un bruit de moteur, voire même une odeur, peut empêcher l'opérateur de "s'y croire" ; seuls les opérateurs ayant une bonne expérience du système à simuler peuvent signaler ces détails à ne pas oublier. Par ailleurs, seuls les mêmes opérateurs, par souvenir des conditions réelles peuvent recréer les conditions psychologiques leur permettant d'oublier la simulation. Un pilote chevronné "ressentira" les accélérations sur un simulateur fixe parce que, par réflexe acquis en vol, il contractera ses muscles abdominaux sur informations d'évolutions provenant de la visualisation et de ses actions sur les commandes. Par contre, un opérateur ignorant tout du vol réel ne ressentira rien.

Il est donc indispensable de recruter les opérateurs de simulation parmi les opérateurs ayant une bonne qualification sur le matériel réel, tout en prenant garde à ce qu'ils soient psychologiquement préparés à accepter la simuation (certains pilotes d'essais n'arrivent jamais à s'y faire).

Par ailleurs, un opérateur ignorant la conduite réelle du système risque d'utiliser les petits défauts de la simulation comme informations complémentaires, parce qu'il ne les identifie pas comme étant des défauts, alors qu'un opérateur entraîné les ignorera volontairement. On peut ainsi voir les ingénieurs chargés d'un système de simulation, mais ignorant la conduite réelle faire preuve d'une dextérité vexante pour les opérateurs chevronnés : en réalité ils pilotent un autre système que le système réel avec des informations différentes, qui n'existent pas dans la réalité.

Ces remarques font ressortir le fait que l'on ne doit pas espérer faire apprendre à piloter sur un simulateur. Un simulateur peut par contre, aider un pilote déjà confirmé à connaître les particularités d'un nouveau système et de entraîner à l'application de procédures particulières. Dans le cas d'un simulateur d'entraînement, il faut donc s'appliquer à reproduire fidèlement la disposition des commandes et des instruments de contrôle pour que l'opérateur puisse acquérir les "automatismes" valables pour le réel.

b) Rendre les organes de commandes aussi réalistes que possibles. C'est certainement le critère le plus facile à respecter. Il faut toutefois distinguer ici les problèmes posés par les simulateurs d'entraînement et les simulateurs d'étude. Comme nous l'avons signalé ci-dessus, il est indispensable de respecter strictement la forme, la disiposition des commandes et les lois d'efforts aux commandes pour un simulateur d'entraînement sans quoi les automatismes acquis en simulation ne seraient pas utilisables dans le cas réel.

Par contre, pour les simulateurs d'étude, le respect du critère d'identité des commandes peut être plus lâche ; il suffit que les commandes soient d'un modèle réaliste. Le pilote sera moins troublé par la présence d'une poignée de manche nouvelle (pourvu qu'elle soit réaliste) que par l'absence de bruit dans la cabine.

C) Rendre les informations de pilotage et de conduite aussi proches que possible de la réalité.

Les informations fournies par les instruments sont très faciles à reproduire. Le problème est plus délicat en ce qui concerne les informations provenant de l'environnement.

De nombreuses solutions technologiques sont disponibles lorsqu'il s'agit de représenter ce que l'opérateur voit du monde extérieur : projection sur écran d'images prises par une caméra se déplaçant par rapport à une maquette, projection d'ombres chinoises etc... Tous ces dispositifs ne fournissent en général qu'une vision sans relief ce qui est suffisant lorsqu'il s'agit de simuler la vision d'un paysage relativement éloigné : le déplacement relatif des objets suffit pour restituer l'impression de relief. Par contre, lorsqu'il s'agit de représenter le champ visuel proche, l'absence de relief est très nettement ressenti et perturbe l'opérateur ; des progrès restent à faire dans ce domaine.

La représentation des forces d'inertie pose un problème de principe impossible à résoudre; seule la reproduction de la trajectoire réelle permettrait de faire subir les forces d'inertie réelles à l'opérateur. Il semble heureusement que l'homme soit plus sensible aux variations de forces d'inertie qu'à ces forces elles-mêmes. Avec des mouvements d'amplitude limitée, il est donc possible de rendre compte de ces variations : les mouvements de la cabine sont ceux de la machine à simuler, filtrés par un filtre passe-haut, le retour en position moyenne étant assuré avec des accélérations inférieures au seuil de perception de l'opérateur.

COMMENT MESURER LA CHARGE DE TRAVAIL ?

Reste maintenant à interpréter les essais effectués soit au simulateur, soit sur véhicules ou système réel.

Nous avons vu que les variations de difficultés d'une tâche ne se traduisaient pas par une variation des performances de l'opérateur : celui-ci compense une augmentation de la charge de travail fournie, mais aucune manifestation extérieure ne permet de le déceler sauf lorsque la compensation devient impossible ; si en effet la charge de travail nécessaire dépasse la charge de travail que peut fournir l'opérateur, ce dernier abandonne certaines tâches et la performance s'en ressent. Sans entrer dans le détail, on peut observer que l'opérateur répartit les paramètresà surveiller en trois classes : ceux qui relèvent de la conduite du système (objectif à long terme), ceux qui relèvent de la sécurité à court terme (se présenter en bonne position et vitesse pour l'atterissage), ceux qui relèvent de la sécurtié instantanée (le franchissement de la limite correspondante conduit à un accident immédiat : incidence). Lorsque la difficulté de la tâche augmente l'opérateur, ne pouvant plus, au-delà d'un certain seuil compenser par augmentation de charge de travail, abandonne progressivement la surveillance des paramètres de sécurité à court terme ; lorsqu'il ne peut même plus assurer la surveillance des paramètres de sécurité instantanée la catastrophe ne tarde pas à survenir.

C'est l'abandon de la surveillance des paramètres de sécurité à court terme qui se traduit par une variation caractéristique des performances de l'ensemble système-opérateur, puisque ce dernier ne parvient pas à atteindre l'objectif de sa tâche. Lorsqu'à la suite d'une augmentation de la difficulté, on observe une variation brusque de performances, on peut en conclure que l'opérateur a atteint la charge maximale qu'il peut fournir. Mais l'observation extérieure de l'opérateur ne permet pas de différencier des charges de travail inférieures.

Certains auteurs ont proposé de confier à l'opérateur une tâche auxiliaire aisément quantifiable et d' augmenter cette charge auxiliaire jusqu'à le saturer (seul phénomène observable) : la charge de travail principale est alors d'autant plus petite qu'est grande la charge auxilaire conduisant à saturation.

Ce principe de mesure repose hélas sur le principe faux de l'additivité des charges de travail. En réalité l'exécution d'une double tâche exige plus que la somme des charges de travail nécessaires à chaque tâche ; il faut tenir compte de la charge de gestion et de coordination des deux tâches (quand et comment passer de la surveillance d'une des tâches à la surveillance de l'autre).

Par ailleurs, la quantification de la tâche auxiliaire pose de nombreux problèmes ; il n'y a aucune raison pour que la charge de travail d'une tâche, même élémentaire comme l'extinction de voyants à allumage aléatoire, soit fonction linéaire des paramètres physiques caractérisant cette tâche.

Force donc est de reconnaître que la méthode de la double tâche ne peut fournir de renseignements valables.

De nombreuses tentatives ont été faites par ailleurs pour corréler des paramètres psysiologiques et la charge de travail. Ces corrélations existent sans conteste : diamètre de la pupille, variabilité du rythme cardiaque, etc... varient avec la charge de travail ; mais ces mesures ne peuvent fournir que des indicateurs de variation instantanée de charge de travail et en aucun cas constituer des mesures absolues et reproductibles, car elle dépendent de beaucoup trop d'autres facteurs et sont beaucoup plus sensibles à ces facteurs qu'à la charge de travail.

Il faut noter toutefois que l'analyse fine des variations de ces paramètres psysiologiques et l'étude de leurs corrélations peuvent fournir un indicateur de charge : des recherches recentes menées dans ce sens en France laissent espérer des résultats intéressants.

Le seul outil actuellement réellement disponible est l'estimation par l'opérateur lui-même de sa charge de travail, par comparaison avec des charges de travail nécessaires pour des tâches de référence. L'expérience montre que des opérateurs, bien au fait du problème de simulation, sont capables de fournir des estimations fiables dans la mesure où ils ont bien compris qu'il ne s'agit que d'évaluer la charge de travail et non de donner un avis sur la sécurité qui en résulte.

Il nous faut enfin citer une tentative intéressant développé depuis un peu plus de cinq ans par l'ONERA et dont le but est de bâtir un modèle mathématique simulant l'opérateur humain dans le cas particulier du pilote de transport effectuant une approche sans visibilité. Le but essentiel de ce modèle est de vérifier que le comportement moyen du modèle, placé face à l'ensemble le plus diversifié possible des conditions rencontrées en vol, réagit de façon la plus voisine possible des opérateurs humains. Une telle vérification à été faite dans de nombreux cas, mais bien des efforts restent à faire. Elle permet cependant, sauf démontration contraire ultérieure, de justifier un certain nombre d'hypothèses de comportements élémentaires invérifiables directement (fonctionnement en séquence de l'opérateur, méthode de lecture des informations, heuristiques de décision, etc...).

Une fois démontrée la validité de ces hypothèses il sera possible d'utiliser le modèle ainsi défini, couplé au modèle de comportement des avions et d'en déduire par mesure directe les quantités d'informations entrantes, sortantes et traitées dans le modèle et d'atteindre ainsi une mesure objective de la charge de travail nécessitée par une tâche donnée. Cet objectif est encore lointain mais il a quitté le domaine de l'utopie pour entrer dans le domaine du probable, sinon du certain.

Nous avons essayé de faire ici le bilan de nos connaissances sur l'opérateur humain et d'en tirer quelques régles de bon sens. Bien du travail reste à faire mais il est certain que si seulement ces quelques régles n'étaient pas oubliées, si les concepteurs de systèmes pensaient au départ à adapter la machine à l'homme et non l'homme à la machine, bien des erreurs, des "fautes de pilotages" seraient évitées.

Il est toutefois rassurant de noter que la notion d'ergonomie de conception a acquis droit de cité dans les bureaux d'étude et que l'ergonome est plus considéré comme un partenaire utile que comme un collègue genant.

DISCUSSION AVIONICS PANEL SPRING MEETING
On
ADVANCED AVIONICS AND THE MILITARY AIRCRAFT MAN/MACHINE INTERFACE
26-29 April, 1982

SESSION Nr. 1 INTRODUCTORY PAPERS-Chmn Dr. G. Hunt, UK

Paper Nr. 1
Title : HUMAN FACTORS CONSIDERATIONS ON THE PERCEPTION OF COLOUR IN THE AIRBORNE ENVIRONMENT
Author : Dr. F. G. Cumming, presented by Dr. J. Laycock
Speaker : Dr. G. Hunt
Comment : Possible advantages which might be derived from improving the man-machine interface in aircraft would be the reduction in flying time required to maintain flying competence, and the ability to get good performance from a wider population of pilots. Do the techniques described by Dr. Laycock offer possibilities of achieving these advantages?

Response : Many of the technologies described were designed to extend the pilot's capability with the result that training requirements would be increased rather than decreased This is particularly true of certain electro-optical sensor options. My personal feeling is that the introduction of more graphic and less tabular information on electronic displays could do much to improve the pilot's workload especially when accompanied by an improved keyboard. This could perhaps reduce training requirements.

Paper Nr. 2
Title : OVERVIEW OF 32nd GCP SYMPOSIUM
Author : Prof Dr Ing K H Doetsch
No Questions

Paper Nr. 3. THE HUMAN FACTOR IN SYSTEMS CONTROL
Author : Gen. J C Wanner
Speaker : Wg. Cdr. D. C. Schuller
Comment : General Wanner, could I suggest that there is one other factor to be considered in the design of cockpit displays and controls and that is the load shedding mechanism of the human being. In a high workload environment a pilot, recognizing that he might be overloaded, has both a practical and psychological need to be able to reduce workload safely. In reducing his workload, he is trained to concentrate on essentials. Therefore he first sheds communications, then navigational tasks and reverts to the basic task of safe flight path control. When the workload reduces he resumes the other tasks. It also follows that modern displays must always retain adequate information for basic flight path control.

Response : Je suis parfaitement d'accord avec vous, vous trouverez dans le papier ecrit ce type de remarques, où effectivement on peut constater que l'opérateur, pour être capable de supporter une charge de travail croissante, est amené à modifier effectivement sa strategie, au debut, éffectivement on cesse les communications, c'est très caractéristique, j'ai fait de nombreuses enquêtes sur des accidents, et l'on constate, que même des pilotes d'éssais entrainés au moment où vraiment l'accident est imminent, en général on n'obtient aucun message, sauf dans des cas très rares, je ne connais qu'un seul cas où l'équipage a effectivement envoyé un message et encore dans ce cas là, l'équipage avait compris qu'il n'y avait plus d'actions possibles, qu'ils ne pouvaient plus rien faire, que l'avion était perdu, qu'ils ne pouvaient plus que s'écraser au sol, et là, effectivement il y a eu un message de l'équipage, dans tous les autres cas, il n'y a pas eu de message. Dans mon cas particulier, je sais bien j'ai eu une minute un quart de vrille à plat impossible à contrôler, et je n'ai envoyé strictement aucun message pendant cette minute un quart. Donc, il est vrai que l'on abandonne d'abord la communication, ensuite, on abandonne les problèmes de navigation pour s'en maintenir aux problemes de pilotage. Je pense même qu'on peut faire plusieurs graduations dans le pilotage, par exemple, que lorsque l'on est en approche, on peut au début laisser tomber, si j'ose dire, le fait d'arriver à l'entrée de bande, on cherche surtout à maintenir l'incidence et les zones horizontales, il y a donc une certaine graduation ou la stratégie change progressivement en abandonnant les charges de travail considerées comme moins importantes, et éffectivement, quand on n'arrive meme plus a controler l'incidence et l'assiette générale de l'avion, et bien là en général cela ne peut plus se traduire que par le siège.

HUMAN FACTORS CONSIDERATIONS ON THE PERCEPTION OF COLOUR IN THE AIRBORNE ENVIRONMENT

by

C. P. Gibson
J. Laycock
Royal Aircraft Establishment
Farnborough, Hants, UK

SUMMARY

With the advent of advanced CRT technology it is now probable that CRTs will become the prime, and certainly the most flexible, display medium in the modern cockpit. The human factors aspects of the use of colour are crucial if optimum advantage is to be made of this coding dimension since many areas remain relatively unexplored.

This paper presents a short review of the various CRT technologies in relation to the CIE system of colour measurement and discusses the applications and possible pitfalls associated with the use of colour as a means of encoding information.

The basic mechanisms, and some of the anomalies, of colour perception are presented and illustrated. These include psychological effects such as the change of perceived hue with luminance, the perceived changes caused by simultaneous colour contrast and the effects of chromatic adaptation.

1 INTRODUCTION

The modern military cockpit is continually becoming more sophisticated offering the pilot an ever growing range of facilities. As a consequence the pilot is increasingly required to make complex cognitive decisions based on his interpretation of the information provided by the aircraft sensors and displays. As the pilot has a limited amount of mental processing resource at his disposal it is essential that information relating to the airframe and its systems is provided in a manner which minimises the amount of cognitive processing if he is not to become resource limited.

Selective use of coding dimensions can reduce the amount of processing resource required to interpret displayed information, and with the technology to implement colour as a coding dimension becoming readily available in recent years, interest has been steadily growing in the use of colour in electronic displays in both civil and military environments. The use of colour can undoubtedly be beneficial in certain circumstances, but it is essential that the properties and peculiarities of the perceptual system are considered in its implementation.

2 APPLICATIONS

There are many ways of using colour to improve the appearance of displays and polychromatic displays undoubtedly possess attention getting qualities. However, it is often the case that operator performance using a polychromatic display is no better or even worse than when using comparable monochromatic device, even if the polychromatic display is 'preferred' by the operator[1]. It is apparent that the benefits which can be gained from the use of colour are rather situation specific. Demonstrable performance gains, using a particular polychromatic display may be reversed if the format or the conditions of usage are changed[2]. In addition, there is at present no unitary standard for the use of colour in displays, design decisions usually being made on a subjective basis. Hence it is probable that confusions will arise when an individual is required to operate more than one system.

There are two major applications of colour for use in displays. These are (1) colour coding; and (2) contrast enhancement.

(1) Colour Coding - The use of colour as an information code can facilitate the formation of an attentional 'set'. By the use of such a 'set' the pilot can effectively tune his visual search mechanisms to the detection of certain classes of information (*ie* colour codes) enabling him to reduce the time taken to detect signals and also to reduce the amount of resource needed to subsequently process the information. It is important however not to employ too many colours, since the effectiveness of attentional 'set' will reduce as the number of coded sub-groups increases, although training and experience may increase the effectiveness.

In this context colour is used either to lable information sub-groups or to display status information. An example of a display where colour labelling could be used to reduce the effect of clutter is shown in Fig 1. Fig 2 illustrates one type of display where colour could be used to assist in the effective display of status information. Here colour may be used as a code indicating a change in state to signify danger or to designate different areas of a plan or system. The use of colour in this context can reduce the effects of display clutter and assist in easy discrimination of particular classes of item, different colours being assigned to information sub groups such that they may be more easily discriminated.

(2) Contrast Enhancement - The use of colour in displays of the outside world can enhance the capabilities of the perceptual system to detect and process information. A drawback of monochromatic displays is that information is displayed solely by modulation of luminance. The limits of perception are thus defined by the modulation obtainable from that display where modulation is usually defined as:

$$\frac{L_{max} - L_{min}}{L_{max} + L_{min}}$$

thus an increase in the modulation the display is capable of producing will usually increase the number of 'grey shades' and the amount of information which can be subsequently perceived. The visual system operates in an approximately logarithmic fashion such that just noticeable differences (JND's) in luminance increments represent continually larger step increases in luminance. Hence the number of 'grey shades' which can be obtained is limited in practice because of the very large increase in luminance required at high display output levels. The use of colour contrast, as opposed to luminance contrast, allows different information zones such as map contours or area boundaries to be detected independently of their displayed luminance. In the extreme it is obvious that two areas of equal luminance but different chromaticity (*eg* red and green) can be perceived as different whereas they would be indistinct if their chromaticities were also equal. So the use of colour contrast in addition to luminance contrast provides an extra dimension along which information can be processed.

We may differentiate between displays which attempt to produce a scene as closely as possible resembling that of the outside world and those in which the chromaticities have been artificially imposed. Thus it would be possible to superimpose information from different sensors (*eg* visual and infrared) which had been assigned different chromaticity codings, to highlight displayed information which was previously not perceivable.

3 COLOUR TERMINOLOGY AND THE CIE SYSTEM

Colour is a term which is often used indiscriminately to indicate some general properties of a psychological sensation. Furthermore, our vocabulary of commonly used colour names is inadequate to precisely describe any one particular colour and it is therefore necessary to have some precise language and system for its specification.

The complete description of a colour requires some definition of the chromaticity and its luminance since when the luminance of a stimulus having a certain chromaticity changes it has theoretically changed its colour. We may define the word colour as: that aspect of visual perception (characteristic of a visible radiation) by which an observer may distinguish between two fields of view of the same size, shape and structure, such as may be caused by differences in the spectral composition of the radiation concerned in the observation.

We may consider there are three properties which define any colour.

(1) Hue.

(2) Saturation.

(3) Luminosity. (Brightness).

Chromaticity is represented as a combination of hue and saturation.

Hue is defined as the "attribute of visual sensation which has given rise to colour names such as blue, green, red, yellow, purple etc but excluding colours in the white, grey, black region". We may consider hue to be the subjective correlate of "dominant wavelength".

Saturation is defined as the "attribute of visual sensation which permits a judgement to be made of the proportion of pure chromatic colour in the total sensation". We may consider saturation to be the subjective correlate of "metric purity".

Luminosity is defined as the "attribute of visual sensation according to which an area appears to emit more or less light". This is related to the objective quantity "luminance". The luminosities of equal energy monochromatic emissions are not equal because the visual system is differentially sensitive to light emissions of different wavelengths. The normalised luminance efficiency function of the eye is given in Fig 3, where it is shown that the eye is maximally sensitive to emissions in the green region of the spectrum, peaking at 555 nm, and increasingly less efficient towards the red and blue ends of the spectrum.

The system of colour measurement in most general usage is that of the Commission Internationale de l'Eclairage (CIE) where the chromaticities of colours are represented on a two dimensional cartesian co-ordinate system and referenced by their x, y chromaticity co-ordinates (Fig 4). The x, y co-ordinates of any chromaticity are derived from its tristimulus values which represent the amount of each of three primaries in a trichromatic system needed to produce a colour match. In a trichromatic system it is not possible to match all chromaticities with an additive combination of the three primaries and hence one of the values may occasionally have to be negative. In order to overcome this problem the CIE chose primaries (X, Y, Z) such that this no longer occurs. The CIE primaries were obtained from linear transformations of the original Wright[3] and Guild[4] data and are unreal in the sense that they are not capable of being produced, but they may be thought of as representing a red, green and blue, which are more saturated than any physical colour. In addition, the Y primary has function identical to the luminance efficiency curve (Fig 3), so that the relative luminance of the colour is indicated directly by the Y tristimulus value. Fig 5 gives the tristimulus values for the CIE 1931 standard observer where any colour may be produced by appropriate addition of the three primaries.

The chromaticity co-ordinates (x, y, z) are obtained from the tristimulus values (X, Y, Z) as follows:

$$x = \frac{X}{X + Y + Z}$$

$$y = \frac{Y}{X + Y + Z}$$

$$z = \frac{Z}{X + Y + Z}$$

In addition $x + y + z = 1$.

Since the sum of the co-ordinates is unity, only two of these can be independent, and chromaticities can therefore be uniquely specified using only two of the co-ordinates.

It is usual to specify chromaticities using the x and y chromaticity co-ordinates, and the complete gamut of chromaticities may be represented in a graphical form on cartesian axes as already referred to in Fig 4. In this diagram the spectrum locus, *ie* the line representing chromaticity co-ordinates of every saturated monochromatic emission in a visual spectrum is shown between 380 nm and 780 nm. The line joining these two points (*ie* the Alychne) encloses the spectrum locus to form the entire colour space as defined by the CIE. Any spectral emission can therefore be precisely located within the CIE chromaticity space. The complete specification of a colour however requires reference to be made to the luminance of the emission and thus a colour is completely specified by x, y, Y where x and y are the chromaticity co-ordinates and Y indicates the luminance factor of that particular source. Thus a total colour space is truly three dimensional as shown in Fig 6 where the third dimension indicates luminance. Thus the apex A represents zero luminance, where no colours exist at all.

In the chromaticity diagram we may conceive of hue as the perceptual change in chromaticity resulting from a source moving around the circumference of the diagram, and saturation as the change resulting from the movement of a source on a line between the white point and a point on the spectrum locus, the most saturated colours having a purity of one.

One of the inherent advantages of such a system is that, because the tristimulus values of a colour mixture are the sums of the tristimulus values of the individual components, the chromaticity of an additive mixture of any two chromaticities may be represented as lying on a line joining them together. The actual values of the resultant depend, of course, on the relative luminance contributions of the individual components.

4 DISPLAY TECHNIQUES

Although there are many forms of colour displays there are at present only two types of colour CRT display which may be considered for use in the airborne environment. These are (1) the penetron display and (2) the shadow mask display.

(1) The penetron CRT employs a two-layer phosphor with each phosphor having a different chromaticity these usually being in the green and red regions of the colour space. The phosphor which is energised and hence the colour which is produced, is dependent upon the EHT voltage. Thus it is possible, as described above, to traverse a line across colour space bounded by the chromaticities of each phosphor. Fig 7 illustrates how most penetron displays will produce chromaticities traversing green, yellow, orange and red portions of colour space.

(2) The shadow mask display, on the other hand, uses a three phosphor system. The phosphors are usually red, green and blue, and are deposited on the face of the screen in a fine matrix of alternate phosphors, such that a repetitive sequence of triads (areas of red, green and blue phosphor dots) is formed. Behind the face of the screen is a perforated metal mask located with one hole for every triad. The three electron guns. are then focused on the holes in sequence, illuminating the required phosphor dots of each triad as the screen is scanned. The perception of a continuous picture thus relies on the ability of the visual system to integrate the discretely illuminated phosphor dots on the screen. Since the shadow mask system uses a three component phosphor it follows from preceding arguments that the colour space covered by such a system is in the form of a triangle whose vectors terminate at the chromaticity co-ordinates of the individual phosphor components (Fig 7). Also shown in Fig 7 are some of the more common phosphors and it can be seen that the saturation capable of being produced by a CRT is limited

particularly around the complementary points, *ie* on the green-blue vector. In addition, the effect of any white light (*eg* sunlight) on the display will be to move the perceived chromaticities towards that white point.

5 PERCEPTION OF CHROMATIC INFORMATION

The CIE system, and others derived from it, allows an objective specification of colour based on the colour matching performance of a number of people having 'normal' colour vision. The collective results of these people represent the performance of the CIE standard observer.

Colour space tells us very little about the performance of the perceptual system however. It does not have a one-to-one correspondence with colour perception; that is, it does not reveal anything about the psychological distances between colours or the equality of saturation changes in differing hues. The perceptual system, whilst predictable under strictly controlled conditions, may sometimes perform in an unexpected fashion under other conditions and it is important to understand the performance under different conditions in order to aniticipate possible problem areas, when using colour as a means of enhancing the reception and processing of information.

Although the processing of chromatic information in the visual system is still not properly understood a general model[5] of how it might occur is presented in Fig 8. The initial processing of information occurs in the retina where there are two kinds of receptor. The rods form part of an achromatic system functioning only during scotopic vision (below approximately $3 \mathrm{cd\,m}^{-2}$) whilst the cones, which mediate colour vision, are used for photopic vision and operate to very high luminance levels. The initial processing in the retina is thought to be performed by three types of cones, whose spectral responses are shown in Fig 9.

After considerable initial processing in the retina the information is thought to be progressively coded before reaching conscious perception in the visual cortex. It is clear that colour difference or colour opponent signals are derived which alter in polarity depending on the relative contributions from their respective complementaries. Thus one opponent pair responds to emissions along a red-green dimension and one to emissions along a yellow-blue dimension where yellow is obtained from the addition of green and red. There is also a channel which signals luminance alone apparently derived from some algebraic summation of the individual channels. Thus the transmission of chromatic information can be represented by two opponent processes and a luminosity signal.

The sensitivity of the perceptual system to changes in hue is not constant across the spectrum (Fig 10). There appear to be two notable peaks in sensitivity: one in the blue region around 490 nm and a second in the yellow region around 590 nm. It is worth noting that the minimum wavelength difference required for the differential naming of colours is much larger than this. However, as a general rule, a change in name will occur most rapidly in the regions where peaks in sensitivity to hue change occur (*ie* orange, yellow, green and cyan, blue, indigo).

The fact that the CIE system provides little indication of the psychological separation of differing chromaticities is illustrated in Fig 11. The Macadams ellipses[6] shown are nine times larger than the original Macadams data. The ellipses represent standard deviations of perceptual colour matches about their central point, and as such represent a measure of the just noticeable differences in chromaticity about the 25 centres. It is clear that noticeable chromaticity differences in the green region require much greater changes in chromaticity than those in the blue or the red region. The ellipses shown in the figure represent (according to Macadam) approximately 3 JNDs at a display luminance of $50 \mathrm{cdm}^{-2}$.

We may thus assume that there are more perceivable saturation increments in the blue and red regions of colour space than in the green region where the eye is maximally sensitive to luminance. So it may be important in some applications to select phosphors and subsequently displayed colours such that the maximum saturation range is achieved. Note that with trichromatic systems using three phosphors in the red, blue and green regions maximum saturation will usually be obtained when the phosphor components are individually energised.

6 CHROMATICITY AND LUMINANCE

The sensation produced by a given chromaticity is dependent on the luminance of the display. The Bezold-Brüke phenomenon[7] is well documented and the change in hue with increasing luminance can be seen in Fig 12. The extent of the hue shift depends on the wavelength selected, but in general reds will become progressively more red as luminance decreases and more orange as the luminance is increased. This effect can occur at luminance levels within the range of modern polychromatic CRTs and would result in a perceived compression or expansion of the colour dimensions in use, especially along the red-green dimension where apparent hue shifts of the order of 20 nm may be found to occur. The data presented indicate the maximum effect with saturated hues. The shift will probably decrease as the hue becomes less saturated, but care should be exercised to ensure that colour codes are not chosen which could be confused when using displays at markedly differing luminances. It is notable that there are three invariant hues which do not change their hue in the yellow, green and blue regions, situated at 571 nm, 506 nm and 474 nm respectively.

The effect of incident light on any polychromatic display is qualitatively predictable from the CIE diagram. If any chromatic display is subjected to illumination by 'white' light (*eg* sunlight) the effect will be to move the displayed chromaticities towards that white point, the extent of the shift being determined by the amount of incident flux. The perceived decrease in saturation usually follows a curved path as it approaches the white point, so that a slight change in hue is also perceived. This change in hue with changes in colorimetric purity has become known as the Abney effect[8].

7 PERCEPTUAL CHARACTERISTICS OF CHROMATIC SPECTRA

One of the properties of the perceptual system is its ability to perceive colours of equal chromaticity but different spectral distributions as equal. The two spectral distributions in Fig 13 are distinctly different but have equal tri-stimulus values and therefore are perceived as identical (*ie* they are metameric).

If the quality of the illumination incident on two metameric surface colours changes they will no longer provide a match since the reflected spectral power distributions will have been differentially weighted. Similarly, it would be possible for two phosphors which appear identical (under identical illumination conditions) to possess different spectral emission characteristics - to be metameric (Fig 13). If identical filters were to be placed over the two phosphors there would no longer be a metameric match because the filters would differentially absorb the phosphor emissions. The perceptibility of the mismatch will depend on the extent of the difference between the two emission spectra of the phosphors but it is clearly undesirable that two displays which have the same chromaticities should appear different when identical filters are placed over them. It is notable that metameric matches will continue to hold even when the state of chromatic adaptation is changed at normal photopic levels.

8 CHROMATIC ADAPTATION

Adaptation of the visual system brought about by viewing a chromatic source will result in a perceptual change of the stimulus being viewed, and also of other stimuli viewed subsequently, until the eyes photochemistry has returned to its original state. Adaptation, that is a change in the perceived colour of a chromatic stimulus, will also occur instantaneously if that stimulus is surrounded by a large field stimulus of a different colour (simultaneous colour contrast).

The perceptual changes occurring at normal levels of exposure indicate that a change in the balance of the retinal receptor sensitivity has occurred and a good approximation of the changes is given by the Von Kries coefficient law.

$$R'_\lambda = k_1 R_\lambda$$

$$G'_\lambda = k_2 G_\lambda$$

$$B'_\lambda = k_3 B_\lambda$$

where R_λ, G_λ, B_λ represent the spectral distribution of the cone receptor elements prior to adaptation and R'_λ, G'_λ, B'_λ the distributions after adaptation. K_1, K_2, K_3 are interpreted as being inversely related to the relative strength of activation of R_λ, G_λ and B_λ by the adapting illumination.

The qualitative changes in the perception of a chromatic stimulus after adaptation to another illuminant can be deduced from the chromaticity diagram in Fig 4. After adaptation to a green stimulus of say 520 nm, stimuli which would previously have appeared to be consistent with their chromaticity co-ordinates will appear to have shifted away from the green region of colour space since the responsitivity of the green receptor channel will have diminished. Thus greens will become progressively desaturated with increasing adaptation to a green stimulus whilst reds, violets and blues will become progressively more saturated. A trichromatic head-down display would therefore appear to be depleted in greens and enriched in reds and blues after adaptation to a bright green head-up display under dim ambient conditions, possibly causing delays or errors in identifying certain chromatic signals.

The extent of the adaptation shift will depend on the field size of the adapting stimulus, length of adaptation and the luminance of the source; the time taken for the visual system to recover, assuming fixation is not returned to the adapting stimulus, will depend on the extent of the original adaptation but may take several minutes. Conversely, adaptation may be maintained indefinitely, if fixation is only momentarily removed from the adapting stimulus.

9 CONCLUSION

In an environment where the pilot is already being asked to perform at levels approaching the limits of his capabilities, any facility which enables him to use his processing capacity more efficiently should be considered. The use of colour can assist in the processing of information, by facilitating the use of an extra perceptual channel and by the use of attentional 'set'.

The available technologies present the system designer with a choice of system capabilities, decisive factors usually being the number of colours required and the maximum display output. As a general rule the number of colours utilised should be kept to a minimum, and in no case larger than six[9] since search times will begin to deteriorate when this number is exceeded.

Finally, the perceptual system does not perceive colour in a linear fashion, and the resulting sensations depend also on factors such as the levels of illumination and the choice of colours. The advantages of colour appear to be situation specific and it is possible that colour may not assist or may even degrade operator performance in some cases. It is therefore recommended that each case be examined separately and that colour should not be used indiscriminately.

Acknowledgments

The authors would like to express their thanks to J Wiley and Sons for the provision of some of the illustrations in this paper.

REFERENCES

1 C. Karner: "Perceived versus actual value of colour coding." Proc Human Factors Society 19th Meeting, Dallas, Texas, pp 227-231, 14-16 October 1975

2 R.E. Christ: "Review and analysis of colour coding research for visual displays." Human Factors 17(6), pp 542-570, 1975

3 W.D. Wright: "A redetermination of the trichromatic coefficients of the spectral colours." Trans Opt Soc London, 30, pp 141-164, 1928

4 J. Guild: "The colorimetric properties of the spectrum." Phil Trans Royal Soc A230, pp 149-187, 1931

5 P.L. Walraven: "A zone theory of colour vision." Farbe 15, pp 17-20, 1966

6 D.L. Macadam: "Visual sensitivities to colour differences in daylight." J Opt Soc Am 32(5), pp 247-274, 1942

7 D.McL. Purdy: "Spectral hue as a function of intensity." Am J Psychology, 43, 541, 1931

8 Abney (in Wyszecki and Stiles): "Color science, concepts and methods, quantitative data and formulas." Pub: J. Wiley and Sons, Inc, 1967

9 R.C. Carter, M.C. Cahill: "Regression models of search time for color coded information displays." Human Factors, 21(3), pp 293-302, 1979

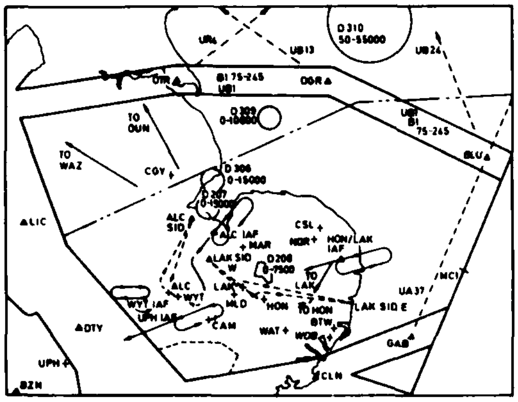


Fig 1 Cluttered monochrome ATC display

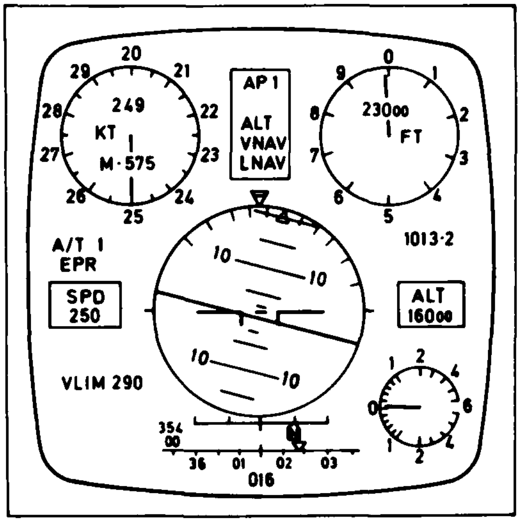


Fig 2 Monochrome status display

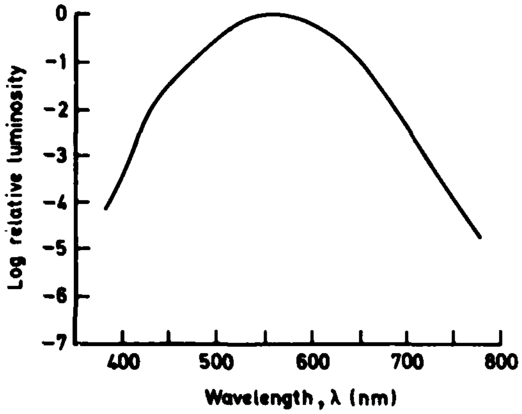


Fig 3 Normalised luminous efficiency function of the eye

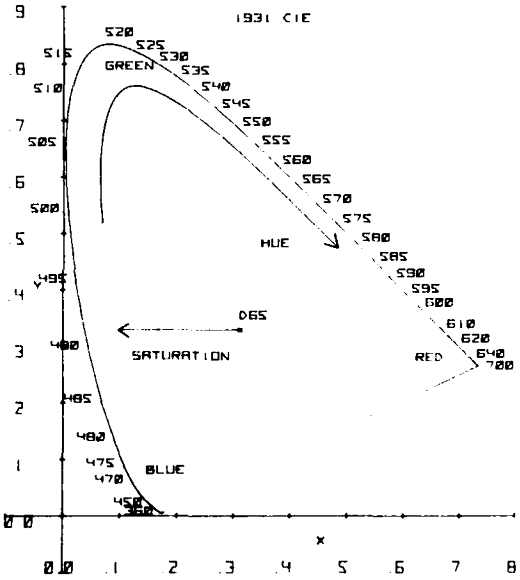


Fig 4 CIE chromaticity coordinate system

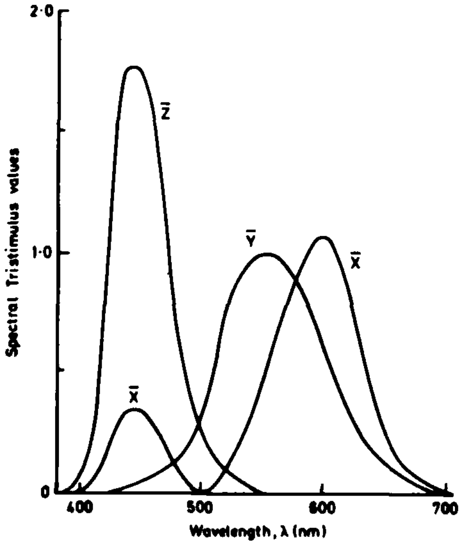


Fig 5 CIE spectral tristimulus values

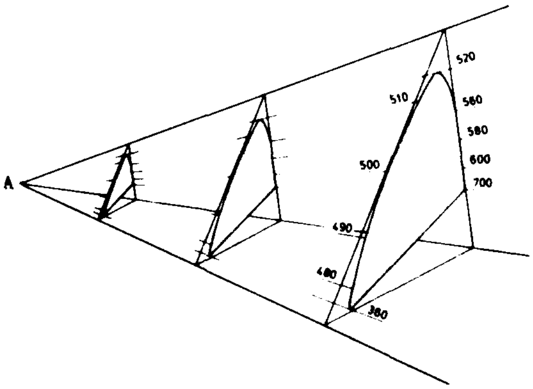


Fig 6 Representation of a total colour space

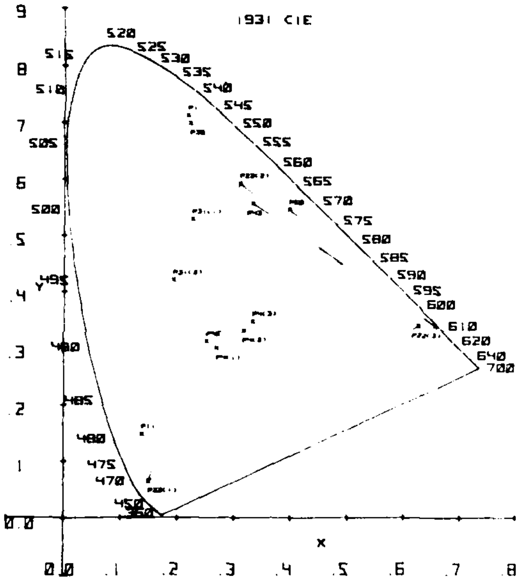


Fig 7 Penetron and shadow mask CRT colour spaces

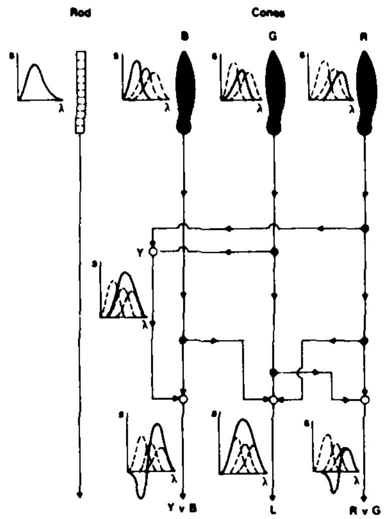


Fig 8 A model of the human colour mechanism

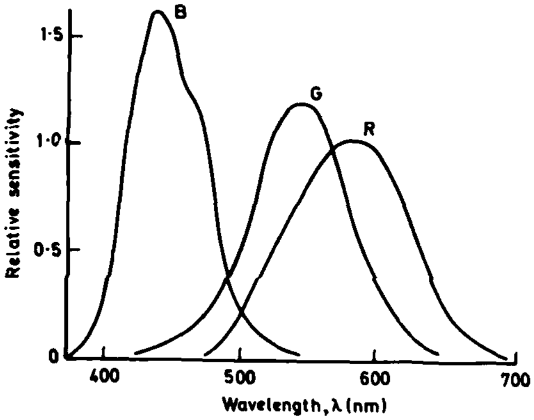


Fig 9 Spectral responses of the three cone mechanisms

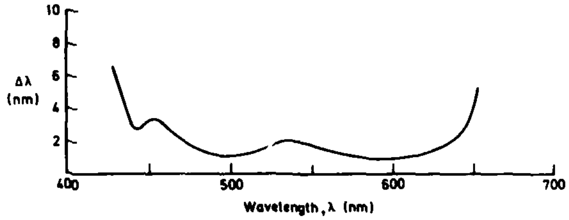


Fig 10 Threshold for hue discrimination across the visible spectrum

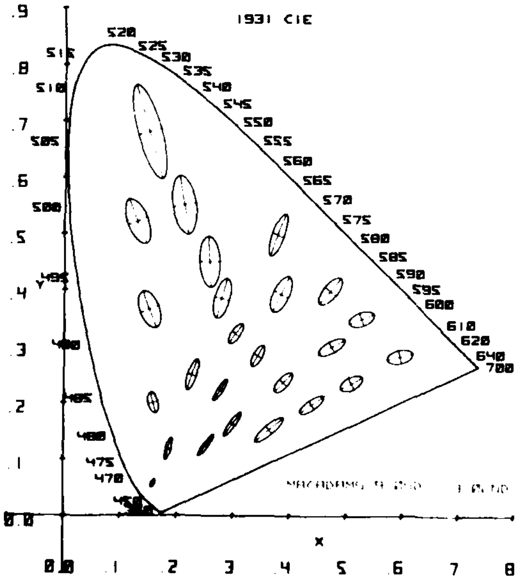


Fig 11 MacAdam ellipses

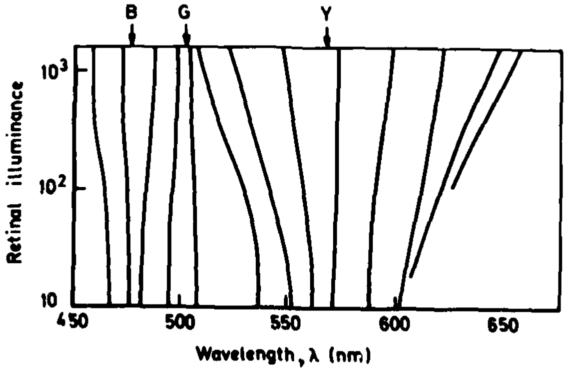


Fig 12 The Bezold-Brüke phenomenon

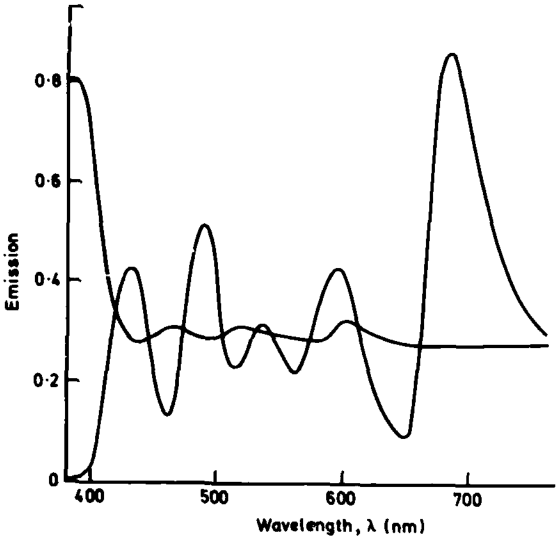


Fig 13 Metameric spectral distributions

ROLE DE LA COULEUR DANS LA SYMBOLOGIE DE PILOTAGE DES AERONEFS

MENU J-P., Assistant de Recherches du S.S.A.

SANTUCCI G.F., Professeur agrégé de Physiologie et Ergonomie Aérospatiales
du S.S.A.

26, boulevard Victor - 75996 PARIS ARMEES -

La couleur n'est pas un phénomène nouveau dans la cabine des aéronefs. Cependant avec l'introduction des tubes cathodiques dans les cockpits et la richesse de la palette disponible, on est loin alors des quelques couleurs pigmentaires utilisées pour les instruments de vol et des trois couleurs principales des sources émissives réservées aux alarmes. Cette richesse de la palette de couleurs des tubes cathodiques, favorable la plupart du temps, peut les desservir. La présentation de nombreuses couleurs peut alourdir ou rendre confuse une prise d'information visuelle. Il convient alors de fixer quelques règles importantes de l'utilisation de la couleur sur de tels supports intègrés dans un concept plus général de pilotage et navigation.

Un autre avantage du tube cathodique qu'il est quasiment le seul à posséder actuellement, est la possibilité qu'une information particulière puisse changer de couleur instantanément et permettre ainsi un codage coloré. Cet aspect évolutif, dynamique du tube cathodique doit être utilisé non seulement pour les structures spatiales (index, aiguilles, position de lignes particulières), mais aussi pour la couleur (modification progressive de la tonalité, de la saturation ou de la luminance d'un symbole).

Nous ne ferons qu'évoquer les diverses technologies d'afficheurs actuellement utilisables (L.C.D., LED...). Ces technologies modernes ne sont qu'à leur début d'utilisation en aéronautique. La couleur occupe une place importante dans le codage de l'information mais les problèmes actuellement rencontrés, de contraste, de graphisme sont de loin les plus importants.

L'étude sera limitée à l'utilisation de la couleur sur les tubes cathodiques.
Un rappel sur le vocabulaire photocolorimétrique, et les technologies disponibles sont détaillés avec leurs caractéristiques particulières, en annexe. L'utilisation correcte de la couleur sera envisagée avant de montrer l'influence de certaines ambiances sur la perception colorée.

Cette démarche suit de près celle que WARUSZEWKSI (1981), proposa l'an dernier. Mais nous insisterons, voire, nous nous opposerons à lui sur l'utilisation propre de la couleur. Les aspects technique et photocolorimétrique ne sont donnés que pour appuyer et éclairer cette approche.

1 - LES TECHNOLOGIES:

Il convient de différencier ce qui est génération proprement dite du graphisme et ce qui est couleur, bien que dans certains cas, technique et couleur soient intriquées plus ou moins confusément.

1.1 La génération du graphisme :

trois techniques particulières sont utilisables;

- le balayage cavalier;
- le balayage télévision;
- le tube multimode.

1.1.1 Le balayage cavalier :

Dans cette technique, la déflexion du faisceau d'électrons décrit directement sur l'écran le graphisme à réaliser. Un tel système permet un tracé de traits très fins et nets en particulier dans le dessin d'obliques et de cercles. Par contre il est difficile de réaliser des surfaces pleines de grandes dimensions.

Le balayage cavalier est le procédé de choix pour l'étude des fonctions se rapportant aux "contours" et pour la génération de l'alphanumérique.

1.1.2 Le balayage télévision :

Sur cet écran est constituée une image selon une technologie particulière dont le standard Européen à 50 Hz est différent du standard Américain à 60 Hz. L'image complète est en fait composée de 2 demi trames du fait de la décomposition de l'écran en un certain nombre de lignes. Une première demi trame est réalisée en balayant sur le tube toutes les lignes impaires. Une deuxième demi trame de lignes paires est ensuite parcourue. La fréquence de rafraîchissement de l'image est de 25 Hz, la fréquence des demi trames de 50 Hz. Ce sont ces demi trames entrelacées suffisamment rapidement et la rémanence des phosphores utilisés qui constituent une image d'aspect temporellement stable.

Le nombre de lignes utilisées est le plus fréquemment de 625 pour l'instant, cependant 1024 lignes vont être disponibles prochainement. Enfin certains constructeurs proposent non plus des fréquences de rafraîchissement à 50 Hz mais à 70 Hz non entrelacés. Ce type de balayage permet la génération aisée de surfaces.

1.1.3 Le tube multimode :

Un tel type de tube associe les deux techniques précédentes. La première demi trame est effectuée sur l'écran. Pendant le retour du spot à sa position initiale avant de décrire la deuxième demi trame, au lieu que ce spot soit éteint, sa tension est plus ou moins modulée et sa déflexion n'est pas rectiligne mais guidée par un générateur graphique. Ainsi pendant le retour trame TV un balayage cavalier peut être écrit sur l'écran. Un tel système permet la génération facile de surfaces ou de contour encore que le balayage cavalier soit essentiellement réservé à l'alphanumérique.

1.2 La réalisation de la couleur :

Les technologies décrites précédemment applicables très facilement en monochrome, peuvent être aussi employées pour générer des couleurs si l'on associe des techniques spécialisées : plusieurs couches de luminophores, plusieurs canons d'électrons.

1.2.1 Le tube à pénétration variable :

Cette technique de réalisation de couleurs est souvent associée au balayage cavalier et elle représente la première technologie des tubes cathodiques couleur ayant été embarqués. De plus c'est sur elle que repose la détermination par GALVES de l'indice de détection et de discrimination.

Un faisceau d'électrons unique est dévié de manière à décrire le tracé voulu comme nous l'avons indiqué lors de la description du balayage cavalier. Schématiquement les luminophores peuvent être considérés comme disposés en couches superposées. Les phospores primaires sont le rouge et le vert. La couleur obtenue est fonction de la modulation de la tension du faisceau d'électrons. Le rouge est obtenu pour les tensions les plus basses de l'ordre de 9 à 10 KV; le vert pour les hautes tensions de 18 à 20 KV. Entre les deux, une tension moyenne de 13 - 16 KV excitera les deux luminophores et la couleur observée sera un jaune.

Ainsi un tel système est capable de présenter trois couleurs discriminables sans erreurs :

Le rouge, le vert, le jaune.

La couleur orange obtenue avec cette technologie risque d'être confondue, selon le réglage du canon d'électrons soit avec le jaune soit avec le rouge.

1.2.2 Les tubes trichromes :

Ils reposent sur l'emploi de trois luminophores émettant chacun dans une des trois couleurs fondamentales : rouge, vert, bleu. L'agencement de ces luminophores varie avec la technique utilisée, et leur densité conditionne la définition des ouvrages. Ainsi il existe les procédés Shadow-Mask, Trinitron, PIL. En aéronautique, essentiellement à ce jour, est utilisé le procédé Shadow-Mask haute résolution, avec trois canons en ligne. La modulation de l'énergie délivrée par chacun des trois faisceaux propre à la couleur fondamentale, permet la génération d'une riche palette de couleurs mais dont aucune n'est sur le lieu spectral du triangle XYZ de la CIE.

2 - UTILISATION DE LA COULEUR:

Un certain nombre d'applications sont classiques. Elles reposent sur de nombreuses études comme le montre par exemple la revue sur ce problème faite par HITT , PUIG(16) ou plus récemment par WARUSZEWKI. On peut schématiquement résumer en disant que la couleur :

- augmente la visibilité des informations par le contraste de tonalité. Il faut savoir cependant que des études menées dans notre Laboratoire et qui seront rappellées ultérieurement, montrent qu'il faut être attentif aux choix des contrastes.
- aide à la localisation des informations.
- permet le regroupement par fonction de pilotage ou de navigation des informations présentées.
- peut être utilisée comme signe d'alarme ou d'alerte. En fait le changement de tonalité n'est pas aussi performant que le clignotement, une méthode déjà bien éprouvée dans les anciens cockpits avec les lampes de couleurs clignotantes.

A côté de ces points classiques nous développerons un certain nombre d'utilisations possibles, rarement évoquées et sur lesquelles travaille notre équipe.

2.1 Pourquoi choisir de grandes surfaces colorées ? :

L'observation des nouvelles symbologies mises au point sur tubes cathodiques de façon empirique par les pilotes et les ingénieurs, met en évidence que la surface éclairée du tube cathodique (T.C) en tête basse se densifie. Certains expliquent celà par des considérations purement liées à la nature de l'information (copie de la boule avec bleu du ciel et marron de la terre, représentation de la densité nuageuse sur le radar météo.). Outre celà, nous y voyons d'autres explications basées sur des expérimentations conduites en 1979 et 1980. Au cours de ce travail nous avons étudié une symbologie de pilotage monochrome qui fut présentée à 15 pilotes de lignes opérationnels. Deux possibilités leur étaient offertes : soit la symbologie en contraste négatif (caractères allumés verts sur fond noir), ou en contraste positif (caractères éteints sur fond homogène vert). 14 pilotes choisirent spontanément le contraste positif. Un seul le refuta, et téléphona rapidement pour revenir sur son jugement.

L'analyse des réponses et des commentaires permet d'expliquer ce choix :
Il y a homogénéité de luminance par rapport à l'ambiance, ce qui diminue les périodes de désadaptation ou d'éblouissement relatifs. Il n'y a plus d'effet "tunnel" comme disent les pilotes, le tube est mieux intégré dans l'environnement. Par ailleurs ce résultat confirmé dans d'autres domaines que l'aéronautique (GRANDJEAN) peut s'expliquer du fait de la création d'une texture de fond sur le tube cathodique, texture qui permettrait un meilleur ajustement de l'accommodation. Enfin ce type de présentation se rapproche beaucoup des supports classiques de présentation d'informations (cet article est écrit en noir sur fond blanc.).

2.2 L'aspect "esthétique" :

Une telle appellation peut faire sourire, lorsque l'on parle d'avion de combat. En fait sous ce vocable il faut penser à deux applications possibles :

- d'une part l'analogie au monde extérieur;
- d'autre part le maintien du pilote dans la boucle.

2.2.1 Couleur et analogie au monde extérieur :

Si l'on observe l'évolution historique des indicateurs classiques, on observe que l'information fut donnée longtemps sous la forme d'indications numériques, soit par l'utilisation de cadrans avec aiguilles ou index (faussement appellés à notre avis analogue, car on ne précise pas analogue à quoi ?), soit sous forme numérique pure.

Puis apparurent des indicateurs analogues au monde extérieur; l'exemple type étant la boule avec le bleu du ciel.

Les technologies ne permettaient pas d'aller aisement au delà. Il n'en est plus de même avec les tubes cathodiques qui autorisent les formes et les couleurs les plus diverses.

Cette représentation analogique est justifiée par l'amélioration de la prise d'informations qu'elle autorise comme le montrent les nombreuses études en cours et qu'il n'est pas de propos ici de discuter. On peut admettre que ceci est vrai au niveau des processus psychologiques de traitement de l'information.

La couleur du monde extérieur doit donc être prise en compte dans la conception des symbologies. Un examen du triangle des couleurs montre qu'il existe des couleurs spectrales "non naturelles"; ainsi les pourpres n'existent pas dans le spectre solaire. On conçoit donc que l'on peut aisement rester dans la philosophie de l'analogie en choisissant judicieusement des couleurs théoriques pour des données de vol non liées au monde exterieur. Pour illustrer, nous prendrons l'exemple du pourpre pour les écarts de route dans l'ILS.

2.2.2 Couleur et "pilote dans la boucle" :

Nous ne voulons pas parler ici de pilote dans la boucle au sens des ingénieurs mais plutôt de pilote en permanence attentif à l'évolution de son système. C'est un fait d'observation courante que si le système est dans l'état souhaité, ce qui heureusement est la plupart du temps le cas, les paramètres n'évoluent pas et il n'y a pas de variation importante dans l'information présentée. Il s'en suit donc une certaine monotonie qui démobilise le pilote. Ses centres d'intérêts peuvent alors se déplacer vers des pensées sans rapport avec la conduite de son aéronef. Comme le dit WANNER, "le pilote vit son petit film intérieur. Il serait donc préférable de lui présenter un bon Western sur l'écran qu'il a en face de lui".

En effet en cas d'incident, on peut à coup sûr, modifier le déroulement de ce Western, alors qu'il sera très difficile d'interrompre le cours des pensées intimes du pilote.

La présentation des informations de vol à bord des aéronefs doit procéder de ce concept. C'est à dire qu'il faut concevoir une symbologie vivante sur laquelle doivent pouvoir se greffer de façon prégnante les variations importantes des paramètres lorsque le système à tendance à sortir des limites attendues. Concrètement pour la vitesse et la direction, on pourrait utiliser un défilement de barres ou de damiers couplés à des variations de saturation, de tonalité.

Il existerait donc une dynamique dans la texture et la couleur de l'image. Si l'avion sort des limites, il est possible faire clignoter la texture et changer la tonalité, il ne s'agit là bien sûr que d'un exemple théorique pour illustrer notre pensée.

On voit donc que l'esthétique de la symbologie joue un rôle non négligeable dans la performance du pilote. Cette notion est en fait le reflet de ce que les pilotes appellent le confort. Ces concepts décrits la plupart du temps avec des termes inhabituels dans le monde technique de l'aéronautique, sont loin d'être négligeables et ne doivent pas être rejetés comme le font certains qui s'attachent à la signification superficielle des mots.

2.3 Représentation d'une 3ème dimension sur T.C :

Un des reproches majeurs que font les pilotes aux tubes cathodiques, qu'ils soient en tête haute ou tête basse, c'est qu'ils perdent la notion de 3ème dimension, présente sur certains indicateurs électroniques tel la boule.

Pour pallier ceci, on peut et on doit utiliser les effets de perspective que l'on peut créer avec la forme de la symbologie. L'optique physiologique nous fournit des élèments de réflexion sur la 3ème dimension et couleur.

Tout le monde connaît l'illusion décrite par PIERON du type des coeurs flottants : des coeurs rouges sur fond bleu, paraissent flotter en avant lorsque l'on bouge le support.

Sur tubes cathodiques, dans certaines circonstances, on peut observer des phénomènes analogues, des inscriptions d'une certaine couleur paraissent en avant par rapport à d'autres, d'une autre couleur. Quel est le paramètre de la couleur qui intervient le plus dans cette sensation ?

Les données de la littérature sur ce problème complexe ne permettant pas de répondre à l'impératif essentiel en aéronautique : être sûr que la sensation individuelle sera en toutes circonstances celle attendue, aussi notre équipe a entrepris une étude de fond sur ce point, mais il est trop tôt pour rapporter les premiers résultats.

Nous pensons avoir fourni quelques élements de réflexion nouveaux ou présenté sous un autre éclairage ce que peut apporter la couleur en aéronautique. Le bilan semble favorable mais il convient d'envisager les difficultés auxquelles on se trouve confronté par l'utilisation de la couleur.

3 - DIFFICULTES DE LA COULEUR:

On peut distinguer deux grandes catégories de problèmes posés par l'utilisation sur tubes cathodiques en aéronautique :

- la première est d'ordre technologique et concerne des aspects tels que fiabilité des composants, stabilité des canons. C'est là le domaine de l'ingénieur que nous n'aborderons pas.

- la deuxième catégorie est représentée par les problèmes psychophysiologiques. La solution de ces difficultés peut passer souvent par la technique. Dans ce cas, cette technique peut avoir à nouveau un retentissement physiologique. C'est pour celà que nous serons amenés parfois à évequer cet aspect technique, non pas dans le détail mais dans ses relations avec les aspects facteurs humains.

Ainsi l'aspect physiologique, l'influence des ambiances ou l'effet des moyens de protection oculaire est abordé sous l'angle psychophysiologique.

3.1 Problèmes physiologiques :

3.1.1 accommodation et couleurs :

Dans les années 50, Yves LEGRAND émettait l'hypothèse qu'une des causes de fatigue visuelle pouvait être liée à la présence d'un pic dans le bleu et d'un pic dans le jaune dans le spectre d'émission des tubes cathodiques noir et blanc. En effet dans l'oeil emmétrope avec cristallin au repos, les rayons lumineux ne focalisent pas dans le même plan selon leurs longueurs d'onde, le bleu focalisant en avant de la rétine et le rouge en arrière de celle-ci. En régime dynamique, il existerait donc en permanence des mouvements de micro-accommodation (de très faible amplitude) pour obtenir une image nette selon les diverses couleurs. Ce phénomène serait donc amplifié dans des présentations multichromes. En fait, il ne s'agit que d'une hypothèse. En l'état actuel, aucune méthode simple n'a permis de vérifier celà en situation réelle de travail. Même en admettant la validité de cette hypothèse, on peut se poser la question de la réalité de la fatigue du muscle ciliaire. Si l'on se réfère à la physiologie des muscles squelettiques, celle-ci nous montre que la contraction statique est davantage épuisante que la contraction dynamique.

Enfin dans le cadre de la fatigue de la fonction visuelle, il faut mettre en parallèle cette éventuelle fatigue accommodative et le gain apporté par la couleur dans la prise d'information.

3.1.2 acuité visuelle et couleur :

Au début de l'utilisation du tube cathodique dans le monde du travail, de nombreuses discussions interminables ont eu lieu sur le choix de la couleur du phosphore pour les tubes monochromes, chacun arguant de données puisées dans la littérature ancienne.

A cette époque, nous avons conduit une série d'expérimentations pour évaluer le rôle de la couleur dans l'acuité visuelle en contraste coloré (SANTUCCI). Ce travail a montré le rôle respectif des 3 paramètres dans la visibilité d'un symbole. Le contraste de luminance assure la meilleure perception puis le contraste de tonalité et le contraste de saturation. Lorsqu'il y a contraste de luminance, l'effet des diverses tonalités est identique; par contre lorsqu'il n'y a pas de contraste de luminance, mais seulement contraste de tonalité, une hiérarchie apparaît entre elles. Ainsi le couple rouge-bleu entraîne une performance nettement meilleure que le couple vert-blanc.

On voit donc que le choix des couleurs à bord d'un aéronef, indépendamment des aspects psychophysiologiques, doit être fait en tenant compte de la physiologie.

Il faut aussi noter, qu'il a fallu conduire des travaux spécifiques pour répondre à un problème que l'on ne pouvait résoudre en empruntant des résultats établis sur des supports différents.

3.1.3 changement de couleur et alarmes :

Un autre exemple de cette méthode de travail à appliquer, est représenté par la question suivante : comment est perçu un changement de couleur en vision paracentrale ?.

Si les phénomènes existant en vision centrale ou en vision périphérique vraie sont déjà abordés, il n'existe pratiquement aucune connaissance sur les processus mis en jeu lorsque le stimulus coloré est situé dans une zone de 2° à 20° du point de fixation. Or c'est la zone moyenne excitée par les tubes cathodiques en aéronautique.

C'est ainsi que bien que nous pensions que le changement de couleur isolé ne soit pas un bon signal d'alarme, nous avons voulu étudier dans quel délai était perçu le changement de couleur d'un pavé de 34' de côté, situé à 8° d'eccentricité. Ce pavé était inclus dans un fond coloré homogène de même luminance. Il n'existait donc dans la majorité des cas qu'un contraste de tonalité. Nous avons aussi testé la situation en contraste de luminance, pavé éteint devenant allumé ou l'inverse.

Les résultats préliminaires montrent les faits essentiels suivants :

- lorsqu'il y a contraste de luminance, le délai de réponse est plus long. Cet élément inattendu, est surprenant, aussi nous poursuivons l'étude de ce phénomène.

- en ce qui concerne l'effet tonalité pur pour le cyan, le pourpre, le vert, le jaune, on ne trouve pas de différence intéressante. Le seul point se détachant nettement est la transition vert-rouge ou rouge-vert qui assure la meilleure performance.

Si ces résultats se confirment, ils sont heureux en ce qui concerne le rouge-vert puisque les stéréotypes classiques sont concordants. Une restriction importante doit être soulignée ; cet effet est masqué lorsqu'il y a contraste de luminance. Ainsi se trouve-t'on conforté dans l'intérêt d'utiliser les fonds lumineux comme nous l'avons déjà évoqué précédemment.

3.1.4 perception visuelle du mouvement et couleurs :

Si l'on veut animer des figurations, il faut être sûr que les sensations désirées seront bien induites chez le pilote. Les caractéristiques de la perception du mouvement en vision centrale ou périphérique ont fait l'objet de vastes travaux pour des stimulations monochromes et en contraste de luminance.

De plus la majorité des études sont réalisées au seuil, c'est à dire adapté à la vision nocturne.

Il est clair que nous manquons de données fondamentales pour l'application aéronautique. Pour répondre à ce besoin, nous avons commencé à étudier la perception du mouvement de stimuli colorés en vision paracentrale. Les résultats acquis à ce jour montre que :

- avec un contraste de luminance important (98 %) entre le fond et le stimulus, la tonalité n'intervient pas sur la qualité de la perception (tonalités testées rouge-vert-bleu).

Ceci est valable pour la vitesse seuil de 6' sec comme pour des vitesses plus élevées (18'/sec).

L'expérimentation portant sur l'absence de contraste de luminance c'est à dire stimulus à 8° d'eccentricité et fond de tonalités différentes mais de même luminance est en cours, ceci se déroulant à un niveau lumineux ambiant nettement photopique.

3.1.5 influence de l'environnement :

Le contexte aéronautique est caractérisé par l'existence d'ambiances lumineuses extrêmes : luminance très basse, vol de nuit ; luminance très élevée, vol en haute altitude de jour.

3.1.5.1 les ambiances nocturnes :

Par définition en vision nocturne, il n'existe pas de vision colorée mais aussi l'acuité visuelle est très basse. Pour ces deux raisons, présenter des informations sur tube cathodique couleur est impossible si l'on veut préserver la véritable vision nocturne. Si celà ne pose pas de problème pour les pilotes de ligne civils, il n'en est pas de même pour les pilotes de chasse. Pour ces personnels, la mission de nuit implique d'ailleurs d'autres impératifs comme dans le vol basse altitude et grande vitesse ou le vol tactique des hélicoptères. Depuis longtemps, des méthodes et des techniques ont été mises au point pour pallier certaines déficiences de la vision nocturne. On peut les classer en 2 grands groupes : aides ou suppléance à la vision de nuit (MENU). Les aides sont des moyens traditionnels (indicateurs des paramètres de vol). En général, ils sont conçus de par leur éclairage pour préserver l'adaptation de la vision nocturne du pilote. Leur efficacité au regard des missions actuelles est cependant très limitée d'où l'apparition de moyens de suppléance tels que amplificateurs de brillance, système F.L.I.R. Pour ces derniers, il vient aisément à l'esprit d'améliorer l'imagerie thermique par l'utilisation des fausses couleurs. Schématiquement ce procédé permet de transcoder les niveaux de luminance en tonalités différentes. Ce procédé est très séduisant mais il faut savoir que l'on va alors définir des couleurs d'objet arbitraires non analogue au monde réel.

En effet, un arbre et un véhicule peuvent avoir une émission thermique identique, ceci se traduirai par un arbre rouge, mais aussi par un moteur rouge. Si les objets sont rapprochés et de formes aussi différentes que celle que nous venons de citer, la distinction se fera sur la morphologie de l'image. Il est aisé de concevoir que cette situation caricaturale ne sera pas fréquente et compte tenu des performances des systèmes on se trouvera souvent dans des situations conflictuelles. La pseudocouleur alors, bien loin de clarifier l'image la rendra plus difficilement interprétable.

Est ce à dire que la couleur doit être éliminée des systèmes de suppléance de la vision de nuit ?. En fait non. Elle permettra de fournir au pilote une symbologie complémentaire de l'imagerie thermique monochrome, ainsi aisément identifiable. Ceci est d'autant plus justifié que ces procédés de suppléance, placent l'oeil en niveau d'adaptation photopique. Les détails fins et les couleurs sont donc perceptibles.

3.1.5.2 les ambiances élevées :

Sans parler des phénomènes tels que l'effet BEZOLD-BRUCKE où la perception du spectre se résume à 2 tonalités bleu et jaune pour une luminance très élevée des tests, la luminance de l'environnement a des effets sur les couleurs issues de tubes cathodiques.

Ils sont liés essentiellement à la réflexion de la lumière incidente sur la face avant du tube. Ceci se traduit par une augmentation de la luminance, la présence de reflets, la désaturation. Le changement de luminance provoque soit un éblouissement, soit un état de désadaptation de la rétine; dans les instants qui suivent, la perception visuelle est altérée jusqu'à ce qu'un nouvel état d'adaptation soit atteint. Il en est de même des reflets qui en outre diminuent les contrastes de l'image. La réflexion de la lumière solaire sur la face avant, par métamérisme, provoque une désaturation des couleurs. Les travaux que nous avons cités concernant l'acuité visuelle en contraste coloré, nous ont montré que la visibilité était moins bonne lorsque les couleurs étaient désaturées.

Ces inconvenients ont conduit les concepteurs de tableaux de bord à proposer divers palliatifs techniques, soit au niveau du tube (filtres), soit au niveau du pilote (lunettes ou visières).

a) <u>Les filtres antireflets</u>:

Diverses techniques sont utilisées pour diminuer l'importance des réflexions au niveau de la face avant, sans dégrader la lumière émise par le tube.

Sans entrer dans le détail technique, on peut considérer qu'il existe 2 grands types :

* des filtres à lamelles qui piègent la lumière extérieure incidente, leur efficacité est bonne mais d'une part ils transforment une image continue en image matricielle, et d'autre part, ils sont directifs, c'est à dire que l'observation de la lumière émise par le tube ne peut être visible que dans un cône bien précis;

* des filtres sélectifs en longueur d'onde conçus pour ne transmettre que les 3 longueurs d'onde fondamentales du tube. Il semble que la technologie actuelle soit complexe et onéreuse. Un espoir existe par l'utilisation de l'optique diffractive.

b) <u>Lunettes et visières</u>:

Pour éviter l'éblouissement du pilote mais aussi pour le protéger contre des agressions lumineuses spécifiques, il est envisageable de faire porter au pilote des systèmes optiques atténuant le flux lumineux ou modifiant sa composition spectrale. L'impact du port de tels équipements sur la perception visuelle doit être étudié. C'est ainsi qu'un travail de ce type nous a montré que l'on pouvait assister à une dégradation importante de l'image aéronautique colorée. Les risques de confusions entre certaines tonalités étaient constants. La conduite la plus sage consisterait à refuser purement et simplement ces visières. Le pilote ne serait plus protégé alors contre un risque particulier dont l'exemple est la brûlure rétinienne par laser.

Les possibilités techniques du système avec tube cathodique permettent un abord plus riche du problème. Il suffit alors de définir de nouvelles couleurs discriminables à travers l'équipement de protection.

3.1.6 Choix des couleurs :

L'utilisation de la couleur comme on l'a vu à travers divers éléments, n'est pas aisée. Il faut savoir comment définir une couleur de façon à ce qu'elle induise toujours une sensation identique chez tous les individus et dans toutes circonstances. Il y a 7 ans GALVES proposait un index de discrimination. Cet index a déjà été repris par des instances internationales et des constructeurs, tel quel ou plus ou moins dénaturé. Avant de discuter cet index, quelques remarques préliminaires s'imposent :

- déterminer un index unique, impose la quantification des stimuli. Les travaux de la C.E ont eu pour but depuis le début du siècle d'établir un langage précis, donc une métrique de la couleur. En effet l'oeil est un capteur biologique qui ne réagit pas comme un capteur physique. En outre, la fonction visuelle est un tout qui comprend aussi bien le capteur que le système de traitement de l'information. La métrique de la couleur a été établie à partir d'observations physiologiques princeps dans les années 20 avec les méthodes et matériels de l'époque. Si certaines expériences complémentaires ont eu lieu depuis, il faut bien constater que les divers systèmes de référence actuels sont souvent le résultat de transformations *mathématiques* ou de *modélisations* validées sur de très petits nombres de sujets. Sans mettre en doute la validité de tels systèmes, on ne doit jamais oublier cet aspect des choses. Il faut bien en connaître les limites d'utilisation. Ainsi il ne faut pas être étonné de ne pouvoir effectuer des mesures fiables dans certaines circonstances (taille, forme du stimulus).

L'indice de détection de GALVES tente de prendre en compte les 3 paramètres de la couleur (luminance, tonalité, saturation), il s'énonce :

$$ID = (IDL^2 + IDC^2)^{1/2}$$

$$IDL = \frac{1}{0,15} \times \log \frac{Ls + Le}{Le}$$

$$IDC = \frac{1}{0,027} \cdot \left[(u'_s - u_e)^2 + (V'_s - Ve)^2 \right]^{1/2}$$

Pour l'aéronautique, il existe une pondération de cet indice. L'indice de détection effectif s'énonce sous la forme :

$$IDE = ID * RCS \times TAF$$

- RCS (Relative Contrast Sensibility normalisé) par la CIE tient compte de la sensibilité relative de l'oeil au contraste en fonction de la luminance de l'écran.

- TAF (Transient Adaptation Factor), rend compte de la perte de caractéristique momentanée en fonction du rapport entre les luminances de la zone d'adaptation et de l'écran de visualisation.

La lecture de la publication de GALVES, montre que cet indice a été mis au point sur un écran à pénétration et n'a donc été vérifié que pour les couleurs rouge, jaune, vert.

Lors de l'expérimentation sur l'acuité visuelle en contraste coloré, nous avions beaucoup plus de couleurs. Nous avons ainsi obtenu sur 90 pilotes de 20 à 50 ans, des résultats sur la visibilité d'un symbole sur tube télévision Nous avons effectué le calcul de l'index pour divers couples colorés. Nous ne rapporterons que les résultats des couples colorés donnant une mauvaise performance (cyan-vert, cyan-blanc, rouge-pourpre). Dans le tableau ci-dessous où sont données les coordonnées u et v des stimulus, on trouve dans les 2 dernières colonnes les index de chaques couples pour un RCS = 0,4 et un TAF = 1.

	u	v		u	v	ID	IDE
Cyan	.145	.304	Vert	.118	.366	2.3	.93
Cyan	"	"	Blanc	.206	.310	2.2	.88
Rouge	.487	.349	Pourpre	.330	.273	6.4	2.56

On observe que la valeur de confort est dans chaque cas largement dépasée. Or nos résultats montrent que les taux de réussite sont pour une sollicitation d'acuité visuelle égale à 5/10 d'AV MONNOYER (détail significatif de 2'19") de

	A V 5/10	A V 8/10
Cyan - Vert	= 15 %	= 3 %
Cyan - Blanc	= 97 %	= 56 %
Rouge - Pourpre	= 22 %	= 1 %

Ces pourcentages sont encore plus bas si l'on sollicite une acuité visuelle de 8/10.

Il semble donc exister une mise en défaut de l'index dans ces circonstances mais celà demande à être confirmé par d'autres expérimentations.

Cependant il faut constater que l'ID ne tient pas compte de la taille des stimuli ou plus exactement de la taille du détail significatif à l'intérieur d'un objet. Ceci met bien en évidence un des problèmes de la métrique lumineuse. La vision d'objet implique certes la mise en jeu d'émission lumineuse par des surfaces mais également l'inter-relation de ces surfaces entre elles : reconnaître un objet demande de prendre en compte d'autres paramètres que la simple luminance. La lecture d'une planche de bord en est un exemple. Il ne s'agit pas de différencier 2 plages lumineuses, il s'agit de discriminer des symboles les uns des autres et par rapport au fond.

D'autres points ont été évoqués à propos de l'indice de GALVES, en particulier sur le fait qu'au départ de l'établissement de son index, il postule un certain nombre de faits établis pour des valeurs de luminance moyenne. Il serait donc hasardeux de vouloir l'appliquer à toutes les conditions rencontrées en aéronautique.

Le mérite de cet index est qu'il est la première tentative pour simplifier le difficile problème du choix des couleurs en aéronautique. Comme toute tentative de simplification, il implique des choix qui peuvent conduire à des situations dangereuses. Nous avons montré que cet index définissait des choix de couleurs, dit confortables et qui en fait conduisaient à un taux de reconnaissance extrèmement faible des symboles.

Il faut donc considérer cet index comme une première approche. Des expérimentations psychophysiologiques doivent être menées pour l'améliorer en prenant en compte, par exemple, le facteur reconnaissance de forme.

ANNEXE

Quelques précisions concernant le vocabulaire :

COULEUR:

Le vocabulaire concernant la couleur utilisé dans cet exposé, est conforme aux définitions de la CIE*. Ceci veut dire que l'on utilisera soit les termes psychosensoriels, soit les termes psychophysiques dans tout leur sens.

Ainsi par exemple, on utilisera soit le terme de luminosité, soit luminance selon que l'energie émise par le tube sera envisagé dans son aspect psychosensoriel ou psychophysique.

SYMBOLOGIE:

Actuellement beaucoup de personnes appellent symbologie, le graphisme présent sur l'écran. Nous pensons qu'il y a là, une dénaturation totale du terme symbologie. Il faut distinguer d'une part, le graphisme qui est le support physique de l'information, et d'autre part l'information elle-même. Nous proposons d'utiliser sous le terme symbologie, le résultat du codage de l'information au moyen du graphisme. Si l'on veut être très précis, cette symbologie peut être subdivisée en 3 classes de codage: signe, symbole, indice.

- signe : codage arbitraire du lien entre réalité et représentation.

- symbole : parenté de forme, couleur, composition entre une réalité

et son expression codée (graphisme).

- indice : interprétation de la réalité ou du codage propre à un individu.

BIBLIOGRAPHIE

1 - GALVES J-P., BRUN J.
Color and brightness requirements for cockpit displays.
AGARD Avionics Technical Panel Meeting on electronic displays, lecture n°6, 1975.

2 - GRANDJEAN E., VIGLIANI E.
Ergonomic aspects of visual display terminals.
Proceedings of the International worshop, MILAN 17-19 march 1980.
Taylor Francis Ltd, LONDON 1980.

3 - HITT W.D.
An evaluation of five different abstract coding methods.
Human Factors, volume 3, N°2, p 120-130, july 1961.

4 - HUSSEY D.W.
Colour displays : their availability, performance and application to improved crew efficiency.
AGARD CP 267, p 19-1 to 19-12.

5 - LAYCOCK J., CHORLEY R.A.
The electro-optical display/visual system interface : human factors considerations.
AGARD AG 255, 1980, p 3-1 to 3-15.

6 - MENU J-P., SANTUCCI G., PAPIN J-P.
Perception visuelle et aides à la vision nocturne.
29ème Congrès International de Médecine Aéronautique et Spatiale, NANCY, 7-11 septembre 1981.

7 - MENU J-P., SANTUCCI G.
Visualisations électroniques et moyens de protection de la fonction visuelle (méthode d'étude).
Société Française de Physiologie et de médecine aéronautique et cosmonautique, 22 janvier 1982.

8 - SANTUCCI G.
Pouvoir séparateur de l'oeil sur tube cathodique couleur.
AGARD CP 255, p 39-40.

9 - SANTUCCI G., VALOT C., NATHIE J.
Acuité visuelle en contraste coloré simultané sur écran TV. Résultats.
Rapport n° 4136/EASSAA/CERMA/RECH., 1977, 61 p.

10 - SANTUCCI G., VALOT C.
Acuité visuelle en contraste coloré sur TV. Résultats complémentaires.
Rapport n° 2158/EASSAA/CERMA/RECH/DR., 1978, 32 p.

11 - SANTUCCI G., VALOT C.
Acuité visuelle en contraste coloré sur écran de télévision. Rôle de la pureté colorimétrique.
Rapport N° 5850/EASSAA/CERMA/RECH/LCBA., 1979, 61 p.

12 - SANTUCCI G., MENU J-P.
Motion perception in pericentral vision on a television screen.
Communication au Symposium OTAN sur la perception du mouvement.
VELDHOVEN, 1980.

13 - SANTUCCI G., PAPIN J-P., MENU J-P., VALOT C.
Réflexion sur le devenir de la cartographie aéronautique.
Travaux Scientifiques des Chercheurs du Service de Santé des Armées, CRSSA, 1980, p 225-226.

14 - SANTUCCI G., MENU J-P., PRADELLA S.
Influence de la visière antilaser jaune sur l'acuité visuelle en contraste coloré sur tube cathodique.
Rapport CERMA/LCBA 81-16, 1981, 22p. (CONFIDENTIEL DEFENSE).

15 - SANTUCCI G., BATEJAT D., MENU J-P.
Evaluation d'une symbologie de pilotage des écarts de trajectoire au moyen du G.I.B.I.
Rapport CERMA/LCBA 81-22, 1981, 30p.

16 - SEMPLE C.A.
Analysis of human factors data for electronic flight display systems.
AFSC AD 884 770, 1971.

17 - WARUSZEWSKI H.L.
Color CRT displays for the cockpit.
AGARD CP 312, 8-1 to 8-22.

18 - WANNER J.C
Critères généraux de sécurité
1980, 31 p.

COLOR DISPLAY FORMATS: A REVOLUTION IN COCKPIT DESIGN

Dr. John M. Reising
Mr. Terry J. Emerson
Flight Dynamics Laboratory
Wright-Patterson Air Force Base, Ohio

SUMMARY

The use of the color displays in the Boeing 757/767 and the Airbus 310 signals a revolution in cockpit design. The advent of the flight-worthy, color cathode ray tubes (CRTs), coupled with advances in computer graphics technology, has freed the cockpit designer from the constraints levied upon him through the use of electro-mechanical devices and monochrome CRTs. The purpose of this paper is to discuss pictorial formats that take full advantage of available graphics and color technology. These formats enable the pilot to have entirely new views of his situation. This is a capability which does not exist in current systems. In addition, color formats have also been developed for head-up and head-down flight, stores management, and engine and systems monitoring, both in the normal and emergency state. By properly designing pictorial formats to give the pilot a more natural, intuitive view of both the outside world and his aircraft systems, he will become convinced of their utility, and the transition into the electro-optical, full-color cockpit will be hastened.

1. INTRODUCTION

Within the last ten years, there has been a radical change in the design of both military and civilian cockpits. As exemplified in the F-18 and the Tornado, as well as in the Boeing 757/767 and the Airbus A310, there has been a shift from cockpit designs using entirely electro-mechanical (E-M) controls and displays to designs which now take advantage of available electro-optical devices, mainly cathode ray tubes (CRTs) (McClellan, 1981).

While initial designs of CRT display formats for aircraft relied heavily on alpha-numeric texts--similar to that found on computer terminals--and on the replication of traditional E-M displays, efforts are under way to explore the use of full-color pictures or cartoons which can be generated by modern digital computers. The final acceptance of pictorial format displays by the pilot community, as well as the designers, will truly mark a revolution in cockpit design.

2. KEY TECHNOLOGIES

There are three key components which, when taken together, will enable the design of full-color pictorial formats. The three factors, digital avionics systems, computer generated imagery algorithms, and full-color shadow mask CRTs, will all play significant roles in the design of cockpits of the future. The paper will concentrate on describing examples of formats for displays which this trio of technologies makes possible. However, before describing formats a few more words about the technologies are appropriate. Aircraft, such as the F-16, F-18, and the Tornado, depend heavily upon digital avionics systems. Advances in this area, such as very high speed integrated circuits (VHSIC), fiber optics multiplex buses, and bubble memories, will enable the processing and storage of tremendous amounts of information. This is a key component in the generating of formats which are designed to present very complex pictures of sensor-blended data. The second factor, computer generated imagery algorithms, is also progressing at a rapid rate, and improvements in the algorithms for handling the hidden line problem, for example, will enable very realistic pictures to be generated. The third component, full-color, shadow mask tubes, is well represented in the designs of new transport aircraft cockpits. Currently, there is a great amount of development activity in the industry to ruggedize the shadow mask tubes for the more severe fighter environment.

3. PICTORIAL FORMAT EXAMPLES

With these three technological areas as background, it is time to discuss the pay-off these technologies provide to the cockpit designer. The range of formats which can be produced through computer generated imagery (CGI) is impressive (Lerner, 1981). When one thinks of CGI it is natural to be reminded of business applications, such as pie-charts; however, Figure 1 shows the amount of detail available. Taking this idea and applying it to cockpits, provides a wealth of potential pictorial views to the display designer (Arnson, 1981). One of the more interesting examples of what can be done with pictorial formats is shown in Figure 2. Here the pilot is sitting above and slightly behind his aircraft; but through CGI his view point can be rotated to any one of an infinite series of points between a look ahead view and a look down or planar view. These kinds of things were never possible before and open up many new areas for design ideas.

3.1 Navigation

On the navigation side, the traditional kind of ground track is shown in Figure 3; but in addition any known threat positions, or terrain or cultural features can be highlighted. Since this is a military application, the threat envelopes can be color-coded to show the lethality of the various threat locations. In addition, the portrayal of a threat in the look-ahead view can also be shown. For example a view of a threat lying on the opposite side of a hill is shown in Figure 4. The threat volume or the airspace is the lined area at the top of the picture. The director channel is obviously supposed to provide the safe path. It is expected that color will be very useful in this type of display. Rather simply, but adequately, portrayed are ground and cultural features such as trees and power line poles.

3.2 Stores

A great amount of information about weapons or stores can be conveyed through the use of pictures. Work has been accomplished on the portrayal of types of stores, status or situation data, selection directions, switching modes, emergency conditions and even target information. This seems to be one of the best examples of where the proper mixture of pictorial information with alphanumerics will provide the most effective display. Figure 5 is a stores display actually photographed off a CRT and represents a format recently evaluated in a simulation study at the Flight Dynamics Laboratory (Aretz, Reising, and Kopala, 1982).

The results of this study show that the pilots performed equally well with pictorial stores formats or with alpha-numeric text. However, the situational awareness provided by the pictorial stores format was received very favorably by the pilots. The recommended format blended color pictorial information with essential text to provide both an overall view of the situation and specific data where needed.

3.3 Systems

Besides showing the pilot his stores' status, pictorial formats can also show the status of such things as hydraulic and electrical systems. The pilot does not wish to see a hydraulic system schematic diagram in real time (see Figure 6) or an electrical system schematic which is even more complex, but rather is interested in seeing what failures have occurred in these systems, what the impact of these failures is on his situation or ability to perform the mission, and what corrective or evasive action he should take. Figure 7 shows that hydraulic circuit 2A has failed and this has caused a loss of nose wheel steering, main gear brakes, and hydraulic operation of the refueling probe. A shaded or cross-hatched border on the display could be a convention used for immediate indication that an emergency condition exists or is impending. Once the pilot is aware of the problem the action items to remedy the situation may be displayed (see Figure 8). He is being directed to get his airspeed down to 200 knots, pull down, twist and then pull out his landing gear handle. The refueling probe can be extended by the emergency extender and upon landing the aircraft he will have braking available through the emergency brakes. The same technique can be used for electrical failures except that it is a little bit more difficult to show the exact part of the airplane which is affected. A view of most avionics bays would depict numerous black boxes. An attempt is being made in Figure 9 to show the impact of being on battery power when the generators have failed. In addition, the emergency procedure is shown in Figure 10.

Briefly, the crew is being told that both generators have failed, and electrical load, trim adjustments and UHF transmissions should be minimized. On-board stores can be jettisoned, fuel transfer to the wing tanks has been lost and the crew should select the option indicated. This selection may be made via a push button switch on the periphery of the display or in the case of a touch sensitive display the desired option may be selected by merely pushing the arrow shown.

3.4 Fuel

Fuel status can be shown (see Figure 11) in one overall view, which indicates the tank location, level of fuel in the tank, and which tanks are transferring fuel. Fuel status information can be combined with a navigation display to provide range available information. An example is shown in Figure 12. The white area of this display could be used to indicate the places the pilot can easily reach under current wind conditions and fuel consumption. The circle which bounds the less densely shaded area describes the maximum range points, and the more densely shaded area is beyond maximum range.

A considerable amount of detailed information is shown on the display through the use of alpha-numerics. Reading clockwise starting at the upper right corner of the display: the pilot has selected destination 5, it is 100 NM away and the estimated or computed time of arrival is 12:40. Present time is 12:27, the aircraft is using 7385 pounds of fuel per hour and at that rate there is 25 minutes of flying time available. Finally there are 3590 pounds of fuel remaining and 1540 pounds of fuel are required to reach destination 5. The pictorial format gives the pilot or operator an excellent perspective of the overall situation; the alpha-numerics provide specifics.

3.5 Engines

Figures 13 thru 18 take the reader through a sequence of engine displays that depict an emergency situation. The first scene (Figure 13) shows a two-engine aircraft, and the status of these engines. Starting at the top a thermometer is used to indicate turbine inlet temperature. The shaded area shows the normal operating range and the top, or upper limit of the normal operating range is shown by the two horizontal lines. The thermometer is also chosen to show exhaust gas temperature. N_1 and N_2 are compressor stages; their performance is shown by the hashed blocks, again the double horizontal line is the limit of the normal operating range. The amount of fuel going into the engine is shown by bars with small circles or bubbles; the radiating lines or flame as shown in the exhaust area indicate a normal condition. In the next view (Figure 14) one engine is in after-burner and the fuel flow is increasing dramatically. The next picture (figure 15) shows that there is an over-speed of the compressor and the exhaust gas temperature has reached a dangerous level.

The shaded border again indicates an emergency situation. The operator is being directed to reduce the left engine throttle setting to zero or off and push forward on the control stick. The display also contains a "clock" in the lower left corner indicating times the troubled engine can operate under various conditions. The next display (Figure 16) shows a fire, and the indication at the top of the picture on the right says that the pilot should use the fire extinguisher to put out the fire. Again, desired throttle settings are included. In the next scene, (Figure 17) the pilot has successfully put out the fire. The right engine is still operating normally and the pilot is being advised to land the aircraft. Finally, if the pilot is not successful, this next scene (Figure 18) gives him a suggested course of action.

4. CONCLUSION

The current phase of the Pictorial Format Program involves the simulation of these and other formats through a contract with the Boeing Military Airplane Company in Seattle. The purpose of the first effort, which was performed both within the Flight Dynamics Laboratory and on a contract with the McDonnell Aircraft Company, was to come up with creative views of advanced pictorial formats (Jauer and Quinn, 1982). The formats will be scrubbed down to get more realistic views, and the simulation will provide both pilot evaluations and much better understanding of the software requirements needed to generate these formats.

REFERENCES

Aretz, T., Reising, J., and Kopala, J. "Stores and Status System Evaluation," Wright-Patterson AFB, Ohio: Air Force Wright Aeronautical Laboratories Technical Report AFWAL-TR-81-(in press).

Arnson, R. "Cockpit of the Future." Machine Design, Vol. 53 (28), December 10, 1981, 31-38.

Jauer, R. and Quinn, T. "Pictorial Formats, Vol. I: Format Development." Wright-Patterson AFB, Ohio: Air Force Wright Aeronautical Laboratories Technical Report AFWAL-TR-81-3156 (in press).

Lerner, E., "The Computer Graphics Revolution." IEEE Spectrum, Col. 18 (2), February, 1981, 35-39,

McClellan, J. "The Era of Electronic Flight Instruments Draws Near." Business and Commercial Aviation, February, 1981, 52-55.

Figure 1. Airborne electronic terrain map

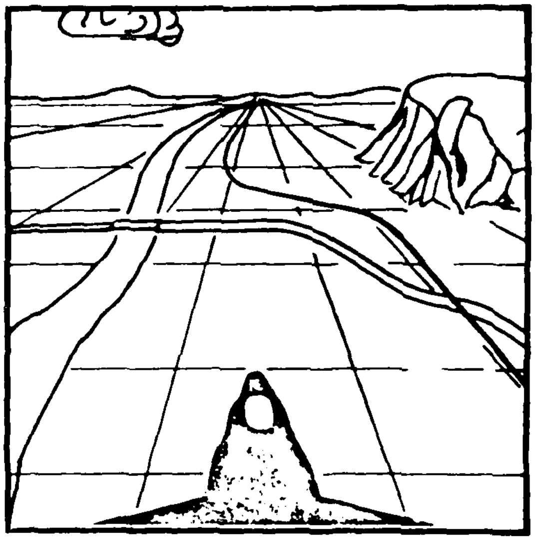


Figure 2. Primary flight - tactical situation display

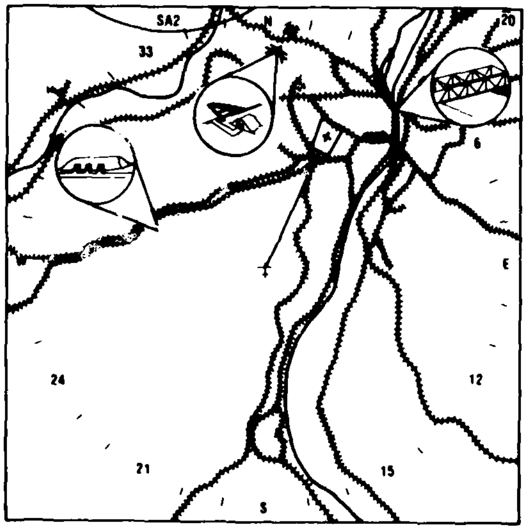


Figure 3. Air-to-ground situation display targets highlighted

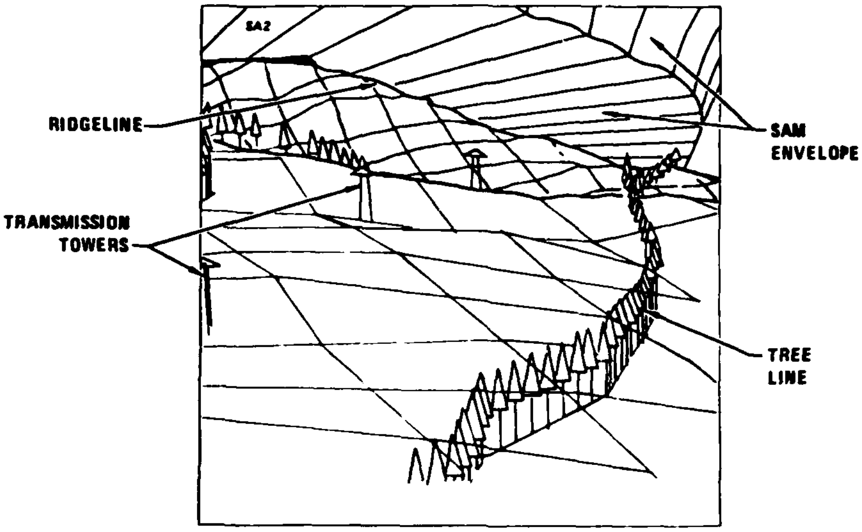


Figure 4. Threat envelope with graphic terrain data

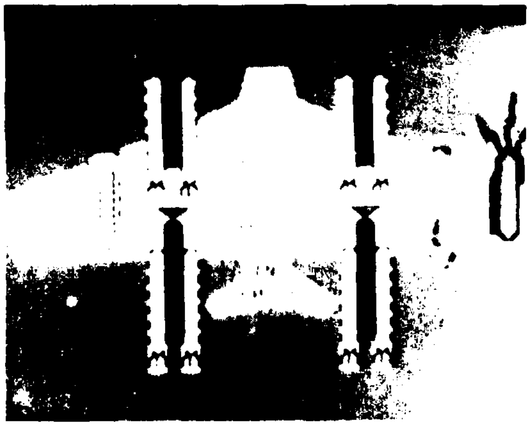


Figure 5. Pictorial stores format

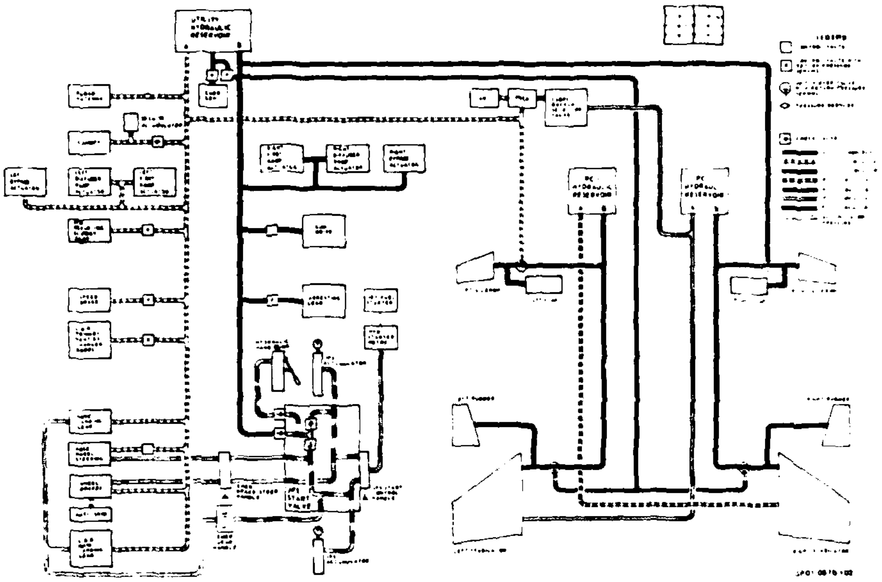


Figure 6. Typical fighter/attack hydraulic system

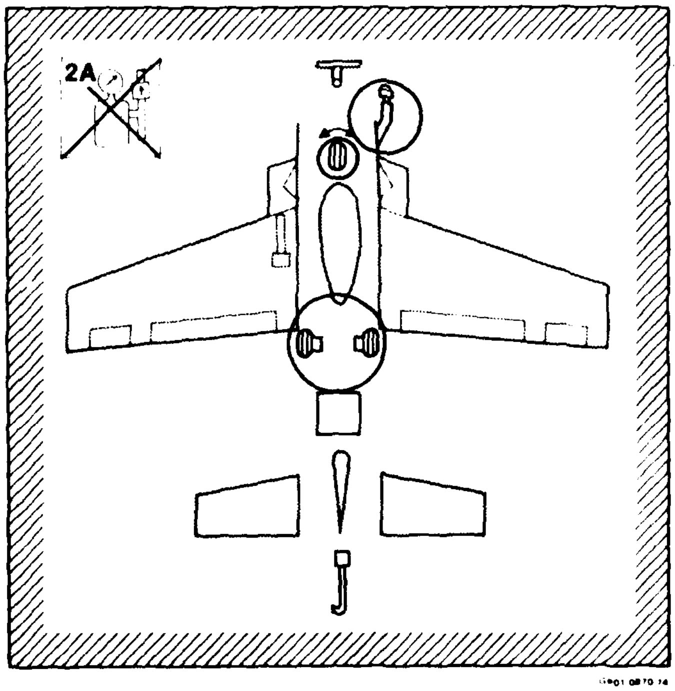


Figure 7. Degraded hydraulic system effects

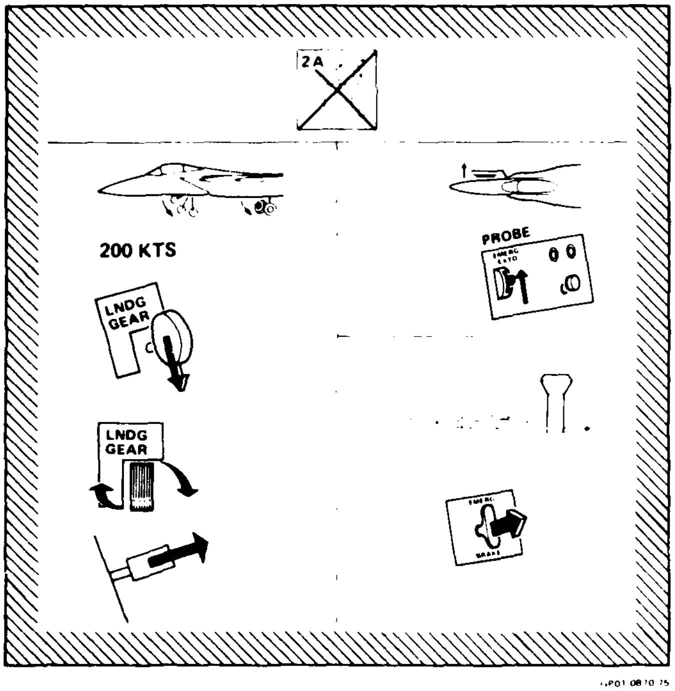


Figure 8. Hydraulic emergency actions

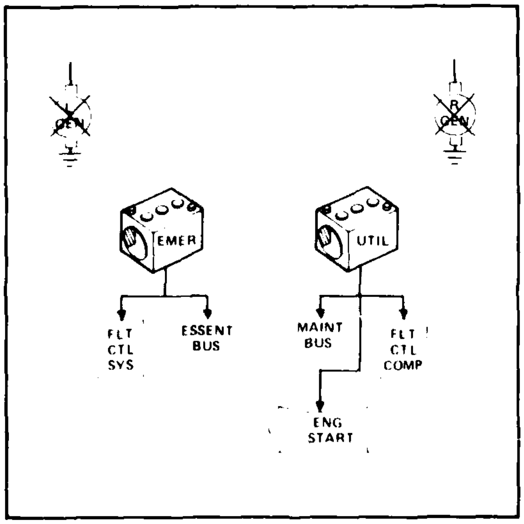


Figure 9. Dual generator failure

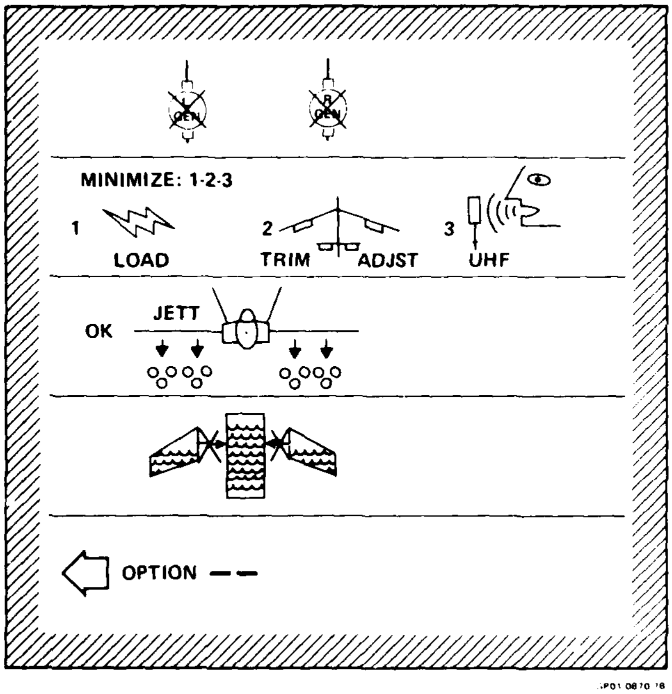


Figure 10. Additional emergency actions for generator failures

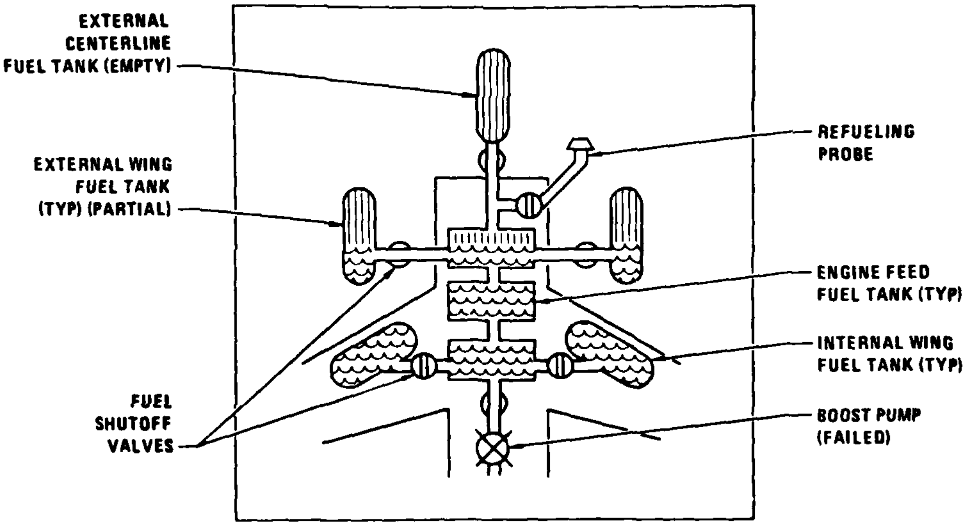
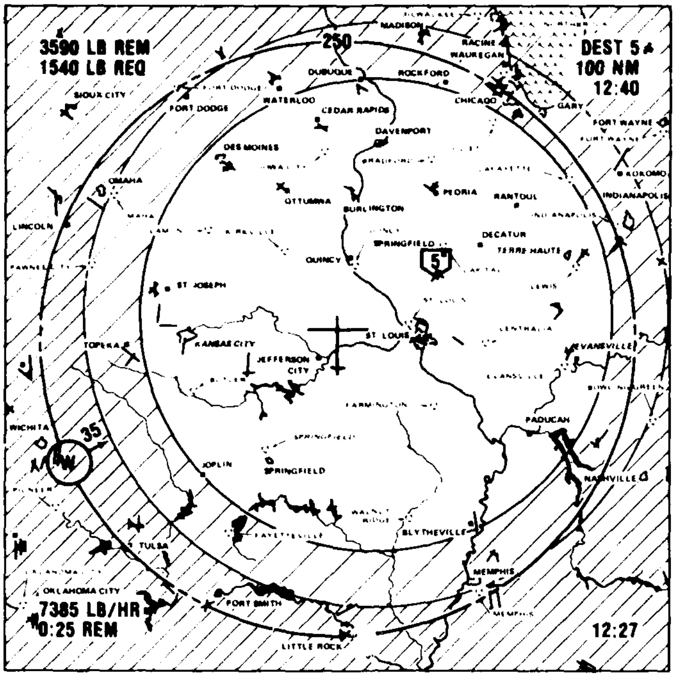


Figure 11. Fuel distribution



GP01 08 0 92

Figure 12. Fuel limited ranges

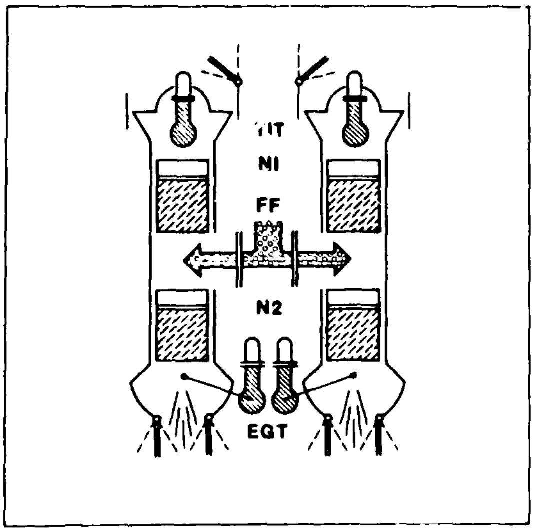


Figure 13. Nominal engine display

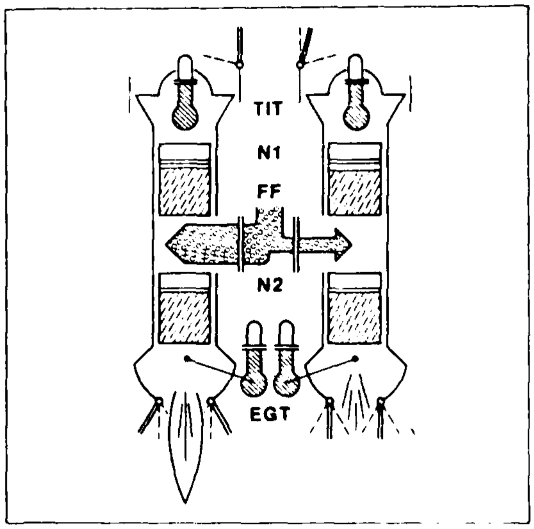


Figure 14. Abnormal engine status

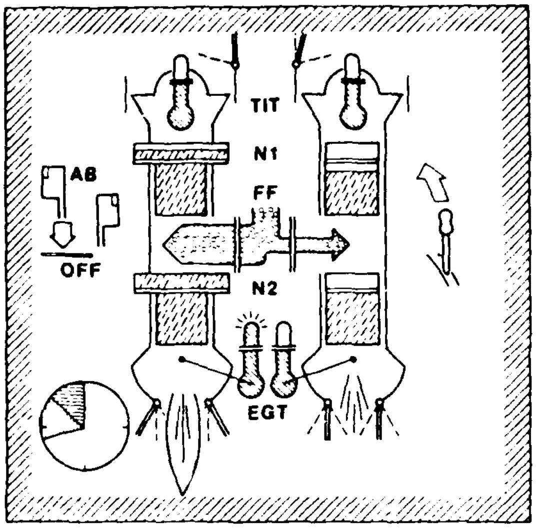


Figure 15. Emergency engine status and corrective action

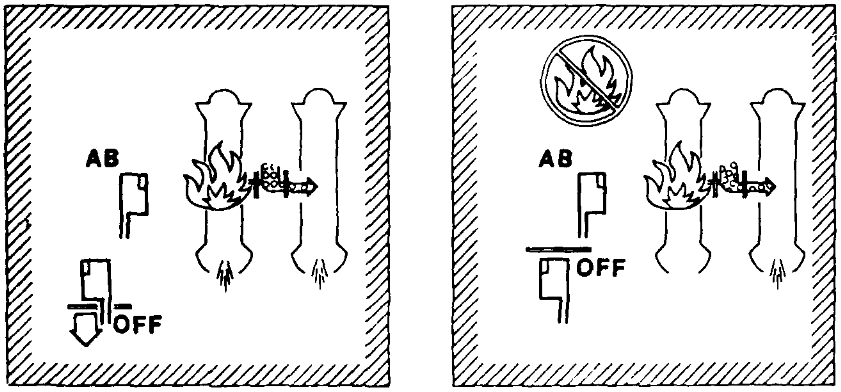


Figure 16. Engine fire emergency procedures

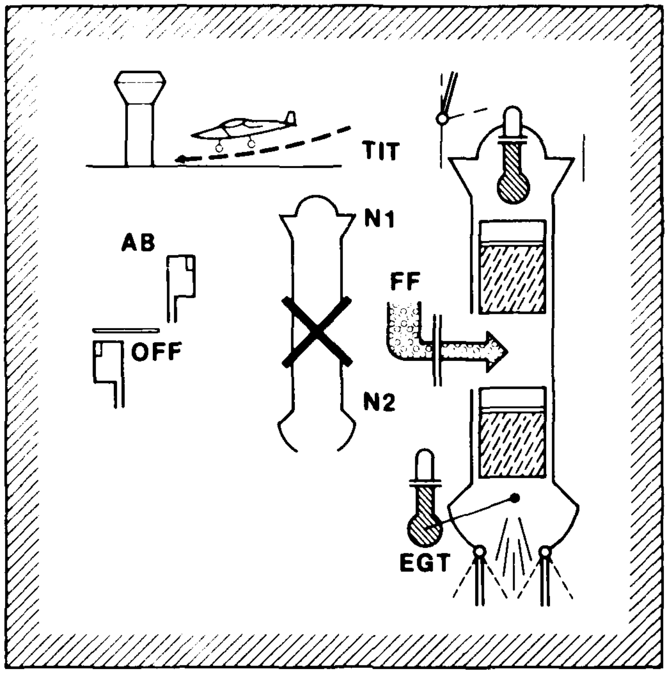


Figure 17. Emergency action/status with extinguished engine fire

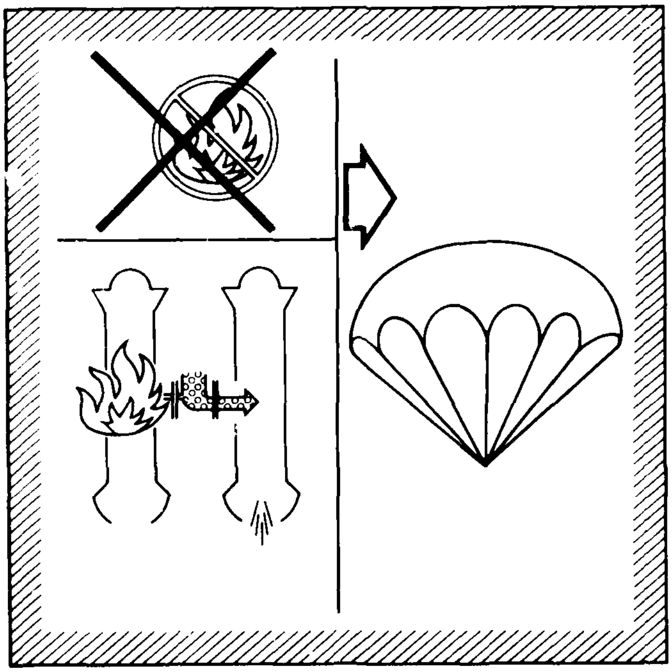


Figure 18. Final engine fire emergency action

THE ASSESSMENT OF COLOUR IN LOFARGRAM DISPLAYS

J. Metcalfe Ph.D
Plessey Electronic Systems Research Limited,
Roke Manor, Romsey, Hampshire, England.

SUMMARY

The work reported in this paper was carried out under U.K. contract number N/CP11045/74/DC28(3)/A1 the object of which was to assess the usefulness of multiple colours in c.r.t. displays. This paper deals with the assessments performed using Lofargram displays. Three phases of the work are reported, namely:

(i) the provision of display equipment;

(ii) an initial 'pairs comparison' assessment;

(iii) a final operator trial assessment.

The results of the two assessments allow conclusions to be drawn on the usefulness of multiple colours in the type of display under consideration.

1. INTRODUCTION

Lofargram displays are formed from spectrum analysed data where each spectrum analysis is painted as a line of intensity modulated dots, successive analyses being painted in raster form to allow a historical record to be built-up. Such display methods have been in use for many years and historically the dots have been painted from a monochromatic intensity scale. It was felt that an investigation should be carried out into the performance of such displays where the monochromatic intensity scale was replaced by a multiple colour scale.

2. THE EQUIPMENT

To allow the assessment of colour scales it was first necessary to provide a colour display system suitable for the type of data to be displayed.

The specification of the display system was:

(i) it must be capable of displaying a matrix of dots taken from a scale of at least 16 colour/brightness levels;

(ii) the matrix must be at least 512 dots per line by 512 lines;

(iii) the colour/brightness of each dot to be defined by 4 bits of information;

(iv) flexibility of display data formatting must be allowed.

To this end a raster scan display system was constructed consisting of an INTERDATA computer for system control, an AMPEX core store for display refresh and a colour monitor display. The system allowed 512 by 512 dots at 4 bits per dot,and the presentation of each dot was defined by reference to a presettable 16 element 'look-up table' containing 4 bits of information for each of the three primary colours at each 'look-up' location. This 'look-up' table system allows 4096 possible colour/brightness values to be used, although at any one time it is only possible to observe a sub-set of 16 due to the limited table length.

3. THE INITIAL ASSESSMENT

The object of the initial assessment was to reduce the number of colour scales such that objective performance measurements could be made on a small number of scales.

3.1 Selection of Colour Scales

The choice of colour scales for the initial assessment was based on two types of scale, namely:

(i) 'two-colour' scales (e.g. where dark blue merges into bright red);

(ii) mixed colour scales derived from a table of relative conspicuousness constructed experimentally (Butler, W.B. et al. 1974) known as TRACOR scales.

Using these criteria 14 different scales were selected for assessment. The scales were known as follows.

Scale	Name
1	Own TRACOR
2	Brown - White
3	Green - White
4	Blue - White
5	Red - White
6	Blue - Red
7	Red - Yellow
8	Green - Yellow
9	Green - Blue
A	Red - Green
B	Green - Red
C	TRACOR III
D	TRACOR IV
E	Modified TRACOR III

Scales C and D are those showing the best performance in the TRACOR trials, 'Modified TRACOR III' has the higher values altered to give less variation in hue, while 'Own TRACOR' was constructed according to the TRACOR table but with as gradual a change in hue as could be found. These latter scales thus represent a combination of the two-colour and the TRACOR scales. The precise details of the scales and video weightings can be found in the reference (Flake, R.G., 1976).

3.2 Assessment Organisation

The initial assessment was performed using a 'pairs-comparison' method. This method involved displaying a pair of Lofargrams on the c.r.t., each Lofargram being formed from identical data but using different colour scales. Every scale option was used alongside every other option thus requiring that, for N scales, N(N - 1)/2 pair tests be performed (i.e. 91 tests for 14 scales). The set of pair tests was carried out using 6 different Lofargrams, containing real-signal data, giving examples of four different signal types. Eight operators were asked to judge in which of the pair of Lofargrams the signals were most readily visible and to indicate the choice by pressing one of a pair of buttons. The operator responses were recorded by computer and stored for later analysis.

3.3 The Results Analysis

The data resulting from the assessment was organised in terms of signal type and as a set of figures for the number of pair tests for which each colour option was preferred to each of the other options. The figures were then arranged as a preference matrix for each signal type. A further matrix was formed of the combined results over all signal types. Figure 1 shows the combined preference matrix result (Reference, Flake, R.G., 1976 gives the full set of results). Considering Figure 1,the matrix is arranged as 14 rows of 14 columns, column 1 lists the number of pairs for which colour scale 1 was preferred to each of the other scales, column 2 the number of pairs for which scale 2 was preferred and so on. Below the preference matrix are two further rows of numbers. The first of these rows gives the proportion of tests in which the appropriate option was preferred. The second row lists the values of 'mean-difference', these values are formed from the proportion value, the variance of the data and the assumption of a normal distribution of the measurements (Flake, R.G., 1976). The mean differences can then be used to form a preference scale as shown in Figure 2. The preference scale runs from -1 to +1 and represents the preference of the option (i.e. a positive value indicates that the scale was preferred in more than 50% of the tests, a negative value is less than 50% of the tests).

3.4 Conclusions of the Initial Assessment

Considering the preference scale (Figure 2), colour options B, 1, A and 6 performed best. These options also gave consistently good performance for the individual signal types. The worst performing scales were 4, 5, 9 and C, these scales were also consistently poor when analysed against the individual signal types. Of the TRACOR scales, 'TRACOR III' performed consistently badly and 'Own-TRACOR' had a high performance coming second best overall. Of the two-colour scales, green-red was the overall best.

To summarize, the best performance was obtained from green-red, Own-TRACOR, red-green and blue-red

4. THE FINAL ASSESSMENT

Having analysed the results of the initial assessment a further assessment was undertaken to test the various colour scales in a more objective manner.

4.1 The Colour Scales

The scales selected for the final assessment use the four scales that were preferred in the initial assessment together with two scales to be used as controls, namely a scale of poor performance (green-blue) and a monochrome green scale of intensity.

4.2 Assessment Organisation

The format of this assessment was to produce Lofargrams using a white noise background with inserted simulated signals of varying amplitude and to ask operators to find the signals and state which type of signal they judged it to be. The same four signal types were used, as previously.

The signals were used at seven different amplitudes to allow a measure of detection performance to be made with respect to signal to noise ratio. Eight operators were used, each seeing all of the displays three times, totalling 24 decisions on each signal/amplitude/colour scale combination (i.e. 4032 decisions in all).

4.3 The Display Format

Each display used in the assessment consisted of a Lofargram made up of seven segments each 64 dots wide forming a display of 448 dots wide by 200 dots high. Each display had three segments containing noise only and four segments with signals. The segments were randomised in their order of use and position on the display to avoid bias due to learning effects. Furthermore it was arranged that in each display one signal was at such an amplitude that it could easily be seen. The operators were asked to view seven displays in a sitting and to mark the signals detected and give an opinion as to which type of signal had been observed.

4.4 The Results

The operator actions were recorded by computer for later analysis. The computer recorded successes of detecting a signal, success of deciding which type of signal and false alarms. The results of the operator actions were grouped into signal type and scale option and analysed statistically with respect to four performance criteria, namely:

(i) 'first detection', the level at which a signal is first detected;

(ii) 'final detection', the level at which a signal is detected and detection is maintained up to the highest level;

(iii) 'first-classification', the level at which a signal type is first correctly identified;

(iv) 'final-classification', the level at which a signal type is correctly identified and the decision is maintained up to the highest level.

Denoting the options as

Option	Scale
1	Monochrome Green
2	Blue-Red
3	Green-Blue
4	Red-Green
5	Green-Red
6	'Own-TRACOR'

The results of the trial showed that the differences in mean performance between the best and the worst colour scales was always less than 1dB for the individual signal types. However, the low values of variance of the measurements did produce some significant differences in mean performance at the 99% confidence level (mainly that option 3 performed poorly, as indicated by the initial assessment). In general there was some interaction between colour scale and signal type such that when the results are arranged over all signal types the maximum difference falls to 0.5dB and when arranged over all assessment criteria falls to 0.2dB. The order of performance was:

Option	Relative Performance (dB)
1	0.0
2	-0.01
5	-0.02
4	-0.08
6	-0.09
3	-0.2

(NOTE:- the detailed results and analysis can be found in Flake, R.G., 1976)

5. CONCLUSIONS

The general conclusion to be drawn from the assessments is that, under the conditions of the trials and for c.r.t. Lofargrams, there is no worthwhile overall performance advantage in the use of multiple colour scales instead of a monochrome green scale.

REFERENCES

BUTLER, W.B., 1974, 'Engineering Guidelines for the Use of Colour in a Sonar Display', TRACOR Sciences and Systems.

FLAKE, R.G., 1976, 'Assessment of Colour in Lofargram Displays', Plessey Electronic Systems Research Limited, Roke Manor Report Number 72/76/154.

ACKNOWLEDGEMENTS

The work reported in this paper was performed at Roke Manor (Plessey Electronic Systems Research Limited) and was supported by the Procurement Executive of the Ministry of Defense. Acknowledgement is given to Plessey for permission to publish this paper.

Option	1	2	3	4	5	6	7	8	9	A	B	C	D	E
1	0	13	17	8	8	20	22	18	17	20	32	11	21	17
2	35	0	19	18	19	32	31	37	21	36	31	19	27	28
3	31	29	0	11	14	27	32	28	19	29	38	17	30	24
4	40	30	37	0	23	40	36	40	20	41	33	33	29	33
5	40	29	34	25	0	34	42	35	27	41	38	20	36	24
6	28	16	21	8	14	0	17	20	12	22	26	18	23	23
7	26	17	16	12	6	31	0	21	18	32	28	16	28	24
8	30	11	20	8	13	28	27	0	15	32	27	16	20	20
9	31	27	29	28	21	36	30	33	0	27	33	22	31	31
A	28	12	19	7	7	26	16	16	21	0	23	14	19	17
B	16	17	10	15	10	22	20	21	15	25	0	10	21	12
C	37	29	31	15	28	30	32	32	26	34	38	0	34	34
D	27	21	18	19	12	25	20	28	17	29	27	14	0	25
E	31	20	24	15	24	25	24	28	17	31	36	14	23	0
	.63	.43	.47	.31	.33	.59	.55	.56	.4	.62	.64	.36	.54	.5
	.34	-.15	.06	-.48	-.43	.24	.14	.17	-.25	.33	.37	-.33	.11	0

FIGURE 1 - PREFERENCE MATRIX, AVERAGE OF ALL SIGNALS

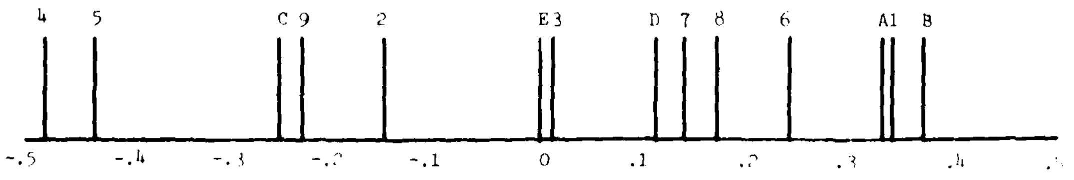


FIGURE 2 - PREFERENCE SCALE, ARRANGED OVER ALL SIGNALS

ADVANCED DISPLAY FOR COMPLEX FLIGHT TRAJECTORIES

Peter B. Lovering
Midwest Systems Research, Inc.
Dayton, Ohio

Sqn Ldr Stuart B. Burdess RAF
RAF Staff College
Bracknell

SUMMARY

A number of cockpit control and display problems were revealed during simulation and flight tests of complex approach trajectories in support of the Microwave Landing System (MLS) Program. Among these problems were pilot orientation with respect to the approach profile and to the runway, verifying proper performance along the approach profiles and cross-checking/monitoring profile computations. Recognizing these problems, the Crew Systems Development Branch, Flight Dynamics Laboratory, Wright-Patterson AFB, initiated a color graphics display research effort aimed at finding some viable solutions. A prototype 2-D graphic flight display was subsequently flown in a flight simulation experiment. The test display format, designed specifically to address orientation and lateral control aspects of the precision approach problem, contained a map display of the approach profile, aircraft attitude, flight director commands for pitch and a 24 second lateral path predictor. Four colors, green, blue, orange and white were used on a black background for the display elements. Eight rated Air Force pilots flew over 260 curved path, multi-segmented glideslope approaches in a variety of simulated wind conditions. Data collection included objective performance with respect to the desired flight path and pilot opinion on each of the new display features. Pilots were favorably impressed with the display concept and strongly recommended further development.

1. INTRODUCTION

A series of Flight Profile Investigations conducted in the 1971-1979 time period revealed a number of problems associated with curved, multi-segmented precision approach paths such as those envisioned in the use of the Microwave Landing System (MLS). Among these were:

a. There was no satisfactory way for the pilot to confirm that all data entry and profile computations were correct during the accomplishment of an approach.

b. It was extremely difficult for the pilot to correlate his position on the approach with that desired. Desired bearing, distance and altitude at checkpoints along the path were indicated on the terminal area charts and three separate instruments were provided in the cockpit for use in the cross-check; however, the pilot simply did not have the time to make use of them.

c. Frequently, pilots complained of losing orientation in the patterns. Often they lost track of their position with respect to the overall profile and the runway and found it difficult to anticipate turns, changes in vertical path, etc.

Recognizing that these display deficiencies posed potentially serious limitations to full utilization of an emerging terminal area navigation system, personnel in the Crew Systems Development Branch initiated a graphic display development effort aimed at providing some viable solutions to the problem.

Development work started in 1978 as part of the MLS effort using a specially equipped T-39A in which a color CRT had been installed for the test. The aircraft was equipped with Time Referenced Scanning Beam (TRSB) receivers, a digital Automatic Flight Control System and a computer and software required for complex trajectory generation. The display was programmed for bench testing and some preliminary dynamic tests were performed in flight. Air Force participation in inflight MLS research and development was terminated on 31 December 1978 before any formal flight testing could be accomplished.

In late 1979, a decision was made to continue research in this area through an in-house simulation effort. Rationale for this decision was:

a. Replacement of the Instrument Landing System ILS) with MLS facilities remains an international goal. If the aviation community including the Air Force, intends to use the system safely and efficiently, several crew/system interface issues must be addressed; displays are one of the most important issues. The Crew Systems Development Branch has more background information and experience with flight crew issues as they pertain to MLS operations than any other Air Force organization.

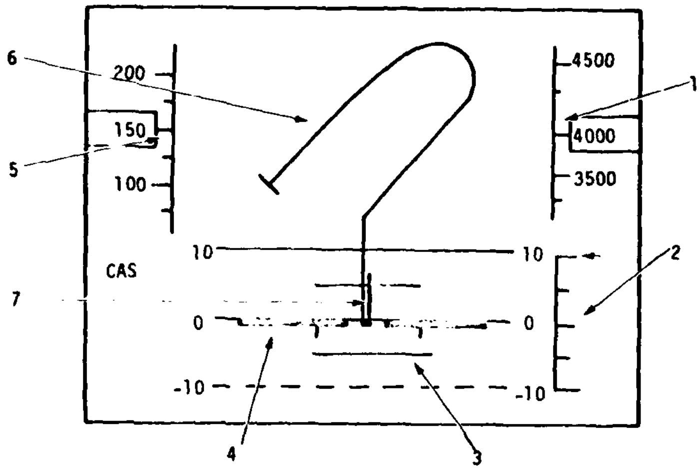
b. Precision navigation problems associated with existing Air Force missions such as the C-130 All Weather Aerial Delivery (AWADS), Low Altitude Parachute Extraction System (LAPES) and others are not unlike those identified in MLS testing, Increased use of digital navigation computers and graphic displays in the cockpit provide a variety of opportunities to improve the kinds of information provided to the pilot flying these missions, thereby improving precision, flexibility and safety with the added benefits of reduced pilot workload,

c. Other emerging technologies such as unconventional flight and trajectory control being examined in Control Configured Vehicles (CCV), the integration of Fire and Flight Control systems (IFFC) and Integrated Flight Trajectory Control (IFTC) all pose formidable challenges to cockpit display designers. At the same time, systems supporting these technologies generate the kinds of information required by the pilot for effective monitoring and control. The problem rests with how this information should be integrated and displayed for cockpit use.

Consequently, in January 1980, an A-7 cockpit simulator was modified for further display testing.

2. DISPLAY

The graphic display shown in Figure 1 was designed with the intent of examining lateral control and display aspects of the problems described previously.



1. Altitude scale
2. Glideslope scale
3. Pitch attitude scale
4. Aircraft symbol
5. Airspeed scale
6. Approach profile
7. Path predictor

Figure 1 - *Test Display*

The airspeed and altitude scales are standard and in use in several head-up and head-down displays. The aircraft symbol and pitch scale is standard in pitch as are the flight director command bars located at the aircraft wingtips. The glideslope indicator and deviation scale are standard except that the scale shows ±50 feet from glideslope center throughtout the approach.

New display features include a scaled picture of the approach to be flown, a twenty second path predictor and an aircraft symbol that rotates to show bank angle against a stationary (in roll) horizon line. The profile was oriented to aircraft heading so that course deviation and intercept angles were shown in a straight forward manner and, when on course, the path approached the aircraft at a rate consistent with ground speed. The path predictor deflected left or right as a function of bank angle and true airspeed.

The overall display was kept as simple as possible for initial testing to allow an evaluation of the integration concept and so that changes or additions subsequent to testing could be based on the pilot evaluators' stated needs. Similarily, the display was standard in the pitch axis to avoid potentially confounding effects on the lateral display evaluation. Basically, it was felt that the profile and changes in the lateral situation and performance displays would be a first step in the right direction and provide at least a partial solution to the problems identified in earlier tests.

3. PROFILE

The profile selected for the experiment was one of the most difficult identified in earlier tests (Figure 2). It consisted of a short 45° intercept leg, a downwind, a 180° turn to final and a 4 mile final approach. All approaches started at 4000' above the ground and terminated at what would be the runway threshold at 50 feet. A five degree descent angle started just prior to starting the turn to final and continued to a point three miles from the runway where the descent shallowed to three degrees.

4. TEST

In June 1980, eight rated Air Force pilots with varing backgrounds were selected to participate as subject pilots in the test. Over 260 approaches were flown by these pilots in a variety of wind conditions. Objective performance data with respect to the desired approach path was collected on these runs along with pilot opinion in regard to the display concept and flyability.

5. RESULTS/DISCUSSION

Three major observations were made by the experimenters concerning the ability of the participants to fly the approach using the two-dimensional display. The first observation involves training. With only a minimal explanation of how the integrated display worked, pilots very quickly established their own techniques for using the display. Secondly, there were no obvious control reversals (pitch or roll in the wrong direction) during the experiment nor were any reported by the subjects. Finally, and perhaps most important, when large deviations from course occurred, there was never any real concern expressed over pilot orientation with respect to the intended path or how he would correct the situation. By visual assessment, the pilot had only to pick the way he wanted to return to course. These three aspects alone indicate that the display concept constitutes, at least partially, a solution to some of the display

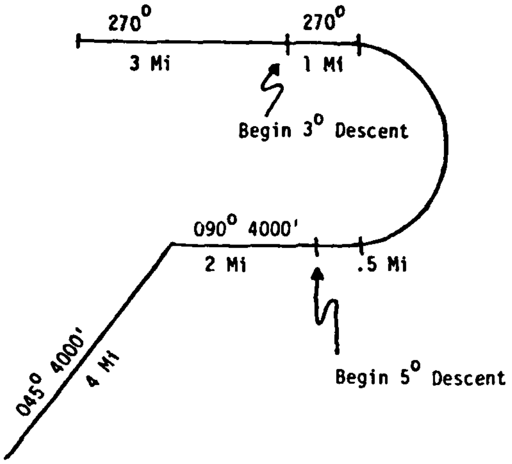


Figure 2 - Approach Profile

problems encountered during the MLS tests.

Overall, pilots felt that their flight performance would have been better using a flight director than it was with the test display. Ironically, however, they rated their ability to use the approach profile, the path predictor, and with one exception the outside-in aircraft symbol equal to or higher than other, more conventional display features. Several factors could have contributed to this inconsistency, among these being familiarity (as reported by one pilot) and over-all display quality. Another pilot, after indicating that he thought performance would be better with a flight director, remarked that "there is no question that the test display is superior to the flight director." This would lead one to conclude that the pilots, at times, were reporting their feelings about the display concept while others were commenting on the quality of the prototype display.

Unanimous preference for the graphically displayed approach profile over a conventional course deviation indicator was significant and due probably to the fact that pilots could look ahead and anticipate lateral control requirements. Positive response to the path predictor--the information it provided and the way in which it operated-- was significant also and points again to the premise that present and future situation and performance information can be used effectively to control an aircraft.

Subsequent to simulation, several pilots stated that they could have flown more accurately during the early stages of the approach but they knew, like ILS, the requirement for precision increases to a maximum on the final segment. Experimenter observations and accuracy data support this in that accuracy on the last segment was second only to the first leg where the simulator was started in a trimmed, on course configuration. It was apparent to the observer that, from about the midpoint of the 180 degree turn, pilots were concentrating on a smooth interception of the final approach leg in a manner very similar to the way they would on a visual approach.

The summation of error data for each segment revealed that the turn to downwind was second to the 180 degree turn to final in maximum error. This can be misleading in that by design, crosstrack error was large throughout the turn. Unlike the 180 degree turn, there was no radius computed or displayed for the tracking task. The pilot had to judge when to start the turn in order to make a smooth transition to downwind. All pilots did this by starting the turn 15-20 seconds prior to reaching the waypoint, returning to course on downwind 15-20 seconds after the waypoint. Effectively, they "cut the corner." Crosstrack error was being summed throughout the maneuver, making it look like a tracking error.

Aside from the performance and pilot acceptance issued addressed during the experiment, there remains the data entry and profile computation problem encountered during MLS testing. The fact that the pilot can see results of the computation process and compare the graphic depiction with the approach plate should eliminate gross errors that could occur during data entry. Similarly, if a computation failure occurs during an approach, pattern distortion should cue the pilot immediately.

Taken one step further, careful integration of the right information into the graphic display could be used effectively to reduce or, in time, eliminate the requirement for frequent and time consuming reference to approach plates during an approach. Historically, approach plates have been a source of consternation to pilots. Problems include lighting, finding a suitable place to mount or rest the publications, and currency.

Overall, results of the experiment were very encouraging in terms of pilot acceptance, performance and the fact that all control, except power, could be maintained by reference to a single display. Obviously, additional backup information such as heading, vertical velocity or flight path angle would be desirable for actual flight. The dependence upon these displays, however, and the requirement to mentally integrate the data from them will be greatly reduced.

6. CONCLUSIONS

a. Pilots were favorably impressed with the new display features.

b. Pilot performance with the display indicated that with further refinement, precision control to ILS or even better standards may be achieved.

c. Training requirements are minimal since lateral control and situation displays are relatively straight forward.

d. The graphic display eliminates the kind of position orientation problem encountered using the Flight Director in complex trajectory operations.

e. A display of this type can be used effectively to increase pilot confidence in profile construction and computation and aid in monitoring system operation.

f. The display provided the kind of information a pilot needs to judge present and furure situation and performance in terms directly related to his flight control tracking task.

7. REFERENCES

Burdess, Lovering, Miller, Park, Warner, June 1981, "Simulation Report -- Advanced Display For Complex Flight Trajectories," Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio 45433.

DISCUSSION AVIONICS PANEL SPRING MEETING
On
ADVANCED AVIONICS AND THE MILITARY AIRCRAFT MAN/MACHINE INTERFACE
26-29 April, 1982

SESSION Nr. 2 COLOUR DISPLAY SYSTEMS-Chmn Prof. Ir. D. Bosman, NE

Paper Nr. 4
Title : HUMAN FACTORS CONSIDERATIONS ON THE PERCEPTION OF COLOUR IN THE AIRBORNE ENVIRONMENT
Authors : C. P. Gibson, Dr. J. Laycock
Speaker : R. A. Chorley
Comment : You suggested that a pilot's subjective impression of the colors in a head-down display may be affected by previous use for an extended period of the head-up display, because of the bright green symbology used in the latter. Is this effect likely to be significant, in view of the extremely small portion of the HUD field of view which is actually occupied by the symbology?

Response : The extent of the change in perceived colors following a period of adaptation to a colored source will depend on several parameters. Adaptation to a bright green head-up display will occur within the retina at the points where the image is located. The degree to which this adaptation is perceived will depend, as you suggest, on the proportion of the field of view. For daylight operations it is unlikely that this will be of practical significance but the effect may be noticeable under dusk or night flight conditions causing the display to appear different than when it is viewed under daylight conditions.

Paper Nr. 4
Title : HUMAN FACTORS CONSIDERATIONS ON THE PERCEPTION OF COLOUR IN THE AIRBORNE ENVIRONMENT
Authors : C. P. Gibson, Dr. J. Laycock
Speaker : R. G. White
Comment : Would green discrimination on a a head-down CRT be affected by using a wide-field of view HUD at night to fly on a LLTV or FLIR picture, when although the HUD luminance would be low it would be fairly even over the whole field?

Response : Any degree of adaptation produced as a result of viewing a dynamic display such as LLTV or FLIR will be more noticeable because a greater area of the retina will have to been adapted. Adaptation will occur when a colored source which is bright enough is viewed for long enough. As such the extent of the adaptation is dependent on the strength of the adapting source and the time for which it is viewed. Provided that the luminance of the display is low enough any adaptational effect will be small. However, the extent to which operational luminance levels may cause significant adaptational effects during night flight conditions is not clear.

Paper Nr. 5
Title : APPORT DE LA COULEUR DANS LA SYMBOLOGIE DE PILOTAGE
Author : Dr G Santucci, Dr J Menu
Speaker : J. Walraven
Comment : With regard to your results on visual acuity measurements employing different colors for opto-type and background respectively , did you control properly for luminance contrast?

Response : Effectivement nous avons controlé la luminance en utilisant un phatandre carriage avec un filtre CIE 31. Nous n'avons pas voulu utiliser la notion de luminosite car notre expèrimentation étant à visée ergonomique, nous avions besoin d'une métrique standard afin d'avoir un language commun avec les fabricants d'équipement. Cependant nous avons regardé la question en utilisant le concept de luminosité il ne semble pas que nos résultats en soient très différents sauf peut ètre en ce que concerne les couples ou intervient le bleu. Mais on ouvre alors un vaste domaine de discussion avec la couleur bleue.

Paper Nr. 5
Title : APPORT DE LA COULEUR DANS LA SYMBOLOGIE DE PILOTAGE
Author : Dr G Santucci, Dr J Menu
Speaker : Prof. D. Bosman
Comment : By applying SNELLEN letters, the visual acuity for colored objects (edges) is measured. With gradual transitions rather than sharp edges (blurred letters) the measured RT may turn out different. Did you explore the effect of spatial frequency content on RT?

Response : Dans cette experimentation seule l'acuité visuelle avec des lettres de SNELLEN a bord, net, a éte etudiee (sharp edges). Les bords flous (blurred letters) n'ont pas ete utilisés: Par contre nous avons realisé, une autre experimentation avec des réseaux carrés ou les mêmes résultats ont éte trouvés. Par contre les réseaux "flous" n'ont pas ete utilises.

Paper Nr. 6
Title : COLOR DISPLAY FORMATS: A REVOLUTION IN COCKPIT DESIGN
Author : Dr J M Reising, T J Emerson
Speaker : D. Beevis
Comment : The results of the Stroop psychological test, among others, indicate that the printed word is a very effective coding medium, to the extent that it can over-ride other coding techniques such as color. Specialized symbols such as those used in the emergency action/status displays shown as examples would, to my mind , be more effective than pictograms or special symbols which have to be learned, and for which far less learning time is available than for the printed word, the optimum might be a suitable mix of words, symbols and pictograms.

Response : Yes. In a recently completed study which examined stores management displays - pictorial vs. text - it was found that the pilots preferred a display which contained both. The pictorial format gave them an overall situation awareness, and the text gave them specific data. In our simulation which will be conducted at the Boeing Military Airplane Co. In August of this year, we will examine the proper mix of pictorial and text - but the emphasis will be on pictorial as the primary means and text as supplementary.

Paper Nr. 6
Title : COLOR DISPLAY FORMATS: A REVOLUTION IN COCKPIT DESIGN
Author : Dr J M Reising, T J Emerson
Speaker : R. G. White
Comment : You believe pictorial displays (as opposed to digital and analogue presentations) will reduce pilot workload. Do you have any evidence for this?

Response : We are just beginning studies of pictorial formats. As of this time I have no hard evidence of a reduction in processing time, for example. In the July-August timeframe we will be conducting a study at the Flight Dynamics Laboratory to examine this question.

Paper Nr. 6
Title : COLOR DISPLAY FORMATS: A REVOLUTION IN COCKPIT DESIGN
Author : Dr J M Reising, T J Emerson
Speaker : Dr. E. B. Davis
Comment : I have been very interested in the picture displays. I would like to hear some comment on the way in which you see the pilot interacting with the picture display. The sort of thing I am looking for is the role of the touch sensing display, in terms of the pilot addressing some particular part of the picture.

Response : Tomorrow we will hear a whole day on voice systems, which is one logical way to interact. We currently use the buttons arranged around the CRT. Touch-sensitive could certainly be used if we could do it in the presence of vibration and g-force. But you could certainly touch a part of the picture and change it. The computer will bring up these pictures at a certain time and the pilot will interact either by voice, touch, or button.
We are running a study right now on how we could change all our stores pictures by voice or button.

Paper Nr. 6
Title : COLOR DISPLAY FORMATS: A REVOLUTION IN COCKPIT DESIGN
Author : Dr J M Reising, T J Emerson
Speaker : R. M. Taylor
Comment : With regard to perspective terrain formats, is there any evidence that view position affects tracking performance, and is there likely to be any requirement for vertical exaggeration of terrain as opposed to 1:1 scaling?

Response : At this time we do not yet have the equipment to provide a dynamic display. The equipment will arrive at the Avionics Laboratory in Jan. 1983. At that time we can examine your question.

Paper Nr. 6
Title : COLOR DISPLAY FORMATS: A REVOLUTION IN COCKPIT DESIGN
Author : Dr J M Reising, T J Emerson
Speaker : Prof. D. Bosman
Comment : A pictogram is a means to perceive a huge amount of prestructured data in a very short time, with the advantage that the central system is not overloaded since the input data is biologically preprocessed by an existing "filter". This is necessary at high workloads, but detrimental to vigilance in low workload situations. Have you experimented with, e.g. time-line-analysis to determine the desirability and effectiveness of pictorially presented information?

Response : In August of this year we will be using the Boeing simulation, mentioned previously, for a high workload interdiction mission. During the mission phases we will monitor performance to look for overloads. We will use monochrome, color stroke, and color raster formats. We will then analyze format and type by mission phase; hopefully, this analysis will provide some data relative to effectiveness of pictorial formats in various mission phases.

Paper Nr. 6
Title : COLOR DISPLAY FORMATS: A REVOLUTION IN COCKPIT DESIGN
Author : Dr J M Reising, T J Emerson
Speaker : R. W. MacPherson
Comment : The pictorial displays you described imply large amounts of data must be handled. Do you believe that current (or perhaps VHSIC) technology is capable of processing the information required for real time or near real-time displays?

Response : In general the answer is yes, but it depends on the definition of real time. For a large scale plan view map display 5 Hz refresh rate may be sufficient, while on a perspective map view, 30 Hz or more may be required. The second point centers on the complexity of the display format. A pictorial format made up of a limited number of vectors, can be generated now. As different features such as texture, shading and sun angles are added, the generation time increases. When the equipment arrives at the Avionics Laboratory in Jan. 1983, this question will be examined in detail.

Paper Nr. 7
Title : THE ASSESSMENT OF COLOUR IN LOFARGRAM DISPLAYS

DISCUSSION

Author : Dr J. Metcalfe
Speaker : Prof. D. Bosman
Comment : You were using a green CRT, but I assume that the light output comes from different phosphors and is not monochrome. Was the green of this phosphor (the green sensation, as you would experience) independent of the video current?
This morning Dr. Laycock and Dr. Gibson showed that the color experience is dependent on the environmental color, did this come into your experiments?
Response : That is correct, it was not monochrome. When the video levels were set up for the various scales, the video weightings for each of the color components were adjusted to ensure that the correct color balance was maintained.
For all of these types of tests we performed these experiments in a darkened room to represent the probable operating conditions.

Paper Nr. 8
Title : ADVANCED DISPLAY FOR COMPLEX FLIGHT TRAJECTORIES
Author : P. B. Lovering, Sqn Ldr. S B Burdess
Speaker : Wg Cdr D. C. Schuller
Comment : Some years ago I took part in an experiment quite similar to the one you have described. It was a VSTOL approach task and like yours had attitude and horizontal situation displays superimposed. The difficulty with the display, which was monochrome, was that when close to touchdown, distinction between the two displays became more more difficult and any distraction due to workload increase could lead to disorientation. In your experiment I was surprised to hear that this difficulty did not occur. The reason would appear to be your use of color to distinguish between the attitude and horizontal situations but I am left with the feeling that when close to touchdown any sudden workload increase due to extraneous factors may result in disorientation. Would you care to comment?

Response : Color was used to separate the various display elements and information types. To date, at least, it seems that it might have helped. I share your concern with regard to disorientation. we will have to be very careful as we add vertical situation information, expanding runway, and proper scaling to avoid too much display activity and resulting confusion. If we cannot keep it simple and straight forward we will have to look for another format.

Paper Nr. 8
Title : ADVANCED DISPLAY FOR COMPLEX FLIGHT TRAJECTORIES
Author : P. B. Lovering, Sqn Ldr. S B Burdess
Speaker : Dr J. Laycock
Comment : The present display obviously includes the element of prediction desired by the pilot. How necessary do you think prediction is and could a flight director produce the same performance from the pilot?

Response : In my opinion, anything that will allow the pilot to "see" ahead will help him in planning his future actions. We tried to combine path prediction, situation and range range rate information in this display in a manner that would accomplish that. Pilots could perform well using the flight director by merely keeping the steering commands centered, but they had little time to sort out and integrate other supporting information to confirm proper steering command operation.

Paper Nr. 8
Title : ADVANCED DISPLAY FOR COMPLEX FLIGHT TRAJECTORIES
Author : P. B. Lovering, Sqn Ldr. S B Burdess
Speaker : R. G. White
Comment : As a supplementary comment to Dr. Laycock's previous question, I would like to say that my work at RAE supported the author's view that a combination of guidance and situation information was better than just a director. The situation information affords the pilot flexibility of action, permits him to make predictions and makes it easier for him to recover a situation following failure of the director.

Response : I agree. This is a key issue. Thank you.

Paper Nr. 8
Title : ADVANCED DISPLAY FOR COMPLEX FLIGHT TRAJECTORIES
Author : P. B. Lovering, Sqn Ldr. S B Burdess
Speaker : Dr. G. Hunt
Comment : Is it possible to isolate the usefulness of color in this display application? Did you go through a phase of using a monochrome version, or were there stages in the evolution of the color display which you can describe.

Response : Colors were changed or modified during buildup and used throughout the experiment. We felt that, as the display developed and work started on the pitch axis, expending runway, etc., color coding would help in the separation of information elements and types of information.

Paper Nr. 8
Title : ADVANCED DISPLAY FOR COMPLEX FLIGHT TRAJECTORIES
Author : P. B. Lovering, Sqn Ldr. S B Burdess
Speaker : Prof. D. Bosman
Comment : You stated that you have only used color in your experiments. Do you intend to extend your experiments to the night flying situation, where with scotopic vision the display will not be seen as color, or else it will be of sufficient illuminance that it will appear blinding.

DISCUSSION

Response : I hope there can be a followup to this effort. At this point there are no plans for that. We may be doing some similar work but with a different display with the 757 equipment.

Paper Nr. 8
Title : ADVANCED DISPLAY FOR COMPLEX FLIGHT TRAJECTORIES
Author : P. B. Lovering, Sqn Ldr. S B Burdess
Speaker : R. M. Taylor
Comment : Did your work shed any light on the relative merits of "inside-out" and "outside-in" references?

Response : No, there was no plan to reopen that question. We felt that the moving aircraft symbol/path predictor combination might be more suitable for approach work so we tried it.

OVERVIEW OF STATE-OF-THE-ART, R & D NATO ACTIVITIES, AND POSSIBLE APPLICATIONS-VOICE PROCESSING TECHNOLOGY

BRUNO BEEK

Rome Air Development Center

Communications Division

Griffiss Air Force Base,NY 13441

SUMMARY

The purpose of this paper is to introduce the subject of Voice-Interactive Systems and its role in military applications. The history and evolution of automatic speech recognition and synthesis is briefly explored and the current state-of-the-art is reviewed. The term "Voice-Interactive Systems" is defined and the advantages and disadvantages of Voice-Interactive Systems are highlighted. Next, previous applications of speech systems to military problems are summarized, the major application areas are described and current development projects in the U.S. and other NATO countries are presented. Special attention is focused on the cockpit application. Several projects in this area are discussed along with a summary of important issues to consider when applying Voice-Interactive Systems to the aircraft environment.

1. INTRODUCTION

The objective of this paper is to provide a broad perspective on the topic of Voice-Interactive Systems, and in particular the use of these systems for cockpit and other military applications. Before the actual application of these systems is discussed it would be helpful to consider such questions as: "How did speech systems evolve?", "What techniques are used to do speech recognition and synthesis?", and "What are the major problems in doing recognition and synthesis?" By answering these questions it is hoped that the reader can gain an understanding of the current capabilities and limitations of automated speech systems. With this backround, the issues of applying speech systems to military problems is undertaken. Because the use of speech systems is now so widespread the treatment here is not exhaustive, but instead is intended to be representative of much of the current research. This paper is tutorial in tone and cannot comprehensively cover all of the topics presented, however, the extensive bibliography provides references for more detailed information for the interested reader.

2. What are Voice-Interactive Systems?

Potential users in industry, the home and the military are starting to become excited about the possibilities of voice interaction with machines. Speech Technology has recently received considerable publicity as new applications are discovered (DODDINGTON, G. R., and SCHALK, T. B., 1981; SIMMONS, E. J., 1979; LEVINSON, S. E. and LIBERMAN, M. Y., 1981). In this section the history of speech technology is traced from the pioneering days in the fifties to the present, and the advantages and disadvantages of speech are discussed. Prior to this discussion, it would be useful to review some terminology. Voice-interactive systems include both automatic speech recognition (ASR) and systems for speech synthesis. "Speech recognition" generally is used to refer to a machine which can analyze or make a decision on a speech signal from a human speaker who utters single words or short sequences of words. "Speech Synthesis", sometimes called voice response or voice output, refers to a machine which can generate a human or human-like vocal response. "Speech Understanding" is sometimes used to refer to machines which can not only recognize complete sentences (as opposed to a single word or short sequence of words) but somehow interpret the meaning of the sentence as well. "Speaker identification" (or speaker recognition) is used to describe a machine which has the ability to determine who is speaking, rather than what is said. There are other useful actions based on speech that can be perfomed by machines including: the capability to recognize what language is being spoken (language identification), the ability to remove noise or interference from speech (speech enhancement), the capability to compress the bandwidth necessary to transmit digital speech (vocoders), the capability to detect abnormal physical or psychological conditions of the speaker (stress analysis), and others. The useful functions being performed by these systems are accomplished through the theory and practice of speech processing technology. How this technology has evolved is the topic of the next section.

2.1. The Evolution of Speech Processing Technology

Speech Processing Technology has been based to a large degree, on early research in such areas as experimental phonetics, the physiology of the human vocal apparatus and auditory system, human perception of speech, and especially acoustics, phonetics. This basic research provided much of the fundamental knowledge which is required to some extent in almost all speech processing systems. One of the first applications of this knowledge to speech processing was reported in 1952 (DAVIS, K. H., et al, 1952) with the demonstration of a successful speech recognition system which could recognize the digits spoken from one talker. One of the first electronic speech synthesis systems was produced even earlier, in 1939 by researchers at Bell Labs (DUDLEY, H., RIESZ,R. R., WATKINS, S. A., 1939) This system was called the vocoder and was the forrunner of the modern vocoder.

Important milestones in the development of speech processing technology occurred in 1956 and 1959, with the first efforts at the incorporation of linguistic information (WRIEN, J. and STUBBS, H. L.; 1956) as the use of a general digital computer (FORGIE, J. W. and FORGIE, C. D., 1959) respectively. One of the first speech recognition systems which could recognize contiuous speech was developed in 1969, and could accomodate a highly constrained vocabulary of 16 words (VICENS, P. J., 1969). Much of this early work was based on the assumption that all the information required to do recognition could be extracted from the spectral envelope of the acoustic speech wave. This resulted in the development of many approaches for spectral analysis of speech, and with these analysis approaches came very sophisticated mathematical techniques for manipulating the acoustic speech parameters. Some of these mathematical techniques are: linear predictive coding (LPC), dynamic programming, the Fast Fourier Transform, homomorphic filtering, among others. Speech recognition techniques which are concerned solely with the manipulation of the acoustic waveform are sometimes referred to as mathematical, pattern matching or statistical approaches. However, an alternate approach was soon to receive considerable attention.

Prior to 1970 most of the work in ASR was concerned with recognizers which could only deal with a very limited vocabulary (typically 50 words or less), spoken in a discrete manner, for a talker who had previously trained the device. In fact, many of these recognizers worked with high accuracy in the laboratory, and a group of researchers at RCA were encouraged enough to form their own ASR company, Threshold Technology,Inc. in 1970. One major exception to the history presented above was the research on speech recognition at IBM. In the late sixties IBM under sponsership from the Rome Air Development Center began research on the complex problem of Automatic Continuous Speech Recognition. (TAPPERT, C. C., et al, 1968,1970,1971 and DIXON, N. R., et al, 1970, 1971, 1972, 1973). The vocabulary of the system was composed of 250 word command language which could generate approximately 14 millions different sentences. The technique used to perform the automatic recognition consested of three principle components, a hardware spectrum analyzer, an acoustic analyzer and a linguistic processor. Each component was designed to process speech independent of the vocabulary. This system proved to be the first working system to perform automatic continuous speech sentence recognition based on a command language. Results, even in the early years, clearly indicated the promising nature of the approch. Although the system had many difficulties (for example the hardware spectrum analyzer), et led shown for the first time, the automatic decoding of sentences by machine. However, the field of speech recognition was sharply criticized in a letter written by JOHN PIERCE, a highly respected scientist at Bell Laboratories (PIERCE, J., 1969). The letter stated that researchers working in speech recognition failed to appreciate the difficulty of their task. Although the letter seemed to put a temporar damper on the enthusiasm for speech recognition, the Advanced Research Projects Agency (ARPA) nonetheless funded a large, 5 year effort in the field in 1971. The ARPA project addressed the problem of speech understanding, rather than speech recognition, and had a number of ambitious technical goals. There is considerable debate even now as to the progress made in the project (KLATT, D. H., 1977; and NEUBERG, E. P., 1975). What is noteworthy is that the approach taken in the project can be considered from the perspective of artificial intelligence (AI). Unlike the mathematical approach, AI presumes that a perfect extraction of phonetic features in speech is not necessary (or maybe even possible) because errors made in this extraction phase can be compensated for by knowledge obtained from so-called "higher sources." This higher order knowledge includes things like syntax, semantics and the pragmatics of discourse. It remains to be seen which approach will be more successful, perhaps a combination of approaches, along with greater computing power will solve many problems. But it is widely agreed that increasing the knowledge of the human speech process is required before the effectiveness of speech systems match the expectations of potential users.

The last half of the seventies has seen increased attention given to the application of ASR technology to a wide variety of real-world problems, with less emphasis being given to more fundamental research. However, there are still many fundamental research problems which remain to be solved, as shall be discussed below. A number of companies, large and small now have speech recognition products commercially available. An increasing number of speech synthesis products are also becoming available in the marketplace.

The current state-of-the-art in speech recognition and synthesis will now be addressed. Practical ASR is restricted to discrete-utterance (a pause must be inserted between words), limited vocabulary and speaker dependent (the intended speaker must train the system for each utterance) recognition for high quality speech. The accuracy of such systems are dependent on a variety of factors but accuracies near 100% in the laboratory and less than 90% in field tests are typical. Synthesis systems are generally of three types: 1. Those which do a simple encoding of the speech signal. An example is a simple digitization of real speech. The synthesis would then be accomplished by digital-to-analog conversion. 2. A complex encoding of the speech signal. An example of this type is linear predictive encoding. Speech is encoded and then stored to form pre-recorded messages, which are synthesized by doing the inverse of the encoding process. 3. Synthesis-by-rule systems which require very little storage of actual speech, but instead accept as input typed commands. The commands are interpreted and a basic set of speech sounds (phonemes) are strung together and modified by a complex sequence of rules. There are three main trade- offs associated with speech synthesis systems. These are: speech quality, memory requirements and message flexibility. The chart below summarizes these trade-offs for the three types of synthesis (GREGORY, P. W., REAVES, J. M., 1981)

SYNTHESIS TECHNIQUES	QUALITY	MEMORY	FLEXIBILITY
1. Simple Encoding	High	Greatest	Moderate
2. Complex Encoding	Moderate	Moderate	Low
3. Synthesis-By-Rule	Low	Low	High

Currently, there are more than 44 companies who produce speech synthesis products (WONG, D., 1981). Excellent summaries of speech processing technology evolution can be found among the references (DENES, P. B. 1975; HYDE, S. R., 1972; REDDY, D. R., 1976; LEA, W. A., 1979).

2.2 Voice-Interactive System Defined

Up until this point all the discussion has been on speech technology, not voice-interactive systems. The term "voice-interactive system" emphasizes the fact that it is the combination of a human a machine that is of interest. The "voice" part of a voice-interactive system can mean either a human voice talking to a machine, or vice versa. Since a human is involved, it is not only speech technology that is of concern, but the psychology and physiology of the man-machine interaction. Researchers involved with speech processing are typically electrical engineers, computer scientists or mathematicians. Those involved with voice-interactive systems have a more behavioral science flavor, and include experimental psychologists and human factors engineers.

What then is meant by term "voice-interactive system"? It could conceivably mean any system involving humans and machines, with speech as the mode of communications. Thus, a digital voice communications system could qualify as a voice-interactive system under this definition. However this is not what is usually meant by the term.

Voice-Interactive System. The interface between a cooperative human and a machine, which involves the recognition, understanding or synthesis of speech, to accomplish a task of command, control or communications, and which involves feedback from the listener to the speaker. With this definition, the digital communications system no longer qualifies, because the system provides an interface between a human and another human, not a machine. Likewise speaker identification or language identification systems do not qualify because they involve noncooperative speakers and no feedback from the speaker (human) and the listener (machine). Figure 1 shows in a very simple way a voice-interactive system: The box labeled "Speech I/O Subsystem" is some type of speech processing technology. Suppose that the voice-interactive system was one in which a human pilot controls certain cockpit functions, and in addition can receive audio warning messages. The diagram of Fig. 1 can then be drawn more specifically as shown in Fig. 2: The interaction diagrammed in Fig. 2 is a fairly complex one and is intended to show relationships among all the elements involved, not any particular system. Notice that the pilot and speech I/O sub-system are both listeners as well as speakers. The situation shown in Fig.2 would work as follows. The pilot controls certain cockpit functions (which have not been specified) by speaking utterances into an ASR device. The controller of the voice-interactive system interprets the results of the recognition and responds with the appropriate controlling actions to the aircraft. Suppose an emergency situation arose for which the pilot was unaware. Presumably, the aircraft would signal this to the controller which would respond with the appropriate synthesized warning message. The pilot would then take corrective action which may require him to use manual controls, and the warning message would be subsequently halted. In this case there is feedback in both directions between man and machine.

2.3. Advantages of Speech Communications

There are a number of good reasons why people might wish to use speech to communicate with machines. There have been many reports which have detailed the relative advantages of speech communications (LEA, W. A., 1968; LEA, W. A., 1979; MARTIN, T. B., 1976). However, there is relatively little empirical evidence which demonstrates the value of speech over other modes of communications, command or control. What empirical evidence does exist seems encouraging. In a famous experimental run at John Hopkins University, it was shown that teams of people interacting together to solve problems could solve them much faster using voice than other modes of communicating (OCHSMAN, R. B., CHAPANIS, A., 1974). Other studies indicating the advantage in terms of speed and accuracy of voice over other modes of communication for certain tasks have been reported. (WELCH, J. R., 1977; HARRIS, S., OWENS, J., NORTH, R., 1979; SKINER, C., 1979; WHERRY, R., 1974; POOCK, G., 1981). Despite the lack of supporting data a list of advantages shall be presented for speech communication in general, and in a later section for the application of speech in the cockpit environment. Many of these arguments for speech are of the "common sense" variety and there are undoubtedly others that could be added to them.

The most powerful reason for using speech is the fact that it is man°s most natural form of communication and does not require special training to learn. A second strong argument for voice is that it frees the hands and eyes for other tasks. Most of the other advantages follow directly from these two. Figure 3 shows a list of advantages of speech communication. The list has been divided into three sections: engineering, psychological and physiological advantages.

2.4. Disadvantages of Speech Communications

The disadvantages of speech communications should be considered carefully. It is important to make a distinction between the drawbacks of speech communications in general and the limitations of current speech technology. The former is relevant in speculating about the long-range possibilities of speech, and the latter is relevant to near-term concerns. The general disadvantages of speech communications are presented below, and those associated with cockpit environments are discussed in a later section. The disadvantages of speech communications involve mainly the effects of a hostile environment on the speech signal directly, or indirectly by a change of the physical or emotional state of the speaker.

3.0 Issues of Cockpit Applications of Voice-Interactive Systems

The use of voice-interactive systems offers the potential for solving critical mon-machine problems in the aircraft cockpit. No where are these problems as severe as in military aircraft, and especially aircraft, capable of high performance. In these aircraft, crew members are often forced to cope with a very high workload, caused by factors such as inefficient crew member stations, poor assignment of operator tasks, and an overwhelming number of displays and indicators. In summary, the human operator is overwhelmed with too much information and has too many visual manual tasks to perform. There has been recent attention placed on using voice-interactive systems in the cockpit to reduce this operator workload problem and solve other man-machine problems. All three services in the United States, many NATO countries and considerable industrial effort has addressed this application of speech technology (LANE, N. E., HARRIS, S. D., 1980; COLER, C. R., 1980; NORTH, R. A., et al, 1980; WICKER, J. E., 1980; HARRIS, S., et al, 1980; WERKOWITZ, E., 1981; REED, L., 1981). Since this conference has an entire paper session devoted to this topic, and because this is a tutorial paper, the discussion to follow is only a summary of the relevant issues and not a detailed technical dissertation.

3.1 Advantages / Disadvantages of Voice Interactive Systems in the Cockpit

It has been recognized that the pilot°s workload in the future high performance attack/fighter aircraft may exceed present pilot avionics interface capabilities. Hence, a real-time voice interactive system offers a potential solution as a method of augmenting current control/display functions. As a result of this realization a number of airframe manufacturers have initiated investigations and experimental design in interactive voice command/feedback systems for single-seat fighter aicraft.

Some experienced military pilots were questioned on the idea of voice command functions for fighter aircraft. In one study, pilots were asked to rate, on the basis of "zero" to "ten", the use of voice command and control system for high performance military aicraft "zero" of course, being "forget the whole idea" and,"ten" being "sounds great". In addition these pilots were opposed to using voice command for important decision making functions such as firing weapons, blow canopy, eject and control trim. However, they were in favor of mode selection and setup functions such as radio channel selection, TACAN ILS, radar, Bomb/NAV mode selection and IFF/transponder setup. Some early results indicate that voice command functions can°t be directly substituted for control/display interfaces of a fighter aircraft.

In addition, the military aircraft environment adds a number of additional problems to automatic recognition subsystems. Some of these are listed in Table 1

TABLE 1

Oxygen Mask	High ambient background noise
Microphone	Preselected Vocabulary
Physical Stress	Non-robust words
Emotional Stress	Human error
Vibrational effects	Overall reliability
Complexity	Cost, Size/Weight
Syntax	

The problems listed in Table 1 cause specific technical difficulties such as word boundary detection, memory requirements, small space, noise stripping, and voice inconsistencies.

Questions arise as to whether training should be done with pilots wearing oxygen masks under actual flight conditions (different G-levels, engine power levels, canopy on / off). Types of signal input to systems must include the affects of regulation, inhaling, exhaling, etc. Results have shown that because breath and background noise cause drop offs at the ends of words, an end point detector based on energy level can't be used, hence more sophisticated automated end point detection is required.

3.2 Speech Synthesis in the Cockpit

Military aircraft applications of speech synthesis systems have also been investigated especially for caution and warning messages. Some of these applications are listed in Table 2.

TABLE 2

Applications of Speech Synthesis Systems

- Voice Warning
- Time-to-Go countdown
- Way point Announcement
- Voice Response for Specific request system data
- Audio Feedback to Voice Commands

A few problem areas resulting from speech synthesis in a high performance aircraft are specific message selection and corresponding voice quality. These synthesis systems must be aware of pilot safety, sound level variation for different noise levels, potential interference with other audio communications, cognitive and attentional demands.

3.3 Summary

It can be said there is general concensus that voice command control, and synthesis systems can provide the military aircrews with a useful adjunct, conventional control and display interfaces and provide warning and status data via speech synthesis. However, in order to apply this technology, many behavioral and human factor problems must be solved as well as some very difficult technical speech recognition issues. Clearly, the question of complexity and overall reliability of a voice interactive system in an aircraft environment must be addressed.

4.0 Other Military Organizations and Applications of Voice-Interactive Systems (BEEK, B., et.al., 1977, 1980)

In addition to utilization of automatic speech recognition for aircraft applications, a number of other military applications are also under consideration. These include:

1. Digital Narrow-band Communications Systems. Digital Communication Systems will encode the speech signal at rates of less than 200 bits/sec to provide jam resistant communications.

2. Automatic speaker verification/identification. An advanced development model has been fabricated, tested and evaluated for a secure access control application.

3. Training Systems. A speech understanding system for air traffic control. This system uses both automatic speech recognition and synthesis to enhance the training of air traffic controllers.

4. On-line Cartographic Processing System. A voice data entry (VDE) system was designed for entering cartographic data to the Digital Landmass System data base.

5. Voice-operated computer input/output. These applications would allow each telephone to be an input terminal. The majority of the above applications will be discussed in considerable detail by the other session papers. The remainder of this section shall be limited to a discussion of the two DOD and NATO advisory groups on voice technology and some current RADC development activities.

4.1 DOD and NATO Advisory Groups on Voice Technology

At the present time, two major military automatic speech recognition and technology groups are pursuing active technical coordination, data exchange and cooperative research projects. The first is the DOD approved Voice Technology for Systems Applications Sub-technical Advisory Group (VSTAG). The purpose of this VSTAG is to provide a forum for technical interaction between scientists and engineers at the working level. Included as representatives to the VSTAG are members of Air Force, Army, Navy, NASA, FAA, Post Office and NSA research laboratories that are engaged in speech processing applications. Table 3 lists the members of VSTAG.

The second is the NATO AC/243 Panel III Research Study Group (RSG)-10 for Speech Processing. The first meeting of RSG-10 was held in Paris, France in May 1978. Meetings are held twice a year and are rotated among the member nations. The technical objectives of RSG-10 are generally to review speech processing topics of military relevance in order to recommend specific Research Projects to be carried out cooperatively among the member nations. Member nations include Canada, France, Germany, Netherlands, United Kingdom and the United States. Table 4 is a list of participants from the seventh meeting of RSG-10.

TABLE 3

Army	
ARI	Army Research Institute
ETL	Engineering Topographic
AVRADA	Avionics Research Development Activity Human Engineering Lab. Communicative Technology Office
Navy	
NAMRL	Naval Aerospace Medical Research Lab.
NADC	Naval Air Development Center
ONR	Office of Naval Research
NOSC	Naval Ocean Systems Center
NPGS	Naval Post Graduate School
NATC	Naval Air Test Center
NNMC	National Naval Medical Center
NWC	Naval Weapons Center
NASC	Naval Air Systems Command
NTEC	Naval Training Equipment Center
NPC	Navy Personnel R / D Center
Air Force	
AFAMRL	Aero Medical Research Lab.
RADC	Rome Air Development Center
AFWAL	Wright Aeronautic Lab.
AFIT	Air Force Institute of Technology
Other Government	
IRS	Internal Revenue Service
USDA	Dept. of Agriculture
NBS	National Bureau of Standards
NSA	National Security Agency
OSDRE	Office of the Under Secretary of Defense for Research and Engineering
NASA	NASA Ames Research Labs
USPHS	US Public Health Service
FAA	Federal Aviation Administration

TABLE 4

Mr JOHN S. BRIDLE	UK	(Chairman)
Dr M. MARTIN TAYLOR	Canada	(Secretary)
Mr PATRICE DESVERGNES	France	
Dr GERHARD VAN DER GIET	FR Germany	
Dr LOUIS C. W. POLS	Netherlands	
Lt J. NELSON	USA	(Specialist)
Dr HELMUT MANGOLD	FR Germany	(Specialist)
Dr JOSEPH J. MARIANI	France	(Specialist)
Dr MELVYN J. HUNT	Canada	(Specialist)
Dr ROGER K. MORE	UK	(Specialist)
Mr R. VONUSA	USA	(U.S. Delegate)

4.2 Air Force Tactical voice communications systems presently are threatened by an evolving enemy jamming force capable of disrupting our vital C2 communications. SEEK TALK, a jam resistant (JR) communications system to be fielded in the mid 1980's, uses present state of the art technology.

Recent RADC research has developed practical very low bit/sec voice digitization techniques. These advances, being rapidly made practical by the development of VHSIC technology, allow the design of adaptive and more powerful jam resistant secure modems. Air Force users are willing to make some sacrifices regarding speaker recognition and voice vocabulary size to achieve significantly higher JR performance at lower cost than present concepts allow.

The objectives of these efforts are to develop bandwidth efficient, flexible, adaptive jamming suppression, spread spectrum modems. These modems would provide high jam resistance by using both very high Time Bandwidth Product (TBP) and jammer deception/analysis techniques. Candidate designs will be developed which will in a general sense be backward compatible with present designs. Breadboard circuitry produced will demonstrate the basic feasibility of the signal processing techniques.

The advanced low bit rate voice processing technique will be integrated with a hybrid FH/PN modem to achieve a high TBP within existing bandwidth constraints. The receiver signal processor will in addition analyze the structure of the received jamming signal to achieve a JR capability in excess of that provided by the processing gain alone. Data coding techniques will be applied to reduce the S/N needed for detection and to detect when signals are becoming unusable.

The RADC in-house program (HF Terminal with ECCM Modem, Speech Recognition/ Synthesis demonstrated a combination of techniques which provide anti-jam voice communication over radio channels whose bandwidth ordinarily supports only conventional non-AJ voice. Moreover, this combination also provides enhanced reliability under noisy (but unjammed) channel conditions. The voice source encoding employs special codes to represent phrases and in some cases sentences, and thus provides a certain significant amount of data compression. The following is a brief description of the major assemblies that made up the experiment. The Speech Recognition Block in figure 5 is a Voice Recognition Module; a source encoder and a micro processor, which reformatted the recognized word designator for input to the ECCM modem for input to the ECCM modem.

a. Voice Recognition Module (VRM)

The VRM is a discrete-word recognizer; that is, it recognizes specific words and short phrases for which it has been trained by the user. The VRM can identify and respond to as many as 100 of these vocabulary words or phrases.

b. Source Encoder

The Encoder is a stand-alone microprocessor that receives the encoded data from the VRM and transfers this data to the Spread Spectrum Modem at a rate controlled by the modem.

c. ECCM Modem

The Modem receives the input data from the Source Encoder and outputs a band spread signal at a slow data rate.

d. Demodulator (ECCM Modem):

The demodulator despreads the received signal and passes the new despread signal to the Voice Synthesizer.

e. Voice Synthesizer

Converts two digit numbers to the word or phrase as assigned by the speech modules software, constructs and outputs a synthesized voice.

The in-house program demostrated the following:

a. Successful modification of an existing band spreading modem to provide the required throughput.

b. Design and testing of the software required to interface three micro-processors and a band spreading modulator/demodulator into an operating Digital Voice System with A/J protection.

c. The operation of the experimental system in a simulated synthesized channel medium (HF) which included jamming with both white noise, and a sweeping jammer.

5. Future Direction

Since its inception, research in automatic speech recognition (ASR) has progressed to the point were military application can be a reality. Progress has been slow but steady and excellent success has been demonstrated on isolated word recognition devices and speech synthesis devices to make them practicable for military use. This has increased the interaction among scientists of various disciplines including interchanges and interaction in acoustic-phonetics, linguistics, signal processing, etc. In fact, as we have seen, international participation in the solution of numerous ASR problems is at hand.

However, although we have come a long way we still have a long way to go. Presently, we are too strongly focused on applications to extend the minimal support given to a number of fundamental issues. In fact, before ASR can even approach human performance, we still need significant advances in acoustic-phonetics relationships and English phonology.

REFERENCE

1. DODDINGTON, G. R. and SCHALK, T. B., 1981, "Speech Recognition Turning Theory to Practice", IEEE Spectrum, p26
2. SIMMONS, E. J., 1979, "Speech Recognition Technology", Computer Design
3. LEVINSON, A. E., and LIBERMAN, M. Y., 1981, Speech Recognition by Computer", Scientific American, Vol 244, No.4
4. DAVIS, K. H., BIDDULPH, R. and BALASHEK, S. 1952; Automatic Recognition of Spoken Digits", J. Acoust Soc. Am. 124(6) p637
5. DUDLEY, H., RIESZ, R. R., and WATKINS, S. A., 1939, "A Synthetic Speaker", J. FRANKLIN Inst. 227, p739
6. WIREN, J. and STUBBS, H. L., 1936, "Electronic Binary Selection Systems for Phoneme Classification", J. Acoust Soc. Am. 30(8)
7. FORGIE, J. W. and FORGIE, C. A., 1959, "Results Obtained from a Vowel Recognition Computer Program", J. Acoust Soc. Am. 31(11)
8. VICENS, P. 1969, "Aspects of Speech Recognition by Computer", Computer Abstr. 13(11), No. 3098, Nov.
9. PIERCE, J., 1969, "Whither Speech Recognition", J. Acoust Soc. Am., Vol 46, p1049
10. KLATT, D. H. 1977, "Review of the ARPA Speech Understanding Project", J. Acoust Soc. of Am., Vol. 62 p1345
11. NEUBERG, E. P., 1975, "Philosophies of Speech Recognition", Speech Recognition, R. Reddy, ed., Academic Press, p83
12. DENES, P. B., 1975, "Speech Recognition Old and New Ideas", Speech Recognition, R. REDDY, ed., Academic Press, p73
13. HYDE, S. R., 1972, "Automatic Speech Recognition: A critical survey and discussion of the Literature", Human Communication A Unified View, E. E. DAVID and P. B. DENES, eds., McGROW HILL, p399
14. REDDY, D. R., 1976, "Speech Recognition by Machine: A Review", Proceedings of the IEEE, Vol 64 p501
15. LEA, W. A., "Speech Recognition: Past, Present, and Future", Trends in Speech Recognition, W. A. LEA, ed., PRENTICE HALL, 1979
16. LEA, W. A., Establishing the Value of Voice Communications with Computers", IEEE Trans on Audio and Electroacoustics, Vol Av-16, No 2, June 1968, p184
17. LEA, W. A. 19796 "The Value of Speech Recognition Systems", Trends in Speech Recognition, W. A. LEA ed., PRENTICE HALL
18. MARTIN, T. B., 1978, "Practical Applications of Voice Input to Machines", Proceedings of the IEEE Vol.64, No.4
19. OCHSMAN, R. B. and CHAPANIS A. 1974, "The effects of 10 communications Modes on the behavior of teams during Cooperative Problem-Solving," International Journal Man-Machine Studies, Vol 6, p579
20. WELCH, J. R., 1977 "Automatic Data Entry Analysis", RADC-TR-77-306, Rome, NY
21. HARRIS, A., OWENS, J., and NORTH, R., 1979, "Human Performance in Time Shared Verbal and Tracking Tasks", WAMRL-1259, Pensacola, FL
22. SKINER, C. 1979, "Vocal and Manual response modes: Comparison using a time-sharing paradigon, "NADC-79-127-60. Warminster, PA
23. WHERRY, R., 1976, "VRAS-A Voice Recognition and Synthesis System," S/D Digest of Technical Papers, Vol III, Los Angeles, CA
24. WONG, A., 1981, "Alternate Coding and Synthesis Techniques," Course Notes, Making Silicon Talk and Listen, Signal Technology Inc., Santa Barbara, CA, Part II, p9
25. LANE, N. E., and Harris, S. A. 1980, "Conversations with Weapons Systems; Crewstation Applications of Interactive Voice Technology," Yearbook on Navy Manpower, Personnel Training, Research and Development
26. WERKOWITZ, E., 1980 "Ergonomic Considerations for the Cockpit Applications of Speech Generation Technology," Proceedings, Symposium on Voice-Interactive Systems: Applications and Payoffs, S. HARRIS, ed., Dallas, TX p295
27. DRENNEN, T. G., 1980, "Voice Technology in Attack/Fighter Aircraft", Proceedings, Symposium of Voice-Interactive Systems: Applications and Payoffs, S. HARRIS, ed., Dallas, TX, p199
28. COLER, C. R., 1980, "Automatic Speech Recognition and Man-Computer Interaction Research at NASA-AMES Research Center", Proceeding, Symposium on Voice-Interactive Systems: Applications and Payoffs, S. HARRIS, ed., Dallas, TX, p249
29. NORTH, R. A., MOUNTFORD, S. J., EDMAN, T., and GUENTHER, K., 1980, "The use of voice entry as a possible means to reduce fighter pilot workload: A practical application of Voice-Interactive Systems", Proceedings, Symposium on Voice-Interactive Systems: Application and Payoffs, S. HARRIS, ed., Dallas, TX, p251

30. WICKER, J. E., 1980, "Some Human Factors Aspects of Real-Time Voice Interactive System in the single-seat fighter aircraft", Proceedings, Symposium on Voice-Interactive Systems: Applications and Payoffs, S. HARRIS, ed., Dallas, TX, p265
31. HARRIS, S., LANE, N. E. and CURRAN, P. M., "The Navy Voice-Interactive Systems and Technology (VISTA) Program", Proceedings, Symposium on Voice-Interactive Systems: Applications and Payoffs, S. HARRIS, ed., Dallas, TX, p311
32. WERKOWITZ, E. 1981, "Air Force Cockpit Utilization of Speech Technology Proceedings, Conference on Voice-Interactive Avionics, S. HARRIS, CHAIRMAN, Warminster, PA
33. REED, L. 1981, "Voice-Interactive Systems Technology Avionics (VISTA)", Proceedings, Conference on Voice-Interactive Avionics, S. HARRIS, CHAIRMAN, Warminster, PA
34. GREGORY, P. W., REAVES, J. M., 1981, "Multistation Voice Data Entry Configuration Study," RADC-TR-81-50, Rome, NY
35. BEEK, B., NEUBERG, E. P., HODGE, D. C., "An Assessment Of The Technology Of Automatic Speech Recognition For Military Applications", IEEE Trans. on ASSP, vol. ASSP-25, No. 4 August 1977.
36. BEEK, B., CUPPLES, E., FERRANTE, J., WOODARD, J., VONUSA, R., "Trends and Applications of Automatic Speech Technology" Symposium on Voice Interactive Systems: Applications and Payoffs, May 1980
37. BEEK, B., "Applications of speech processing for military applications", A. L. GILBERT, ed., in Proc. Workshop on Military Applications of Artificial Intelligence, White Sands Missile Range, Juarez, Mexico, Oct. 1976, pp. 302-318.
38. BEEK, B. and R. VONUSA, "An automatic isolated word recognition system-study and evaluation," Rome Air Dev. Cen. Tech. Rep. RADC-TR-70-129, Rome, NY, Oct. 1971.
39. BEEK, B., et al., "Automatic Speaker Recognition System," Presented at the Agard Conf. on Artificial Intelligence, No. 94, London, England: Harford House, 1971.
40. TAPPERT, C. C., DIXON, N. R., BEETLE, D. H., and CHAPMAN, W. D., "The Use of Dynamic Segments in the Automatic Recognition of Continuous Speech", Technical Report No. RADC-TR-70 (prepared by IBM), May 1970.
41. KLATT, D. H., and STEVENS, K. N., "Sentence Recognition from Visual Examination of Spectrograms and Machine-Aided Lexical Search", Conference Record of the 1972 Conference on Speech Communication and Processing, AFCRL-72-0120, Special Report No. 131, February 1972.
42. TAPPERT, C. C., DIXON, N. R., BEETLE, D. H., and CHAPMAN, W. D., "A Dynamic-Segment Approach to the Recognition of Continuous Speech: An Exploratory Program", Technical Report No. RADC-TR-68-177 (prepared by IBM), June 1968.
43. TAPPERT, C. C., DIXON, N. R., RABINOWITZ, A. S., and CHAPMAN, W. D., "Automatic Recognition of Continuous Speech Utilizing Dynamic Segmentation, Dual Classification, Sequential Decoding, and Error Recovery", Technical Report No. RADC-TR-71-146 (prepared by IBM), 1971.
44. DIXON, N. R., and TAPPERT, C. C., "Toward Objective Phonetic Transcription-An On-Line, Interactive Technique for Machine-Processed Speech Data", IEEE Transactions on Man-Machine Systems, Vol. MMS-11, No. 4, 1970, pp. 202-210.
45. DIXON, N. R., and TAPPERT, C. C., "Strategic Compromise and Modeling in Automatic Recognition of Continuous Speech: An Hierarchical Approach", Journal of Cybernetics, Vol. 1, No. 2, 1971, pp. 67-79.
46. DIXON, N. R., and TAPPERT, C. C., "A Method for On-Line Interactive Transcription of Quantized Speech Data", presented at the Eightieth Meeting of the Acoustical Society of America, Houston, Texas, November 3-6, 1970.
47. DIXON, N.R., and TAPPERT, C.C., "Derivation of Phonetic Representation by Combining Steady-State and Transemic Classification in Automatic Recognition of Continuous Speech (ARCS)", Conference Record of the 1972 Conference on Speech Communication and Processing, AFCRL-72-0120, Special Report No.131, February, 1972.
48. TAPPERT, C.C.; DIXON, N.R., and RABINOWITZ, A.S., "Application of Sequential Decoding for Converting Phonetic to Graphemic Representation in Automatic Recognition of Continuous Speech (ARCS)", Conference Record of the 1972 Conference on Speech Communication and Processing, AFCRL-72-0120, Special Report No.131, February, 1972.
49. DIXON, N.R., and TAPPERT, C.C., "An Multi-Stage, Sequential Strategy for Automatic Recognition of Continuous Speech", Workshop on Automatic Pattern Recognition Problems in Speech (preprints of technical articles), Rome Air Development Center and IEEE, sponsors, September, 1971

DIAGRAM OF A GENERAL VOICE-INTERACTIVE SYSTEM

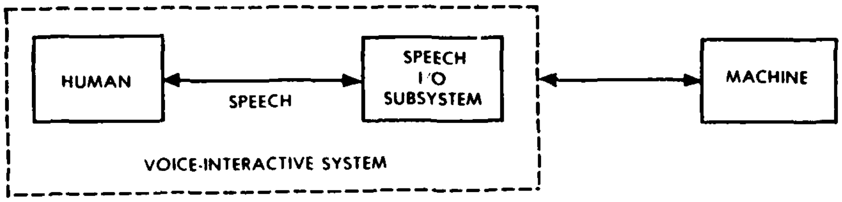


Figure 1. DIAGRAM OF A GENERAL VOICE-INTERACTIVE SYSTEM

VOICE-INTERACTIVE SYSTEM IN COCKPIT SETTING

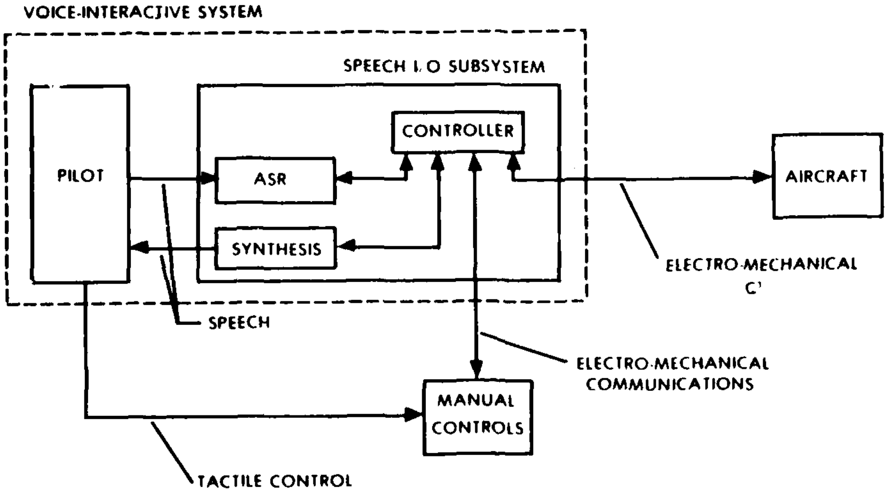


Figure 2. VOICE-INTERACTIVE SYSTEM IN COCKPIT SETTING

ADVANTAGES OF SPEECH COMMUNICATIONS

ENGINEERING

1. Can be faster than other modes of communications.
2. Can be more accurate than other communication modes.
3. Comptatible with existing communication systems, e.g. telephones.
4. Can be more accurate at tasks currently performed by humans, e.g. automatic speaker verification vs identity verification by human visual inspection.
5. Can reduce manpower requirements.
6. Can be the most cost-effective man-machine interface.

PSYCHOLOGICAL

1. Most natural form of human communication.
2. Best for group or team problem solving.
3. Universal (or nearly so) among humans and requires no training.
4. Can obtain valuable information regarding the emotional state of the speaker.
5. Can reduce visual and motion information overload.
6. Can reduce visual and motor workload.
7. Increases in value proportional to the complexity of the information being processed.
8. Can reduce errors for tasks involving considerable cognitive (as opposed to perceptual) effort.

PHYSIOLOGICAL

1. Requires less effort and motor activity than other communication modes.
2. Frees the eyes and hands and does not require physical contact with a transducer.
3. Permits multi-modal operation.
4. Is possible even in darkened environments.
5. Is omni-directional and does not require direct line of sight.
6. Permits considerable operator mobility.
7. Contains information about the identity of the communicator.
8. Contains information regarding the physical state of the communicator.
9. Simultaneous communications with humans and machines.

Figure 3. ADVANTAGES OF SPEECH COMMUNICATIONS IN GENERAL

DISADVANTAGES OF SPEECH COMMUNICATIONS

1. Competing acoustic sources may interfere with speech. These include noise, distortion, and other talkers.
2. A variety of physical conditions can change the acoustic characteristics of speech, including vibration, g-forces, and physical orientation of the speaker.
3. Human fatigue can result from prolonged speaking and fatigue may change speech characteristics.
4. Physical ailments such as colds may change speech characteristics.
5. Speech is not private and may be observed by others.
6. There is no permanent record of speech unless recorded explicitly (not true of typing).
7. Psychological changes (stress for example) in the speaker may change his speech characteristics.
8. Microphones are required for speech input, acoustic speakers for speech output.
9. Speech synthesis may interfere with other aural indicators.
10. Speech synthesis is a more serial information channel than visual displays and can be slower.

Figure 4. DISADVANTAGES OF SPEECH COMMUNICATIONS IN GENERAL

HF TERMINAL
WITH ECCM MODEM, SPEECH RECOGNITION/SYNTHESIS

DEMONSTRATION

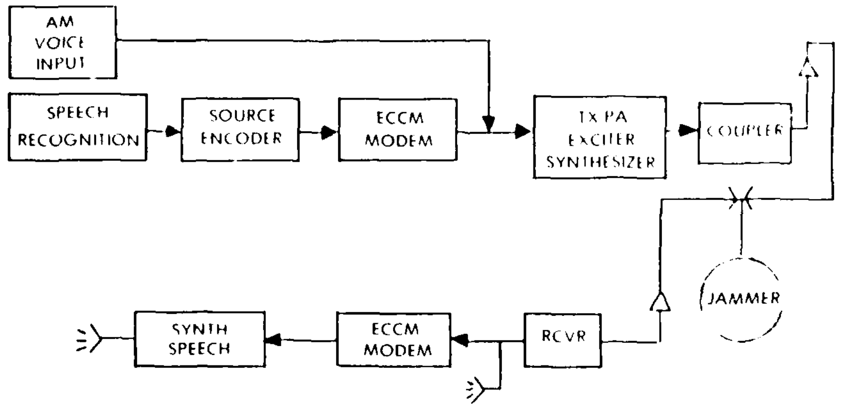


Figure 5. BLOCK DIAGRAM OF HF TERMINAL

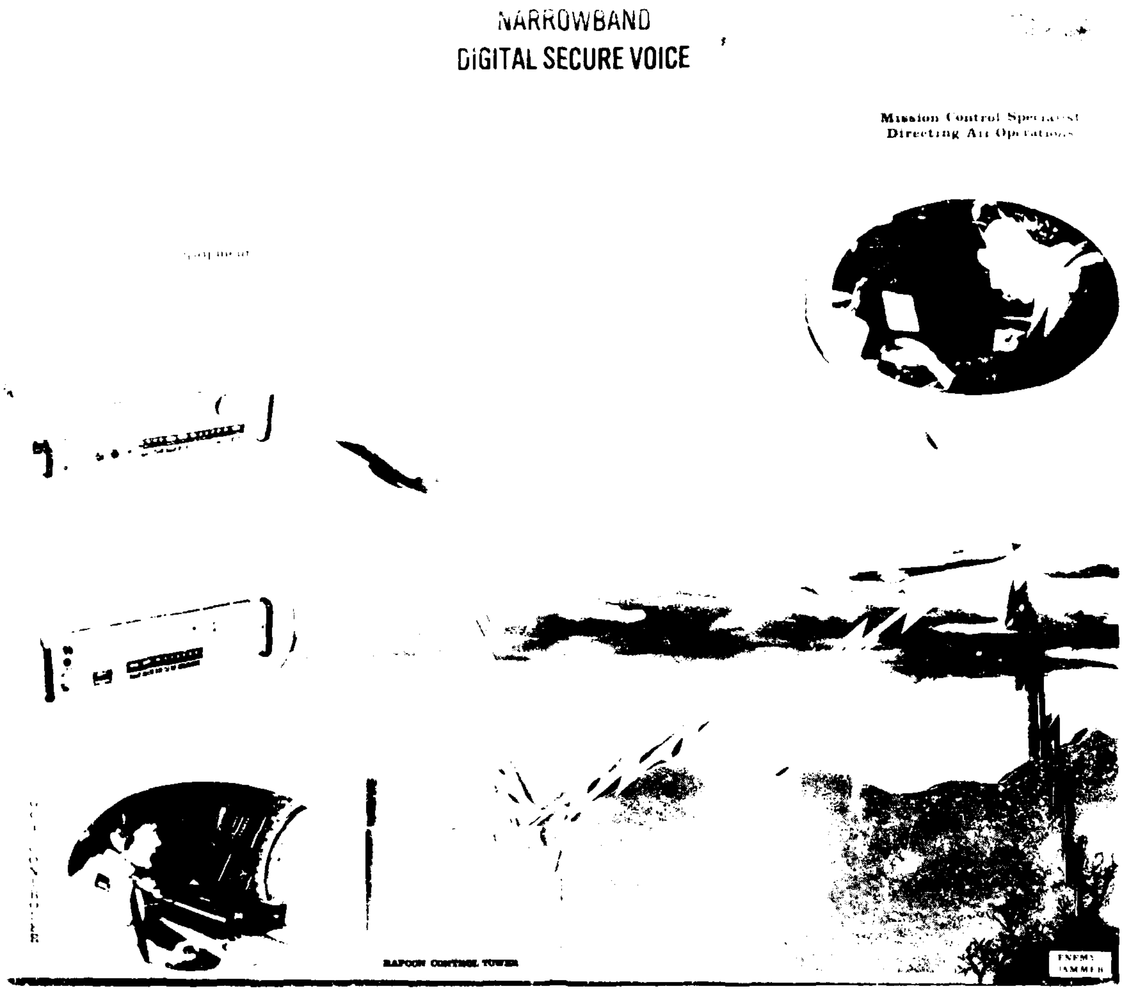
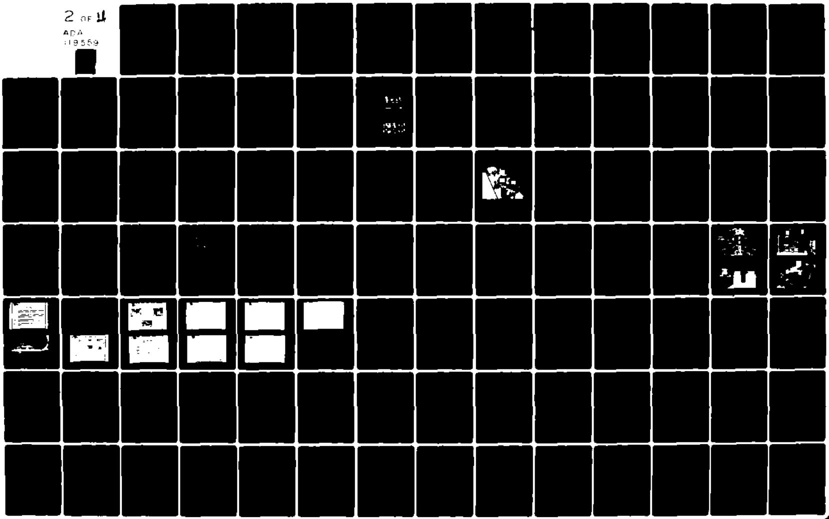


Figure 6. NARROWBAND DIGITAL SECURE VOICE

AD-A119 559 ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT--ETC F/G 1/3
ADVANCED AVIONICS AND THE MILITARY AIRCRAFT MAN/MACHINE INTERFA--ETC(U)
JUL 82
UNCLASSIFIED AGARD-CP-329 NL

2 OF 4
ADA
119559



CHARACTERISTICS OF THE HUMAN INFORMATION CHANNELS AND CONCLUSIONS FOR VOICE INPUT/OUTPUT

H. Mutschler

Fraunhofer-Institut für Informations- und Datenverarbeitung
Sebastian-Kneipp-Str. 12-14, 7500 Karlsruhe 1 (FRG)

SUMMARY

Including input and output in man-machine communication the specific characteristics of the human oral and aural channels must be taken into account. The channels' modality represent a relevant factor in human information processing, particularly in attention, perception and memory. A literature review of modality specific effects in human information processing is presented and conclusions are drawn for the military applications of voice input and output. There is an increase of the human's ability to divide his attention when different modalities are concerned and different subsystems for spatial and verbal informations are involved. Reaction times are generally smaller for auditory than for visual presentation. There is a superior performance of the short-term memory for auditorily presented verbal information, if no verbal informations must be handled during the retention period. If modality compatibility between stimulus and response as well as modality-coding compatibility is warranted, time-consuming transformations are avoided.

1. INTRODUCTION

According to the rapid development, voice input and output systems become feasible alternatives to conventional mechanical input and optical output systems in man-machine communication. As Figure 1 shows, the spatial or verbal[1] informations out of the machine can be coded optically or acoustically and the verbal informations into the machine can be coded mechanically or vocally.

Voice output is the acoustical coding of information per speech and voice input is the vocal coding of information per speech. Instead of the visual/manual channel they need the aural[2]/oral channel so that informations can be further processed by the human information processing system. To evaluate the benefits of voice input and output for man-machine communication one has to consider

1) the technical aspects of voice input and output systems, e.g. the limitations of actual voice input systems such as recognition errors,

2) the physical aspects of acoustical signals such as their sequential and transient characteristics,

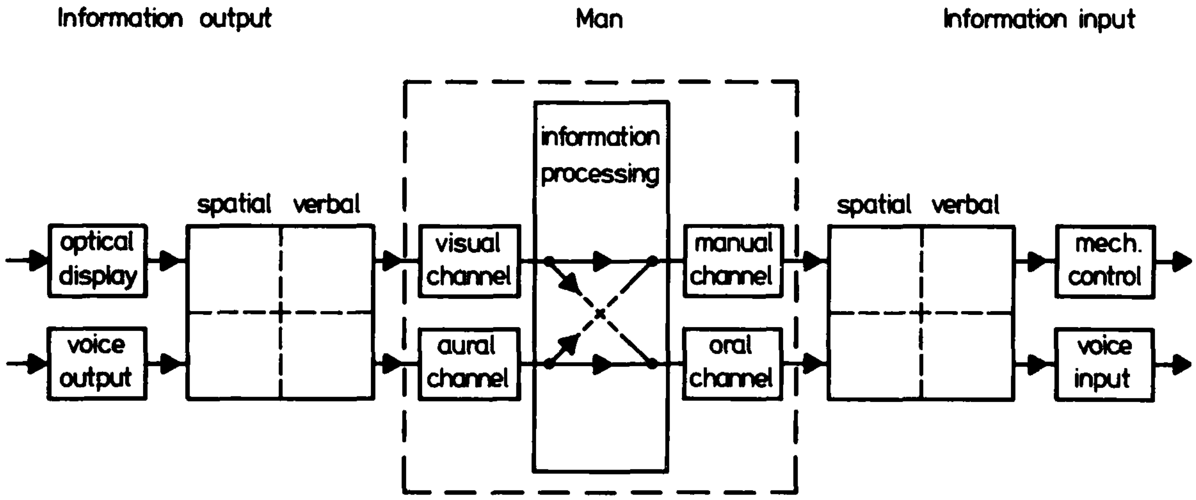


Figure 1: Visual/manual and aural/oral channels for human information processing in man-machine communication.

---

1) "Verbal" as opposed to "spatial" is used as type of information and as opposed to "symbolical" as textual code of information.

2) "Aural" and "auditory" are used as synonyms.

3) the physiological aspects of hearing and speaking such as hearing thresholds, and

4) the psychological aspects of the central processing of auditory informations such as time-sharing abilities.

The present paper wants to focus on point 4) and review the psychological literature dealing with modality related differences in human information processing (chapter 2). Subsequently, some criteria of using voice input and output in military applications are extracted out of these psychological findings (chapter 3). For a compact clear presentation the references are often cited in a simplifying manner. But the results are always obtained under specific conditions to be looked up in the references.

2. MODALITY EFFECTS IN HUMAN INFORMATION PROCESSING

Out of the different fields of psychological research

- attention,
- detection, recognition and identification
- short-term memory, and
- transformations

between modalities are considered because

- they represent some essential psychological factors in man-machine communication and
- they reveal modality related differences between modalities leading to consequences for the applications of voice input and output.

Other fields of psychological research such as problem solving are disregarded because they don't reveal such distinct modality related effects.

2.1. ATTENTION

Because of the severely limited capacity of the human to deal with incoming information at some stages of the analysis only a small portion of the incoming information is selected for further processing. The study of this limitation and selection is the study of attention (NORMAN, 1969). The object of attention is sensated stronger and clearer and comes to consciousness more quickly (shortening the reaction-time), than the objects that we are not attending to. The attention is the condition for perceiving and processing informations. The limits of simultaneous processing are set by the overall difficulty of the analysis, so that we can perform one difficult task or several easier ones, but only up to some limiting level (NORMAN, 1969; TREISMAN and DAVIES, 1973; BROOKS, 1968). There are two types of processing models which can explain the limitations of attention: The serial process which can do but one thing at a time and switches rapidly among the tasks (single-channel theory); a parallel process which can do a limited number of things simultaneously without switching (NORMAN, 1969). A final evidence for the validity of one of the models is still pending.

There is a considerable increase of the human's ability to divide his attention (time-sharing) between two inputs when these are in different modalities (GOPHER, 1980; TREISMAN and DAVIES, 1973; BROOKS, 1968). This means that there is effectively more capacity available when two modalities are monitored than one. But the resulting performance does not reach the performance when carrying out these two tasks separately, since there is an overall limit to the capacity of the perceptual system (TREISMAN and DAVIES, 1973; HARRIS, 1978). Dividing attention is more difficult with the progress of information processing because the "bottleneck" for information processing becomes more and more narrow from perception until response selection and execution (HARRIS, 1978). The perceptual system consists of a number of relatively independent subsystems or "analyzers". Because division of attention is easier when two tasks use different subsystems (TREISMAN and DAVIES, 1973), the type of the informations is an essential parameter regarding time-sharing with different modalities:

If spatial informations must be handled simultaneously with verbal informations two different subsystems are concerned, one for the spatial and one for the verbal informations. In consequence, time-sharing can be performed easily in tasks, e.g. with spatial informations presented visually and verbal informations presented auditorily, or with spatial informations being responded manually and verbal informations being responded orally. E.g., a manual tracking task is performed better when simultaneous responses of verbal informations are made orally and not manually (MOUNTFORD and NORTH, 1980). But also with oral responses there are still some decrements in tracking performance (HARRIS, 1978; MOUNTFORD and NORTH, 1980).The results of the experiment of MOUNTFORD and NORTH, 1980, are depicted in Figure 2, which reveals the advantages of voice data input/manual control time-sharing conditions over manual data input/manual control conditions.

If two different verbal informations must be handled simultaneously the degree of information processing must be considered. For the case of peripheral processing level (e.g. detecting particular syllables) or early verbal processing level (e.g. detecting terms out of a particular category) there is a better time-sharing performance with different modalities (TREISMAN and DAVIES, 1973; ROLLINS and HENDRICKS, 1980). With further processing the use of different modalities doesn't increase performance since vision and hearing share a single semantic system (TREISMAN and DAVIES, 1973; ROLLINS and HENDRICKS, 1980).

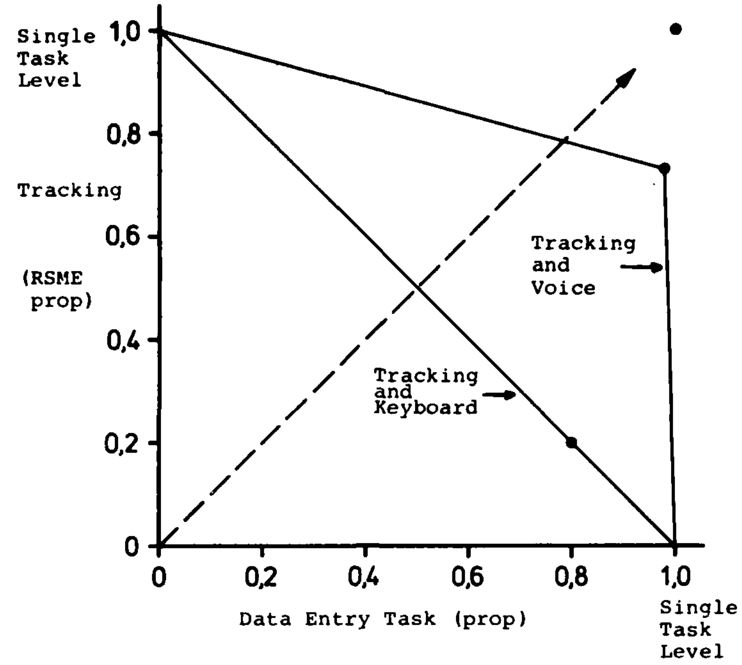


Figure 2: Performance Operating Characteristics in time-sharing tasks with the same modality (tracking and keyboard) and with different modalities (tracking and voice) by MOUNTFORD and NORTH, 1980.

Division of attention with different modalities of verbal information was studied by TREISMAN and DAVIES, 1973. Two lists of items were presented simultaneously in the same modality or each in a different modality. They had to be monitored for the occurence of a defined target with a physical property (containing the syllable "end") or a semantic property (all animals' names). If the subjects knew in advance which channel would receive the target they could focus their attention, if they did not know it they had to divide their attention. As Figure 3 shows, about 20-40% more targets were detected if the lists were presented in different modalities (AV, VA) rather than in the same modality (AA, VV). But even in different modalities, the performance with divided attention never reached the performance of focused attention.

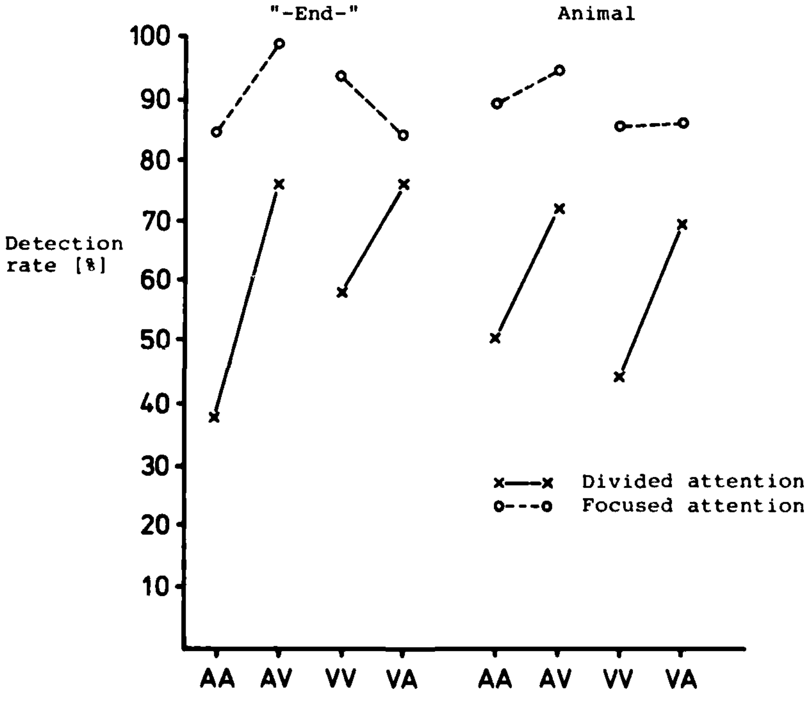


Figure 3: Mean percent targets detected in the experiment of TREISMAN and DAVIES, 1973, where two lists had to be searched for a defined target simultaneously. A = Auditory, V = Visually.

The physical features of the stimuli determine which channel of information is chosen for attention. Thus, even when focusing on one voice, gross changes in another voice on the unattended channel, especially changes in the sex of the speaker, are noticed (MASSARO, 1975) and attention could be switched to the other voice if wanted. If these physical cues fail, we use psychological ones, such as the grammatical or semantic content of the spoken material. This is illustrated with the cocktail party problem in a crowded room where one is suddenly attended to a interesting conversation while listening to another one.

2.2. DETECTION, RECOGNITION AND IDENTIFICATION

Attention is the condition for perception (e.g. detection of a signal) and further information processing by the cognitive system, such as pattern recognition and identification. The information about incoming signals is extracted by a number of different specific analyzing mechanisms.The outputs of the analyzers are combined, forming a hierarchical process whereby the outputs of one level of analyzers are analyzed by yet another (NORMAN, 1969). Pattern recognition and identification are possible results of this process of extracting parameters from sensory events. There are some modality dependent differences in detection, recognition and identification by the auditory and visual system:

Detection rate and speed is generally higher for auditory presentation than for visual presentation (warning effect). E.g., the pure reaction time to a visual stimulus takes 1/5 s, to an auditory stimulus 1/6 s (MASSARO, 1975). But the senses are specialized for different tasks: The time-oriented characteristics of the auditory system result in a higher performance of the auditory system as opposed to the visual system in identifying pattern at high rates of presentation and in reacting on time differences (FREIDES, 1974; RÖNNBERG and OHLSSON, 1980). On the other hand, the space-oriented characteristics of the visual system result in a higher performance of localization judgements. Therefore, spatial informations are often transformed into a visual code before decision making (FREIDES, 1974). Auditory signals improve the alertness for following or immediately preceding signals, auditory ones or visual ones. E.g., auditory clicks after a visual reaction signal (light) speed the simple reaction time to the light much more than the reverse (FREIDES, 1974).

2.3. MEMORY

The general notion of the human memory system includes roughly three types of memories differing in completeness, duration and coding of the stored information, i.e. sensory information storage, short-term memory and long-term memory. First, information just being taken up by the sensory system is stored completely and briefly in the sensory information storage. The information here is raw and unprocessed in a modality specific manner just like a photography for visual information up to several 100 ms (iconic memory) or like a tape for auditory information up to 2 s (echoic memory) (JÜTTNER, 1979). After this sensory information storage, the information is identified and encoded into a new format and retained temporarily in a different storage system, the short-term memory. The stored information is the conscious section of the whole memory and consists of 3-10 items up to 20 s long (JÜTTNER, 1979; NORMAN, 1969). Since the short-term memory shows several modality-specific effects, it is discussed more in detail below. Then, if extra attention is paid to the information, or if it is rehearsed frequently enough, the information is transferred to a permanent storage system, the long-term memory. This memory is practically unlimited and can be maintained for life provided that the information is encoded in a semantic code, i.e. not modality specific, and is organized in an efficient manner (JÜTTNER, 1979; NORMAN, 1969). While informations of the short-term memory is held in consciousness, informations of the long-term memory must be brought back into consciousness (NORMAN, 1969).

Considering only the short-term memory one has to differentiate between verbal and spatial information. Concerning verbal information, auditorily and visually presented verbal information (names, letters or digits) is stored in the phonemic short-term memory (REEVE and HALL, 1976), but there is a superior performance of the short-term memory for auditorily as opposed to visually presented verbal information ("modality effect") (RÖNNBERG and OHLSSON, 1980; FREIDES, 1974; BENCOMO and DANIEL, 1975). It is assumed that each channel has a certain capacity: a minimum of about 4 items for the auditory channel and a maximum of about 3 items for the visual channel of verbal informations (RÖNNBERG and OHLSSON, 1980). This phenomenon can be explained either by the processing theory, supposing a superior processing capacity for auditory input with one storage (CRAIK, 1969; WATKINS, 1972), or by the storage theory, supposing two storages with a larger capacity for the auditory as opposed to the visual memory of verbal informations (MURDOCK and WALKER, 1969; NILSSON et al, 1975). Auditory superiority is greatest with brief retention intervals of a few seconds where the voluminous echoic memory supports the phonemic short-term memory, and disappears with long intervals (BURROWS, 1972).

Consistently with this modality effect, the human transforms visually presented verbal information from the visual to the auditory channel using the most efficient strategy for retaining verbal material (RÖNNBERG and OHLSSON, 1980). This can be observed with the rehearsal process: For better retaining a subject says visual verbal informations, e.g. written letters, hears himself saying it, and then remembers the auditory image. As the auditory image fades, he repeats it to refresh it. Mostly, the rehearsal is subvocal (NORMAN, 1969). Consequently, another intervening verbal task during rehearsal disturbs this process and reduces recall performance (BROADBENT et al, 1978; REEVE and HALL, 1976).

Spatial informations such as geometric figures are stored in the nonverbal visual short-term memory (REEVE and HALL, 1976; PARKINSON, 1972). It holds a maximum of approximately five items. After this maximum has been passed items are recoded into a phonemic form to make use of the better recall from the phonemic short-term memory (REEVE and HALL, 1976; JÜTTNER, 1979). If verbal informations must be handled during the retention period then spatial information is recalled better than verbal information (e.g. the visual or auditory names of the symbols) because of interference effects between verbal informations (REEVE and HALL, 1976; TERNES and YUILLE, 1972).

Interference effects between recall of informations and response execution were studied by BROOKS, 1968. Each word of a recalled sentence was successively categorized as a noun or a non-noun. The example "a bird in the hand is not in the bush" would have produced the sequence, "no, yes, no, no, yes, no, no, no, no, yes". Or, each corner of a recalled line diagram was successively categorized as a point on the extreme top or bottom or as a point in between. The example of Figure 4, a "F", would have produced the sequence "yes, yes, yes, no, no, no, no, no, no, yes". The subjects were given three different ways of signalling the sequence: a) saying "yes" and "no" as above, b) tapping with the left hand for each "yes", and the right hand for each "no", and c) pointing to a "y" for each "yes" and an "n" for each "no" as in Figure 5.

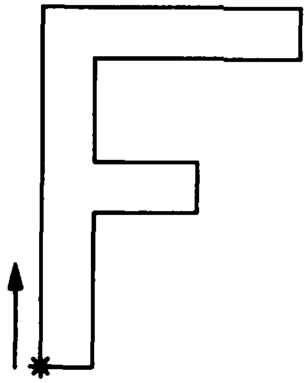


Figure 4: A sample of the line diagrams in BROOKS, 1968. The asterisk and arrow showed the subject the starting point and direction for categorization.

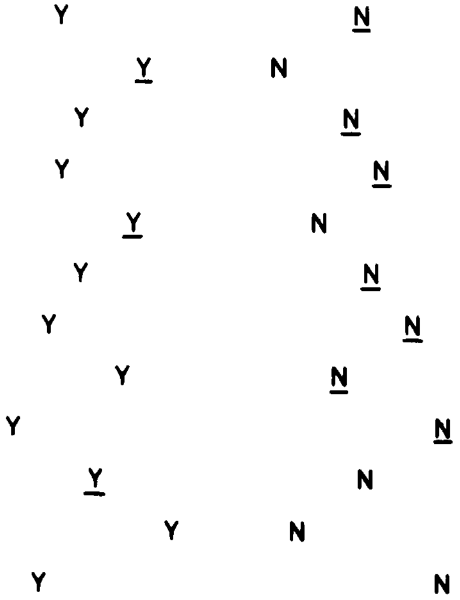


Figure 5: A sample output sheet for the pointing condition in BROOKS, 1968. The underlined letters are those which would be pointed to in categorizing the sentence "a bird in the hand is not in the bush." The letters are staggered to force close visual monitoring of pointing.

	Response		
Referent	Vocal	Tapping	Pointing
Sentences	13.8	7.8	9.8
Diagrams	11.8	14.1	28.2

Table 1: Mean response time in seconds of categorizing sentences and diagrams with different response modes (BROOKS, 1968).

As Table 1 shows, the longest average time were found with vocal responses to sentences (both verbal) and pointing responses to diagrams (both spatial) revealing interference effects relating to identical information type of recall and response. For the visually presented, but subvocally rehearsed sentences there is also a modality related interference effect.

Interference effects between retention of informations and simultaneous shadowing aurally presented words reveal the results of REEVE and HALL, 1976, in Figure 6. The best recall was obtained with geometric figures in lack of modality or coding interferences, while the visual names interfered with the shadowing material as to coding and the auditory names as to modality and coding.

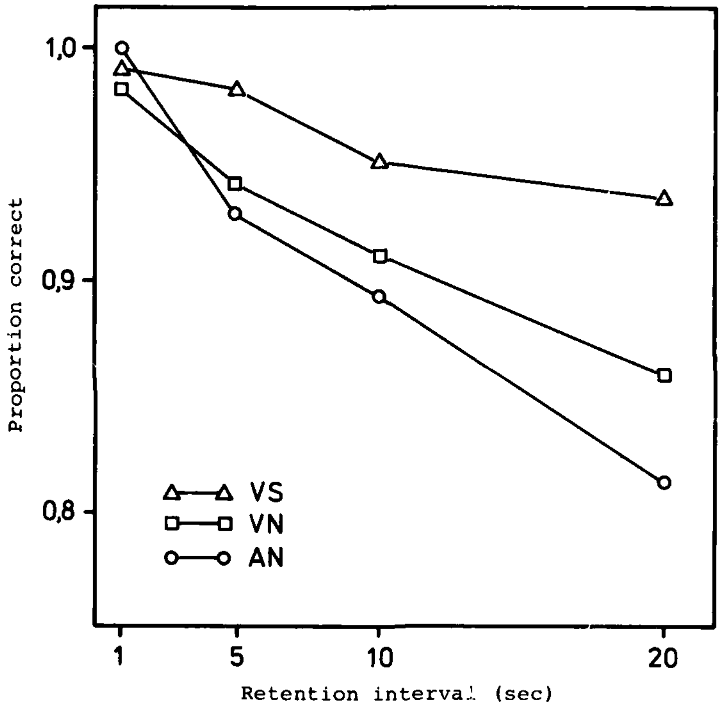


Figure 6: Proportion of correct recall responses over retention intervals.
VS = Visual symbols, VN = Visual names, AN = Auditory names (REEVE and HALL, 1976).

2.4. TRANSFORMATIONS

There are convenient transformations of informations between modalities in the course of human information processing. First, as shown above, visual verbal informations or sometimes even spatial informations are transformed into an acoustic form for a better retenting in the phonemic short-term memory with the technic of subvocal rehearsal. Second, in tasks of cross-modal comparison or decision making transformations are made into the most adapted modality for the required task, e.g. spoken spatial informations into a visual code (FREIDES, 1974; TREISMAN and DAVIES, 1973). Third, for stimulus-response translation modality transformations from the stimulus modality into the response modality have to be performed, e.g. with a vocal reaction on digits (TEICHNER and KREBS, 1974).

Coding transformations have been proved as an additional factor in choice reaction times. E.g., a manual reaction on a visual position-coded stimulus with 2 alternatives needs about .3 s (no transformations), on a visual verbal stimulus another .1 s (coding transformation), and an oral reaction on a visual position-coded stimulus additional .1 s (modality transformation) (TEICHNER and KREBS, 1974). If one doesn't know the modality of the attended stimulus, switching attention between modalities may take more than .1 s (LA BERGE, 1973).

3. CONCLUSIONS FOR VOICE INPUT AND OUTPUT

According to the cited studies of the psychological research several conclusions can be drawn concerning military applications of voice input and output. If one disregard the technical as well as the physical and physiological aspects advantages of voice input/output over mechanical input and output systems can be expected in following man-machine situations, supposing a certain amount of task-loading:

1) Time-sharing tasks where rather low or different stages of information processing are addressed, such as monitoring a tactical display for the occurence of predefined symbols while checking a list of status reports per voice output. The visual detection task is much disconnected from the more demanding task of auditorily comparing status values with the desired values.

2) Tasks with verbal informations, such as naming any devices or parts of a device, e.g. the preselection of reconnaissance cameras inclusive specification of the focussing parameters by voice input. The modality - coding compatibility between the auditory-oral channel and the verbal informations supports the oral camera command of the camera name and the parameters digits and letters. No recoding is necessary from the verbal terms into localization decisions as for the case of information input with buttons.

3) Tasks with acoustic informations, such as transfering man-man communication into a man-machine communication, e.g. accomplishing the order from the senior officer to select another radio frequency. For this kind of tasks voice input would be an appropriate device because stimulus-response compatibility supports the oral action for frequency selection succeeding the acoustic order to do it. Staying on the acoustical level needs no translating of the informations into another modality.

4) Tasks with presentation of informations which have a high priority, such as indicating malfunctions, e.g. pointing out a falling oil pressure. The warning effect of acoustical informations can be used in voice warning systems to draw the attention of an other while busied person onto a warning message per voice output. This kind of task is yet realized and is a subject of several studies (SIMPSON and WILLIAMS, 1980; GORA, 1981).

5) Tasks with informations to be memorized for several seconds, such as searching for a couple of just announced target points on a map. The higher capacity of short-term memory for aurally received informations would facilitate the remembering of the names and coordinates announced by voice output (or by a human voice, of course).

A main difficulty of voice input and output is its conflict with human speech communication. Both are using the aural/oral channel and both are converging - to some degree - onto the unique semantic processing system. To reduce this conflict one should use different physical features for man-machine and man-man communication. E.g., a ground proximity warning per voice output for a pilot listening to the voice of a controller could be announced by a pure tone or realized by a voice synthesis with a high pitch.

Besides these psychological aspects of voice input and output the technical, physical, and physiological aspects have to be taken into account. On the one hand they open new criteria for the application of voice input/output such as a variable distance between user and machine and the lacking need to direct oneself toward the information output. But on the other hand they reduce the fields of application. E.g., the necessary speaking consistency for voice input make applications in emergency situations difficult where stress impairs speaking consistency. Or, speaking all the day could cause hoarseness and would also impair recognition performance of voice input. All theoretical considerations have to be proved with experiments under realistic conditions where new aspects such as acceptance by the user could appear.

4. REFERENCES

BENCOMO, A.A.; DANIEL, T.C., 1975, "Recognition Latency for Pictures and Words as a Function of Encoded-Feature Similarity", Journal of Experimental Psychology, Vol. 104, No. 2, 119-125.

BROADBENT, D.E.; VINES, R.; BROADBENT, M., 1978, "Recency Effects in Memory as a Function of Modality of Intervening Events", Psychological Research, 40, 5-13.

BROOKS, L.E., 1968, "Spatial and Verbal Components of the Act of Recall", Canad. J. Psychol./Rev. Canad. Psychol., 22(5), 349-368.

BURROWS, D., 1972, "Modality Effects in Retrieval of Information from Short-Term Memory", Perception and Psychophysics, 11, 365-372.

CRAIK, F.I.M., 1969, "Modality Effects in Short-Term Storage", Journal of Verbal Learning and Verbal Behaviour, 8, 658-664.

FREIDES, D., 1974, "Human Information Processing and Sensory Modality: Cross-Modal Functions, Information Complexity, Memory, and Deficit", Psychological Bulletin, Vol. 81, No. 5, 284-310.

GROPHER, D., 1980, "On the Training of Time Sharing Skills: An Attention Viewpoint", Proceedings of the Human Factors Society, 24th Annual Meeting, 259-263.

GORA, E., 1981, "Bericht zum Symposium Aviation Psycnology", Ohio State University, Institut für Psychologie und Erziehungswissenschaften, Universität München.

HARRIS, S.D., 1978, "Human Performance in Concurrent Verbal and Tracking Tasks: A Review of the Literature", Naval Aerospace Medical Research Laboratory, Special Report AD A060493.

JÜTTNER, C., 1979, "Gedächtnis", Ernst Reinhardt Verlag München, Basel.

LA BERGE, D. 1973, "Identification of Two Components of the Time to Switch Attention: A Test of a Serial and a Parallel Model of Attention", in: Kornblum, S., "Attention and Performance IV", Academic Press New York and London.

MASSARO, D.W., 1975, "Experimental Psychology and Information Processing", Rand McNally College Publishing Company, Chikago.

MOUNTFORD, S.J.; NORTH, R.A., 1980, "Voice Entry for Reducing Pilot Workload", Proceedings of the Human Factors Society, 24th Annual Meeting, 185-189.

MURDOCK, B.B., Jr.; WALKER, K.D., 1969, "Modality Effects in Free Recall", Journal of Verbal Learning and Verbal Behaviour, 8, 665-676.

NILSSON, L.-G.; WRIGHT, E.; MURDOCK, B.B., Jr.; 1975, "The Effects of Visual Presentation Method on Single-Trial Free Recall", Memory and Cognition, 3(4), 427-433.

NORMAN, D.A., 1969, "Memory & Attention", John Wiley & Sons, Inc., New York, London, Sydney, Toronto.

PARKINSON, S.R., 1972, "Short-Term Memory while Shadowing: Multiple Item Recall of Visually and/or Aurally Presented Letters", Journal of Experimental Psychology, 92, 256-265.

REEVE, R.A.; HALL, R., 1976, "The Storage of Physical and Name Properties in Short-Term Visual Memory", Memory & Cognition, Vol. 4(1), 6-10.

RÖNNBERG, J; OHLSSON, K., 1980, "Channel Capacity and Processing of Modality Specific Information", Acta Psychologica, 44, 253-267.

ROLLINS, H.A., Jr.; HENDRICKS, R., 1980, "Processing of Words Presented Simultaneously to Eye and Ear", Journal of Experimental Psychology: Human Perception and Performance, Vol. 6, No. 1, 99-109.

SIMPSON, C.A.; WILLIAMS, D.H., 1980, "Human-Factors Research Problems in Electronic Voice Warning System Design", Conference on Manned Systems Design, Freiburg, Preprints, 94-106.

TEICHNER, W.H.; KREBS, M.J., 1974, "Laws of Visual Choice Reaction Time", Psychological Review, Vol. 81, No. 1, 75-98.

TERNES, W.; YUILLE, J.C., 1972, "Words and Pictures in a STM Task", Journal of Experimental Psychology, 96, 78-86.

TREISMAN, A.M.; DAVIES, A., 1973, "Divided Attention to Ear and Eye", in: Kornblum, S., "Attention and Performance IV", Academic Press, New York and London.

WATKINS, M.J., 1972, "Locus of the Modality Effect in Free Recall", Journal of Verbal Learning and Behaviour, 11, 644-648.

6. ACKNOWLEDGEMENT

This research was supported by the German Federal Ministry of Defence.

ERGONOMIC REQUIREMENTS FOR VOICE PROCESSING SYSTEMS

Dr. R. Seifert and Dr. P. Bubb
Messerschmitt-Bölkow-Blohm GmbH
Military Aircraft Division
Postfach 80 11 60
8000 München 80 - Germany

Summary

"Human voice" is used in modern aircraft no longer for intercommunication and air-to-ground communication only. "Voice" functions are verbal warning, verbal threat and guidance information, voice transmission and verbal control of system functions. Ergonomically we have to deal with this "audio interface" systematically.

The voice functions of the audio interface are classified as being output, output/input, and input functions. Their application is discussed, and the methods for voice generation and voice recognition are described and compared. As far as information is available, ergonomic requirements for voice generation, transmission and recognition techniques are discussed which can be derived based on the articulation index assessment and other technical data. Besides these more equipment oriented requirements, information oriented requirements are needed concerning the coding and the organization of the information. These requirements aim at optimizing the demand on man's information perception and processing capabilities, resulting from the use of various voice functions. It turns out, that further research is recommended to enable us to better define these information requirements with regard to the different voice functions and voice generation methods.

1. Introduction

The technology development in electronics has had the result, that man's voice is no longer used for person-to-person communication only. To-day "voice" must be looked at as being the main composite of the "audio interface" between man and the display/control system. Growing diversification of applications of voice interface functions bears the danger of overloading the audio interface respectively the aural information processing channel of man.

All audio and voice input/output functions designed into a display/control system share in loading man's aural information processing channel. Consequently in the engineering design process for future display/control systems "ergonomic interface control" is gaining a new meaning and increasing importance.

This paper is meant to evoke a comprehensive understanding of the ergonomic needs in designing the audio interface of display/control systems.

The scope of the presentation is:

- classify the voice functions of the audio interface
- survey the use of these voice functions
- evaluate voice generation and conversion methods
- introduce ergonomic requirements for voice function design and test within the audio interface.

The paper is limited to the audio interface in fighter aircraft display/control system application.

2. Classification and Use of Voice Function

2.1 Classification of Voice Functions

Present developments show that we have to classify the voice functions applicable in military aircraft into the following:

- Verbal warning as a composite of the central warning system.
- Speech transmission in digital intercommunication systems.
- Verbal guidance based on data link used for transmission (command and control, ATC-messages).
- Verbal control in multifunction display/control systems.

For completeness of functions possible (which are audios at present):

- Verbal threat information (on the basis of the radar warning system).

These audio-interface functions in man-machine systems require different techniques for their realization:

- o Verbal warning, verbal guidance and threat information require speech generation techniques.
- o Speech transmission requires analog/digital and vice versa conversion techniques.
- o Verbal control requires speech recognition techniques.

Nevertheless from an ergonomic point of view we have to consider these functions and techniques jointly as being composites of the audio interface. For all these interface functions we have to provide design and test requirements, which assure intelligibility, discriminability, validity and reliability within the man-machine system concerned.

This classification is based on the growing application of digital voice processing systems. With the introduction of these systems, we have to develop a new concept, a comprehensive concept of using man's aural-channel as a man-machine interface.

"New techniques in aircraft are necessary only, if they can be applied to functions which otherwise cannot be mastered by man". This statement was made by Senders, 1981. It does not preclude the use of voice functions for single seater aircraft. It only tells the designer not to become too enthusiastic in using the voice channel as man-machine interface.

2.2 Use of Voice Functions in Fighter Aircraft

2.2.1 Verbal Warning

One of the first voice warning systems we learned about was a "natural voice tape system" manufactured by Nortronics, and flight tested from 1963 onward. It was tested in the F-100F, F-104G, A-4C, and others. Teledyne and other firms followed with manufacturing such systems.

It seems, that the design requirements for "verbal warning signals" given in MIL-STD-1472C (1981) are mainly based on those systems.

Meanwhile the faster more flexible and more reliable digital systems exist. The MIL-STD-1472C recommends speech processing only "to increase or preserve intelligibility". With the digital systems available, and the above stated possibilities of use of voice functions, this recommendation has become outdated. The same applies to other recommendations, e.g. the "nonspeech alerting signal" preceding a warning. Based on the findings of Carol A. Simpson and D.H. Williams, 1980 this can no longer be recommended.

On the other hand, looking into the publications on simulator and flight test experiments, we do not find a substantial preference for verbal warnings against the conventional audios, both in combination with the visual warnings. Even for the "response time" to a warning signal the results differ considerably.

In summary "response time" measurements show:

- o significantly shorter response times for verbal warning against visual warning Nortronics, 1966, Reinecke, 1981.
- o less difference in response time between verbal + visual against audio + visual (Wheale, 1981), but greater difference (in favour of verbal) under high workload conditions (Kemmerling et al., 1969).

The latter fact is important for fighter application, comparing audio and verbal signals: to the "lyre bird" audio warning you can response only after having checked its meaning on the central warning panel. To a verbal you can react without crosschecking - provided that you know you can rely on your system. Normally visual crosschecking is done by pilots. But this could make a difference in combat situations, where the pilot does not have chance of looking away from his attack display.

Most of the simulator and flight test results cannot be compared because of different test layout concerning:

- o type of air or simulated air task used in the experiment
- o aircraft system used (fighter, carrier, helicopter etc.)
- o warning composites compared e.g. visual with voice (Nortronics), visual + audio with visual + voice (Wheale) etc.
- o type of voice used, natural or artifical, intonation, matureness and other factors
- o message format applied.

Summarising the various results, the conclusion is:

- verbal warnings have a semantic advantage against audios, - both in combination with visuals
- the fact that man's aural channel is susceptable to be shut down under extreme workload does not preclude the use of verbal warnings, because this affects audios as well
- the MIL-Bus compatibility requirement for the warning system has consequences for the "type of voice" used for verbal warnings. The speech intelligibility criteria have to be linked to storage and channel capacity considerations
- a general requirement for discriminability of the signal or message sources within the display/control system has to be derived and applies to all voice functions used in the audio interface of the system
- application in the A/A fighter role of more than one single seat aircraft or one or more two seat aircraft being involved in A/A combat does have the consequence, that either the ongoing tactical intercommunication would have to be interrupted in case a warning occurrs, or - possibly on pilot option - verbal warning is suppressed.
- application in the A/G fighter role would have the same consequences, except in case of a one single seat aircraft A/G interdiction mission.

2.2.2 Speech Transmission

In future fighter aircraft it is possible to digitize the intercommunications system (ICS). R.F. Bolt and B.D. Sanderson, 1981 state the performance deficiencies of today's analog ICSs:

- poor isolation between communication channels
- poor EMI isolation
- lack of flexibility in station selection and system configuration.

The "speech transmission equipment" requirements and recommendations given in MIL-STD-1472C need updating in the light of these developments.

Specific systems are not discussed in this paper.

2.2.3 Verbal Guidance

"Data link" is one of the means of future air traffic management systems. One question considered in present concept and equipment developments is: "how should the communications be shared between the data link and R/T?" (Cox, 1979). In the light of the audio interface it is not only the question of sharing between data link and R/T. It is moreover a question whether or how far the data link share would increase, if we use the audio interface in addition to the visual display of data link messages. The analysis has to differentiate between:

- communications to be presented on visual display only
- communications to be presented on both the visual and the audio display.

In the military environment the main benefit of data link combined with verbal guidance lies in saving bandwidth of the communications transmission channel, and therewith increasing ECM-resistance.

Voice generation on aircraft can be performed with the same (redundant) equipment, that is used for the generation of verbal warnings.

For fighter application the constraints described with regard to verbal warnings apply to verbal guidance as well. For fighter application a data link with visual display, combined with a verbal guidance system does provide wide variability of use in different flight and mission phases. Thinking of the mission the application probably is limited to the pre-combat phases. Thereof the penetration phase is of particular interest in terms of "enemy detectability".

2.2.4 Verbal Control

Speech recognition techniques represent a great challenge. They open up a great number of possibilities for man communicating with systems, even long distance via the world wide telephone network.

As far as it's application in future fighter aircraft is concerned speech recognition techniques open up the possibilities to use the human voice as "control element" in addition to switches, knobs and other control elements.

Although the validity requirements for speech recognition in conjunction with verbal control are extremely high, the technical realisation in aircraft application allows some concessions compared with "general purpose" systems. The aircraft system is not required of being capable to recognise "any voice", it is only required to recognise the individual pilot's voice.

This feature is applicable for single seat fighter in the A/G interdiction role.

For the A/A fighter role the applicability is highly doubtful because of the high intercommunication load in the combat phase.

2.2.5 Verbal Threat Information

With increasing weapon launch capabilities of rockets (AMRAM, ASRAM) the threat reaction times available or allowed in fighter aircraft decrease. Possible benefit of verbal information on threats should be taken into consideration in future ECM system analysis.

Voice generation for verbal threat information would be based on the same equipment as for verbal warning and verbal guidance.

3. Voice generation and recognition methods

3.1 Voice generation methods

There are three different voice generation methods:

- Signal form coding
- parametric coding and
- text syntheses

3.1.1 Signal Form Coding

"Signal Form Coding methods" we call all those methods, which directly store and reproduce a given signal, such as a word or a sentence. In the present literature these methods are also called "word generation methods". As all of the techniques existing are used for "word" or speech generation, we have to differentiate between them. At present there are three techniques:

- tape recording techniques
- PCM techniques
- delta modulation techniques

3.1.1.1 Tape Recording

This is the oldest and most known method, to store words and/or sentences on magnetic tape. The advantage is a relatively good quality of voice reproduction (as long as the tape is good), and is the recording time capacity.

Yet other disadvantages have prevented their break through in application to fighter aircraft. The disadvantages are:

- low vibration tolerance
- inflexibility of voice message formats
- long search time for messages
- low message repeat capability

Nevertheless we must admit, that most research investigations are based on this technique. It was the first that existed and was applied in aircraft.

3.1.1.2 PCM-Technique

The analog voice is digitized using a certain clock or tact frequency, and is stored digitally in a RAM or ROM memory or is transmitted via radio. The advantages of this technique are:

- high fidelity of the reproduced voice
- signal to noise ratio of the radio transmission being nearly independent from distance.

Disadvantage: for a storage of 1 s of speech at least 12,000 x 12 bit are required, if the frequency range requirement of MIL-STD-1472C shall be met. Slightly better dynamics are achieved by applying logarythmic distortion of the analog signal (before it is digitized), but the disadvantage stated remains the same.

3.1.1.3 Delta Modulation

Fig. 1 shows a simple example of delta modulation. A delta modulator consists of a comparator in the forward path and an integrator in the feedback path of a simple control loop.

The comparator output reflects the sign (plus or minus) of the difference between the analog input signal and the integrator output. The comparator is clocked in order to produce a synchronized and band limited bit stream. Normal integration of the bit stream and low pass filtering are able to compose the audio signal.

Delta modulation is more efficient than PCM-technique, because of the relatively slow changes of the amplitude of human speech.

Advantages:
- o high fidelity of the reproduced voice
- o lower storage capacity required

Disadvantage: For this good quality of the human voice reproduction a relatively high clock rate is required. - This disadvantage can be reduced somewhat by use of continuously variable slope delta modulation or of adaptive delta modulation. The use of the redundancy principles of human speech could also lead to lower clock rates and thereby lesser storage capacity needed.

3.1.2 Parametric Coding

Due to the physical voice generation in the vocal tract and due to the redundancy in the human voice there are characteristic frequencies which predominantly contribute to the tone pattern of human voice. Fig. 2 shows as an example a spectrogram of the sentence: "that you may see" (Flanagan, 1965).

Based on these spectrographic characteristics human speech can by generated synthetically using the following methods:

- o formant synthesis
- o linear prediction coding synthesis.

3.1.2.1 Formant Synthesis

If the spectrogram of a spoken word is known, it can be generated by composing it of the spectral density patterns being characteristically and essentially for that word.

Fig. 3 shows a block diagram of a simple three-formant synthesizer. The outputs of a tone generator (for the vocal sounds) and a noise generator (for the unvoiced sounds) are connected to three bandpass filters. These filters are frequency variable within their bandwidth and include amplitude multiplying capabilities. The output of all three filters is combined in an amplifier.

Fig. 4 shows a spectrogram of a synthesized speech (generated by formant synthesizer) and that of the original speech utterance.

The following frequency bands are used normally for the bandpass filters:

pitch frequency	F_0 :	50 - 250 Hz
first formant	F_1 :	200 - 900 Hz
second formant	F_2 :	600 - 2500 Hz
third formant	F_3 :	1500 - 3000 Hz
fourth formant	F_4 :	3000 - 4000 Hz
noise filter	F_n :	3000 - 8000 Hz

Historically in the "Dudley Voder" ten formants had been used by Dudley (1939) up to 7500 Hz.

3.1.2.2 Linear Prediction Coding Synthesis (LPC)

LPC synthesizers are similar to the formant synthesizers, only they apply digital filter technique, using lattice filters, whilst formant synthesizers use analog filters. Therefore formant synthesis is more frequency oriented and LPC more time oriented.

Fig. 5 shows a block diagram of a LPC-synthesizer. In the ROM at the upper left side the speech parameters are stored. This type ROM is required in the formant synthesizer (Fig. 3) as well.

Both methods reproduce total words or sentences only, not phonems or syllables.
Therefore the quality of a specific set of synthesizer depends mainly on the quality of the speaker's spoken words and/or sentences stored in the above ROM.

3.1.2.3 Text Synthesis

Text synthesis is similar to LPC synthesis. Only with this technique the so called allophons of the phonems are stored, and the words are synthesized by composing their phonems. This technique allows greater text variability, yet the quality of speech intonation is lower than with the LPC and formant synthesis techniques.

3.1.2.4 Storage Requirements of the Voice Generation Methods

Fig. 6 shows the storage capacity requirements of the various voice output systems. The rational of Fig. 6 is: for 1 s speech output a given system has to process a given number of kbits, depending on the voice generation method used.

With PCM technique more than 60 kbit per second speech output are required, for delta modulation between 15 and 60 kbit per second. For adaptive delta modulation the requirement it is somewhat lower. Parametric coding methods, such as formant and LPC techniques require 5 to 10 kbit per second speech output.

Phonem synthesis has the lowest bit stream or bit rate requirement.

These rates are required only for speech generation. In case stored words or sentences are to be addressed only, the bit rates required are considerably lower.

3.2 Speech Recognition Methods

As far as speech recognition is concerned we have to consider

(a) recognition of single words only or of sentences

(b) speaker dependent and speaker independent recognition.

As Fig. 7 shows, at present our systems are capable only to reliably perform the most simple task, to recognise words, if the speakers voice is known by the system. The individual methods available are similar, they follow the functional block diagram shown in Fig. 8.

In general most of the voice recognition systems consist of two components:

- pattern detection and preprocessing
- pattern recognition and classification

(1) pattern detection and preprocessing

The spoken control message is analyzed digitally or analog. Existing equipments differ considerably concerning the level of detail of this analysis, e.g. number of frequency lines of the Fourier analysis. In the second step the words as such are to be isolated (by detecting the beginning and the end of a word). Loudness and time-length of the words are to be standardized for internal equipment use.

(2) pattern recognition and classification

By comparation with the patterns stored, the message is identified, recognized and classified. Finally a decision is made to accept or reject the control message.

4. Ergonomic Requirements for Voice Input/Output Functions for System Specification

4.1 General Remarks

Ergonomic requirements for system specification have to include:

- design requirements
- test requirements, by which the fulfilment of the design requirements and the operational acceptability of the functions can be assessed
- function application recommendations

MIL-STD-1472C, 1981 includes some design requirements for verbal warning signals, speech transmission equipment and test requirements as far as speech intelligibility is concerned.

For future fighter aircraft an extended specification is required in which ergonomic/technical requirements are added, all voice functions are treated jointly and in their combinations with audio signals used, whether as warning signal or as threat signal.

4.2 Ergonomic Design Requirements

A systematic breakdown of the ergonomic design requirement criteria is shown in Fig. 9.

This breakdown covers

- The voice functions concerned.
- The design task (Mutschler, 1981) concerned.

(1) Voice functions

The various voice functions partly require specific ergonomic treatment. The voice functions concerned were classified (see para. 2) into:

- output function, as in verbal warning, threat, and guidance information
- combined input/output function as in speech transmission
- input function, as in voice control.

(2) Design task

The ergonomic design requirement criteria are to be grouped according to the levels:

- adaptation to the sensoric and motoric faculties of man
- information coding
- organization of the information (within a message)

The predominant ergonomic requirement concerning all verbal output functions is: each message shall be understandable, intelligible. One measure for speech intelligibility is the articulation index, AI, (French and Steinberg, 1947). Beranek, 1947 has provided the octave band method, by which an appropriate estimation of the AI can be performed.

According to MIL-STD-1472C the total bandwidth from 200 Hz to 6100 Hz is divided into five octave bands, with the middle frequencies of 250, 500, 1000, 2000 and 4000 Hz. Each octave band contributes to the articulation index proportionally to the signal to noise ratio, weighted with a factor B, depending on the octave frequency band. Fig. 10 shows the influence of the signal to noise ratio on the part or portion of the AI for the octave frequency bands.

In communications equipment design there is a tendency to use 3000 Hz as cut-off frequency for voice transmission. It can easily be shown, that this is unacceptable. Fig. 11 shows the spectrum of an average speech level (Bürk, 1981) superimposed on a typical aircraft noise spectrum at the crew members ear (Wheeler et al., 1981). From this results an articulation index of AI = .53. With less damping (lower curve + 4 dB) the AI drops to .43. If low pass filtering (cut-off at 3000 Hz) is applied to the speech signal, the AI drops from .53 to .48, and from .43 to .39 respectively.

The tolerance zone of transducers of +0/-3 dB (tolerance zones are not specified in MIL-STD-1472C) does decrease the AI additionally by .1. That means: a single word intelligibility of 95 % would in the worst case decrease to 78 %. This simple example shows that in noisy aircraft environment a cut-off frequency of 3000 Hz is unacceptable.

For radio transmission, tape recorder use, and for PCM and delta modulation methods an additional criterium for the electroacoustic non-linearities has to be included, which is not done as yet in MIL-STD-1472C. Electroacoustic non-linearities increase the intermodulation factor and increase the distortion factor. An intermodulation factor of 5 % or more results in a reduction of the AI. (Fig. 12).

The requirement to use a cut-off frequency of not less than 6000 Hz for voice generation and transmission equipment has consequences for the application of formant and the LPC methods as well. It is not acceptable to use the lower three formants only. The fourth and fifth should also be included.

For speech recognition systems it is difficult to state technical requirements. It shall be adaptable as to the speaking speed, and shall have a sufficient tolerance against speaking speed variations. At present certainly each pilot must have his individual "speech recognition ROM", that can be plugged into the recognition equipment.

Systems with a frequency range from 200 Hz to 6000 Hz will have a better recognition capability. This would allow to store speaker recognition capability under different ambient noise levels into system. This would allow reliable speech recognition even in fighter environment.

Another problem of speech recognition are g-manoeuvres. Breathing actions against high g-manoeuvres preclude voice input, and therewith the application of voice control in A/A combat.

Coding of information

For this design task appropriate requirements are still left to be defined. They comprise:

- compatibility of semantics applied for different voice functions and tasks
- the syntax used for verbal output functions with such characteristics as typical, unmistakable, short phrases etc. (see also Simpson and Williams, 1980)
- identification and discrimination of different voice output channels, e.g. use of different speakers
- method of alerting by type of voice used vs. alerting by tone or keyword.

A number of definite requirements for verbal warning were stated already in 1971 by Birkhahn and Steininger. They do not differentiate between coding and organization of information. Nevertheless they are worth being repeatedly stated here:

- Intelligibility scores should be computed for each message.
- The phenomenon of the variability of subjective intensity sensations with words of equal loudness spoken in a sequence, known as time-and-order effect, must be taken into account and compensated for.
- The number of consonants before the first vowel of a word should be as small as possible.
- The sequence of words in a message should be fixed experimentally. In case time does not allow this, the most common sequence should be chosen.
- Each message should started with a different word which should assume the function of a key stimulus.
- The pilots should be made familiar with each message through intensive training.
- The expression of the voice should be adapted to the urgency of the message.
- Only urgent warnings ("reds") should be included.
- The information shall be given redundantly by the communication panel and by the repetitive warnings.

These requirements are applicable to other voice output functions as well. Other detail requirements are left to be derived.

4.3 Test

Ergonomic design requirements are useful only, if and as far as their fulfilment can be tested.

The articulation index of voice output equipment is a criterion that can be tested. For other criteria as intermodulation or distortion factor test criteria are available as well.

For the criteria stated under coding of information and organization of information there is a lack of objective test criteria and methods. For these criteria test requirements are limited to the subjective methods of rating scales, semantic profiles.

4.4 Recommendations

At last recommendations (Fig. 13) are to be made about which voice generation techniques are qualified for different voice functions. It is to summarize that only delta modulation and parametric coding techniques are relevant for most applications. Delta modulation is suitable for online transmission as well. The bit stream needed in this case depends on the sampling rate and may be between 15 - 60 kbit/sec. Text synthesis is applicable for all voice functions. But because this technique has deficiencies as far as text intonation is concerned, its applicability in modern fighter cockpits is doubtful. There is only one, yet presently not realized application: the speech transmission using an unlimited vocabular with extremely low bit rates. The applicability of text synthesis for speech transmission depends on a good compiler, which is able to transform written words to allophones, or which is able to accept spoken words and to transform them to allophones. In the near future this seems not to be achievable.

Consequently we are left with LPC, formant and delta modulation being the applicable voice generation methods. These require a human speaker for recording text repertoire required. With these methods the process of recording is the most critical task. Sophistication and imagination is needed to apply appropriate intonation and variation of intonation over the text repertoire, an intonation matching the objective of the various messages to be generated within that repertoire.

For direct voice input systems exist little experience exists about variations of human voice with environmental and task stress. But one simulator experiment gives the following conclusions (Laycock, 1980):

"The above small series of experiments indicates:

(1) Direct voice input produced faster entry times than keyboard entry and thus required a reduced period of divided attention between the data entry task and the primary flying task.

(2) The accuracy of data injected into the system was far superior with direct voice input than with keyboard input.

(3) The (simulated) flying task was degraded less when using direct voice input than when using keyboard input, especially under high workload conditions.
However it is suggested that the cognitive loading may be equivalent for the two tasks at any instant.

(4) The experimental methodology adopted when investigating alternative methods of data entry whilst flying is critical if true effects are to be observed.

(5) Naive subjects are not suitable for the investigation of complex systems."

5. Concluding Remarks

It was shown, that the audio interface is emanating to become a more and more complex interface, which has to be carefully treated and monitored throughout the design and development process.

Information coding and the organization of information have not yet been investigated under the assumption of the combined use of different verbal output functions. If verbal warning is used in combination with verbal guidance and/or threat, the attention demand for alerting and function discrimination may be unduely increased. Besides that the priority scheme could become highly complex or even too complicated and unfeasible.

Further research is required to clarify the scope and the limitations of voice output and input functions applicability particularly for fighter aircraft.

References:

/1/ Beranek, L.L., 1947
The Design of Speech Communication Systems
Proc. Inst. Radio
Engrs., 35, 880-890, 1947

/2/ Birkhan, G. and K. Steininger, 1971
Psychological Evaluation of Voice Warning Systems in Airplanes
Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt e.V. (DFVLR),
Abt. Luftfahrtpsychologie, Hamburg

/3/ Bolt R.F. and B.D. Sanderson, 1981
A Multiplexed Digital Voice Intercommunications System Compatible with Future
Voice Conversion Techniques
AGARD-CP-311 (see /4/)
Aural Communication in Aviation, AMP-Meeting, Soesterberg, March 30 - April 2,
1981

/4/ Bürk W., 1981
Lärm: Messung, Bewertung und Wirkung auf den Menschen, in H. Schmidtke (Hrsg)
Ergonomie, Carl Hanser Verlag, München, Wien, 1981

/5/ Cox, M.E., 1979
Data Link - The Key to Improvements in Civil/Military Air Traffic Management
AGARD Conference Proceedings No. 273, Air Traffic Management, Civil/Military
Systems and Technologies, Copenhagen, Denmark 9. - 12. Okt. 1979

/6/ Dudley, H., 1939
The Vode, Bell Labs. Record 17, 122 - 126, 1939

/7/ Flanagan, J.L., 1965
Speech Analysis, Synthesis and Perception. Reihe: Kommunikation und Kybernetik in
Einzeldarstellungen. Band 3, Springer Verlag, Berlin, Heidelberg, New York 1965

/8/ French N.R. and J.C. Steinberg, 1947
Factors Governing the Intelligibility of Speed Sounds, J. Acoust. Soc Am.
19, 1947, 90-119

/9/ Kemmerling P., et al., 1969
A Comparison of Voice and Tone Warning Systems as a Function of Task Loading
Techn. Rep. ASD-TR-69-104
WPAFB, Ohio, 1969

/10/ Laycock J. and J.B. Peckham, 1980
Improved Piloting Performance Whilst Using Direct Voice Input.
Royal Airforce Establishment, Technical Report
RAE-TR-80019, Februar 1980

/11/ Mangold, H., 1981
SPRAUS gibt jedem Computer Stimme, Funkschau 4/1981, 66-70

/12/ MIL-STD-1472C
Human Engineering Design Criteria for Military Systems, Equipment and Facilities;
May, 1981

/13/ Motorola Semiconductors Inc.
Continuously variable slope delta modulater/demodulator, MC 3417/MC 3418/MC 3517/
MC 3518 Specification and Application Note.
Motorola Inc. 1978

/14/ Mutschler, H., 1981
Sprach-Ein- und -Ausgabe: Ergonomische Gestaltung für den praktischen Einsatz
FhG Berichte 1/2-81, Karlsruhe

/15/ NORTHROP NORTRONICS
NORTHRONICS Voice Warning Systems Technology Status
Manuscript of Status Report, 1966

/16/ Reinecke, M., 1981
Voice Warning Systems:
Some Experimental Evidence Concerning Application
AGARD-CP-311,
Aural Communication in Aviation AMP-Meeting, Soesterberg, March 30 -
April 2, 1981

/17/ Senders, 1981
Univ. Toronto
Paper presented at the 1981 Symposium on Aviation Psychology
Ohio State University, April 20-24, 1981.

/18/ Simpson C.A. and D.H. Williams, 1980
Response Time Effects of Alerting Tone Semantic Context for Synthesized Voice Cockpit Warnings
Hum. Factors, 1980, 22(3), 319-330

/19/ Wheale, J.L., 1981
The Speed of Response to Synthesized Voice Messages
AGARD-CP-311
Aural Communication in Aviation AMP-Meeting, Soesterberg, March 30 - April 2, 1981

/20/ Wheeler P.D. and S.G. Halliday, 1981
An Active Noise Reduction System for Aircrew Helmets. AGARD Conference Proceedings No. 311, Aural Communication in Aviation, Soesterberg, Netherlands 30. March - 2. April 1981

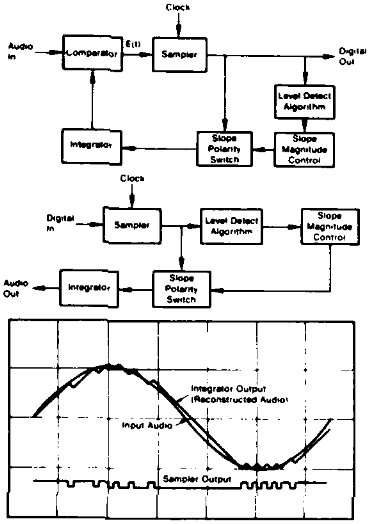


Fig.1 Delta Modulation: Encoder, Decoder, Audio Input Signal and Reconstructed Audio Signal (Motorola, 1978)

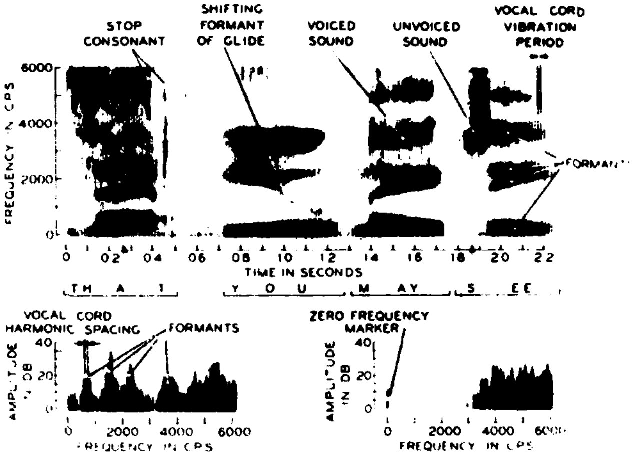


Fig.2 Broadband Sound Spectrogram of the Utterance "That You May See" (Flanagan,1965)

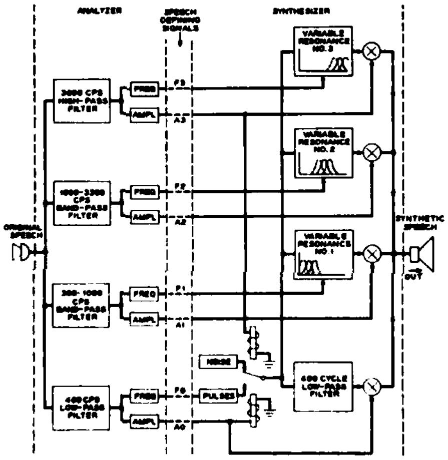


Fig.3 Parallel Coded Formant Vocoder (Flanagan,1965)

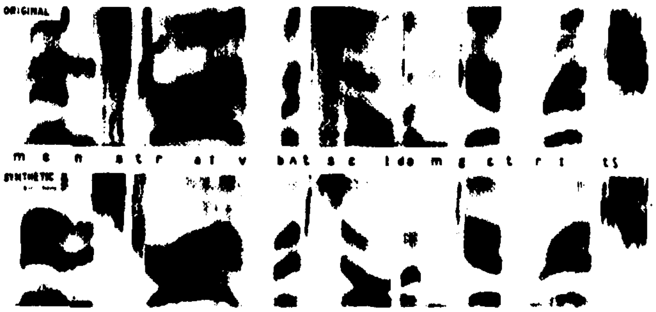


Fig.4 Spectrograms of Synthetic Speech Produced by a Computer Simulated Formant Synthesizer and of the Original Utterance (Flanagan,1965)

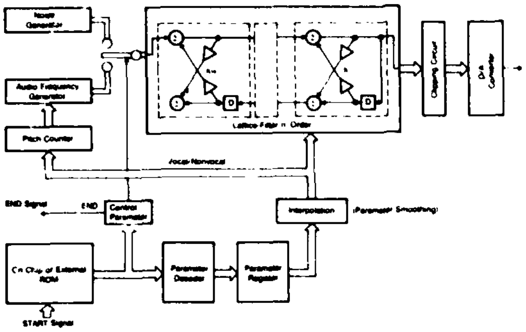


Fig.5 Schematic Diagram of a Linear Prediction Coding Synthesizer (Hitachi)

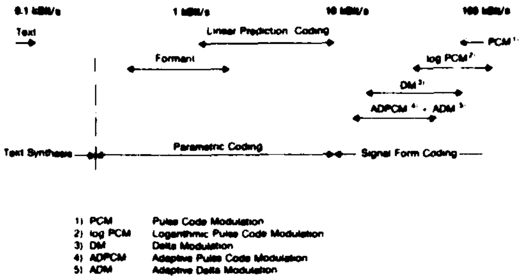


Fig.6 Comparision of Storage Need of the Different Voice Generation Systems

Recognizable by Systems	Speaker Dependent	Speaker Independent
Single Words	yes	no
Sentences	no	no

Fig.7 Speech Recognition Capability of Present Systems

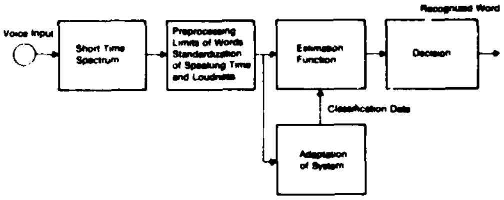
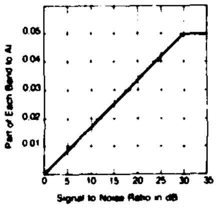


Fig.8 Word Recognition (Mangold,1981)

Design Task \ Voice Function	Verbal Warning, Threat & Guidance	Speech Transmission	Verbal Control
Adaption to Sensoric and Motoric Faculties	● Speaking Speed ● Frequency Range ● Loudness Signal to Noise Ratio Noise Attenuation ● Intermodulation/Distortion Factor ● Characteristics of Earphones	● Speed Depending on Speaker ● Frequency Range ● Loudness Signal to Noise Ratio Breathing Induced Noise Noise Attenuation ● Intermodulation/Distortion Factor ● Characteristics of Microphone (Peak Clipping) & Earphones	● Input Speaking Speed ● Speech Constancy ● Signal to Noise Ratio ● Breathing Actions against G maneuvers ● Speaker's Training
Coding of Information	● Semantics ● Syntax ● Vocabular Fixed/Variable ● Identification and Discrimination ● Attention Demand	● Depending on Speaker and Convention	● Semantics ● Number of Words ● Length of Words ● Discriminability of Words ● Memory Demand on Man
Organization of Information	● Sequence of Information ● Priority of Information ● Loudness Weighting with Respect to Other Audio Channels ● Compatibility of Information of Equipments ● Respect to Time Order Effects	● Depending on Speaker and Message	● Activation Deactivation of Verbal Control ● Pause Between Words ● Response Time ● Feedback ● Compatibility of Information of Equipments

Fig.9 Design Demands as a Function of Design Task and Voice Function



No	Octave Band Hz		Middle Frequency Hz	Rating Factor B_i
1	180	355	250	1.1
2	355	710	500	2.3
3	710	1400	1000	5.4
4	1400	2800	2000	7.0
5	2800	5800	4000	4.2

$$AI = \sum_{i=1}^{5} B_i \, a_i$$

Fig.10 Estimation of Articulation Index (Beranek)

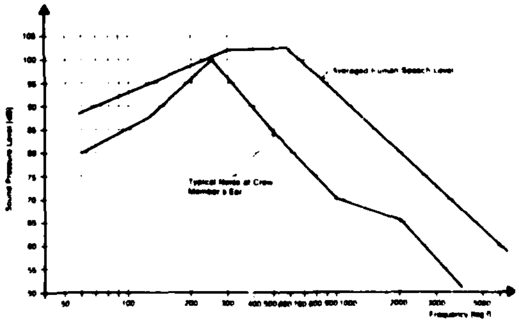
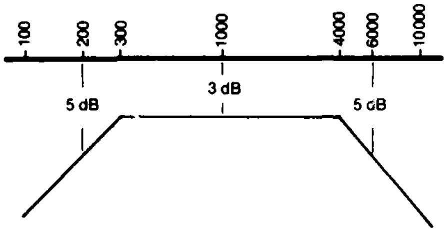


Fig.11 Averaged Speech Level (Bürk,1981) and Typical Aircraft Noice at Crew Members Ear (Wheeler,1981)

● Noise Level	> 30 dB
● Frequency Response	200 - 6100 Hz



● Distortion Factor*)	≤ 3 %
● Intermodulation Factor*)	≤ 5 %
● Intelligibility of Sentences	
in Laboratory	> 99 %
in Real Life Situation	> 90 %

*) Definable only for Tape, PCM and Deltamodulation

Fig.12 Demands for Voice Transmission Systems

	Signal Form Coding			Parametric Coding		Text Synthesis
	Tape	PCM	Delta	Formant	LPC	
Speech Transmission with Digital Intercom	- -	0	+ +	- -	- -	(+ ?)
Verbal Guidance with Data Link	- -	- -	-	+ +	+ +	0
Verbal Warning	- -	-	+	+	+	0
Verbal Threat Information	- -	-	+	+	+	0

Fig.13 Recommendations of Different Voice Generation Methods and Voice Function

APPLICATION, ASSESSMENT AND ENHANCEMENT OF SPEECH RECOGNITION FOR THE AIRCRAFT ENVIRONMENT

By

Richard Vonusa, Edward Cupples, Lt Silvi Steigerwald, Capt Jeffrey Woodard and Capt Joseph Nelson

United States Air Force
Rome Air Development Center (RADC)
Griffiss AFB, NY

SUMMARY

The Rome Air Development Center has sponsored considerable research and development in the area of speech processing over the last fifteen years. The main thrust of this R&D has been in ground applications, such as: speech recognition for cartographic data input, very low data rate speech communications, speaker identification/verification, language identification, and speech synthesis. The objective of this paper is to show the importance and relevance of two areas of this R&D to aircraft cockpit speech recognition tasks. To be specific, these two areas are speech enhancement techniques for noise suppression and the development of performance measures for speech recognition devices. In addition, a recently initiated application of speech recognition in an airborne environment will be discussed.

It is widely recognized that the acoustic environment in aircraft cockpits is likely to be harsh; yet, relatively little work has been done on addressing this problem by the development of automated techniques for speech enhancement. Such techniques in addition to other noise reduction techniques should improve the performance of speech recognition devices by improving the signal-to-noise ratio. A system called the Speech Enhancement Unit (SEU) has been used to reduce radio communication noises successfully in ground applications and has improved the signal-to-noise ratio by as much as 12db for random wideband noise. The techniques used in the SEU will be discussed and the prospects for using this (or similar) technology for cockpit application will be examined. The issue of assessment/evaluation of speech recognition devices continues to plague users, researchers and others interested in the technology. One important aspect of this problem is that of developing a meaningful performance measure. Such a measure can be used as a figure-of-merit for device performance. The weaknesses of probability of error will be discussed and a figure-of-merit based on information theoretic concepts will be proposed. The application of discrete-utterance speech communications has been proposed for very low data rate speech communications. It is suggested that the advantage gained in the communications anti-jam margin may be worth the inherent limitations of communicating using speech recognition/synthesis technology. This concept will be discussed and a narrowbandwidth communicaton system will be outlined, along with potential problems using this approach.

1. INTRODUCTION

RADC has been active in the speech processing area since the early 1960's. Emphasis at that time was on the development of techniques for fully automatic speaker dependent isolated word recognition on the 100 most commonly occurring English words.

Since that time RADC has vastly expanded its scope and is presently sponsoring research and development in numerous speech processing areas. RADC's program in speech processing involves the development of capabilities for the automatic recognition of languages, speakers, and keywords or phrases. Various audio data manipulation techniques such as speech speed-up/slow-down, instant audio recall, audio looping and silence removal capabilities have been developed to aid in real-time analysis of the speech signal. In addition, an advanced development model Speech Enhancement Unit (SEU) has been built and successfully tested. The SEU automatically and in real time can improve the signal-to-noise ratio of speech degraded by both narrowband and wideband noise. The SEU has been successfully used to substantially reduce radio communication noises without significantly attenuating or distorting the imbedded speech. This is discussed in greater detail in this paper.

Several speaker-dependent, isolated word voice data entry systems have been developed for various cartographic applications for the Defense Mapping Agency (DMA). In addition, RADC has active programs in the areas of connected speech recognition, solid state word recognition systems, and low data rate transmission for narrowbandwidth communications. This developmental experience has allowed RADC to critically examine the issue of Automatic Speech Recognition (ASR) device performance measures. A method of evaluation based on information-theoretic concepts is described.

Of particular interest is how this technology can be used in the military environment, particularly in the airborne environment. The application of this speech processing/recognition technology to be used in the aircraft is discussed.

2. THE ROLE OF AUTOMATIC SPEECH RECOGNITION (ASR) IN THE AIRBORNE ENVIRONMENT

It is a known fact that the military flight crew workload is becoming increasingly more demanding because of an increase in the number of flight tasks brought about by technology improvements, increased air traffic, more complex flight tasks, and a desire to reduce the number of flight crew members. At the current pace it is inevitable that the crew workload in the mid 80's will become excessive. For example, the pilot is required to devote constant manual and visual attention in order to perform mission oriented functions such as rapid changes in navigation, airborne weapons, and sensor systems. The present method of performing these critical functions is via manual operation of switches and keys. The increase in the number of manual tasks has made it difficult to perform all the necessary functions and maintain constant control of the aircraft. Therefore, it is necessary, that a more efficient means of performing these tasks be developed.

A promising technology that may relieve the flight crew workload is to augment some of the manual functions by the implementation of automatic speech recognition (ASR) as a method of interactive avionics communication. By utilizing ASR techniques the flight crew members can devote a larger portion of time and attention to the flight critical tasks. Fully developed ASR techniques have the capability to provide fast, convenient interactive communications in the aircraft and allows flight crew members to efficiently complete tasks with less conscious attention and without utilization of hands and eyes. By reducing the manual manipulation of switches and keys the hands and eyes are free for primary flight tasks.

Another area in which ASR can be of great value is in airborne narrowband communications. There is considerable interest in narrowing the bandwidth required for intelligible speech transmission over air-to-air and air-to-ground radio frequency (rf) communication channels. This interest is spurred by crowded rf communication links, lower channel noise, and increased jamming resistance. One method of obtaining a large reduction in the bandwidth required to transmit speech is to utilize ASR techniques.

2.1 Speech Enhancement

The use of Automatic Speech Recognition (ASR) to relieve flight crew workload and to provide narrowband communications for airborne operations is highly desirable. Unfortunately no ASR system exists that can cope with the harsh, noisy airborne environment. Current commercial ASR equipment has not been designed to operate in the airborne environment. For this reason a considerable amount of attention has been given to reducing the effects of the airborne environment on ASR.

There are many environmental effects that cause poor operation of an ASR system in the aircraft environment. Some of these effects are aircraft noise, breathing noise, operator stress, operator fatigue, effects of gravitational forces on operator's speech, etc. Although all of these environmental effects must be reduced, much attention has been given to reducing the acoustic noise generated by the aircraft. The level and characteristics of this noise can vary considerably, depending on such conditions as type of aircraft, location of the ASR microphone, facemask or no mask operations, and status of aircraft.

The areas of concentration in reducing the effects of this noise have been in the development of more robust recognition algorithms and the development of techniques to reduce the acoustic noise before recognition processing begins. One area which has generated some interest for removing aircraft noise has been the area of speech enhancement. Some of the problems with these techniques have been high spectral distortion, limited noise adaptation, and distortion characteristics that vary with input signal noise level and spectral shape.

Rome Air Development Center (RADC) has been developing speech enhancement technology to improve the quality and intelligibility of speech signals that are masked and interfered with by communication channel noise. RADC's interest in speech enhancement is not only in improving the quality and intelligibility of speech signals for human listening and understanding but to improve spee ' signals for machine processing as well. Speech technology such as speaker identification and keyword recognition being developed by RADC requires good quality signals in order to provide effective results. The development of automatic real-time speech enhancement technology is therefore of high interest to RADC for this technology is required to improve the quality of degraded speech signals to an acceptable level for these systems.

Exploratory development work at RADC has led to the development of an Advanced Developmental Model enhancer called the Speech Enhancement Unit (SEU). This unit, which uses a high speed digital array processor in conjunction with time, frequency and root-cepstral algorithms, provides an on-line, real-time capability to remove frequently encountered communication channel interferences with minimum degradation to the speech signals. The types of interferences or noises removed can be classed into three groups; (1) impulse noises such as static and ignition noise, (2) narrowband noise which includes all tone-like noises, and (3) wideband random noise such as atmospheric and receiver electronic noises. Tests have shown that the SEU can reduce all of these types of noises simultaneously while improving both the quality and the intelligibility of the speech signal. The capability to remove both narrowband and wideband random noise without degrading the quality of the speech signal may make these speech enhancement techniques applicable to improving the performance of Automatic Speech Recognition (ASR) in the airborne environment. The SEU's ability to remove narrowband types of noises automatically and in real-time by as much as forty (40) decibels would allow the removal of such aircraft noises as power converter hums, periodic aircraft vibrational noises, aircraft compressor noises, and other rotational noises associated with the engine. Since the noise removal process causes little distortion to the speech signal and removes a minimum amount of the speech signal, this spectral noise removal process should remove all narrowband noises without having detrimental effects on the recognition accuracy of the ASR system.

The SEU's ability to remove wideband random noise automatically and in real-time may allow the removal of much of the unstationary noise generated by the aircraft. The wideband noise removal process is a root-cepstral process that can improve the signal-to-noise ratio of noisy communication channels as much as 12 to 14 decibels. An improvement of this amount in the signal received at the input of an ASR system could improve the performance of an ASR system vastly.

The wideband noise removal process used is a subtractive process that is accomplished in the spectrum of the square root of the amplitude spectrum. While this function is not the same as the cepstrum (the cepstrum is the spectrum of the log amplitude spectrum) since it resembles the cepstrum it is referred to as the root-cepstrum. In this method of noise reduction the average root-cepstrum of the noise in the input signal is continually updated and subtracted from the root-cepstrum of the combined speech and noise. Because the random noise concentrates disproportionately more power in the low region of the root-cepstrum than does the speech, the subtracted reconstructed time signal produces an enhanced speech signal.

There are two reasons why this technique of wideband noise removal is encouraging for the successful removal of aircraft noise for ASR. First the noise removal technique used is independent of the spectral shape of the noise. This indicates that the enhancement unit should theoretically adjust to the aircraft noise. The second encouraging reason is that the enhancement transformation used, unlike the spectral subtraction methods which can cause high distortion, causes very little distortion to the speech signal which is important to the recognition accuracy of any ASR equipment.

The SEU's capability to reduce narrowband and wideband noise without causing distortion that is detrimental to the human listener appears to indicate that the speech enhancement techniques used may improve the recognition accuracy of ASR equipment that must function in the noisy airborne environment. For this reason RADC is planning a series of carefully controlled tests to take place this spring. The tests, which will utilize two commercially available speech recognizers and the SEU, will determine what the effects of various types of noise are for these recognizers and what effect the SEU has on the recognition accuracy of these ASR systems for training with and without the enhancer.

2.2 Performance Measurement

For any speech recognition device to be useful for an airborne application, it must have very good accuracy. With the advent of many commercial speech recognition devices, how does the system manager make the selection for the particular airborne application? The current performance measure of most recognition devices is expressed in terms of percent accuracy.

This performance measure may be meaningful to some commercial vendors, but does not imply how well an ASR system will work for a particular military application. For this reason, the use of a standardized, universally accepted performance measure is important in providing a common basis for comparing results of different speech recognition devices operating with different vocabularies. The following discussion shall focus on developing a meaningful performance measure that can be used as a figure of merit for comparing speech recognition devices.

The recognition accuracy or alternatively the probability of error has a number of difficulties for use as a figure of merit for discrete-utterance speech recognition. The major problems with using total probability of error are: (1) the inability to deal with utterances not in the vocabulary; (2) the inability to handle word boundary violations; (3) the failure to deal with insertions or false detection of non-existent utterances; (4) the failure to incorporate the distribution of errors across all vocabulary items; and (5) the dependency on the decision-rule used and the input probability density. To amplify on point (5), it must be realized that the decision rule should be one which minimizes the total error. However, this minimization cannot be done without knowledge of how often each vocabulary item occurs. This data is often omitted or it is just assumed all vocabulary items are equally likely. It is desirable for the decision-rule and input probability density to be explicitly incorporated in the measure of performance.

Having shown why a performance measure like total probability of error is inadequate, it is proposed that a measure based on information theory be used. A brief introduction of terms will be presented, which will be followed by a synopsis of other performance measures based on information-theoretic concepts, and finally a new performance measure will be described.

A generalized communications model can be viewed in the following way:

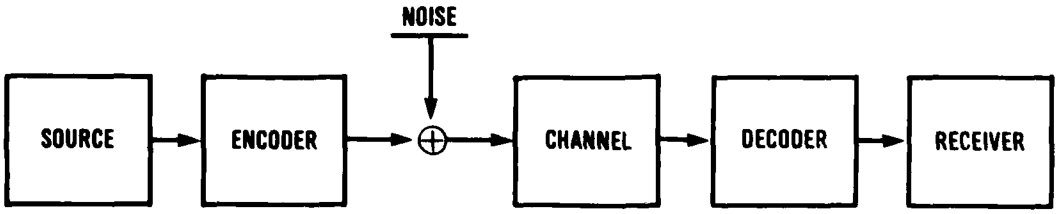


FIG. 1 GENERAL COMMUNICATIONS SYSTEM

A message is generated by a source, encoded, sent through a communications channel (which may be corrupted by noise), decoded, and observed by a receiver. This model can be applied to a discrete-utterance automatic speech recognition (ASR) device as shown below:

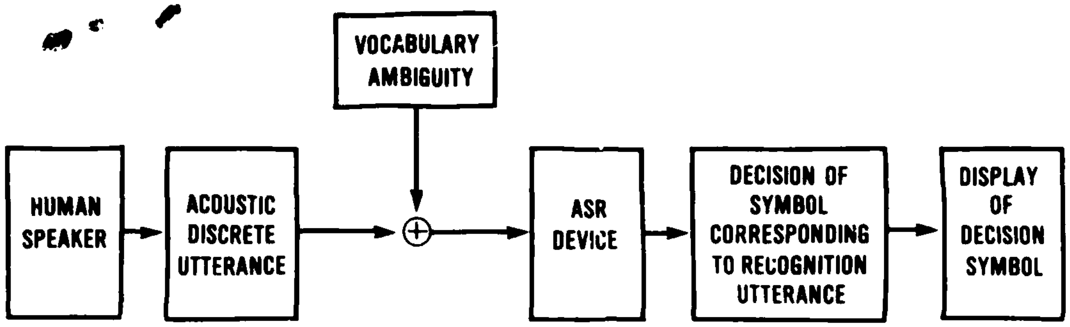


FIG. 2 ASR SYSTEM AS A COMMUNICATIONS PROCESS

As shown, a human speaks a sequence of discrete utterances, which have a certain ambiguity associated with them, into an ASR device, which decides which utterance was spoken and displays the decision. Effectively, an input acoustic utterance X_i is input into an ASR device which then outputs a certain symbol Y_j.

We now define an input vocabulary by the set $(\mathbf{X})$ which consists of the elements $(X_1, X_2, X_3 \ldots X_i \ldots X_n)$. In many speech recognition experiments, it is assumed all utterances are equally likely to be spoken or:

$$P\,(X_i) = \frac{1}{n} \text{ for all } i.$$

The entropy H (x) is now introduced and is defined by:

$$H(x) = -\sum_{i=1}^{n} P(X_i) \log_2 P(X_i) \text{ bits/utterance}$$

and for the special case where all utterances are equally likely:

$$H(x) = \log_2 n \quad \text{bits/utterance}$$

To provide an example of what this means in terms of vocabulary size, suppose a vocabulary has 1024 utterances, then the entropy is: $H\,(x) = \log_2 1024 = 10$ bits/utterance. Generally, the higher the entropy, the harder the recognition task, not considering possible ambiguities.

The forward entropy H (X/Y), or equivocation is a measure of the amount of information lost in a communication channel. This is defined in terms of output probabilities $P(Y_j)$, and conditional probabilities $P\,(X_i/Y_j)$, the measure of likelihood that utterance X_i was spoken given that the symbol corresponding to utterance Y_j was recognized.

$$H\,(X/Y) = \sum_{i=1}^{n} \sum_{j=1}^{m} P\,(Y_j)\; P\,(X_i/Y_j)\; \log\; P\,(X_i/Y_j)$$

A quantity called mutual information denoted by I (X, Y) can be defined in terms of entropy and equivocation by:

$$I\,(X, Y) = H\,(X) - H\,(X/Y)$$

Mutual information can be thought of as the difference between the information sent and the information lost or as the information received at the ASR output.

The preceding definitions provide the basis for a review of information-theoretic concepts of several other performance measures. Gary Goodman (GOODMAN, G., 1976) used these concepts in developing models of lexical ambiguity or vocabulary difficulty. It was implied that these concepts could also be used for a device performance measure. Goodman based the performance on equivocation and called the quantity, $2^{H(X/Y)}$, the effective vocabulary size. Although equivocation incorporates explicitly the input probability density and the distribution of errors made in the channel, it does not, in itself, constitute a measure of device performance. This is because the amount of information lost in an ASR process is meaningful only when compared with the amount of information transmitted.

Martin Taylor (TAYLOR, M.M., 1980) proposed using concepts of information theory to evaluate ASR devices. Taylor suggested using a measure called "Effective Vocabulary Capability" to be used as a figure-of-merit. This quantity is defined as $2^{I(X,Y)}$. In theory, this quantity specifies the largest vocabulary size the device can recognize at any arbitrarily small error rate. This measure has the same limitations as Goodman's and, additionally, is dependent on an estimate of device error probability and does not seem to be generalized across vocabularies.

A group at IBM (JELINEK, F., et al, 1977) proposed using an entropy measure they call "perplexity" to correspond to vocabulary or task difficulty. This measure does not take into account acoustic ambiguity, only grammatical structure, so it is inappropriate to use as a measure of device performance.

A final performance measure to be discussed (but not based on information theory) has been proposed by Roger Moore (MOORE, R., 1979). Moore developed a model of human recognition performance that serves as a standard for the performance of an ASR device. The model is based on experimental data from human perceptual experiments and is used to predict human recognition performance for any vocabulary desired. Moore introduces a term called "Human Equivalent Noise Ratio (HENR)" which corresponds to a specific Signal Noise that a human would be operating under to obtain a specific recognition of a particular vocabulary. The HENR can be graphically demonstrated by the following:

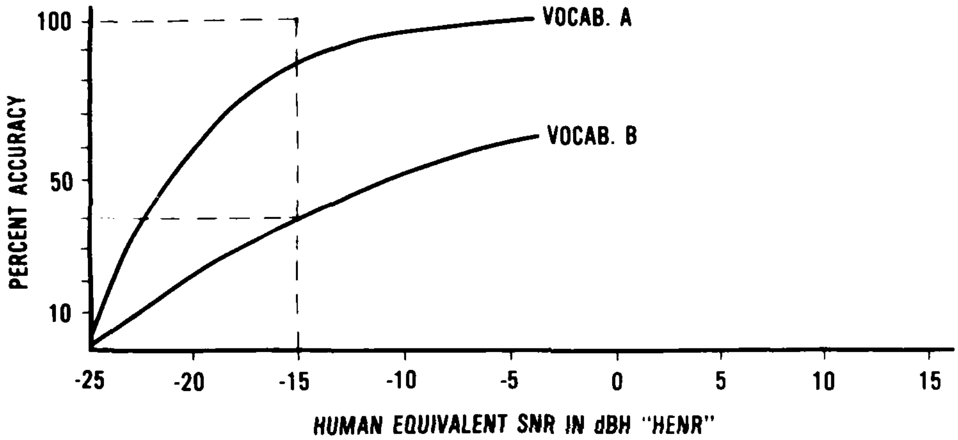


FIG. 3 OUTPUT OF MOORE'S MODEL OF HUMAN RECOGNITION

Curves like the above can be generated for any vocabulary by inserting different levels of noise and then noting the human recognition performance. The same type of test can be done using the accuracy obtained by an ASR device. Using Moore's model, different vocabularies can be compared for difficulty and any device may be compared with another by testing *each with only one* vocabulary. *The performance* measure which is used as a figure of merit is the HENR. The major problem with Moore's idea is the fact that device performance (and human perceptual performance) is measured initially in terms of recognition percentage and the problems associated with this have been already mentioned.

All the performance measures mentioned have been concerned with vocabulary difficulty, task difficulty or device goodness. These measures are not necessarily inappropriate for their intended use, but seem wrong to use as measures of device recognition performance for any given task; however, by using some of the above ideas and incorporating similar information-theoretic concepts, it is hoped to describe a meaningful device performance measure. A meaningful performance measure is one which specifies the amount of information lost in a recognition process relative to the amount of information transmitted. The ratio $2^{H(X/Y)}/2^{H(X)}$ specifies this relationship. An equally meaningful, but more convenient ratio is H (X/Y)/H (X) which is simply the ratio of equivocation to entropy. Its range is: $0 \leq \frac{H(X/Y)}{H(X)} \leq 1$

This ratio is easily interpreted as the proportion of information lost in the recognition process. Let H (X/Y)/H (X) be called the Relative Information Loss (RIL). A RIL-like measure has been used previously in speech communication research by Miller and Nicely (MILLER, G. and NICELY, R,, 1955) who concluded that the H (X/Y) probabilities must be obtained from a large number of samples to be unbiased. This RIL value would appear to be an appropriate measure of ASR device performance because it solves many of the problems already alluded to and, particularly, it can account for input probability densities and will incorporate error distributions across all vocabulary items. The RIL measure can take on values between 0 and 1 with lower values indicating better performance. Using the RIL as a measure of device performance will be a good indicator of performance for a certain vocabulary but will not be able to determine comparative performance when several devices are tested on different vocabularies. This is where Moore's HENR becomes important.

Suppose that in the process of human speech recognition experiments, human performance on a particular task was measured in terms of RIL instead of recognition percentage. A family of curves can be obtained using several vocabularies. This is depicted graphically in the following:

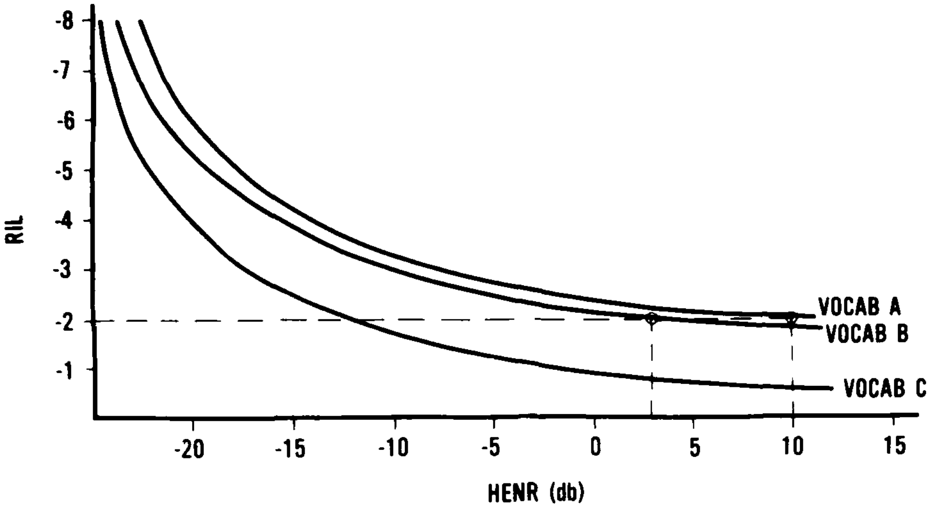


FIG. 4 MEASURE OF VOCABULARY DIFFICULTY USING RIL

The use of the combination of the RIL and HENR would work as follows. First, the confusion matrices derived from human recognition experiments would be used in Moore's model so that the outputs of the model are curves like that shown in Figure 4. Next comes device testing. A device to be evaluated is tested with any vocabulary and the performance is determined in terms of one RIL value. Referring to the family of curves previously derived from human recognition experiments, the HENR value is read off the curve corresponding to the vocabulary used for testing the device, at the value of RIL the device achieved. For example, (looking at Figure 4) assume a device achieved a RIL value of .2 for vocabulary A. The corresponding HENR value would be 10dB. This value remains constant for any vocabulary for a particular device. Another device is tested on Vocabulary B and achieves a RIL of .2. The corresponding HENR value is 3dB. The second device would be worse than the first because it had a lower HENR. This fact is proven by examining the RIL value it would have achieved at the same HENR for vocabulary A.

By combining the use of the RIL ratio to be used as a measure of how well a device performed on a particular task with Moore's HENR, a method of evaluating ASR device performance has been achieved. This evaluation requires only one test per device on any arbitrary vocabulary. Although Moore's HENR is an implicit measure of vocabulary difficulty, it is the explicit figure-of-merit to be used for comparing different devices. RIL is only a way of quantifying the results of recognition tasks, human or machine. This theory will be tested on several vocabularies such as the digits, the English alphabet and 26 arbitrary words to determine its usefulness as a real-world performance measure.

2.3 Narrowband Communication

There is, and has been, considerable interest in narrowing the bandwidth required for intelligible speech transmission in air-to-air and air-to-ground communication channels. This interest is spurred by crowded rf communication links, lower channel noise, increased jamming resistance, and cost advantages.

There are several ways currently used to reduce the bandwidth required for speech transmission. State-of-the-art voice transmission systems use waveform coding algorithms which digitize and quantize the speech signal efficiently. The bit stream sent to the receiver is then used to reconstruct an approximation to the original waveform. Most waveform coding methods for speech can be adapted for non-speech signals as well. Waveform coding includes methods such as Pulse Code Modulation (PCM) and its variations, Adaptive Predictive Coding (APC), Sub-Band Coding (SBC) and Adaptive Transform Coding (ATC). All of these methods substantially reduce the bandwidth for voice communications, but to achieve any rate less than about 5K bits/sec which is typical for waveform coding, other methods must be used.

Coders which reduce a voice bit rate to what is considered low (less than 5K bits/sec) are called vocoders. In vocoding, or analysis-synthesis coding, the bit stream sent to the receiver is used to construct a new waveform that approximates the original. The theory behind vocoding is that specific knowledge about how the speech signal was formed is quantified and used to parameterize the signal. Some systems which fall into this category are Channel Vocoders, Homomorphic Vocoders, and Linear Predictive Coding (LPC) Vocoders. In all of the above named vocoders, only the speech parameters are transmitted to the receiver instead of the digitized and coded waveform, thus reducing the bandwidth. A novel approach to reduce the bandwidth required to transmit speech is to use Automatic Speech Recognition (ASR) techniques. The application of such a system to narrowbandwidth speech communications is as follows:

The human speaks a word or phrase into the ASR system by use of a microphone. The ASR system makes a recognition on the word or phrase, but the word or phrase itself is not transmitted. Instead, a previously assigned code (number or character) is transmitted. The code transmitted corresponds to a location of a word or phrase (the same or different from that spoken) that has been stored previously such as on a digital magnetic disc located at the receiving terminal. The received code is then deciphered and the stored word or phrase is accessed from the disc, converted to an analog speech signal and outputted to a headphone. In this way, only a code representing a word or phrase need be transmitted over the channel and hence the channel bandwidth requirements are reduced substantially over those normally required for analog or digitally encoded speech.

Word recognition systems can reduce communication channel bandwidth to under 100 bits per second. Although this indicates tremendous advantages in communication technology, several limitations relating to present word recognition systems exist. Some of the limitations which must be considered when applying this technique are: (a) vocabulary size restrictions, (b) vocabulary composition restrictions, (c) word rate restrictions, (d) loss of speaker identity, (e) recognition errors, (f) word rejection errors, and (g) environmental noise restrictions.

In most applications these limitations may be traded off against one another. It is likely that vocabulary size and composition restrictions would not be critical as there are many operational communications protocols which could easily limit the number of words or phrases used, and although there are certain troublesome words which may be confused with other words in the vocabulary (such as "tower" and "power"), these words can be replaced with less acoustically similar synonyms. For applications where a very quick response is required, the word input rate or recognition could be a major problem. However, word input rates are increasing, and as continuous speech systems are developed, this problem can be minimized somewhat. Lack of speaker identity would certainly be a major limitation of any communication system using ASR as a front-end. This is because the words "spoken" at the receiving terminal have been previously recorded by any arbitrary speaker. Thus there is no way a listener knows what emotional inflections are in the message and unless there are other suitable means for obtaining the speaker's identity such as channel or frequency indicators, there is no way to know who is doing the talking. However, since the binary data representing a spoken word is in the digital domain, there are certain advantages that result. One is that the binary data can be encrypted. Another advantage is the excellent noise immunity that digitized data possesses. The result at the receiving end is digitized speech with a speech to noise ratio and intelligibility which is independent of the transmission channel.

Word recognition errors (where a word is misrecognized or substituted for another word) could be another major problem. This type of error may go unrecognized at the transmitting terminal, but could result in an unintended message at the receiving end. There are at least three safeguards against this type of error. The first is the use of "action" words at the transmitting end which initiate the actual transmission of a message. The use of action words allows an operator at the transmitting end the opportunity to check the ASR system's recognition for accuracy before the digital data is actually sent. He can easily correct any errors by the use of appropriate feedback (either audio or visual) and correction words. This process is slower than without the use of action words. The second safeguard is the use of syntax and semantics by the ASR system. A syntactic error such as the message, "Land the aircraft machine gun." would be flagged as an error because the use of "machine gun" at the end of the sentence is not syntactically correct. A semantic error such as, "Land the aircraft on the control tower." would be flagged as an error because although "control tower" is syntactically correct as used in the message, it is obviously not semantically correct. The third type of safeguard is the use of automatic error correction algorithms which can automatically detect ASR errors and correct them by the use of probabilistic data tables. The use of one or more safeguards would appear to limit most of the detrimental effects of word recognition errors.

Although most of the limitations in the use of ASR systems for narrowband ommunications have been touched upon, in many operational scenarios these limitations may be outweighed by some of the advantages of ASR. As one example, consider the anti-jam margin gained by the use of a tactical communications system using ASR for narrowband communications over normal analog voice. Assume bandwidths of 80Hz for the narrowband system and 3000 Hz for the analog voice system. The processing gain which is an indication of the anti-jam margin improvement is given by the equation:

$$PG = 10 \log \frac{Bwc}{Bwi}$$

where Bwc is the bandwidth of the channel and Bwi is the information bandwidth.

Thus the narrowband system can provide a 15.7 db improvement in anti-jam margin over the analog voice system.

RADC is looking at several other methods utilizing ASR technology for narrowband communication. One method uses a vector quantization approach. This approach has been successful at about 800 bps transmission rates and techniques to reduce the transmission rates are being explored. The vector quantization approach separates the articulatory mechanism into a number of finite LPC models. A dictionary of the models is stored, input speech is compared to the existing models and a match is obtained. A code is stored for this particular model and this code is transmitted to the synthesis end. A synthesizer (based on the model dictionary) reconstructs the message for playback to the listener.

A second method involves isolated word recognition technology. A laboratory system based on this technology has proven to be successful at transmission rates of about 400 bps. Isolated words are recognized by an ASR device and again, a code is assigned to the word based on the number of allowable vocabulary choices. This code is transmitted along with pitch, gain, and time warping information to the synthesis end. Here, a synthesis-by-rule program is used to reconstruct the message.

A third method uses a phonemic recognition approach to automatically recognize input speech. Because of the limited number of phonemes in the English language, phonemes can be coded in a very few bits. Theoretically, phonemes can be coded with as few as 6 bits. With an average phoneme rate of about 12 per second, it is possible to transmit the speech at 6 x 12 or 72 bits per second. However, phonemic recognition is a very difficult problem and real-time operation is currently beyond the state-of-the-art. Therefore, this approach will require much more research before system implementation.

In summary, it can be seen that word recognition devices can be used to narrow the bandwidth of voice communication systems. The degree to which the bandwidth can be narrowed is dependent on the vocabulary size and the input word rate, both of which are dependent on the application. Whether these techniques can apply to a particular voice communication system is highly dependent on the communication system's function and on the ability of the ASR system to operate ccurately in the environment. The use of ASR for narrowband communications in the airborne environment is therefore dependent to a large extent on the ability of the ASR device to perform accurately in the harsh airborne environment.

3. CONCLUSION.

The use of Automatic Speech Recognition for control of airborne functions, to query avionic systems, and for narrowband air-to-air and air-to-ground communications is operationally highly desirable. However, there are several problems associated with the implementation of ASR in the operational environment. One such problem is that of the noisy environment and its effect on ASR performance. RADC is interested in determining if the speech enhancement technology developed for removing noise and interference contained on voice communication channels can be applied to removing the noise encountered in various other environments. The use of this enhancement technology for removing a variety of noises for ASR devices appears to be promising. For this reason a series of tests is being planned and will be conducted this spring to determine if the speech enhancement techniques developed will improve the performance of several commercial ASR devices in noisy environments.

The use of ASR technology to provide a narrowband communications capability is currently of high interest. Although there are several current problems with utilizing ASR in various environments, several ASR technologies are promising to provide rates of less than 400 bits per second.

Current measurement techniques are of little value in determining the performance of ASR devices in particular applications. A performance measure is needed so that ASR technology can be compared and ASR devices selected for various military and commercial applications. A theoretical measurement method based on information theory has been presented that may provide a meaningful ASR measure useful for predicting the performance of a particular ASR device for a given application.

4. REFERENCES

GOODMAN, G., 1976, "Analysis of Languages for Man-Machine Voice Communications," Ph.D. dissertation, Carnegie-Mellon University.

JELINEK, F., et al., 1977, "Perplexity, A Measure of Difficulty of Speech Recognition Tasks," Journal of the Acoustical Society of America, 62, supp. 1.

MILLER, G. and NICELY, R., 1955, "An Analysis of Perceptual Confusions Among Some English Consonants," Journal of the Acoustical Society of America, 27, no. 2.

MOORE, R., 1979, "Evaluating Speech Recognizers," White Paper, Dept of Elec. Engineering", University of Essex, England.

TAYLOR, M.M., 1980, "Issues in the Evaluation of Speech Recognition Systems," Second Draft of NATO AC 243 (Panel III/RSG 10) Report.

WEISS, M. and ASCHKENASY, E., 1978, "The Speech Enhancement Advanced Development Model", RADC Technical Report Number TR-78-232

WEISS, M. and ASCHKENASY, E., 1981, "Wideband Speech Enhancement Addition," RADC Technical Report Number TR-81-53

DIRECT VOICE INPUT FOR THE COCKPIT ENVIRONMENT

Ronald Bell
Martin E Bennett
William E Brown

Flight Automation Research Laboratory
Marconi Avionics Limited
Rochester, Kent ME1 2XX
United Kingdom

SUMMARY

This paper discusses the many aspects of applying speech recognition technology in aircraft cockpits.

Centralised input media of this type affect the structure of the whole avionics suite because of the need for interconnection with many controlled subsystems and the necessity of high integrity operation. Section 2 reviews the implications of Direct Voice Input (DVI) system integration. Section 3 deals with the requirements for a speech recognition system applicable to the cockpit environment; in particular the problem of noise is discussed and the need for flight trials highlighted.

Any equipment used in the cockpit relies on its acceptability to the pilot for success. The 'pilot interface' presents many questions and is the subject of Section 4.

Finally, Marconi Avionics' involvement in the study of Direct Voice Input is detailed in Section 5, with an outline of the current programme of work.

1. INTRODUCTION

Modern military pilots are faced with an unprecedented visual and manual workload because of the need to fly fast, agile aircraft to the limits of their performance envelopes and simultaneously manage complex avionic suites. This problem has been compounded in recent years by the drive towards all-weather capability, which has required more sophisticated guidance and flight management equipment, and air-superiority which requires increased manoeuvrability and has subsequently led to a predominance of single seat aircraft and to the reclining of seats. On the one hand more cockpit real-estate is necessary for systems management and on the other less is available within easy reach of the primary flight controls. Another factor of note is that at times of confrontation the pilot's desire is to have hands on throttle and stick (HOTAS) and eyes out of the canopy, detracting from his ability to make full use of his target tracking, countermeasures and weapons-management systems. Head-up and helmet-mounted displays have provided the means of feeding information to the pilot whilst 'eyes out', what is now needed is a medium for systems operation that does not require manual or visual attention.

Direct Voice Input (DVI) would appear to offer a solution to this problem for a number of reasons. Primarily, speech allows the entry of commands or data independent of hand and eye activity; indeed, since the co-tasking capabilities of the brain are more efficiently utilised when different faculties are employed, the degradation of the primary task is minimal. Further, a DVI system requires no cockpit real-estate itself and, since it provides a centralised input medium, will relegate many system controls to a reversionary, and therefore less critical, role.

This paper discusses the implications of using DVI in an aircraft, the current capabilities of speech recognition equipment and how DVI will affect pilot activity.

2. IMPACT OF DVI ON THE COCKPIT

DVI technology provides a centralised data-entry/mode-control medium which if incorporated in an aircraft cockpit has major ergonomic and avionics-package implications. It must be stressed that DVI is not an 'add-on' avionics package to increase aircraft performance but that its inclusion has many repercussions throughout the whole cockpit, influencing both design philosophy and physical implementation.

A prerequisite for the use of DVI or any other centralised input medium (CIM), such as multi-function keyboards, is that it maintains the high standard of reliability and integrity currently provided by existing discrete switches and controls. There are several aspects to this, some of which are peculiar to CIMs.

Of principal consideration in integrating a DVI unit with an avionics suite is the interconnection between it and the many subsystems under control. Centralised avionic bus structures, such as Mil Std 1553B, permit access to major avionics packages, such as a radio channel controllers and display format generators, for bi-directional information transfer, and will ensure that the reliability and integrity requirements are met and that equipment interconnection is manageable.

The question of speech recogniser performance, and especially matching decision accuracy, is an important one to the suitability of such equipment for aircraft use. Preliminary tests have shown (LAYCOCK, J., PECKHAM, J.B ..., 1980; NORTH, R.A., et al ... 1980) that voice data entry is comparable or superior, in terms of speed of data entry, accuracy and level of primary task degradation, to multifunction keyboards, even for recognisers of average performance. Errors that do occur are of two types: mis-recognition or non-recognition of an utterance, and coping with these is chiefly a matter of procedure and is dependent on the nature of the system under control. A later section (Section 4) discusses this topic in more detail.

An aspect of particular importance is that of equipment reliability. A failure of the DVI equipment must not prevent the successful completion of a mission and it is therefore essential that reversionary controls are available to the pilot. Here, compatibility is the major concern and certain restrictions are apparent. The alternative media must not be of the type where physical position indicates system status, for example toggle switches and rotary selectors with legends would not be compatible. Careful choice of controls can permit a fully compatible control suite to be implemented. Discrete two positional (e.g. ON/OFF) switches could be of the non-latching, push button type where current status is indicated by either an internal or adjacent lamp. Rotary selectors would be required to be continuously rotatable and to have an associated display which changes to indicate the new status whenever the control is moved. An alternative centralised input medium such as a multi-function keyboard would be an ideal reversionary input device since this would interface directly with the avionics bus and hence perform a comparable task to that of DVI.

Reporting the execution of commands is another factor affected by integrity considerations. It is a fundamental requirement that feedback of system activation or status change comes from the unit under control and not from the DVI system. Other issues further influence the type and location of the feedback though these are concerned more with pilot ergonomics than system integration and are therefore discussed in Section 4.

In summary then, the integration of Direct Voice Input technology with an avionics suite is not a task that can be approached in an ad-hoc fashion but one that requires careful consideration of numerous aspects if the integrity of system control is to be maintained.

3. AUTOMATIC SPEECH RECOGNITION (ASR) TECHNOLOGY

The combat aircraft environment is a particularly demanding one for a speech recognition system, not only because of acoustic noise but also due to the physical and mental stresses on the pilot which can affect his voice in unpredictable ways. The majority of work on the use of DVI in the cockpit has centred around obtaining tape recordings during several phases of flight and using the recordings as an indicator of voice pattern changes and to test various available recognisers. Because of the lack of interaction between pilot and machine, however, the recorded utterances are not truly representative of the type the recogniser would receive in use. Consequently it is essential for recognition systems to be developed that are suitable for flight trials; in this way their viability can be properly assessed and the ergonomics of their use and integration investigated.

There are several requirements that a recogniser should fulfil to be of use in this application. Primarily, since the objective is to reduce pilot workload, he must be allowed to speak as naturally as possible. Thus, as commands will typically be of several words, a connected-word capability is essential, particularly where speed of response is critical. Also, the vocabulary size must be sufficient to allow many systems to be controlled without the pilot having to use an obscure coded message. Here we can make use of the fact that pilots are used to, and under stress will revert to using a structured command language in communication with the ground or co-pilot; this type of interaction is incorporated into a system by the use of a syntax which represents all the valid word sequences that constitute commands to the DVI system. In speech recognisers the syntax description is used to limit the number of words being looked for to those which are valid at that point in a command. For example, in tuning a radio to a specific frequency the recogniser would look for the key-word 'RADIO' and would then expect a sequence of digits within the range of valid frequencies; having recognised 'RADIO', therefore, there is no reward in looking to see if NAV-FUNCTION alternatives have been said. Such 'active vocabulary limiting' provides performance advantages over testing for all words at all times.

A connected-word recogniser of large vocabulary guided by a fully user-definable syntax represents the state-of-the-art in commercial speech recognition systems, but, for airborne applications such equipment must also have capabilities beyond anything yet produced.

The area presenting most problems is that of noise, in which are considered all aspects of the environment that affect the acoustic signal. Combat aircraft display very high levels of ambient noise, both of a 'structured' nature due to machinery and 'white' due to air turbulence. In each case this noise tends to be steady state, or at worst slowly varying, and current signal processing techniques can cope with these to a large extent. Coupled with these sources we have, in aeroplanes, to consider the effects of face masks and their oxygen system. The mask itself produces a combination of effects: firstly it acts as a resonant chamber, principally in the region of the third and higher formants; secondly as a filter and, thirdly, it restricts the jaw movement of the pilot and prevents proper articulation of some allophones. These effects might seriously limit a system based on the preliminary segmentation of an utterance into phonemes. Where this is not done the effects are largely negated by training the recognition system with the face mask worn. The oxygen system produces two types of noise: breath noise from turbulence inside the mask and 'clicks' from valve components. As the 'clicks' are of very short duration their influence on the comparison of a complete utterance is minimal. In the case of breath noise, current signal processing techniques cannot cope completely with the problem and account has to be taken in the recognition strategy of its effects.

It cannot be claimed that all the problems of cockpit noise have been solved, but sufficient is known to produce a recogniser robust enough in the presence of noise for preliminary flight trials to reveal any further aspects that need to be accounted for.

The environmental problems affecting the pilots of combat aircraft are less understood for their effects on speech; hence this too is an area where flight trials are necessary to show the full influence of high workload, fluctuating G-levels, buffeting and vibration (in helicopters particularly) on the pilot's ability to communicate orally.

An experimental flightworthy DVI system to meet the above requirements is currently being developed by Marconi Avionics under contract to the Ministry of Defence/Department of Industry. This equipment is further detailed in Section 5.

4. DVI AND THE PILOT

Before contemplating the serious use of such a new technology in a military aircraft it is essential to ensure that proper consideration has been given to how the DVI system will be integrated with the pilot. Indeed, it is probably true to say that such considerations will be the key to success. The five main areas of the 'pilot interface' that relate to DVI system design are: the ergonomics of use, operational feedback, pilot and system training, reversionary controls and the acceptability of the new technology. Each is discussed, in turn, below.

Ideally the pilot should be able to issue verbal commands to the system in the same manner as he would to a second crew member. However, practical limitations prohibit such freedom and certain constraints have to be accepted.

An efficient artificial grammar has been developed over many years for radiotelephonic use and hence flight crew are familiar with such procedures. Thus, provided that the DVI system is resilient towards the short pauses and unsolicited sounds which occur in free flowing speech, the application of artificial grammar does not constitute a significant restriction. A similar argument exists for the choice of vocabulary words where again radiotelephonic communication has done much towards alleviating the problems of language redundancy. In general, undesirable vocabulary words are easily identified by the rule of thumb that if the words cause confusion to a human listener then they are unlikely to yield high DVI recognition performance. However, given that the words do not sound confusing and that feedback compatibility is maintained then there is no reason why a particular pilot should not use a vocabulary and grammar of his own choice.

A subject of concern among potential users is the possibility that DVI could reduce the executive authority of the pilot. This would obviously be undesirable and in order to avoid such problems a number of factors of DVI operation must be considered. The two most significant aspects are as follows.

Firstly, there must be no ambiguity as to whether an utterance is intended as a command to the DVI system or not. Therefore until verbal switch-on techniques have been thoroughly investigated and shown to be reliable it is desirable to have a "press-to-talk" (PTT) switch so that the DVI system ignores all utterances made when this switch is not depressed.

Secondly, consideration has to be given to when command execution may proceed. For low integrity, non-critical systems the authorisation to execute may be implicit in the command phrase but for high integrity operations the pilot may wish to verify that his command has been properly interpreted before giving his permission to continue, in the form of an executive control word such as "EXECUTE" or "ENTER". At all times it is essential that the pilot has a facility to abort a command which is in error or is no longer appropriate. This is possible through the use of a permanently active control word such as "RESET" or by releasing the PTT switch before the command has been completed.

Any system which involves data entry and/or mode control must provide adequate feedback of command execution and system status to the operator. Since the prime motivation behind avionic DVI systems is to reduce pilot workload and permit him to control his avionic systems while flying head-up and HOTAS, it is important that the system feedback design is in keeping with these objectives. As can be seen from the system block diagram of Figure 2, suitable feedback media exist in the form of the Head Up Display (HUD) and Helmet Mounted Display (HMD) for long term visual feedback and from a speech synthesis device for short term audible feedback. Feedback design is therefore concerned with ensuring that these facilities are used in a manner which provides maximum assistance to the pilot.

In general, under the high cockpit workload conditions the feedback must be a clear confirmation that the requested action has taken place. Hence to tune the radio to channel number five for example, the pilot might say "SELECT STUD FIVE", stud being a military channel designator. In response to this the pilot would expect to see or hear "STUD FIVE SELECTED". To inform him that he has asked for channel five to be selected is of little assistance in such a task and is unnecessarily time-consuming.

The choice between visual and aural feedback is largely dependent upon the system being controlled and the mission phase and should be made with due regard to the following points.

i) The length and complexity of the message
ii) Whether or not there is a need to retain the information for later reference
iii) Is there a possibility of information clutter?
iv) Does the information relate to events in time or continuously changing data?
and v) Load distribution among the pilots' senses.

In many cases inherent feedback is available, for example when changing a display format, and beneficial redundancy can be obtained by using visual and aural feedback together. It is of course essential for integrity that the feedback information is obtained from the system being controlled and not directly from the DVI system.

The design of feedback for command abortion and error recovery warrants particular attention to ensure that concise and helpful information is provided. The system must leave the pilot in no doubt as to the current status of command servicing but, at the same time, must not supply nuisance information. For error recovery, experience gained from radiotelephone practice can again be used to benefit. In general, the most useful information to the pilot is that which tells him either that his command has been properly serviced or that the command should be repeated. Initial studies indicate that more sophisticated procedures rapidly become so complex as to be totally impractical.

The inclusion of DVI into the cockpit has training implications on both the pilot and the DVI system itself. These will be discussed in turn.

Since speech is a natural communication channel, pilot training requirements should be minimal if a DVI system with the capabilities previously outlined is employed. Essentially such training will consist of a familiarisation period during which the pilot can become accustomed to having DVI control available and hence learn to speak naturally to it. Except in single seat aircraft care will of course have to be taken to ensure that no inter-crew confusion arises as to whether a verbal command is directed at the DVI system or another crew member. One possible solution is to assign a name to the DVI unit and prefix all DVI commands with that name.

An area of potential hazard in using DVI is the possibility that the pilot may become overdependent upon it to the detriment of his ability to use effectively the reversionary controls. Evidence gathered from recent flight-deck system failures in civil aircraft indicates that some less experienced flight crew can have difficulty when forced to revert to fundamental flying skills. Pilot training must ensure that this problem does not arise.

In order to deal adequately with international and regional speech variations (as well as different languages) the DVI system must be loaded with representative vocabulary word templates which characterise the speaker. This requirement should present little operational inconvenience since modern technology permits compact, non-volatile storage of such information in the form of, for example, cassette tape, read only or bubble memory. Before flight the data can therefore be loaded in a similar manner to that used for mission and stores management information.

The process of DVI system training involves obtaining representative template data from sample utterances made by the speaker. There is however an obstacle that currently prevents the acquisition of the quintessential template.

The problem is that it is not possible to extract from free flowing speech that section which corresponds to the word it is desired to train; therefore the template must be derived from an isolated utterance. A word spoken in isolation is uncharacteristic because of two factors; one linguistic and the other ergonomic. Coarticulation (the 'blurring' of the phonemes at the junction of two spoken words) alters the allophonic content of a word depending on the context in which it is said and speaking a word in isolation, out of context and with no feedback, is unnatural, not to say tedious, if several examples of many words are required.

A possible compromise solution is to train on isolated utterances, giving consideration to the human factors aspects, and then to adapt the initial template by learning the various pronunciations during use. A considerable amount of current research is addressing such possibilities but this work is still relatively immature and will be unsuitable for avionic applications until it has been proved to be both efficient and reliable. In the mean time a significant amount of study as part of a flight trials programme is required to establish how involved the training procedures need be. That is, to determine whether sample utterances need to be obtained from a pilot situated in a well simulated, or indeed real, airborne environment who is under the impression that he is using the DVI system or if it is sufficient for him to sit in his cockpit and speak the vocabulary words while the aircraft is in the hangar.

Since DVI will be used as a centralised data entry and mode control facility it is essential that adequate reversionary controls are provided. As previously mentioned such controls must be both ergonomically and instrumentationally compatible with DVI. In order to avoid possible pilot confusion it is important that system effects and resulting feedback are identical irrespective of whether verbal or manual commands are used. There are also advantages to be had from making the verbal and manual operational procedures as similar as possible so that the pilot does not have to remember complex alternatives

The concept of DVI in the cockpit constitutes a major change in current procedures. It is therefore essential that pilots perceive the new equipment as being truly beneficial. To this end it is important that the DVI equipment is of high performance, is reliable and is easy to use. Any attempt to incorporate inferior equipment has a serious risk of merely generating aircrew scepticism towards the whole technology with very damaging effects.

Finally, it is important to ensure that DVI is applied in an appropriate manner and not regarded as a solution to all pilot problems; if the existing system is good then there is little justification for change. However, the current cockpit environment is such that there is no doubt that DVI is capable of simultaneously reducing pilot workload and increasing his effectiveness.

5. MARCONI AVIONICS INVOLVEMENT IN DVI

Marconi Avionics Limited have been actively involved in speech technology for the cockpit since the mid-1970's, when a two year contract jointly funded by the Ministry of Defence and the Company was awarded to the Flight Automation Research Laboratory (FARL) of Marconi Avionics to study the applicability of DVI to combat aircraft. During this contract a demonstration cockpit was constructed (see Figure 1) which allowed various speech recognition techniques to be examined and their relative performance levels assessed. This work confirmed the feasibility of DVI as a means of reducing pilot workload and improving cockpit ergonomics but also emphasised the need for equipment robust enough for use in real flight trials.

The above contract was completed in December 1979 and subsequently FARL has produced a design for a powerful DVI system with sufficient inherent flexibility to ensure that the required ergonomic and application studies can be carried out with ease in order that the full benefits of DVI technology may be exploited. This design draws upon the work of several UK research establishments and will represent the state-of-the-art in the field.

The current programme of work is committed to producing experimental flightworthy prototype equipment of such a standard that a proper flight trials programme may be carried out. The equipment performs connected-word recognition on a vocabulary of two hundred user defined words under the guidance of a fully user-programmable syntax. It will be produced initially in a 1-ATR sized box with interfaces to the aircraft audio network, programmable output and management of pilot/co-pilot switching. The unit is capable of hosting software for full integration with, for example, a Mil Std 1553B based avionics suite.

Current work is jointly funded by the Ministry of Defence, the Department of Industry and Marconi Avionics Limited with flight trials scheduled for early 1983 in the Royal Aircraft Establishment BAC1-11 aircraft at Bedford, England.

ACKNOWLEDGEMENTS

The authors wish to thank Marconi Avionics management for permission to publish this paper and the Ministry of Defence and Department of Industry for their support of the technical development of DVI within the Flight Automation Research Laboratory of Marconi Avionics Limited.

REFERENCES

LAYCOCK, J., PECKHAM, J.B., 1980
"Improved Piloting Performance whilst using Direct Voice Input",
Technical Report No: 80019, Royal Aircraft Establishment.

NORTH, R.A., MOUNTFORD, S.J., EDMAN, T , GUENTHER, K., 1980
"The use of voice entry as a possible means to reduce fighter pilot workload: a practical application of voice interactive systems". Proceedings of symposium: Voice Interactive

Systems: applications and payoffs, sponsored by: The Voice Technology for Systems Application Subgroup of The Department of Defense Human Factors Engineering Technical Advisory Group.

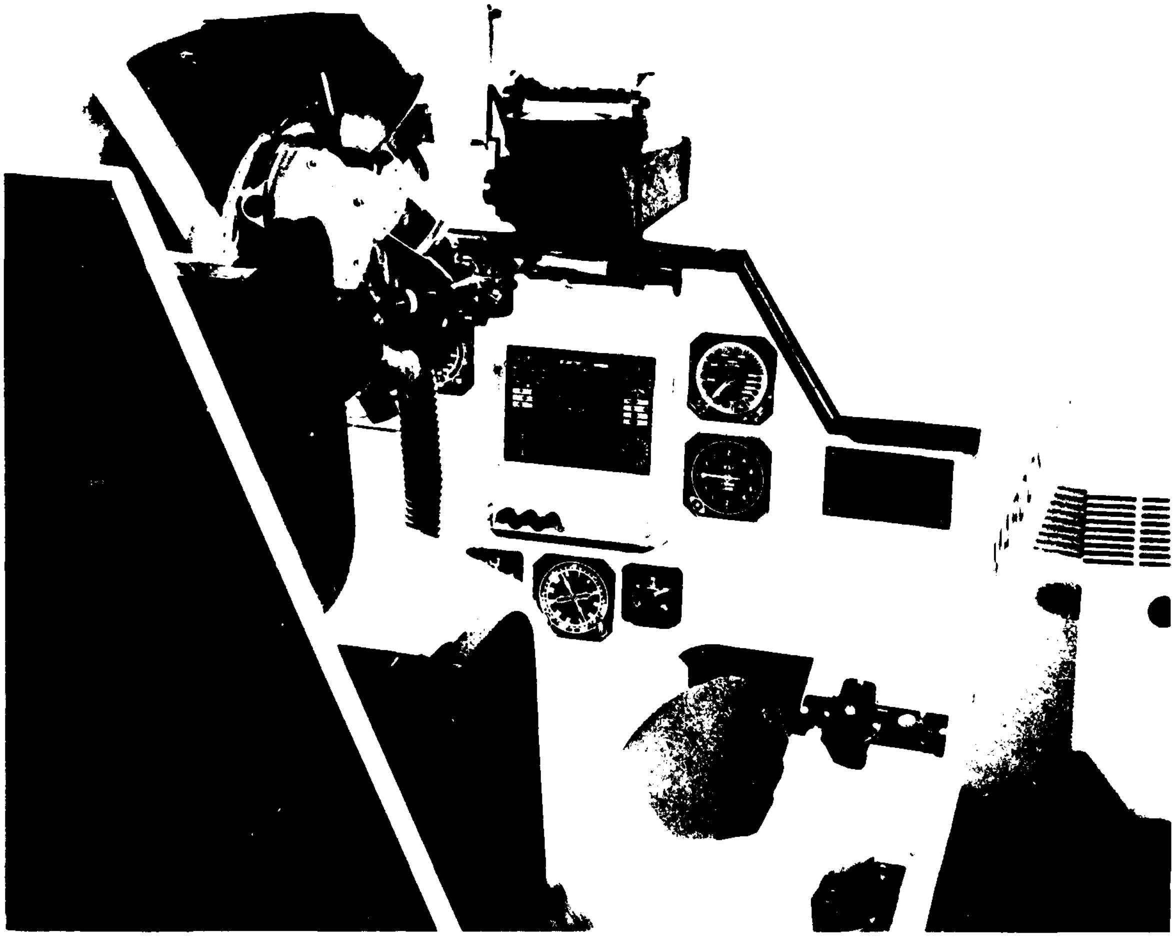


FIGURE 1. MARCONI AVIONICS DVI DEMONSTRATOR

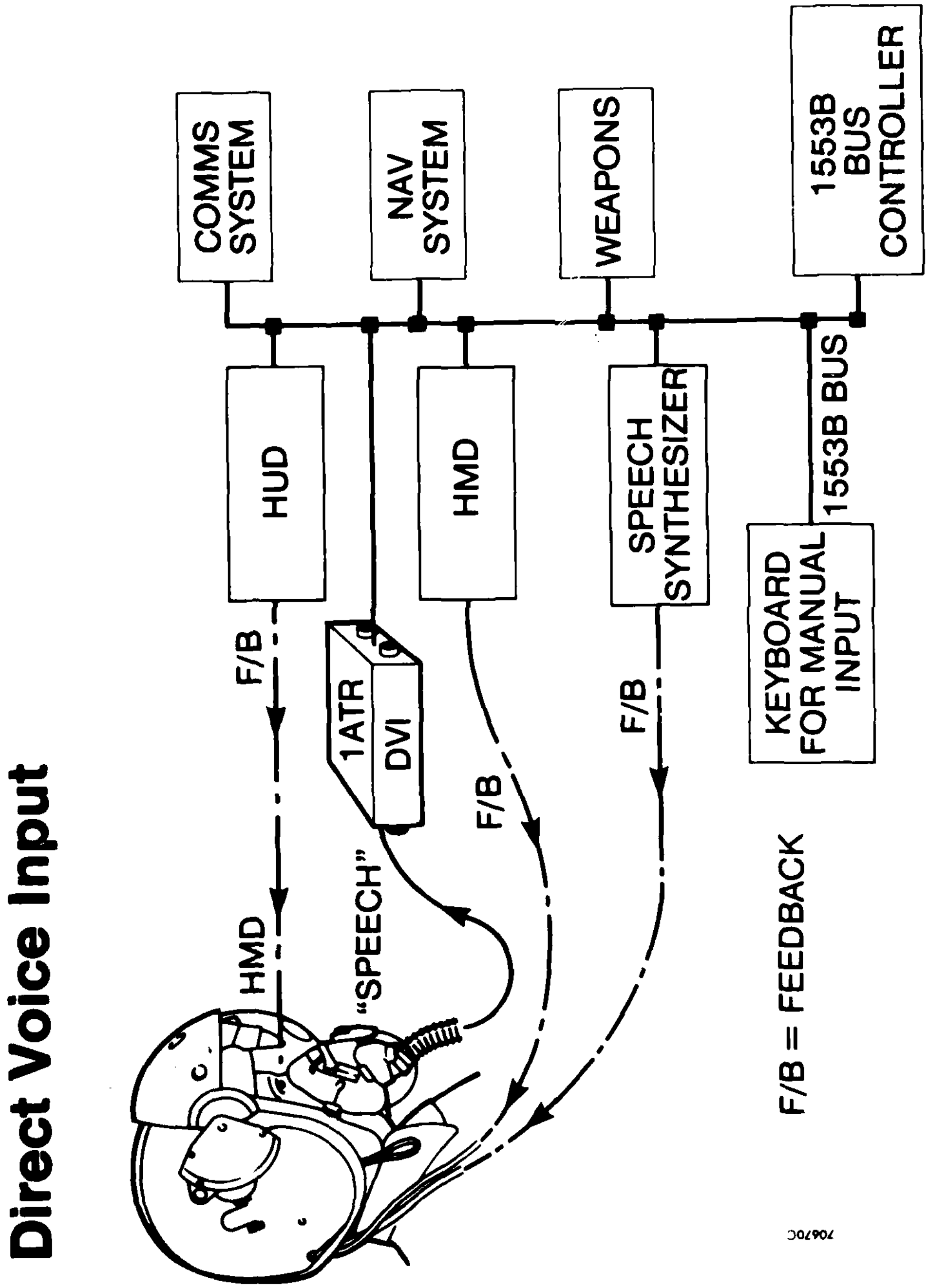


FIGURE 2. DVI SYSTEMS INTEGRATION VIA MIL-STD-1553B

VOICE INTERACTIVE SYSTEM DEVELOPMENT PROGRAM

DR. JOHN C. RUTH
GENERAL DYNAMICS CORPORATION
FORT WORTH, TEXAS

MR. A. M. GODWIN
GENERAL DYNAMICS CORPORATION
FORT WORTH, TEXAS

MR. ERIC B. WERKOWITZ
U.S. AIR FORCE FLIGHT DYNAMICS LABORATORY
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

SUMMARY

As avionic system complexity increases, the pilot of a single seat-fighter is challenged to simultaeously fly the airplane while operating the sophisticated offensive, defensive and communications equipment. The pilot must commit his eyes to achieve a head-up situation awareness and his hands to effectively control the aircraft. This paper addresses the use of Voice Interactive Systems (VIS) (based on computer recognition and voice synthesis technologies) as a method of achieving an enhanced interaction between the pilot and the weapon systems. To validate this concept, three fundamental questions are addressed:

1. Is the use of VIS really a viable alternative to the more traditional methods?
2. Assuming that VIS is viable, which functions best lend themselves to this approach and offer the highest payoff in terms of overall weapon system performance?
3. Can the voice recognition technology base be extended sufficiently to provide reliable operation in the stringent combat aircraft environment?

In cooperation with the United States Air Force and Navy, the General Dynamics Voice Interactive Systems Development Program provides a systematic approach to the evaluation of VIS functional concepts, technologies, human factors considerations and developmental hardware and software. Laboratory testing, integrated cockpit man-in-the-loop simulation testing and flight testing with appropriate analysis and evaluation are being accomplished to address the answers to the three fundamental questions.

1. INTRODUCTION

In recent years, the advent of digital systems coupled with advances in solid-state technology have made it possible to mechanize an increasing number of functions within a given space. Some of the principal beneficiaries of these developments have been space critical applications such as the modern attack aircraft. The typical aircraft of today embodies a wide variety of offensive and defensive capabilities. The achievement of these capabilities has not, however, been without penalty. The increases in avionic system complexity have also increased the burden upon the aircrew. In the case of the single-seat, high-performance fighter, this burden is approaching a critical level. Here the pilot must simultaneously fly the airplane and operate the offensive, defensive and communications equipment. For the most part, this burden falls upon his hands and his eyes. Scenarios arise where the tactical situation demands that the hands be kept on the control stick and the throttle with the eyes focused outside the cockpit, while the practical situation requires that one hand be used to operate avionic systems and that the pilot's focus continually be transitioned between inside and outside. These conflicting demands can affect both survivability and mission effectiveness. Indeed, there is currently a lively debate over whether some missions, such as low-level night attack are feasible for single-seat aircraft because of this problem.

The purpose of the Voice Interactive Program is to evaluate the use of computer voice recongition and synthesis technologies as an alternate method of achieving interaction between the pilot and the weapons systems. The ultimate goal is to off-load tasks from the pilot's hands and eyes to his voice and ears, thereby enabling him to exercise hands-on, head-up control of the airplane a higher percentage of the time, particularly during critical periods, while providing a means of simultaneously achieving positive control over avionic system operation and system status and information feedback. This verbal interaction between the pilot and the system is called Voice Interactive. The process of using verbal commands to control system functions is called Voice Command. It is predicated upon the use of computer-based voice recognition technology to identify and classify verbal commands and, subsequently, to initiate the appropriate system response.

On the surface, the concept of using computer voice recognition and synthesis technologies as an alternative combat aircraft command and control medium appears to be very promising. However, some key questions remain to be answered. These questions are as follows:

1) Is the use of voice interactive really a viable alternative to more traditional methods?

2) Assuming that voice interactive is a viable concept, which functions best lend themselves to this approach and offer the highest payoffs in terms of overall weapon system performance?

3) Can current state-of-the-art of voice recognition technology provide reliable operation in the stringent combat aircraft environment?

To address these key issues, an orderly, phased program was planned and is being conducted. This program has been divided into four distinct phases, each with a separate purpose. The initial phase, Phase 0, was dedicated to conducting two types of test in the laboratory: (1) perform man-in-the-loop tests in simulated cockpit environments to determine if the use of voiced commands is a viable concept, and (2) simulation of the flight environment to assist in voice recognition technology development and performance testing. Phase I of the program will be the initial flight test of a voice recognition unit that has been designed for airborne operation. The sole purpose of this phase is data collection on system performance to be used in further technology development. During Phase II, the emphasis will be on determining and flight testing specific functions for both voice command and voice synthesis. A study is currently being conducted to select those functions that appear to offer real payoffs in terms of survivability and overall weapon system performance. This phase will feature the first fully interactive voice system. The final phase, Phase III, will occur only if Phases I and II are successful. It would feature a full-scale engineering development of an airborne voice-interactive system and would include a one-year squadron level evaluation of voice interactive.

2. VOICE INTERACTIVE - A VIABLE ALTERNATIVE?

The question of whether or not a voice interactive system is a viable alternative method of avionic command and control should, more properly, be divided into three separate but related questions: (1) Is voiced system response a viable approach? (2) Is voice command a viable control method? and (3) Is an integrated combination of the two a viable concept?

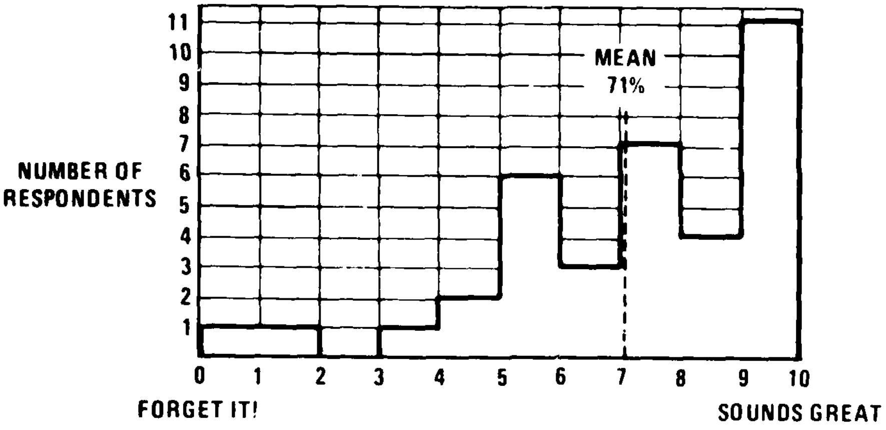
With regard to the first question, there is ample historical precedent for the use of voiced inputs from the avionic system to the pilot. Such diverse aircraft as the B-58 and the F-15 have featured voice warning systems and, more recently, a contract has been let to install such units on USAF F-4s. Also, a recent study conducted by General Dynamics resulted in a recommendation that a voice warning system be placed on the F-16. Another fairly recent development is a voice ground-proximity warning system that is currently being actively marketed for aircraft of all types. All of these systems to date have, however, been confined to the use of voice strictly to fulfill a warning function. Such useage does little to answer the question of whether voice response is a viable concept when used in a broader context. It has established the fact that the use of voice response is not dependent upon technological development as is the case with voice recognition. It has also established the fact that, within certain well-defined limitations voice response is indeed a viable apprach.

The question of whether or not voice command is a viable approach is a complex one. There are really two facets to this question. The first is the matter of pilot acceptance. Clearly, the time and effort put into the development of the technology would be wasted if the pilots refused to accept or use the capability provided. Accordingly, one of the efforts undertaken in the first year of this project was to conduct a pilot opinion survey. This survey surprisingly revealed that most respondees not only recognized the need for assistance in avionics control but were very receptive to the concept of using the voice for this purpose. A summary of the results of the survey are provided in Figure 1.

The second facet of the question of the viability of voice command is simply this: "Would it be an improvement over the methods currently employed?" If so, how much of an improvement? What are the payoffs in terms of overall pilot/weapon system performance? These questions are not easily answered. Analytical methods alone will not suffice. The resolution of these issues requires extensive test and analysis in the laboratory and in flight test.

In order to begin the process of providing answers, it was decided to conduct a series of tests in a realistic simulated flight environment. The facility used for this purpose was the Research and Engineering (R&E) Simulator. The R&E Simulator is a fixed-base flight simulation system that features a visual scene projected on a 24-foot dome. A cockpit mockup of any desired configuration can be operated within the dome. For this series of tests, the cockpit configuration used was that of the joint Air Force, Navy, NASA Advanced Fighter Technology Integrator Program AFTI/F-16 flight test airplane. The AFTI/F-16 cockpit features dual multipurpose displays (MPDs) that are used in a time-multiplexed fashion to exercise control over many of the avionic equipments and modes. These include the radar, radar homing and warning, electro-optical, stores management, and some flight control modes. The voice recognition system that was used was designed and manufactured by Lear Siegler Inc. (LSI). It was a breadboard version of a flightworthy system that is currently being developed by LSI under contract to General Dynamics for use on the AFTI/F-16. It was interfaced with the simulator via a MIL-STD-1553 multiplex data bus.

"HOW DO YOU FEEL ABOUT USING A VOICE COMMAND SYSTEM IN A HIGH PERFORMANCE MILITARY AIRCRAFT?"



- 36 TOTAL RESPONDENTS:
  - ✓ Military Pilots, 39% Current
  - ✓ 50% Had Combat Experience
  - ✓ Averaged 2910 Flight Hours

Figure 1 SUMMARY OF PILOT OPINION SURVEY

For this test series, voice command was utilized to control the dual multi-purpose CRT displays. The test subjects were all former military fighter pilots. An air-to-ground mission was selected as depicted in Figure 2. The data collected included flight parameters, flight control inputs, discrete events, video recordings of pilot actions, and subjective data from pilot questionnaires. The basic idea was to place the test subject in an essentially 100% workload situation and then to impose additional tasks upon him. On one run, these additional tasks would involve all manual actions and on the other run, some of these tasks could be accomplished using voice command. The relative distraction level of each approach could then be estimated by monitoring how well the test subject was able to perform his primary task while coping with the added tasks. In this case, the primary task was flying the airplane in formation in the manual terrain following/terrain avoidance mode, maintaining a 200 feet clearance over the terrain at an airspeed of 480 knots. The added tasks consisted of such things as responding to threats, evaluating system failure reports, and reconfiguring the ordnance selected for release. The measure of pilot performance on the primary task was obtained by monitoring altitude, heading and airspeed errors and control stick inputs. A Fast Fourier Transform was used to transform flight control inputs from the time domain into the frequency domain. A sample plot for one test subject where he was responding to a threat from an enemy aircraft is shown in Figure 3. The plot clearly shows that in this particular case, the pilot has more positive control over the aircraft where voice control was available than when only manual control was available.

Although simulator availability restricted the tests somewhat, we were able to get data from four test runs, two with voice control and two manual, for four test subjects. At the end of the runs, each test subject was asked to rate the two approaches to control from the standpoints of workload and overall effectiveness. A summary of workload ratings is provided in Table I where the number to the right of each set of ratings blocks is the average score. This subjective data indicates that the pilots generally thought that their workload was lower when they had voice control. A summary of the effectiveness ratings is provided in Table II. In this case, the pilot's opinion on overall effectiveness was not significantly in favor of either approach except for stores management where voice was favored. Most of the pilots commented at the end of the experiment that voice-commanded control allowed more time for instrument crosschecks during the terrain-following task and provided more head-up time for target acquisition and weapon delivery in the target area.

- **MISSION - NIGHT INTERDICTION**

MISSION PHASES

- ✓ Low Level Manual Terrain Avoidance Penetration
- ✓ Visual Weapon Delivery
- ✓ Target Egress

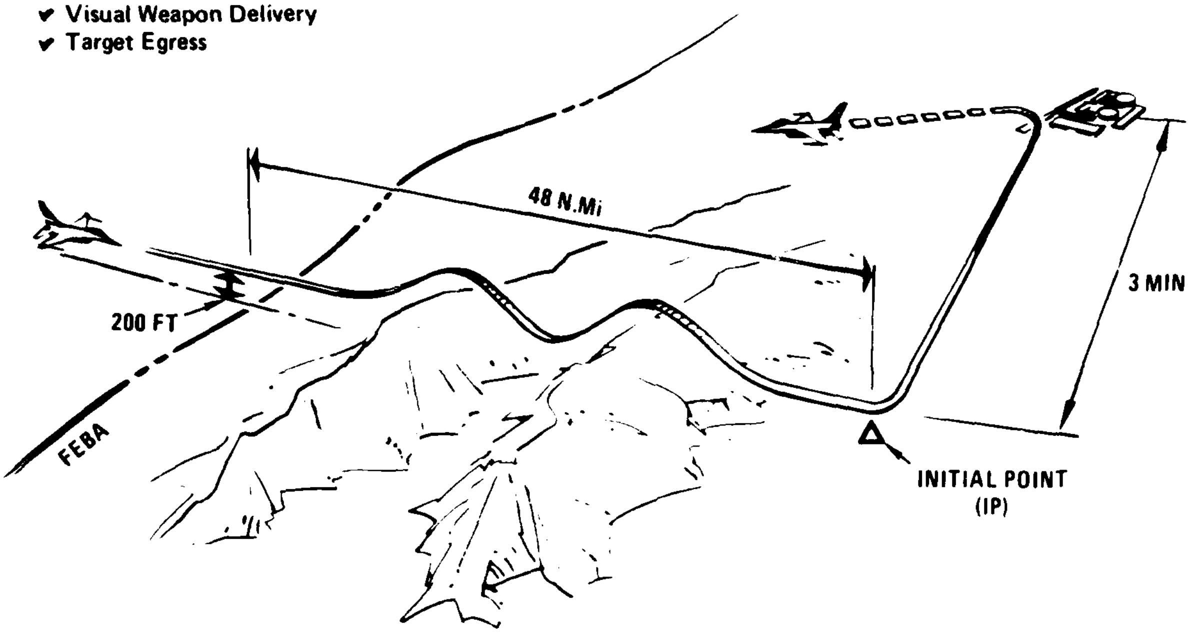


Figure 2 AIR-TO-GROUND MISSION SCENARIO USED FOR MAN-IN-THE-LOOP TESTS

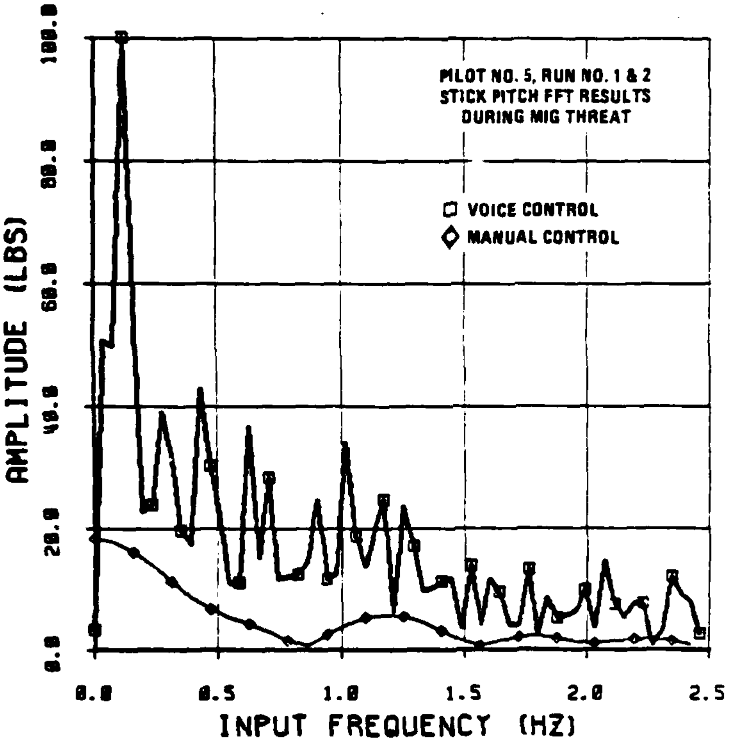


Figure 3 TYPICAL FFT PLOT THAT SHOWS A DEFINITE ADVANTAGE TO VOICE COMMAND

TABLE I - SUBJECTIVE WORKLOAD RATINGS

	VOICE CONTROL WORKLOAD RATING						MANUAL CONTROL WORKLOAD RATING					
	VERY HIGH 5	HIGH 4	AVERAGE 3	LOW 2	VERY LOW 1	AVER SCORE	VERY HIGH 5	HIGH 4	AVERAGE 3	LOW 2	VERY LOW 1	AVER SCORE
PERFORM COMPLETE MISSION		3	3		2	2.88		3	5			3.38
DISPLAY MANAGEMENT		1	2	3	2	2.25		1	5	2		2.88
SENSOR MANAGEMENT			2	4	2	2.00			3	5		2.38
FIRE CONTROL SYSTEM MANAGEMENT			4	2	2	2.25		2	2	4		2.75
STORES MANAGEMENT		3	3		2	2.88	2	3	2	1		3.75
MISSION PHASE MANAGEMENT			2	4	2	2.00		2	1	5		2.63

TABLE II - SUBJECTIVE EFFECTIVENESS RATINGS

	VOICE CONTROL EFFECTIVENESS RATING						MANUAL CONTROL EFFECTIVENESS RATING					
	TOTALLY EFFECTIVE 5	EFFECTIVE 4	EFFECTIVE/ INEFFECTIVE 3	INEFFECTIVE 2	TOTALLY INEFFECTIVE 1	AVER SCORE	TOTALLY EFFECTIVE 5	EFFECTIVE 4	EFFECTIVE/ INEFFECTIVE 3	INEFFECTIVE 2	TOTALLY INEFFECTIVE 1	AVER SCOR
PERFORM COMPLETE MISSION	3	4	1			4.25	4	3	1			4.38
DISPLAY MANAGEMENT	3	2	3			4.0	2	3	2			4.0
SENSOR MANAGEMENT	5	3				4.63	4	4				4.5
FIRE CONTROL SYSTEM MANAGEMENT	3	5				4.38	2	4	2			4.0
STORES MANAGEMENT	4	4				4.5	2	3	3			3.88
MISSION PHASE MANAGEMENT	6	2				4.75	5	3				4.63

In some respects, the objective data analysis reinforced the pilots' opinions. This analysis was based exclusively on pitch and roll inputs to the control stick because there were insufficient throttle or rudder inputs on any of the runs to yield useful data. As was shown in Figure 3, this analysis provided an indication of the pilot's ability to exert positive control over the aircraft by measuring the frequency of his inputs to the control stick. A tabulation of the results of the analysis is presented in Tables III and IV for four events for each pilot. Since each pilot made two runs each with voice control and manual control, a comparison of the two methods yields two data points per pilot, per event. The events included a very short duration task (fault analysis), two intermediate length tasks (reaction to threats) and one longer task (weapon selection reconfiguration). The numbers in the tables disclose which approach, if either, was superior in terms of frequency of stick inputs (amount of time spent controlling the aircraft) during the event. An examination of these numbers reveals an apparent correlation between task length and the effectiveness of voice-control. The weapon change task was the longest and here voice control had a decided edge. Response to the SAM threat was the next longest task and, again, voice control had a significant advantage. Both the fault analysis and MIG threat response tasks were of either discrete or very short duration and there was no distinct advantage for either approach during these events. Thus, a preliminary conclusion, based upon admittedly brief data, is that voice control is a viable command and control option, being either equal or superior to manual control. It is planned to gather additional experimental data this year to either confirm or deny this conclusion.

TABLE III - OBJECTIVE WORKLOAD RATINGS

TASK	VC	MC	NSD
FAULT ANALYSIS	3	5	
MIG THREAT	4	4	
SAM THREAT	5	2	1
WPN CHANGE	6	2	

VC - VOICE COMMAND
MC - MANUAL CONTROL
NSD - NO SIGNIFICANT DIFFERENCE

TABLE IV - OBJECTIVE EFFECTIVENESS RATINGS

TASK	VC	MC	NSD
FAULT ANALYSIS	2	1	5
MIG THREAT	2	2	4
SAM THREAT	5	0	3
WPN CHANGE	5	1	2

VC - VOICE COMMAND
MC - MANUAL CONTROL
NSD - NO SIGNIFICANT DIFFERENCE

The third question related to the viability of an integrated combination of voice command and voice response has not yet been addressed in detail. Although the fully-interactive voice system would seem to be the key to true head-up operation, the implementation of such a system must be carefully considered in the light of the overall audible input spectra (communication channel inputs, warning tones, etc.) that the pilot must hear and interpret. The final answers as to the viability of voice interactive can come only from flight test. Such a flight test program is planned on the AFTI/F-16 following a preliminary series of test flights to determine if voice recognition technology can provide reliable operation in that environment.

3. FUNCTIONAL UTILIZATION

The subject of voice interactive viability is closely interwoven with functional utilization as well as the method of implementation. The investigation of viability as a generic topic might well satisfy the pure researcher but in the practical world it is considered viable only if it enhances specific, required functions. Thus, function and mechanization studies are engendered. The determination of functional mechanizations and the consequent payoffs must, of necessity, address a specific aircraft configuration. Inevitably, the selection of a specific configuration will impose constraints upon the potential functional utilization of voice. Thus, the first step in the design of the integrated voice system is to identify these constraints. In general, these constraints will involve interface considerations, configuration limitations and safety considerations. The next step is to perform a mission task analysis to determine high-workload segments and which specific functions within those segments could be performed using voice and would appear to offer a payoff either in terms of time savings or lessened dependence upon the pilot's hands or eyes. The final step is to optimize the voice mechanization through the use of preliminary simulator mechanization and man-in-the-loop tests. Some functions will not be considered for mechanization by voice until we have a great deal more confidence in speech recognition technology than we currently have. These functions include moving control surfaces, operating the landing gear, eject, release stores, jettison and blow canopy.

Ease of interfacing and system integration must be a primary consideration in any mechanization of a voice system. In the U.S., most modern avionic systems are integrated via one or more MIL-STD-1553 multiplex data buses. It is clear that the easiest, most cost-effective method of integrating the voice system would be via such a bus. This approach, however, automatically limits voice functions to only those equipments that are also on the bus. Illustrated in Figure 4 is the AFTI/F-16 dual-bus system. The voice command equipment is being placed on the display bus, called D Mux, because it is the most lightly loaded bus and because, during Phase I, control of the Multipurpose Displays is the major function to be implemented by voice.

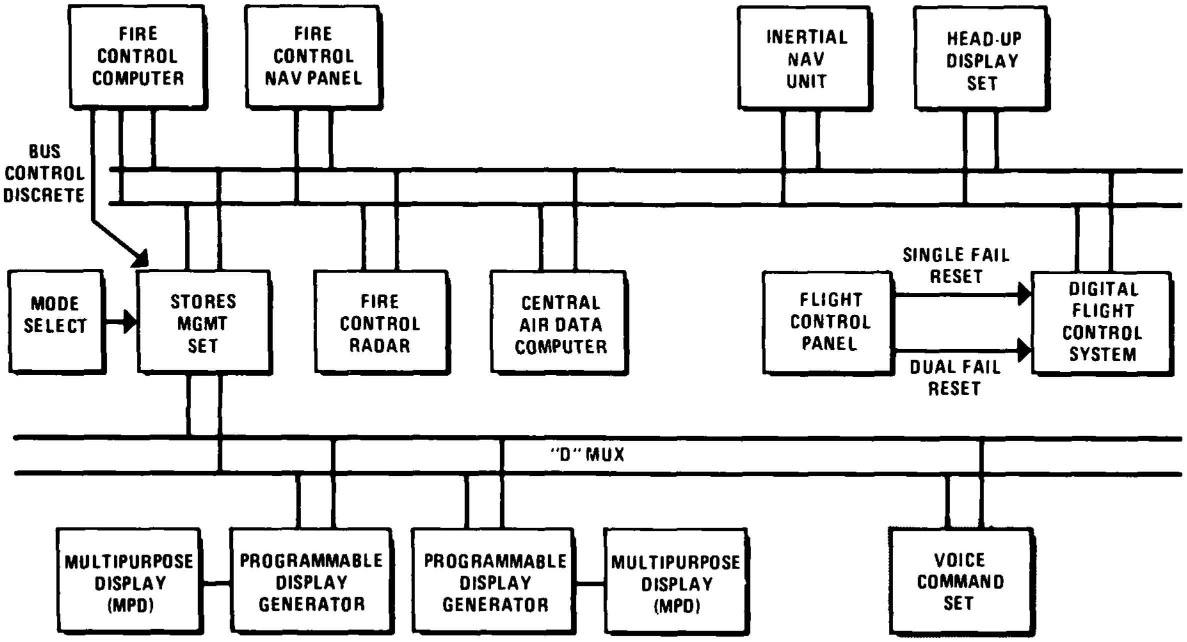


Figure 4 AFTI/F-16 AVIONIC ARCHITECTURE WITH VOICE COMMAND SET ON "D" MUX BUS

To a limited extent, the first AFTI/F16 flight test series may provide some insight into the functional utility and viability of voice command. During this phase, voiced control of the dual multipurpose displays (MPDs) and the four Mission Phase Control Switches will be provided (see Figure 5). The Mission Phase Control switches permit the selection of the basic operational modes: air-to-surface; air-to-surface guns; air-to-air missiles; air-to-air guns; or navigation (if no switch is selected).

The first functionally-oriented flight testing for voice is planned to occur during Phase II on the AFTI/F-16. A study is currently being conducted under the sponsorship of various U.S. Air Force and Navy agencies to determine what the Phase II voice mechanization should be. We currently plan to retain for Phase II the basic Phase I set of functions and, in addition, we plan to implement additional functions that the study indicates have high payoff potential. Also being considered for Phase II is the addition of a voice synthesis capability in order to achieve true voice interaction. Once the synthesis capability is included, other functions such as voiced warnings and event enunciations become easily achievable. Inclusion of such functions must be carefully considered in the light of the overall aural spectrum that the pilot must listen to. Only when the benefits are clear and non-interfering should such functions be mechanized.

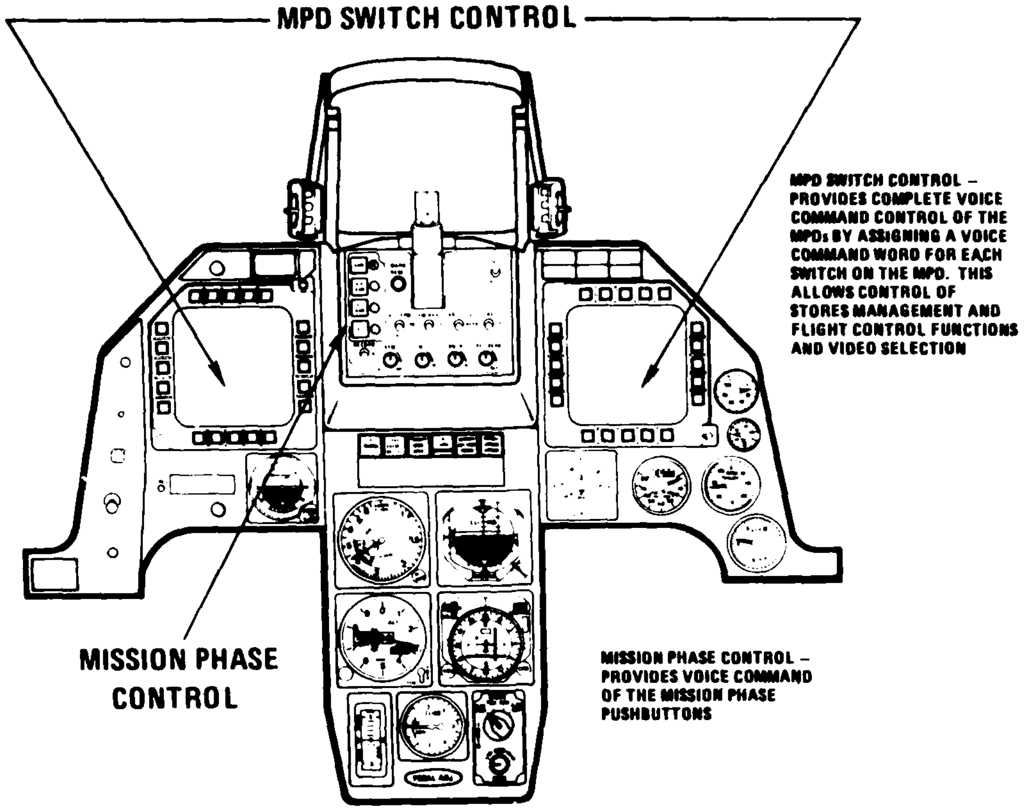


Figure 5 AFTI/F-16 PHASE I VOICE COMMAND MECHANIZATION

4. ENVIRONMENTAL EFFECTS

Equally as fundamental as viability and functional utility is the question of whether or not voice recognition technology can be made to provide acceptably reliable operation in the very stringent environment of the cockpit aircraft. It was recognized early in the project that the greatest potential drawback to the use of voice command in the cockpit is the degradation of system performance due to factors peculiar to the airborne environment such as the oxygen mask and the effect of physical and emotional stress on the human voice. Understanding this total environment and its effect upon voice recognition performance is essential. It is also very difficult since the total combat aircraft environment cannot be recreated in the laboratory. It is, however, possible to individually reproduce in the laboratory most of the suspected error sources. A centrifuge, for instance, can be used to subject a test subject to closely controlled acceleration levels and to determine the effects of the acceleration on his voice characteristics. Similarly, other aspects of the airborne environment such as background noise, vibration, etc. can be individually reproduced. Then each individual condition can be treated as an independent error source.

In a modified form, the foregoing is the approach being taken on this project. The principal modification made was in recognition of the fact that the oxygen mask is a constant presence and that its effects, whatever they may be, are superimposed on the other environmental factors. Thus, the oxygen mask is used in all tests. The tests for acceleration (up to six Gs), background noise (up to 115 db) and vibration effects (to expected F-16 levels) were performed by the Air Force Aerospace Medical Research Laboratory (AMRL) using their facilities; i.e., centrifuge, noise chamber, vibration table. A small (15 word) vocabulary was selected to be repeated in random fashion by the test subject under each test condition. This vocabulary consists of the digits zero through nine and the following words: FREQUENCY; ENTER; CCIP; THREAT; and STEP. In each case, the utterances of the test subject were recorded on audio tape. These tapes constitute an important part of a data base that is being assembled by General Dynamics for use as a principal tool to help extend the state-of-the-art of voice recognition for operation in the airborne environment. Similar tapes have been made both on the ground and in flight at General Dynamics in production F-16s. Copies of all tapes are made available to participating firms.

To date, two firms have been accepted as participants. The first of these was Lear Siegler Incorporated (LSI) Instruments Division. Partial funding for the development of a flightworthy LSI voice recognition system has been obtained from the Air Force under the AFTI/F-16 contract and LSI is currently under contract to General Dynamics to provide this equipment. Delivery of the flightworthy LSI system is expected in the second quarter of 1982. The second firm accepted for participation is ITT Defense Communications Division. ITT has initiated the development of a flyable version of their system. In addition, preliminary talks have been held with several other potential suppliers

The next step in establishing the credibility of voice recognition technology relative to its ability to provide acceptable performance in the combat aircraft environment is flight test. The initial flight test series for voice command will occur on the AFTI/F-16 in late summer of 1982. It is planned that this test series will be followed in 1983 by another test series during Phase II of the AFTI/F-16 program where the emphasis will be placed upon investigating the functional utility of voice interactive systems and determining the resultant payoffs in terms of overall weapon system performance improvements and/or increased survivability. However, it should not be assumed that the flight test programs will provide the final answers, particularly on voice command. Based on present perceptions of speech recognition state-of-the-art, it appears that the optimal cockpit integration of voice command systems will require an extensive study of their performance in the operational environment. In this context "optimal cockpit integration" refers to the systems chosen for voice control, the manner in which commands are given (vocabulary and syntaxing scheme), error rate for voiced commands and the need for additional training by the pilot while maximizing his workload reduction. Arriving at this optimal configuration will be a formidable task, for measures that achieve one of the three objectives may adversely affect one of both of the others. As an example, should the recognizer be unable to reliably discriminate among the vocabulary items, it may be tempting to reduce the number of items to be chosen from through use of a "taller" syntax tree; i.e., one with more nodes. Although error rate may improve with such a change, the additional steps required to complete a task will increase the pilot's verbal workload.

It is unlikely that flight test programs will provide the required data to effectively refine these system features and procedures. This is due to the fundamental difference between the flight test and operational environments and the unique qualities of voice command. The flight test environment is not characteristic of the operational domain for several reasons. Among these is the difference between test pilots with thousands of hours of flight time and line pilots many of whom may be relatively inexperienced. If stress is a significant source of speech variance, to see more recognition errors among the line pilot users may be expected. Another possible difference is the amount of interest focused on the recognition device during a flight test. Since past studies have shown that "cooperative" users achieve much better results with speech recognition devices it is likely that operational pilots will be less successful in daily use of the system when it becomes just another piece of the aircraft and their motivation to "make it work" wanes.

If we accept these arguments, the question then becomes "What data is needed to improve the voice command interface and how can it be collected in the operational environment?" The most useful data to collect would be that which directly pertains to failures to accomplish voice command tasks correctly. These failures may be partitioned into two classes, human error and machine error. The first error class includes wrong word entries (the use of a synonym for one of the voice command system vocabulary items or the improper sequencing through a syntax tree) and "clipping" verbal inputs with the voice command system push-to-talk switch by indexing it after beginning to speak or releasing it before finishing. Machine errors are divided into two classes, rejections and substitutions. Rejections occur when the system lacks the confidence to choose between/among two or more vocabulary items. Substitutions occur when the recognition system chooses the wrong word.

In order to reduce these errors, we will need to know such information as their rate of occurrence, the proportion of errors of each class, environmental conditions at the time of the error (G-loading, altitude, airspeed, etc.), the command entered and, in the case of a substitution error, the word recognized. The collection of this data would allow system refiners to concentrate their efforts on the largest classes of errors. This list is by no means exhaustive. Other data such as errors in each mission phase and the time into the mission could give inferential insight into the role of pilot stress or fatigue on the voice command system's performance.

Once the probable source of errors is defined, there are a number of implementation factors that can be manipulated to attempt to improve the system. These include vocabulary changes to remove acoustically similar words and changes in the way that vocabulary templates are generated for the recognizer. If these measures are not totally sufficient then the error analysis can be used to focus recognition algorithm refinement into the most promising areas.

Of course the problem of data collection must be resolved. Since this paper has emphasized the single-seat fighter aircraft, it is clearly impossible to use observers and it is recognized that pilot reports will yield limited data. A possible solution is for the recognizer to monitor its own performance by a combination of inductive and deductive "reasoning". The problem is for the device to "realize" that an error has occurred and then to obtain and store the necessary data for a post-mission dump. In some cases this will be a trivial problem. Obviously if a rejection error occurs the device "knows" it was not able to make a choice. It can then store the template of the inputted word for later analysis along with the relevant data which may be garnered from the data bus. Ultimately, the information would be loaded into the F-16 Data Transfer Cartridge and then into a ground-based information system for later analysis.

The problem of identifying a substitution error is more complex. One possible approach is to add a control word to the system vocabulary such as "error" or "mistake" so that the pilot could tag such failures. The problem command could then be identified in a string of inputs by comparing the tagged string to the next related system input (either verbal or manual). The additional data could then be stored as in the case of the rejection error. Push-to-talk problems could be identified by examing the acoustic signal just after pushing the button and just prior to its release. If the bandpass filter bank of the system indicates non-breath noise energy it could be assumed that the utterance was in progress before/after the index/release of the button. Data of this type when combined with subjective opinions of the user pilots should provide much of the information required to make voice command a reliable system interface.

The methods proposed in this section could be implemented either prior to fleet introduction of voice command or in parallel with operational deployment if the systems are predominantly software configured to allow for cost effective modifications. Obviously, only a relatively small number of units would have to have this additional data collecting capability if care was taken to collect data from a representative sample of users. To further enhance the realism of that data collection environment perhaps these special units could be installed only in aircraft participating in combat simulations such as the USAF's Red Flag exercises or RCAF's Maple Leaf events.

5. SUMMARY

The future of voice interactive in military aircraft is very dependent upon three factors; operational viability, functional utility, and operational reliability. The Voice Interactive program is designed to provide an orderly in-depth investigation into each of these areas of concern. A graphic portrayal of the program is provided in Figure 6.

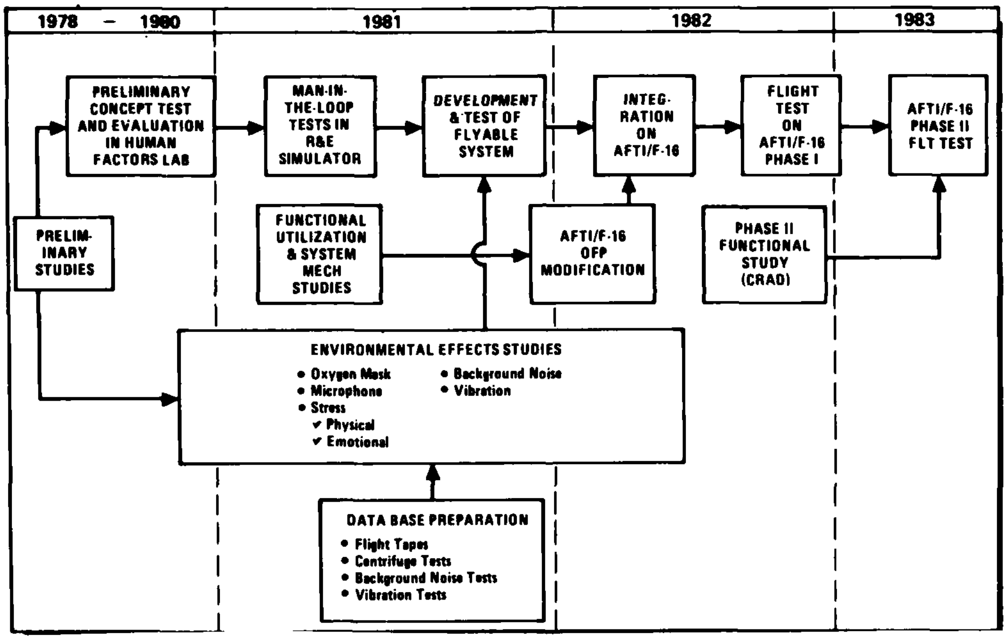


Figure 6 VOICE INTERACTIVE DEVELOPMENT PROGRAM ROADMAP

The operational viability and functional utility of voice interactive systems are being investigated and evaluated using simulation and man-in-the-loop testing as the primary tools. The goal is to determine if the use of voice command offers significant payoffs in terms of improved overall pilot/weapon system performance.

Operational reliability refers to the capability of voice recognition technology to provide an acceptably high level of performance in the intended environment; in this case the combat aircraft. An integral part of the voice interactive program is a systematic investigation of the effects of this environment upon the human voice and its consequent effects upon voice command system performance. The investigation is making use of environmental simulation on a centrifuge, a noise chamber and a vibration table as well as on-aircraft ground testing on F-16 aircraft. Planned for 1982 is a series of flight tests in the AFTI/F-16 to determine the composite effects of the high performance aircraft environment to be followed, starting in 1983, by a second test series designed to investigate functional utility and payoffs. A possible method of continuing the investigation at the operational unit level is discussed.

It is anticipated that the voice interactive program at General Dynamics will result in the first voice recognition system to be designed for and tested in the military aircraft environment and that the result will constitute a significant advancement in airborne command and control.

VOICE INTERACTIVE SYSTEMS TECHNOLOGY AVIONICS (VISTA) PROGRAM

LOCKWOOD W. REED

US ARMY AVIONICS RESEARCH AND DEVELOPMENT ACTIVITY
FORT MONMOUTH, N.J. 07703

ABSTRACT

This paper is intended to describe the Avionics Research and Development Activity's (AVRADA) program to introduce voice recognition and response into the Army aircraft environment. The emphasis of the paper will be on program structure; however, preliminary testing results will be presented where available.

AVRADA has initiated a program entitled "Voice Interactive Systems Technology Avionics (VISTA)." The VISTA program will take a phased approach to the introduction of voice I/O equipment into the Army aircraft environment. The first phase of the VISTA program will utilize the extensive acoustical analysis and simulation facility of AVRADA to systematically evaluate the performance of candidate, off-the-shelf, voice I/O equipments in various Army aircraft noise environments.

The subsequent phases of the VISTA program will include the interface of selected voice I/O equipments with the AVRADA developed integrated Avionics Control System (IACS). This will permit the evaluation of the voice I/O equipments in the simulated noise environment while actually performing voice-controlled aircraft radio and frequency selection. As the predictability of the voice I/O equipment in the simulated aircraft noise environment is established, the testing of selected voice I/O equipments will begin in actual aircraft. It is hoped that this testing will provide a baseline of information from which specifications and requirements will be written for the development of the Army aircraft unique voice I/O equipment. The aircraft testing will culminate in the integration of voice I/O equipment in AVRADA's System Test Bed for Avionics Research (STAR) aircraft.

The STAR aircraft is a UH-60 Black Hawk helicopter which will be configured to include a 1553 multiplexed data bus and a multiplexed digital audio bus (DMAS). In this environment, the voice I/O system will have access to all the audio intercom systems for voice I/O purposes and all the avionics for control applications. Applications testing will be performed in the STAR aircraft to determine which of the aircraft operational functions would be suitable for voice control and response.

It is felt that the VISTA program directly addresses the subject matter of category V "Aural and Oral Channels" regarding speech systhesis and direct voice input for the control of onboard systems.

INTRODUCTION

As the complexity of aircraft missions increases, there is a commensurate increase in the number of functions and operations to be performed by the pilot and crew of a given aircraft. Recently, military single-seat rotary aircraft have been proposed, compounding the problem of the man-machine interface.

This problem can be significantly reduced if the following three basic requirements can be satisfied: (1) the pilot can maintain hands on flight controls throughout the entire operation of the aircraft (2) the pilot's visual attention can be directed toward the flying of the aircraft (particularly important for Nap-of-the-Earth flight) (3) the pilot can still control all necessary aircraft subsystems under the conditions of (1) and (2).

Preliminary investigations by the Avionics Research and Development Activity (AVRADA) and many other governmental and industrial concerns have indicated that an integrated system of voice recognition and voice response can meet all the above requirements.

In order to investigate the potential advantages of Voice Technology, AVRADA has initiated a program entitled Voice Interactive Systems Technology Avionics (VISTA). The VISTA program is taking a phased approach to the introduction of voice recognition and response equipment into Army aircraft. Before detailing the phases of the VISTA program it would be appropriate to describe here the AVRADA facilities which will support the VISTA program. AVRADA maintains an extensive Computer aided Design and Audio Analysis Laboratory. The Audio Analysis Laboratory consists of two sound chambers (one Anechoic Fig 1, and one Sound Absorption Fig 2).

Each chamber is tied via audio signal and digital data lines into the test equipment rack (Fig 3) which contains signal measuring amplifiers, two audio spectrum analyzers, various filters and equalizers, and audio recording equipment. The equipment in the test rack is in turn connected to the main laboratory computer system (Fig 4) consisting of a 16-bit mini-computer, 17 terminals, line printer, parallel I/O to test equipment and 80 mbyte disk drive, and a high speed array processor. The computer system maintains two operating systems, one single user real time operating system and one multi-user, multi-tasking operating system. A second 16-bit interactive graphic computer is tied into the sound absorption chamber and will be used exclusively for testing and evaluation of voice recognition equipment. AVRADA's Audio Analysis laboratory contains one of the most extensive libraries of Army aircraft noise environment tape recordings. The recordings were taken in the field at various Army installations using AVRADA's portable audio analysis equipment which consists of a precision portable audio recorder, sound level meter with 1/3 octave and narrowband filter sets and strip chart recorder. Recordings were made in several OH-58, UH-1, AH-1, CH-47, OV-1D, CH-54, and a UH-60 aircraft in various modes of flight from hover to tactical maneuvers.

VISTA PROGRAM

The first phase of the VISTA program (Fig 5) consists of writing software for our in-house computer systems to aid in the testing and evaluation of voice recognizers (the software will be discussed in greater detail under test procedures), and the evaluation of selected off the-shelf voice recognizers. The use of off-the-shelf recognizers has a twofold benefit. First, testing procedures applicable to all recognizers can be developed economically, and secondly, the performance of off-the-shelf recognizers can yield baseline cost/performance information to which more sophisticated recognizers can be compared. Recognizer testing during phase one will be performed exclusively in the Audio Analysis Laboratory. Testing in the aircraft will be limited to the generation of recognizer training/test tape recordings made in the aircraft to be used as a validation check on the accuracy of the chamber tests.

As the recognizer test/evaluation software and procedures are finalized, phase II of the VISTA program will begin (Fig 6). Phase II involves applying the testing software and procedures developed during Phase I to more sophisticated (and more costly) commercial and non-commercial voice recognizers. In addition, since high ambient noise is a prime concern for any attempted installation of voice recognition equipment in Army aircraft, testing will be performed by front-ending the above recognizers with off-the-shelf noise reduction devices in addition to the various noise canceling microphones already in use.

As the predictability of various voice recognizers is established, Phase III (Fig 7) of the VISTA program will begin with the installation of selected recognizers in AVRADA's Systems Testbed for Avionics Research (STAR) aircraft. The STAR aircraft (Fig 8) consists of a UH-60 helicopter modified to include a MIL-STD-1553 data bus, and various avionic subsystems (i.e., radio, navigation, night pilotage, etc.), all of which are connected to the common 1553 data bus. Sound recordings and measurements have been made in this aircraft and are being used in chamber environment simulations of the aircraft. Figure 9 shows the acoustic frequency spectrum taken in the aircraft at two locations, the cockpit and midship. The sound level has been measured at 103 db on the A weighted scale in the cockpit and 107 dBA amidships. Testing in the STAR aircraft will primarily be directed toward applications and operations for voice recognizers in the aircraft. To obtain meaningful results from the testing it will be necessary for the recognition equipment to be integrated into the aircraft data bus and to have access to all subsystems. To accomplish this and still have the flexibility of evaluating many different types of recognizers, a problem is created since most non-commercial and all commercially available recognizers do not have any MIL-STD-1553 data bus interface.

The approach taken to solve the problem is to install a general-purpose militarized computer (Fig 10) which will serve many functions. First, the computer will act as an intelligent interface providing the MIL-STD-1553 bus interface hardware and the data bus control software for the aircraft side of the integration. Second, since the large majority of commercial and non-commercial recognizers communicate via RS-232 or RS-422 hardware, the computer will provide several of these interfaces. Third, the operating system software of the computer will be designed so as to minimize the impact of changing from one recognizer to another. Fourth, the computer will contain all the software for a given control scenario. As an illustration, the use of a recognizer to control the onboard radios will be totally controlled by the computer. At any point in the scenario the computer will restrict the recognizer to a specific subset of its vocabulary to reduce the chance of false recognitions. When an utterance is made and the recognizer outputs its best guess, the computer will decide what to do with the response, what equipments are to be affected, and what 1553 data bus message will be sent. By dividing a control scenario into specific software modules keyed to generic recognizer responses, minimal impact on the computer software is achieved when changing voice recognizers. Only that software which extracts the generic information from a particular recognizer message need be changed.

To complement the contribution of the industrially available recognizers to the VISTA program, work will begin in house during Phase IV (Fig 11) to develop and test voice recognition and noise cancellation algorithms tailored to the Army aircraft environment. The high speed array processor mentioned previously will be used exclusively for voice recognition and noise cancellation algorithm testing, to permit real time response.

The emphasis of the VISTA program has been directed toward the voice recognition problem because technically it is the more risky half of an integrated voice interactive system. However, voice response does present unique problems of its own primarily in the area of human factors. Technically there are many implementations of voice response available, each offering certain advantages. For the most part, the selection of a given voice response unit is a tradeoff between intelligibility and digital storage capacity but even here the technology is converging in that new more memory efficient encoding algorithms are being developed and less expensive higher density memory chips are continually being introduced. The VISTA program is addressing voice response as an integrated complement to voice recognition. Presently a speech synthesizer is interfaced into AVRADA's computer facility for applications testing in the noise environment. The specific synthesizer used was selected for its ability to be programmed in-house. To this end a program was written (referred to as a Speech Editor) which enables various vocabularies to be stored on disk. These vocabularies can be accessed by several programs for intelligibility testing and applications testing in conjunction with the voice recognition equipment. Beginning in Phase III, various voice response units will be evaluated for intelligibility. Much of this intelligibility information should be available to the VISTA program through other Tri-Service efforts. The VISTA program will initially evaluate the available voice response intelligibility data for its application to the Army noise environment. Where data is still needed regarding the Army specific acoustical environment (i.e., radio and intercom systems as well as noise), the necessary testing will be performed under the VISTA program.

VISTA VOICE RECOGNIZER TESTING TECHNIQUES

At present the formulation of standards for recognizer testing is in its infancy and as yet no established recognizer testing standards or criteria exist. One of the chief difficulties in the formulation of standards for recognizer evaluation has been the determination of what criteria will yield meaningful information about the performance of voice recognizers in many diverse environments. This, unfortunately, creates the classic "chicken and the egg" problem for those who wish to apply this technology. The VISTA approach has been to devise a series of test and evaluation procedures applicable to the Army aircraft environment.

Figure 12 shows the typical test setup for recognizer testing. Recordings of aircraft noise are equalized and played into the sound absorption chamber. The output of a precision microphone, located in the chamber, is fed into a measuring amplifier and a spectrum analyzer to make adjustments in overall intensity and spectral content. The voice recognizer and a CRT terminal located in the chamber are connected to the Interactive Graphic Host Computer. Specialized software running on the host computer performs applications testing of the recognizers and recognizer comparative testing. Test results are then printed on the line printer.

The initial voice recognizer testing is limited to the two modes of recognizer operation--Unrestricted Vocabulary Search (UVS) and Restricted Vocabulary Search (RVS). UVS involves computer software which prompts the test subject (via CRT) with each word of a selected vocabulary. The computer permits the voice recognizer to search its entire vocabulary for a best match based on a predefined recognition threshold. If the utterance does not exceed the recognition threshold for any of the stored vocabulary words, a reject response is output from the recognizer to the computer. Likewise, if the voice recognizer perceives the utterance as noise, an appropriate response is output to the computer.

All responses generated by the recognizer are stored in a disk file. The RVS involves an Applications Simulation Program (ASP) running on the host computer. The ASP controls the voice recognizer as it would be in an actual aircraft application (i.e., radio control, navigation control, etc). At any point in the scenario the ASP restricts the voice recognizer to a specific subset of words in its vocabulary. Using radio control as an example, the ASP initializes to a command mode in which the user may request the status of a given radio. In command mode the recognizer is restricted to matching only those words which designate the various radios. At this point in the scenario it is neither necessary nor desirable to have the recognizer attempt to match an utterance to any other portion of the recognizer vocabulary. In actual field operation restriction of the vocabulary will decrease the occurrences of false matches by the recognizer and hence increase the reliability of the entire system. The RVS testing will give a measure of the relative reliability between restricted and unrestricted vocabularies as well as a closer measure of the performance which can be expected from a given recognizer in the field.

The following discussion describes a typical test session, delineating the test parameters and test results.

Radio control was selected as a candidate application because of the level of tasks to be performed and the fact that it is a non-flight control critical operation. Having selected radio control, the tasks to be performed were delineated and two basic functions were selected: the cycling of power and the selecting of frequency to a specific radio. The typical Army aircraft complement includes four radios: two VHF FM radios; one VHF AM radio and one UHF AM radio. Based on the above information, a vocabulary for the recognizer was devised (see Fig 13). It should be noted that the selected vocabulary contains two utterances which sound alike except for their endings ("Foxmike 1" and "Foxmike 2") and two utterances sound similar ("Victor" and "Enter"). These words were chosen to yield some information concerning the critical nature of sound alike words. Training patterns using the vocabulary of Figure 13 were made for several test subjects under four different conditions. The four conditions involve the use of two different microphones and training the recognizer with each microphone in the "Quiet" and in the "Candidate noise" environment. The noise environment selected for all training and testing is that of the UH-60 Black Hawk (the STAR testbed aircraft, see Fig 14). The training program resident on the host computer guides the test subject through the training process. After training is completed, the voice pattern stored in the recognizer is up-loaded into the host computer by a program called VOXDSK. VOXDSK handles all up-loading and down-loading of voice patterns.

Incorporated into VOXDSK is a mandatory request to the operator for header information concerning the test subject (Fig 15). The information includes the subject's name, the creation date and time of the voice pattern files, the condition of the test subject, the test conditions, the type of recognizer, the number of training passes and the number of words. VOXDSK reads the header file created by the operator and checks it for the required information. When VOXDSK is satisfied, it creates a composite file which includes the test subject header and the voice pattern (Fig 16). This self-documentation approach insures the traceability of voice pattern history and will minimize errors due to the incorrect use of voice pattern files. Having trained the recognizer, the testing procedures can now begin. This paper will be limited to a discussion of the procedures and preliminary results of the Unrestricted Vocabulary Search tests. The first step in the testing procedures is to create a test header file. This file is similar to the training header file except it refers to the specific test conditions which may be different from the training conditions. If a question mark is inserted into any information field (i.e., the "Date.Time" field) that data will be automatically requested from the operator at test time. Both the training and the test result files are uniquely numbered by a six-digit date field followed by a four-digit 24-hour time field separated by a period. When the test program runs, it creates a test results file. The operator is then prompted to enter the time of the test; the test program then looks up the voice pattern file used in the test and appends the training header to the test header in the test results file. For the UVS testing the subject is prompted, via the CRT, by the host computer with the vocabulary of Figure 13 stored in a prompt file. When the test subject responds to the prompt, the recognizer outputs its best match response (or no match response, if below the rejection threshold or noise) to the host computer. The host computer outputs all recognizer responses to the test results file for later comparison. When the data in the prompt file is exhausted, the testing program terminates. A comparison program automatically initiates at the termination of the test program and outputs all the header information contained in the test results file to the line printer; the program then begins comparing the response data in the test results file to the original prompt file. The results of the comparison are output to the line printer along with three columns of information (Fig 16). The information includes: an accuracy column with the number and percentage of totally correct responses; a reliability column which contains the number of totally correct responses plus the number of negative responses (a negative response is one in which either the recognition threshold is not exceeded or the recognizer perceives noise) and the percentage of same; and a latency column which is the difference information between reliability and accuracy. Because Reliability combines the total number of correct responses with the total number of negative responses it yields the percentage of the time (based on usage) the recognizer will not get the aircraft into trouble by going into the wrong mode of operation. The latency data yields the percentage of time a response would have to be repeated.

For the radio control vocabulary, an entire test run can be completed in an average of one minute and thirty-five seconds. For the same test conditions ten contiguous runs are performed by the computer in a total time of approximately 16 minutes. It is evident that, due to the rapidity of the testing procedures, many test condition variations can be tried in a relatively short period of time.

TEST RESULTS

The following discussion will be limited to the preliminary tests which were performed using the UVS technique. The results of those tests are summarized in Figures 17 and 18. The following conditions were adhered to for all testing: UH-60 noise at 103 dBA (Fig 17) and 107 dBA (Fig 18); microphone position just brushing the test subject's lips; the recognizer connected to the standard Army aircraft intercom system; the vocabulary of Figure 13 trained with five passes per word; approximately one second delay between word prompts; and a recognition threshold of 105 (NOTE: Each pattern is composed of 128 bits; a recognition threshold of 105 would require the recognizer to match 105 of 128 bits before outputting a match response).
The test results of Figures 17 and 18 represent the compilation of up to eighty tests per subject (10 iterations per test condition). They are ordered from the highest to the lowest accuracy for each test subject. It can be immediately observed that for each test subject, the highest recognizer accuracy was achieved for the vocabulary trained in the actual noise environment. This confirms the results of similar tests performed in different environments by other agencies. Another important feature of the test results is that in all cases, the Electret microphone achieves the most accurate results when

the vocabulary is trained in the noise and the least accurate results when training in the noise is not employed. This apparent paradox can be explained by comparing the frequency response characteristics of each microphone (Fig 19). The Electret microphone has a broader frequency response; therefore, the contribution of noise to the pattern generated by the Electret microphone is more significant than the same pattern made in the noise with the M-87 microphone. Although the wider frequency response of the Electret microphone passes more noise, it also passes a greater portion of the low-frequency spectrum. This appears to account for the Electret microphone producing the most accurate recognition results for every test subject. The apparent ability to trace recognizer performance to microphone characteristics does provide a means of test result validation. As the number of test subjects increases, particular attention will be given to see if this trend continues.

Even now, a deviation from this trend is used to prompt a reexamination of a test subject's training pattern for accuracy.

RESEARCH AREAS

In the near-term testing of the VISTA program, we will be concentrating on the following areas: the front-ending of recognizers with off-the-shelf noise cancellation devices; the significance of Army aircraft vibration on human speech; the establishment of a restricted vocabulary for near-term application; the electrically vs acoustically mixing of noise and speech for training purposes; and the effect noise has on the character of human speech. The latter research area will be a joint effort by the Army (AVRADA, Ft Monmouth) and the Navy.

To date, many different techniques have been developed for the cancellation of noise. Many of these techniques have resulted in a significant loss in intelligibility; however, this loss of intelligibility, while significant to a human listener, may not affect voice recognition equipment. The VISTA program will therefore investigate the effects of applying existing noise cancellation techniques to voice recognizers.

The use of a reference voice will play a significant role in the investigation of vibration on human speech. The reference voice will be created using a recording of a selected subject played back through an artificial voice transducer. This reference voice will be used for training as well as testing the recognizer. Recordings will be made of test subjects and the reference voice in both the chamber aircraft noise environment and the actual aircraft noise environment. Because in actual flight the reference voice will not be subject to vibration, it is hoped that a comparison of the various test results will yield meaningful and repeatable information regarding the effects of vibration.

AVRADA will maintain a complete electrical hot bench of the STAR aircraft. This will provide an ideal environment for meaningful human factors work directed toward the implementation of voice recognition equipment in the Army aircraft environment. It is AVRADA's desire to enter into a cooperative arrangement with other governmental human factors agencies whereby those agencies would utilize AVRADA's STAR hot bench and STAR aircraft to perform human factors analyses in a relevant Army aircraft environment. Through this human factors work, a restricted vocabulary for near-term applications will be defined.

Because of the high ambient noise found in Army aircraft, it is undesirable to require training in the noise. Therefore, experiments will be conducted in electrically mixing the noise with the speech in the quiet for recognizer training. The resulting test data will be compared to the same test conditions using training patterns made by acoustically mixing the speech with the noise at the microphone. Because the speech in the former case will be generated in the quiet, as far as the test subject is concerned, any effect the noise has on the speech will not be reflected in the electrically mixed voice pattern. To investigate the effect of noise on speech, experiments will be conducted by subjecting the test subjects to noise via a high-quality headset. Care will be taken to insure that the test subject hears the same level and balance of sidetone (subject's own voice) and noise in the headset. The subject's voice, which is now essentially in the quiet (because the only noise is in the headset which has minimal leakage), will be recorded and analyzed for aberations traceable to the effect of the noise. The intent of the speech analysis is to determine if an apparatus can be devised to artificially shape speech produced in the quiet, giving it the characteristics of speech produced in the noise.

CONCLUSION

Although the preliminary test results are encouraging, it must be remembered that they were taken under ideal conditions. For all testing, the microphone was positioned just brushing the test subject's lips; however, a test was run with one test subject placing the microphone approximately four millimeters from the test subject's lips. The test results showed a 50% decrease in recognition accuracy for the same conditions as those with a microphone touching lips. Although the results are preliminary, it is apparent that the signal-to-noise ratio is a key factor in recognition accuracy. Another problem arises because of the automatic gain controls (AGC) found in most aircraft intercom systems. When there is no voicing for a period of time, the AGC increases the intercom sensitivity. If the first utterance spoken is intended for the recognizer it will likely be rejected because of the distortion caused by the AGC adjusting the gain during the utterance. This is demonstrated in the test results of all test subjects. No attempt was made to set the AGC before beginning the test; as a result, 90% of the first utterances were rejected which resulted in the lowering of the accuracy score by approximately 4%. The AGC has a release time of 10 seconds and the prompts are issued every second; therefore, after the first utterance the AGC has little effect. Some side tests were performed by making an utterance before signaling the computer to begin the test, and in each case the accuracy of the first test word increased to a point comparable to the other vocabulary words.

The VISTA program is the first in-depth attempt to apply voice recognition and response to the Army aircraft environment. Participation by other governmental agencies is being sought for cooperative efforts utilizing AVRADA facilities for the application of this technology to the Army aircraft environment.

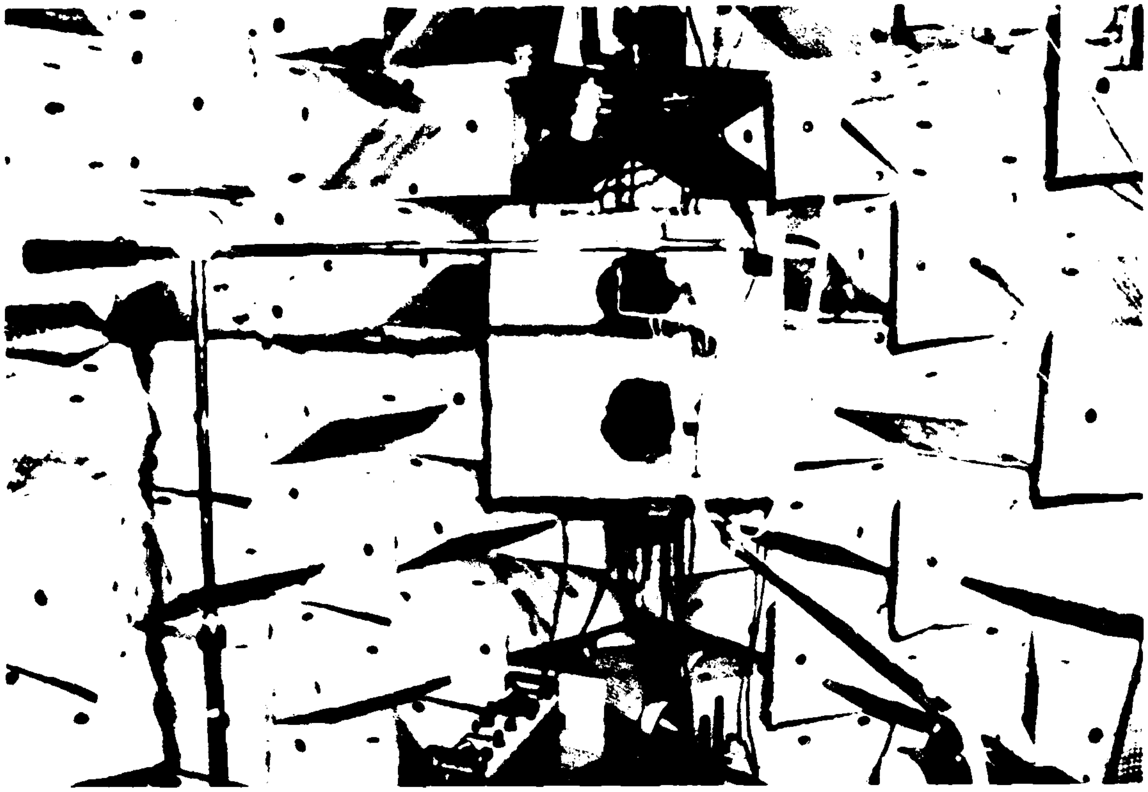


Figure 1

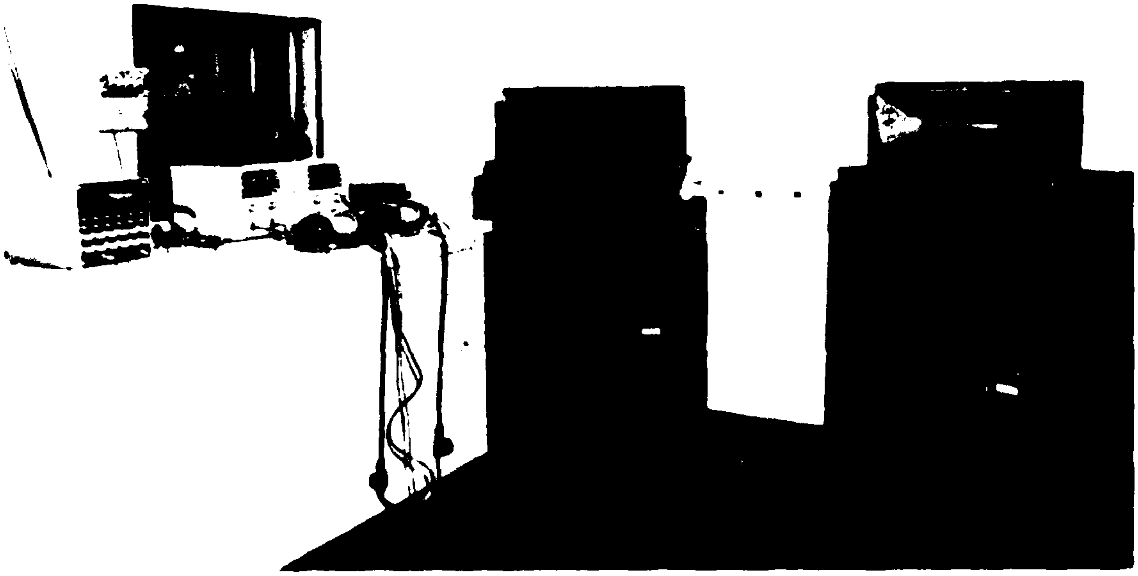


Figure 2

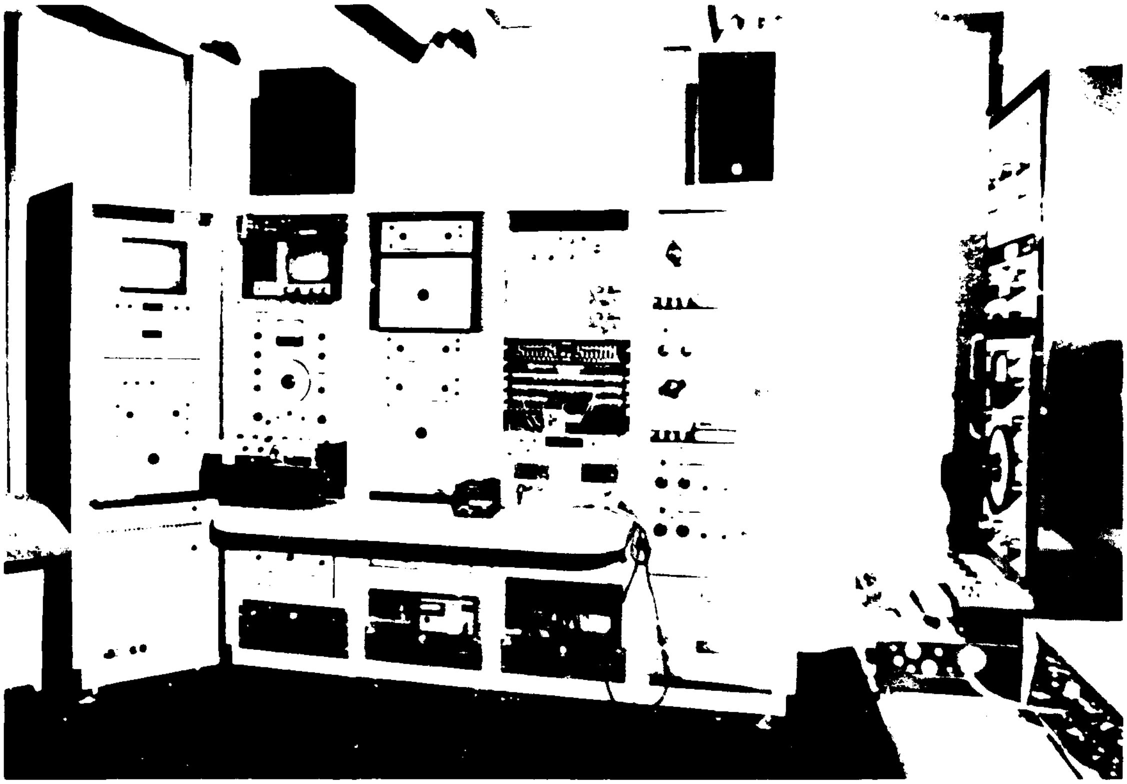
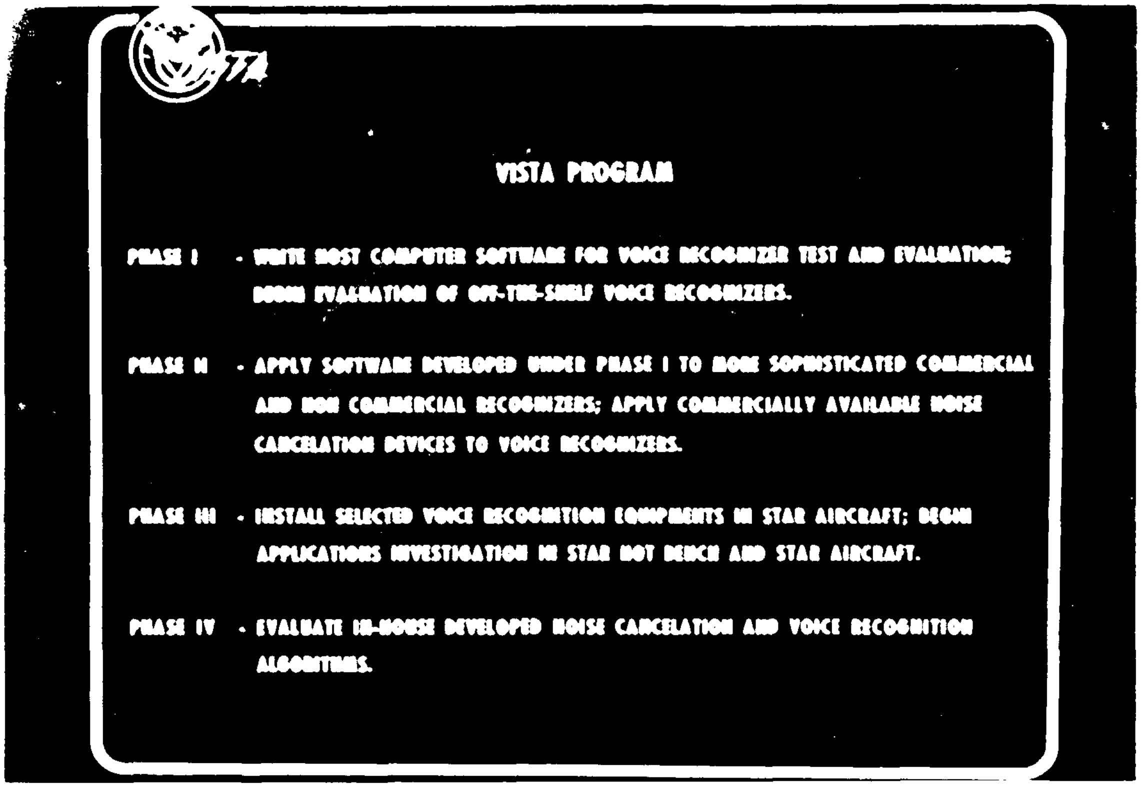


Figure 3

Figure 4



VISTA PROGRAM

PHASE I - WRITE HOST COMPUTER SOFTWARE FOR VOICE RECOGNIZER TEST AND EVALUATION; BEGIN EVALUATION OF OFF-THE-SHELF VOICE RECOGNIZERS.

PHASE II - APPLY SOFTWARE DEVELOPED UNDER PHASE I TO MORE SOPHISTICATED COMMERCIAL AND NON COMMERCIAL RECOGNIZERS; APPLY COMMERCIALLY AVAILABLE NOISE CANCELATION DEVICES TO VOICE RECOGNIZERS.

PHASE III - INSTALL SELECTED VOICE RECOGNITION EQUIPMENTS IN STAR AIRCRAFT; BEGIN APPLICATIONS INVESTIGATION IN STAR HOT BENCH AND STAR AIRCRAFT.

PHASE IV - EVALUATE IN-HOUSE DEVELOPED NOISE CANCELATION AND VOICE RECOGNITION ALGORITHMS.

Figures 5, 6, 7 and 11

Figure 8

Figure 9

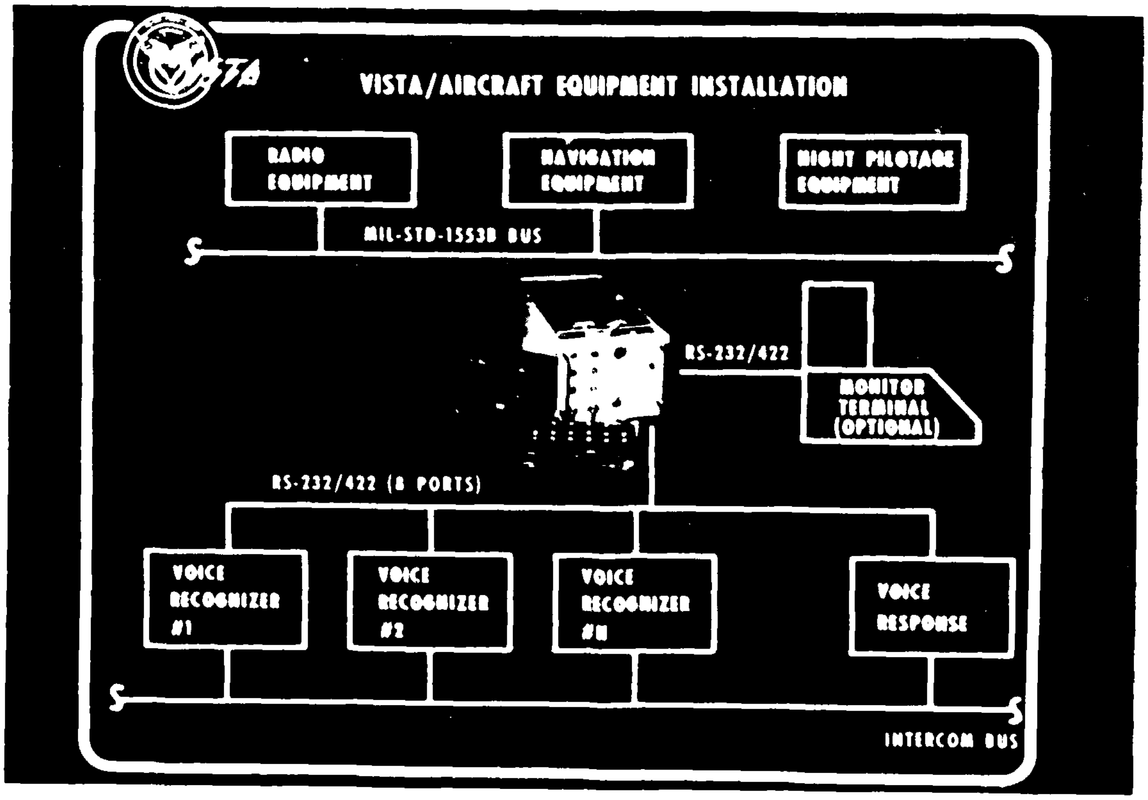
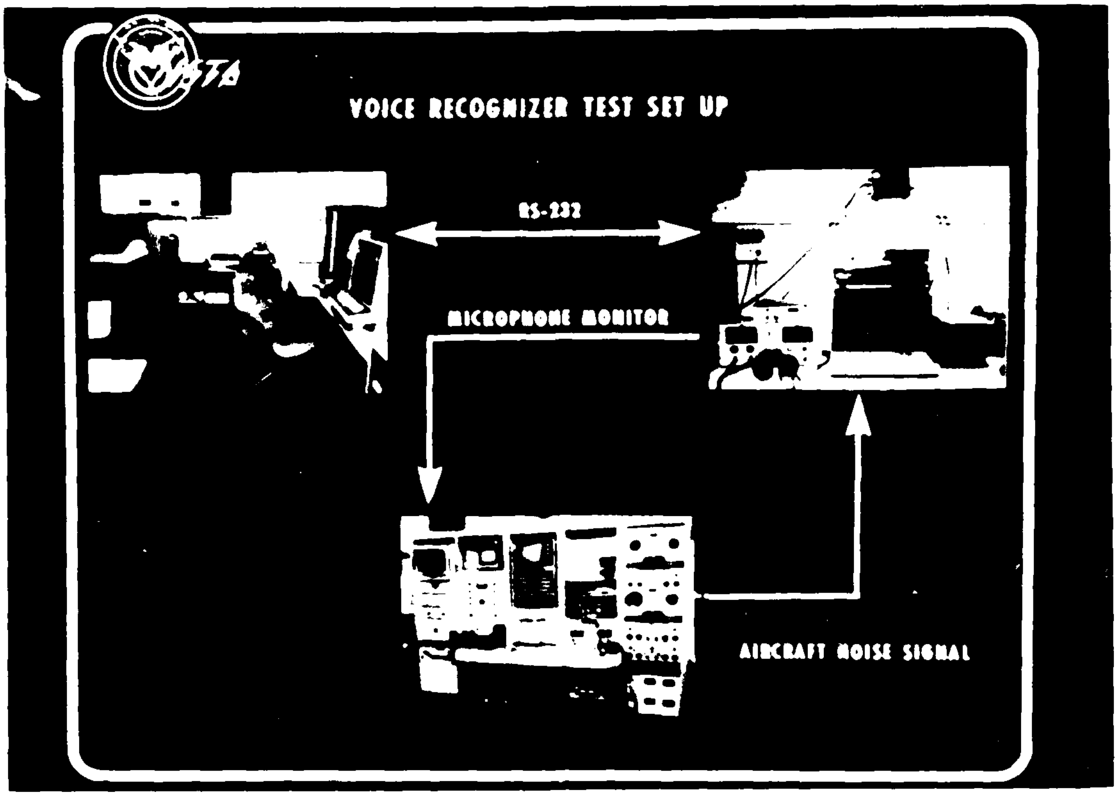


Figure 10



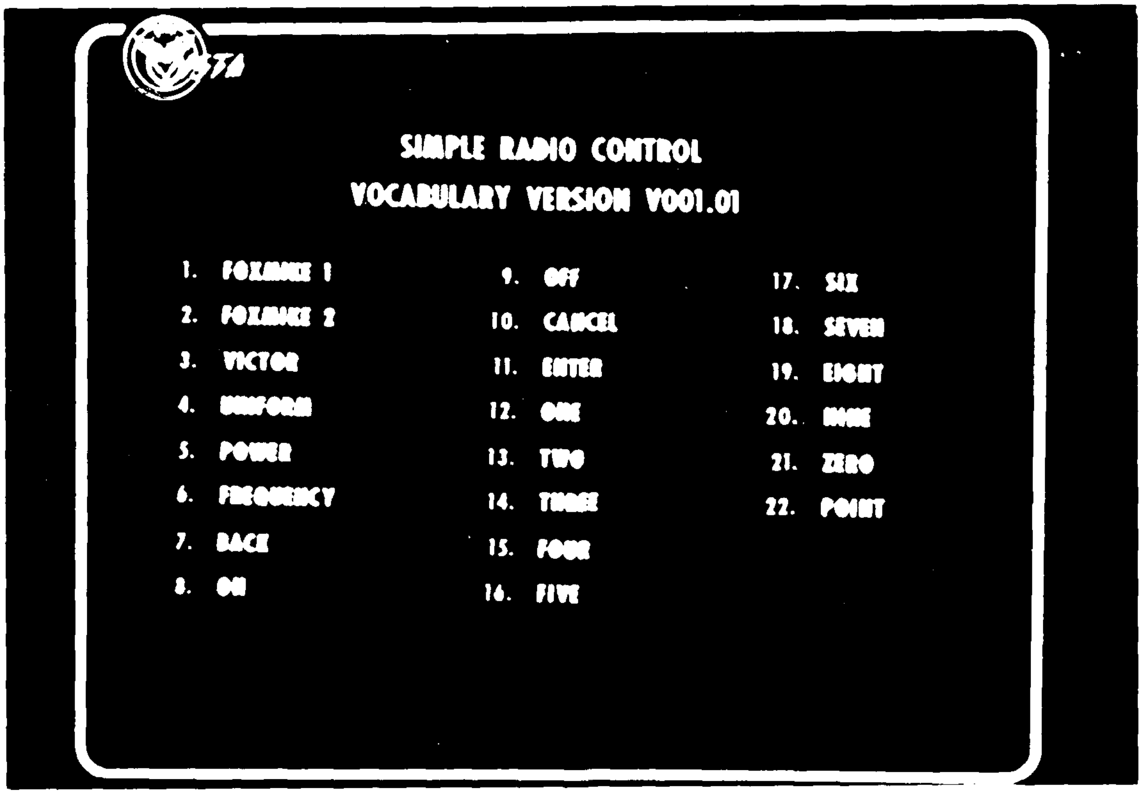
VOICE RECOGNIZER TEST SET UP

RS-232

MICROPHONE MONITOR

AIRCRAFT NOISE SIGNAL

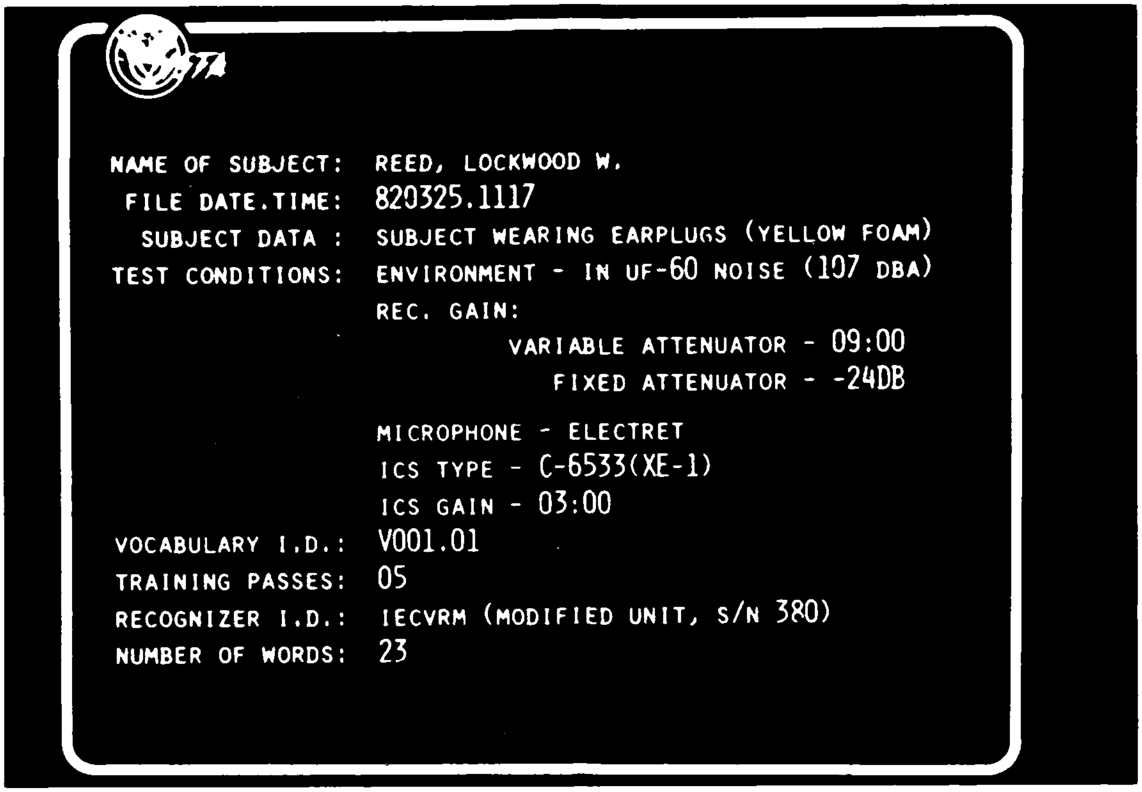
Figure 12



SIMPLE RADIO CONTROL
VOCABULARY VERSION V001.01

1. FOXMIKE 1
2. FOXMIKE 2
3. VICTOR
4. UNIFORM
5. POWER
6. FREQUENCY
7. BACK
8. ON
9. OFF
10. CANCEL
11. ENTER
12. ONE
13. TWO
14. THREE
15. FOUR
16. FIVE
17. SIX
18. SEVEN
19. EIGHT
20. NINE
21. ZERO
22. POINT

Figure 13



```
NAME OF SUBJECT:   REED, LOCKWOOD W.
 FILE DATE.TIME:   820325.1117
  SUBJECT DATA :   SUBJECT WEARING EARPLUGS (YELLOW FOAM)
TEST CONDITIONS:   ENVIRONMENT - IN UF-60 NOISE (107 DBA)
                   REC. GAIN:
                             VARIABLE ATTENUATOR - 09:00
                                FIXED ATTENUATOR - -24DB

                   MICROPHONE - ELECTRET
                   ICS TYPE - C-6533(XE-1)
                   ICS GAIN - 03:00
VOCABULARY I.D.:   V001.01
TRAINING PASSES:   05
RECOGNIZER I.D.:   IECVRM (MODIFIED UNIT, S/N 380)
NUMBER OF WORDS:   23
```

Figure 14

Figure 15

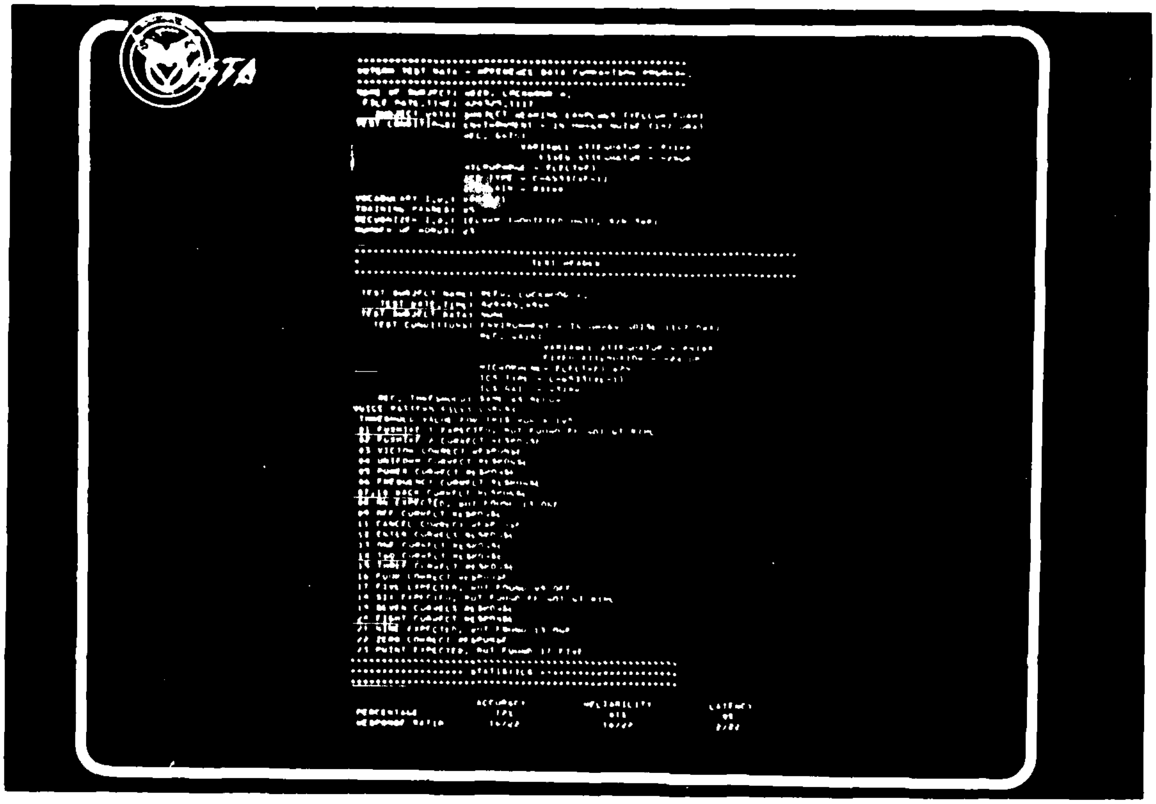
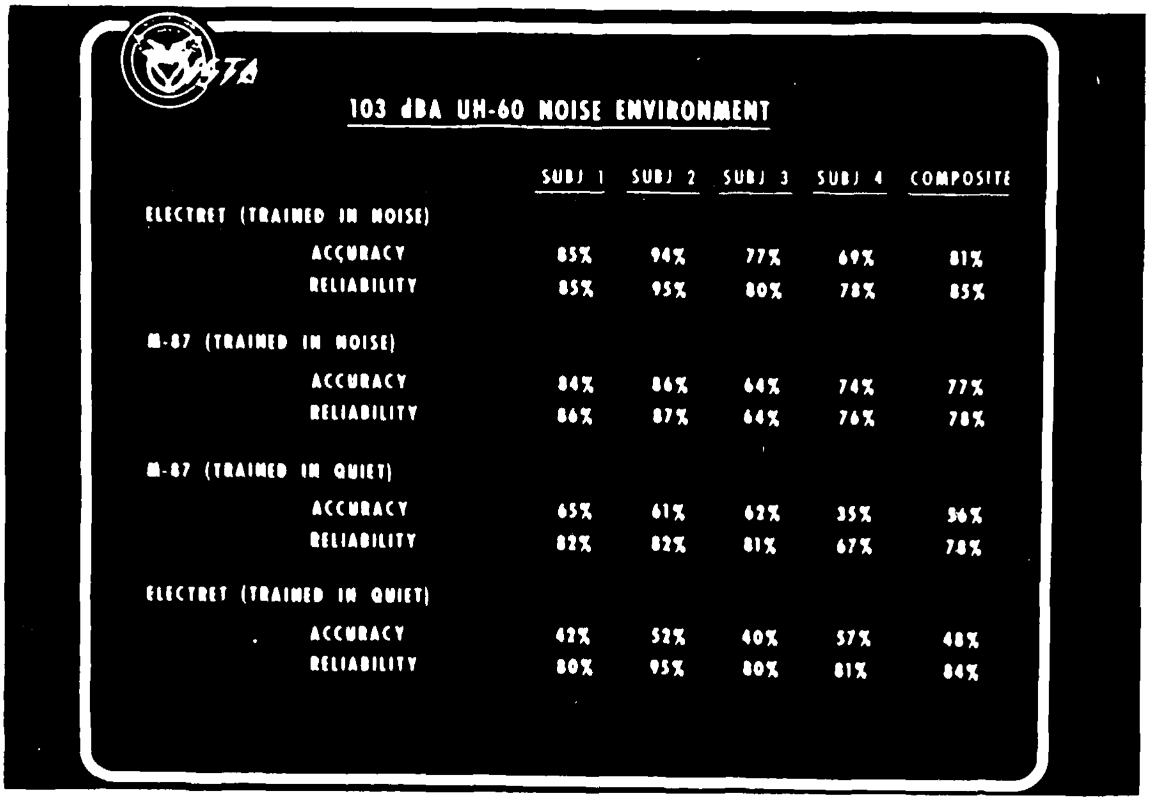


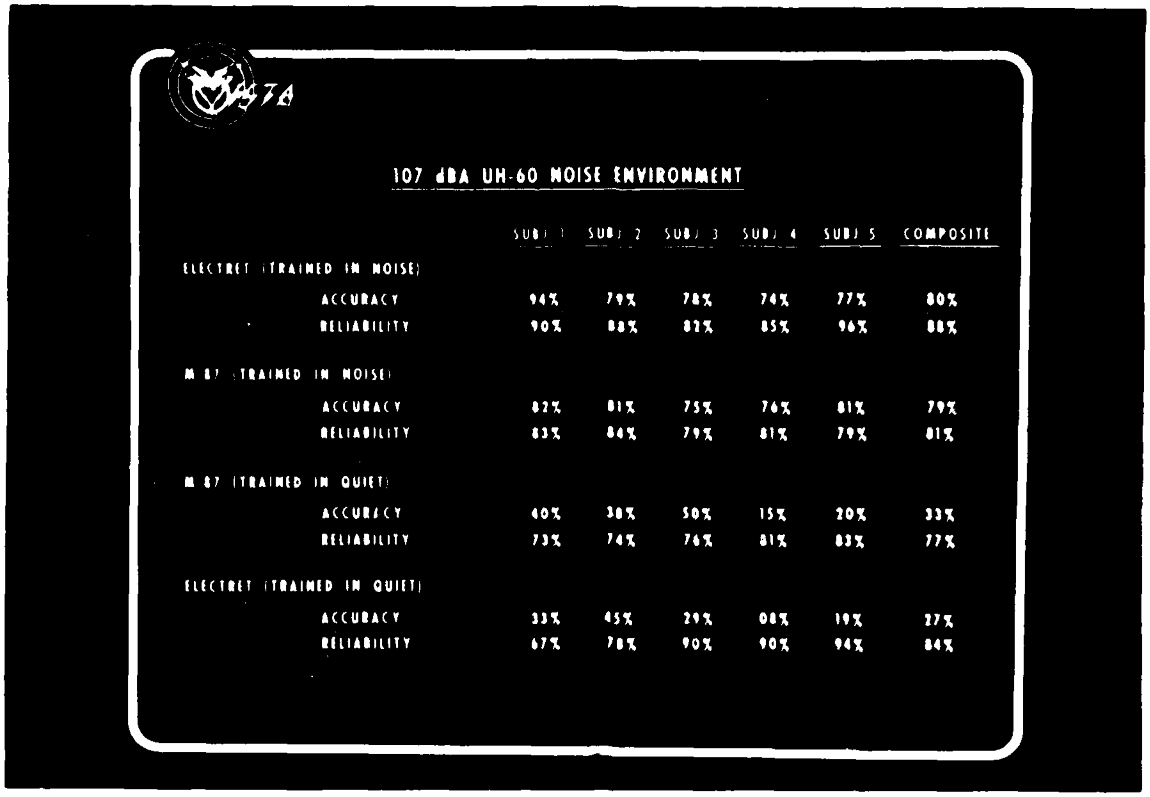
Figure 16



103 dBA UH-60 NOISE ENVIRONMENT

	SUBJ 1	SUBJ 2	SUBJ 3	SUBJ 4	COMPOSITE
ELECTRET (TRAINED IN NOISE)					
ACCURACY	85%	94%	77%	69%	81%
RELIABILITY	85%	95%	80%	78%	85%
M-87 (TRAINED IN NOISE)					
ACCURACY	84%	86%	64%	74%	77%
RELIABILITY	86%	87%	64%	76%	78%
M-87 (TRAINED IN QUIET)					
ACCURACY	65%	61%	62%	35%	56%
RELIABILITY	82%	82%	81%	67%	78%
ELECTRET (TRAINED IN QUIET)					
ACCURACY	42%	52%	40%	57%	48%
RELIABILITY	80%	95%	80%	81%	84%

Figure 17



107 dBA UH-60 NOISE ENVIRONMENT

	SUBJ 1	SUBJ 2	SUBJ 3	SUBJ 4	SUBJ 5	COMPOSITE
ELECTRET (TRAINED IN NOISE)						
ACCURACY	94%	79%	78%	74%	77%	80%
RELIABILITY	90%	88%	82%	85%	96%	88%
M 87 (TRAINED IN NOISE)						
ACCURACY	82%	81%	75%	76%	81%	79%
RELIABILITY	83%	84%	79%	81%	79%	81%
M 87 (TRAINED IN QUIET)						
ACCURACY	40%	38%	50%	15%	20%	33%
RELIABILITY	73%	74%	76%	81%	83%	77%
ELECTRET (TRAINED IN QUIET)						
ACCURACY	33%	45%	29%	08%	19%	27%
RELIABILITY	67%	78%	90%	90%	94%	84%

Figure 18

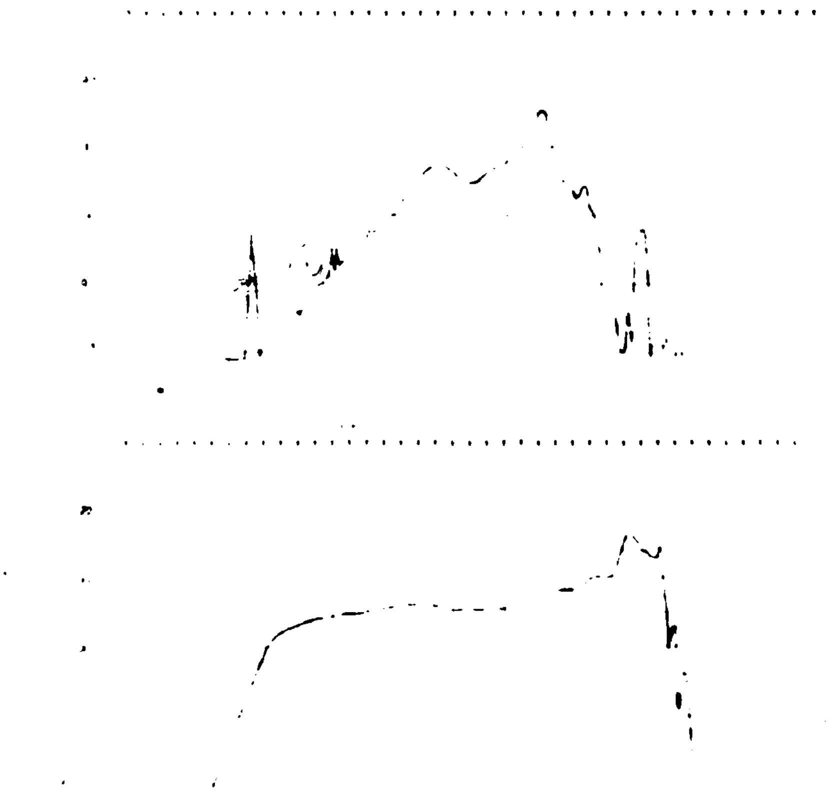


Figure 19

UTILISATION DES TECHNIQUES VOCALES DANS UN AVION DE COMBAT: PREMIERS ENSEIGNEMENTS

par

J.R.Costet et J.M.Malterre
Crouzet S.A.
25 Rue Jules Vedrines
26027 Valence-Cedex
France

C.E.V.Bretigny
France

L'intérêt des techniques de parole (reconnaissance et synthèse) pour les futurs avions de combat est maintenant admis par un nombre croissant d'utilisateurs.

Les principales origines de ce nouveau besoin sont connues :

- les nouvelles définitions du cockpit avec en particulier l'inclinaison vers l'arrière du siège du pilote, pour de meilleures tolérances aux facteurs de charge, ont comme conséquence la réduction des surfaces frontales disponibles

- l'accroissement des possibilités des capteurs embarqués et de la complexité du système d'armes , qui se traduit par la nécessité d'un dialogue de plus en plus riche et versatile

- une charge de travail élevée dans des environnements difficiles

- le coût des versions biplace.

De nombreux travaux sont en cours aux Etats Unis et ailleurs pour étudier les possibilités d'emploi de la parole.

La Société Crouzet a engagé depuis plusieurs annees un programme d'étude et d'expérimentation du dialogue vocal à bord des avions de combat. Ce programme est supporté par les Services Officiels Français, notamment la Direction des Recherches et Etudes Techniques (DRET) et le Service Technique des Télécommunications et des Equipements Aéronautiques (STTE). Il est mené en collaboration avec Les Centres d'Essais en Vols.

Les travaux de recherche fondamentale qui ont rendu possible ce programme ont été menées par un laboratoire du CNRS, le LIMSI.

Cet exposé est en deux parties :

- la première partie est un descriptif des techniques employées et des problèmes rencontrés

- la seconde partie est consacrée à l'aspect expérimental et aux premières appréciations portées portées par les représentants des futurs utilisateurs.

PREMIERE PARTIE

PROGRAMME

Le programme comporte une importante partie expérimentale associée à un effort d'étude continu.

Ce programme a plusieurs objectifs :

- d'une part il doit valider la technique de reconnaissance dans un environnement embarqué militaire

- d'autre part il doit fournir des données de base qui permettront ultérieurement de définir comment, selon quels critères, et à quels types de fonctions le dialogue vocal peut être appliqué.

- L'expérimentation en simulateur est une étude ergonomique qui a pour but d'étudier l'insertion du dialogue vocal dans une phase de vol correspondant à une charge de travail réaliste et bien connue à l'avance. Dans notre cas précis il s'agit de combat Air Air.

- L'expérimentation en vol se fera en deux temps :

  . validation d'un dialogue limité dans un environnement réel couvrant tous les cas de vol

  . synthèse à bord d'un avion doté d'un système d'armes moderne des deux aspects précédents : le dialogue fonctionnel et le fonctionnement dans un environnement embarqué.

Les études associées à ces expérimentations sont elles aussi de deux types :

- Etudes théoriques destinées à faire évoluer les caractéristiques de la reconnaissance, pour l'adapter de mieux en mieux aux besoins futurs.

- Analyse des résultats fournis par les essais et amélioration des performances. Cet aspect est évidemment étroitement lié au déroulement des expérimentations.

PRINCIPE DU DIALOGUE VOCAL

Le dialogue vocal dans un avion de combat comporte plusieurs éléments :

L'importance du bouclage doit tout d'abord être soulignée. L'expérience montre que de sa qualité dépendent le confort du pilote et les performances de reconnaissance.

- Le pilote doit toujours avoir sans effort et dans toutes les circonstances une perception claire et immédiate de l'état dans lequel se trouve le système de reconnaissance : en attente, message reconnu, rejet ou confusion.

- Le vocabulaire employé et sa syntaxe (règles qui régissent la logique de prononciation des mots du vocabulaire dans les commandes complexes) doivent être naturels, simples à employer et faciles à retenir (100 mots constituent un vocabulaire important).

- Le bouclage peut être visuel ou auditif. La synthèse de parole constitue un auxiliaire indispensable de la reconnaissance comme moyen de confirmation. En utilisation normale on doit pourtant éviter son emploi systématique, qui peut être ressenti comme ennuyeux.

LA TECHNIQUE UTILISEE

Les principales caractéristiques de la reconnaissance que nous utilisons sont les mêmes que la grande majorité des techniques actuellement utilisées :

Pour le moment, on utilise une méthode de reconnaissance monolocuteur de mots isolés ; de plus cette reconnaissance s'effectue de façon globale au niveau acoustique.

La reconnaissance est globale : cela veut dire que le mot* est considéré comme une entité unique et que c'est la forme toute entière qui est reconnue, et non pas, par exemple, des unités plus petites (phonèmes ou autres) constitutives des mots d'une langue. Il s'ensuit deux choses :

- Il faut faire un apprentissage au cours duquel la forme de tous les mots est communiquée à la machine, formant ainsi un jeu de références. Les différentes méthodes se distinguent par le nombre de passes d'apprentissage (de 1 à 10 en général).

- La reconnaissance peut s'effectuer sur n'importe quelle forme sonore, et fonctionne en particulier pour toutes les langues.

Le fait que la reconnaissance s'effectue au niveau acoustique signifie qu'elle n'utilise que des informations acoustiques ; ceci confère une importance particulière au problème du bruit et à celui de la prise de son, de la qualité des microphones etc... Dans notre cas toutefois, la reconnaissance est aidée par des informations d'ordre syntaxiques.

La reconnaissance ne fonctionne correctement que si le locuteur est celui qui a fait l'apprentissage. Cette caractéristique est liée aux deux précédentes.

Pour pouvoir être reconnus, les mots prononcés doivent absolument être encadrés de courts silences, d'environ 200 millisecondes.

---

*Mot est à considérer au sens large : ça peut être une locution complète, par exemple "Niveau de carburant".

Le processus de reconnaissance comporte un traitement en plusieurs étapes :

- L'acquisition du signal acoustique, et sa numérisation après passage dans un banc de filtres : on obtient ainsi un sonagramme numérique (représentation dans le plan fréquence-temps de l'énergie. C'est une étape délicate qui doit être franchie dans de bonnes conditions.

La compression, variable selon les méthodes de reconnaissance, a pour but de ne retenir dans la forme acquise que les traits pertinents, paramètres caractéristiques du mot prononcé. Pour un mot donné, l'ensemble de ces paramètres constitue une référence qui occupe une place moindre que celle du sonagramme. En phase d'apprentissage, les références sont rangées en mémoire l'une après l'autre. En phase de reconnaissance ces paramètres constituent la forme comprimée du mot à reconnaître.

- La comparaison s'effectue successivement entre toutes les références et la forme comprimée du mot à reconnaître de façon classique par un algorithme dynamique (Dynamic Time Warping). C'est une phase couteuse en temps.

- Le résultat de la comparaison est une décision qui répond à la question : le mot qui vient d'être prononcé peut-il être assimilé avec un haut degré de probabilité à l'un des mots du vocabulaire de base ?

RESULTATS OBTENUS AU SIMULATEUR

Du point de vue des performances, l'expérimentation en simulateur a permis de mettre en relief un aspect important de la reconnaissance de parole : un processeur de reconnaissance n'a pas de performances en propre ; les résultats obtenus dépendent bien sur de la méthode employée, mais aussi d'un grand nombre de facteurs extérieurs ; les performances recueillies doivent donc être associées à un contexte très précis.

Contexte :

- Un niveau de bruit assez élevé en cabine simulateur,dû à la ventilation des tubes cathodiques, le micro utilisé étant un micro rail non protégé.

- Le pilote dispose sur la manette des gaz d'un interrupteur de commande du microphone.

- Le vocabulaire comporte environ 60 mots, dont 20 chiffres et nombres.

Les trois facteurs les plus influents sur les performances ont été :

- la qualité de l'apprentissage, et notamment la possibilité de vérifier et éventuellement de remplacer certaines références,

- la qualité du dialogue avec en particulier un retour d'information immédiat, une commande de micro facile, et un vocabulaire aisé à retenir,

- l'entrainement du sujet, facteur très important dans l'obtention de bonnes performances.

Les premiers "vols" effectués ont donné des résultats relativement médiocres, de l'ordre de 75 % - 80 %, mais on a pu voir rapidemment après quelques heures d'utilisation que les résultats se stabilisaient autour dès valeurs suivantes :

Lors d'une interception représentant une charge de travail assez élevée, on obtient en moyenne pour 100 mots prononcés :

- 2 à 5 rejets (souvent sur le même mot)

- 0 ou 1 confusion.

Certains sujets ont pu obtenir des scores de l'ordre de 100 %, grâce à une concentration élevée. (Des scores de cet ordre sont assez facilement obtenus au laboratoire, en l'absence de tout autre charge active).

INFLUENCE DE L'ENVIRONNEMENT

Les études en laboratoire à partir de bandes magnétiques enregistrées dans diverses circonstances se révèlent en général assez délicates à faire ; ceci s'explique par la difficulté d'obtenir l'enregistrement d'échantillons de parole dans des conditions répétitives, ne différant que par le degré d'importance de la contrainte ou du paramètre que l'on veut étudier : accélération, bruit, etc...

En général, plusieurs facteurs interfèrent ; néanmoins, ces enregistrements ont permis d'évaluer l'influence des principaux facteurs physiques :

- les accélérations : la reconnaissance semble praticable jusqu'à environ 4g, mais probablement sur un vocabulaire restreint.

Les distorsions de la voix sous facteur de charge ont deux causes différentes : les difficultés de respiration et les mouvements du masque.

- Les vibrations : elles occasionnent une chute de performances, particulièrement dans la bande de 4 à 10 Hz, en fonction de l'énergie injectée.

Les principales difficultés viennent du bruit dans le masque :

- le bruit de respiration,

- le bruit des clapets

- le manque d'étanchéité sur le visage permettant momentanément au bruit ambiant de pénétrer dans le masque.

Les reconnaissances effectuées avec masque au laboratoire dans des conditions reproduisant le débit d'air normal au sol ont donné des résultats satisfaisants.

Les surpressions du mélange air-oxygène dans le masque, correspondant à un mode secours, empêchent toute reconnaissance, à moins qu'un apprentissage ait pu être fait dans ces conditions particulières.

Dans l'état actuel des choses, l'obtention de performances satisfaisantes en vol parait nécessiter trois conditions :

- un positionnement répétitif du masque, de manière à assurer la constance des conditions de prise de son

- l'utilisation d'un interrupteur de commande du microphone, facilitant le contrôle de l'élocution et la séparation respiration - parole

- l'entrainement du locuteur.

DEUXIEME PARTIE

Au 15 Mars 1982, les essais relatifs à la commande vocale se résument :

- aux essais en simulateur (Istres)

- à la définition et réalisation du chantier d'implantation d'une maquette de dialogue vocal embarquable à bord d'un avion d'armes Mirage III R (Brétigny).

1 - ESSAIS EN SIMULATEUR

1-1 Objectifs

La mise en place du système de dialogue au simulateur d'Istres, répond aux objectifs suivants :

- la validation des techniques de reconnaissance et de synthèse de parole dans l'ambiance simulateur

- l'étude de l'intégration des procédures de dialogue vocal en situation opérationnelle sur avion de combat

- l'adaptation des pilotes aux conditions d'utilisation.

1-2 Architecture du système

Au niveau industriel , il est constitué de la maquette autonome de dialogue vocal qui :

- gère les procédures nécessaires à l'apprentissage, reconnaissance, définition des modifications de dialogue et syntaxe, ainsi que l'exploitation des essais

- effectue la reconnaissance des ordres et la synthèse des messages

au niveau simulateur, l'environnement expérimental retenu est une cabine chasseur moderne.

Le systeme comprend :

- une cabine chasseur
- un ensemble de calculateurs de simulation
- une salle de suivi d'essais permettant le dialogue Pilote/Ingénieur.

Il faut noter, pour les besoins de l'essai :

- la presence de 2 microphones independants (respectivement pour le dialogue pilote/ingenieur et le dialogue pilote/système vocal)

- le choix à discretion de l'ingénieur entre le dialogue Pilote/maquette en micro ouvert, ou en micro commande

- la presence en cabine d'une commande "temps réel", permettant dans ce dernier cas au pilote de commander le micro.

1-3 Aspects fonctionnels du système

L'implantation de la technique vocale permet précisément :

- la SYNTHESE au niveau du pilote, de divers messages (suivant un ordre de priorité)

MESSAGES DE PANNES

MESSAGES DE LIMITE DE DOMAINE

MACH TROP ELEVE

VITESSE TROP ELEVEE

INCIDENCE TROP ELEVEE

MESSAGES DE CONSIGNES OPERATIONNELLES

HAUTEUR DE SECURITE

dès que les conditions requises sont présentes.

- la reconnaissance d'ordres pilote agissant sur le SNA (système de navigation et d'armement) et le PA (pilote automatique).

* Le VOCABULAIRE, défini au préalable, obéissant à une syntaxe donnée (actuellement, seuls les mots isolés sont reconnus), a été retenu pour son aptitude à la reconnaissance et son aspect opérationnel.

* 2 catégories de commandes ont été sélectionnées :

COMMANDES STABLES

Elles font l'objet d'action manuelle sur des interrupteurs ou des rotacteurs à position stable. Dans le cadre de la simulation, elles peuvent être actionnées soit vocalement, soit manuellement, par sélection de mode sur le pupitre ingénieur.

COMMANDES RADAR	1 LIGNE/2 LIGNES/4 LIGNES
(sur poste commande du radar)	SILENCE EMISSION BALAYAGE...

COMMANDES INSTABLES

Elles sont actionnées normalement par poussoir instable d'où la possibilité qu'elles offrent d'entrelacer, en temps réel, les commandes vocales et manuelles.

SELECTION AIR/AIR

COMMANDE RADAR

COMMANDES PA (Bip - Trim)	DROITE, GAUCHE suivi de la route d'arrêt (ex : DROITE - 3 - 5 - 0) PIQUE, CABRE, suivi de la pente relative (ex : CABRE - 5) PALIER

L'ordre, ainsi donné vocalement, se traduit donc immédiatement après sa reconnaissance par le changement d'état des systèmes concernés : Radar, Pilote automatique, et donc de leurs signalisations.

- LA REPONSE EN SYNTHESE VOCALE à certaines questions élaborées par le pilote, faisant donc intervenir les 2 chaînes de la commande vocale, que sont la reconnaissance et la synthèse.

A l'interrogation

ALTITUDE, il sera répondu au pilote la valeur de l'altitude actuelle.

1-4 INTEGRATION du SYSTEME dans le boucle pilote

La tâche de reconnaissance du système vocal se manifeste au pilote par la synthèse du mot reconnu suivi :

- soit de l'exécution de l'ordre (manoeuvre et/ou chargement d'état visualisés en HUD ou HDD)
- soit de la synthèse du paramètre sollicité (ex (Pilote) : ALTITUDE ?
  (Retour) : 15500 pieds)
- soit de la synthèse du diagnostic, si le mot n'a pas été reconnu
  (ex : REPETEZ, MAUVAIS DEPART...)

A noter que le pilote peut opérer :

- soit en MICRO OUVERT, c'est à dire que la reconnaissance fonctionne continûment
- soit en MICRO COMMANDE, c'est à dire que la reconnaissance n'est effective que sur ordre du pilote (le pilote doit appuyer sur le switch de l'ordre de 100 ms avant de prononcer un mot).

1-5 Résultats

Les essais en simulateur effectués à ce jour, ont mis en évidence les points suivants :

* La synthèse vocale constitue un apport extrêmement précieux d'avertissement dans les phases où la charge de travail du pilote est importante et risque de polariser le pilote en dehors des notions de limites opérationnelles.

* L'intérêt de poursuivre vocalement des manoeuvres ou changements d'état de SNA, commences manuellement, (ou vice-versa) a été souligné.

Cette notion d'entrelacer les commandes vocales et manuelles reste néanmoins à approfondir, car les essais se sont déroulés dans une cabine chasseur, conçue hors du concept vocal, et donc, par principe, non optimisé pour l'entrelacé.

* Un diagnostic précis des causes ayant présidées à la non reconnaissance d'ordres doit répondre à l'attente du pilote.

* Le choix du vocabulaire doit être effectué suivant les critères de sélectivité, d'adaptation operationnelle, de capacité de reconnaissance et de prononciation instinctive.

* La prononciation de mots isolés constitue une limite importante, surtout en ce qui concerne les commandes ayant pour effet un changement de trajectoires. (Cde PA), par suite des délais de transmission des mots enchainés.

* La nécessité de procéder à l'entrainement des pilotes afin d'accélérer les processus de la nouvelle boucle, [pilote → Commande vocale → Avion → Pilote] .

* La nécessité de garder une position fixe du microphone au cours des phases successives d'apprentissage et de fonctions opérationnelles.

* La position "micro ouvert", c'est à dire, la configuration du système en reconnaissance permanente, semble prématurée ; il lui est préféré la situation "micro commandé", oû le système est initialisé avec précision par le pilote.

2 - ESSAIS EN VOL

2-1 Objectifs

En vue d'entreprendre les essais de reconnaissance et synthèse de la parole sur avion d'armes, le Centre d'Essais en Vol de Brétigny a effectué sur un mirage III R un chantier d'implantation des equipements de dialogue vocal.

Ces essais consisteront à mettre au point . la notion de dialogue vocal à bord d'avion d'armes en étudiant :

- l'influence des facteurs* modifiant la voix du pilote sur la reconnaissance de parole (accélération, vibrations, dépression,...)

- la synthèse de certaines alarmes et manoeuvres

- l'appel de certains paramètres du vol sur demande pilote

- la commande de certains équipements particuliers tels que l'autocommande ou le poste de radio UHF principal.

2-2 Composition du système embarqué

Ce système comprend :

EN POINTE AVANT

- 1 Calculateur nécessaire à la gestion du système, à la reconnaissance et synthèse

- 1 Enregistreur magnétique à cassettes numériques et son alimentation destinés :
  . à fournir à la maquette embarquée les données numériques correspondant au vocabulaire à reconnaître et synthétiser
  . à enregistrer la totalité des informations nécessaires à l'exploitation des vols (paramètres du vol, sonagrammes...) sous forme numérique.

- 1 Magnétophone à cassettes destiné à enregistrer le signal audio, en provenance du microphone et du calculateur.

EN CABINE PILOTE

- 1 boitier de commandes et de visualisation, situé en haut de la planche de bord, à la place de la semelle du viseur, permettant :
  . la mise sous tension du système
  . l'arrêt de la synthèse
  . le signalement de l'état : "prêt pour reconnaissance".
  . la visualisation sur écran à cristaux liquides, par 2 lignes de 20 caractères, de données inhérentes au système (information, diagnostic, commande, états de mémoire...)

---

* Un certain nombre de passages en centrifugeuse, caisson d'altitude et pont vibrant, ont permis de sérier certaines difficultés inhérentes au système (cf LAMAS).

- Un poussoir de commande situé sur le manche, permettant d'effectuer la reconnaissance en "micro commandé".

- 1 boitier de tests dont le rôle est de permettre au pilote de tester la synthèse vocale des pannes et manoeuvres retenues pour ce système.

En outre, 2 inverseurs de secours permettent la déconnexion totale des systèmes d'alarme avion de base et synthèse vocale en cas de doute du pilote sur l'occurence de telles pannes, et le rétablissement des liaisons normales en provenance du microphone en cas de pannes du système vocal.

- 1 poste de commande radio UHF, à affichage des fréquences manuel ou vocal, à liaisons entièrement numérisées.

- 1 poste de commande du stabilisateur de trajectoire (autocommande), comportant 2 boutons poussoirs lumineux, (embrayage du stabilisateur et tenue d'altitude) pouvant être activés manuellement ou vocalement.

Il faut noter que l'état du poste de commnade est indépendant du choix de la manière d'activation des modes présentés (manuel ou vocal).

2-3 Aspects fonctionnels du système

- Synthèse des pannes

Les pannes faisant l'objet d'une synthèse sont les suivantes :

Panne hydraulique 1/2/secours

Panne trim automatique

Panne basse pression carburant

Panne pression huile

Panne pression et température cabine

Panne batterie

Panne génératrice

Panne alternateur

Panne régulateur d'oxygène

Panne anémomètre

- Synthèse de changements d'état

. sortie du train et verrouillage

. transferts des réservoirs de carburant

. débrayage du stabilisateur de trajectoire.

A noter qu'un ordre de priorité est établi pour tenir compte de messages simultanément sollicités.

Dans le cas de panne doublée d'une alarme sonore, l'effacement de cette alarme sonore lèvera l'interdiction de transmission en message synthétisé.

- Appel de paramètres du vol

Le pilote peut, lorsqu'il le désire, demander en clair, la valeur des paramètres suivants :

. le Mach
. l'altitude
. l'incidence
. la vitesse propre
. la distance et le relèvement par rapport à une balise sélectée
. l'altitude
. le carburant restant.

- Manoeuvres vocales à disposition du pilote

. Embrayage et débrayage du stabilisateur de trajectoire
. Embrayage de la tenue d'altitude
. Sélection de fréquences UHF.

Il faut noter que la mise en service de ce système vocal implique la possibilité de vérifier à tout instant, par lecture directe sur la planche de bord ou sur le boîtier de visualisation, ainsi que par synthèse de diagnostic, l'ensemble des éléments de vol faisant l'objet de cette phase d'essais vocaux.

PERFORMANCE DECREMENTS ASSOCIATED WITH REACTION TO VOICE WARNING MESSAGES

John Wheale
RAF Institute of Aviation Medicine
Farnborough, Hampshire, England

ABSTRACT

Voice warning messages are being adopted as an alternative to audio warnings because they can be readily understood, generate fast reaction times and supposedly allow a smooth transition from message to action. This experiment evaluated the effectiveness of synthesized voice messages using measures of performance decrement and response time in the context of a central warning system with audio, voice and visual indicators. The subject's task was to maintain accuracy on a psychomotor tracking task whilst responding to warnings. The results show that the various combinations of warning types could not be differentiated with respect to performance decrement on the primary task. The data for reaction time show that audio warnings produce the fastest responses, followed by voice warnings, with CWP indicators producing the slowest responses. The implications of the results for the role of synthesized voice warning messages in central warning systems is discussed.

INTRODUCTION

In the visually overloaded environment of the flight deck of commercial jet transport aircraft, indications of aircraft malfunctions have often been presented in the auditory channel. There are substantial reasons for such auditory alerting; with auditory signals the visual sense is released for other tasks and attention may be directed elsewhere; response times (RT) are shorter to auditory than visual stimuli; auditory alerts can be delivered by equipment that is not in prime panel space; the response to auditory alerts is not limited by head orientation; audition is the alerting sense and is less susceptible than vision to the effects of vibration, low oxygen levels, decreased blood supply to the brain, and glare. However, the use of warning sounds (audio warnings), such as the firebell, for example, has been brought into question by recent data which have shown that audio warnings are often unnecessarily loud (Patterson and Milroy, 1979) and too great in number to be easily remembered (Patterson and Milroy, 1980). Indeed, the research has substantiated in large part the claims by pilots that audio warnings in commercial transports are confusing, interfere with conversation, and make clear thinking difficult (Du Ross, 1978).

One solution to this problem would be to substitute or supplement audio warnings with voice warnings in which a verbal message, indicating the nature of the aircraft emergency, is presented to the pilots. Voice warnings have all the human factors advantages that audio warnings have but, additionally, the recognition of a voice message should be immediate and accurate whereas the accuracy of recognition of an audio warning is related to the total number of audio warnings used and to the similarity of their temporal patterning (Patterson and Milroy, 1980).

The use of a voice warning to signal aircraft emergencies is not a new idea; indeed, Kemmerling et al. (1969) stated that voice warnings have been operationally possible for military aircraft since 1958. At the present time the use of voice messages is gaining favour as technical development in the electronic storage and processing of voice data progresses (Simpson and Williams, 1980). The problem now is to determine, on the basis of human factors evidence, what rôle voice warnings can and should take in a centralized warning system. Voice warnings could be used to supplement a limited number of audio warnings or they could replace audio warnings completely even for immediate-action alerts. The future role of voice warnings on the flight deck can only be determined if we have an accurate understanding of their effectiveness relative to audio and central warning panel (CWP) alerts.

Kemmerling et al. (1969) showed that voice warnings were actioned more effectively than audio warnings because on receipt of a voice message the pilots initiated emergency drill without cross-checking the central warning panel. The pilots always referred to the CWP on receipt of an audio warning before initiating a response to the emergency. This difference in pilot behaviour was manifest by the finding that the reaction time to voice warnings was significantly shorter than to audio warnings. Kemmerling et al. (1969) also recorded the deviation in simulator airspeed, altitude and pitch attitude ten seconds before and ten seconds after the presentation of an auditory alert. There was no significant difference in the amount of deviation produced by the two types of auditory warnings on these flight parameters. Hart and Simpson (1976) found differences in the amount of attentional capacity required to perceive electronically-synthesized voice warning messages. An increase in linguistic redundancy, achieved by presenting monosyllabic key-words in a sentence format, decreased the amount of attentional capacity required to process the messages, the latter being measured by use of a concurrent time-estimation task known to be sensitive to variations in processing capacity. They also reported that the degree of familiarity of a warning message was directly related to the amount of attentional capacity required to comprehend the message.

Thus, the evidence suggests that voice warnings are more effective than audio warnings because, being directly comprehensible and overlearned, voice messages require less attentional capacity for recognition than do audio warnings. Furthermore, if this hypothesis is correct then a response to a voice alert will cause less disruption of the primary flying task than will a response to an equivalent audio alert. Consequently, voice warnings should be effective because they are easier to understand and they facilitate emergency response. It is because voice warnings are perceived to be advantageous from the human factors viewpoint that several authors have predicted a rapid expansion of their use on the flight deck (Klass, 1981; Sexton and Jones, 1981).

The purpose of the experiment reported here was to compare different combinations of audio, voice and CWP warnings, representing possible future warning systems for commercial transport aircraft, by measuring both the speed of response and the primary task performance decrement. The RT data have been reported elsewhere (Wheale, 1981). Performance decrement on the main task was measured precisely by monitoring behaviour on a simulated flying task both before and after presentation of voice, audio and CWP alerts

The experiment was part of a research programme, funded by the Civil Aviation Authority, which examined the rôle of voice warning messages on the flight decks of commercial transport aircraft.

METHOD OF EVALUATION

Warning Systems

In the experimental study there were, for each of the four conditions, 24 possible alerts which were presented using visual, audio or voice indicators. The system used was a derivation of the HS 146 warning panel with master caution lights set in the main field of vision and an annunciator panel, which provided detailed information, positioned to the right of a tracking display. The annunciator panel was sub-divided into three groups of Red (6), Amber (14) and White (4) illuminated legends providing emergency, advisory and information alerts respectively. Four warning system designs were used (Wheale, 1981) and in each warning system an alert consisted of an illuminated legend and a flashing attention-getting light of the appropriate category centrally located. These visual displays were selectively supplemented with a voice message or an audio warning (see Table 1). If an alert had an audio or voice component the onset of the sound was coincident with the onset of the visual indicators. For each alert there was a response button which eliminated the visual indicator but it did not cancel the audio warning or the voice message. The audio warning repeated for five seconds and the voice warning repeated once to give a total duration of five seconds.

TABLE 1

ARRANGEMENT OF AUDIO WARNINGS AND VOICE MESSAGES
IN THE FOUR EXPERIMENTAL CONDITIONS

Condition A	Red Alerts (6) supplemented with audio warnings
Condition B	Red Alerts (6) supplemented with voice messages
Condition C	Red Alerts (6) supplemented with audio warnings Amber Alerts for Flight Deviations (4) supplemented with voice messages
Condition D	Red Alerts (6) supplemented with audio warnings Amber Alerts (14) supplemented with voice messages White Alerts (4) supplemented with voice messages

Figures in parentheses show number of different alerts employed.

The audio warnings used in the experiment were selected from a variety of aircraft and were chosen because of their distinctiveness and generality (see Table 2). The voice messages were produced by a Votrax ML-1 Speech Synthesizer. The wording of the message is shown in Table 3; the voice messages were in the key-word format as recommended by US line pilots surveyed by Williams and Sympson (1976). Each voice message began with the word "Warning" which was included to alert and to gain attention. The 'white' or 'information' alerts were in a sentence format.

TABLE 2

EXPERIMENTAL AUDIO WARNINGS: NAME, AIRCRAFT OF ORIGIN AND DESCRIPTION

Warning	Source	Description
Fire	BAC 1-11	Ringing bell
Undercarriage	L 1011	Horn
Take-off Configuration	BAC 1-11	Intermittent horn
Disconnected Autopilot	B-747	Siren being started repeatedly
Overspeed	BAC 1-11	Clacker

TABLE 3

EXPERIMENTAL VOICE WARNING VOCABULARY

Category	Emergency	Voice Message
RED	Engine Fire	Warning : Fire No. 1 Engine
		Warning : Fire No. 2 Engine
	Stall	Warning : Stall
	U/C Unsafe	Warning : Undercarriage Unsafe
	Configuration	Warning : Configuration
	Autopilot Disconnect	Warning : Autopilot Disconnect
AMBER	Fuel Pressure Low	Warning : Fuel Pressure Low
	Oil Pressure Low	Warning : Oil Pressure Low
	Engine Vibration	Warning : Vibration No. 1 Engine
		Warning : Vibration No. 2 Engine
	Electrical Smoke	Warning : Smoke Electrical
	Fuel Temp High	Warning : Fuel Temperature High
	Ice Detected	Warning : Ice Detected
	Hydraulic Pressure	Warning : Check Hydraulic Pressure
	Air Conditioning	Warning : Air Conditioning
	Engine Overspeed	Warning : Engine Overspeed
	Glide Slope	Warning : Glide Slope
	Sink Rate	Warning : Sink Rate
	Excessive Air Speed	Warning : Air Speed High
	Altitude Alert	Warning : Altitude
WHITE	Radio Fan Off	The Radio Fan is Off
	Emergency Lights	The Emergency Lights are On
	Cross Feed Open	The Cross Feed is Open
	Flt Recorder Off	The Flight Recorder is Off

TEST PROCEDURE

The subjects were briefed about the nature and purpose of the experiment, before being introduced to one of the four warning systems, to which they were randomly allocated. Subsequently, the subjects were familiarised with the warnings and the psychomotor tracking task. Each subject listened to all 24 voice messages three times. If the warning system included audio warnings (i.e., conditions A, C and D) the subject listened to a recording of the warnings until he could identify them all without error on three successive presentations. Additionally, the subjects were exposed to the operation of all 24 alerts on the annunciator panel and were required to check the appropriate response button for each alert. This was followed by a ten-minute practice period on the psychomotor tracking task. The tracking task displayed on a CRT involved keeping the intersection of horizontal and vertical cursor lines in the middle of a stationary central square. The cursor lines were externally controlled by pseudo-random inputs which the subject had to counteract by manipulating a two-axis joystick. The program for the task was run on a PDP-8 computer using a Digital Equipment Corporation 388 display unit. The screen diameter was 406 mm with an active area equivalent to the length of the cursor lines, i.e., 228 mm. The stationary target square had sides of 30 mm. The screen was viewed from a distance of 450 mm. In preliminary trials, four pilots were employed to set the tracking task at a level of difficulty that required constant but not intense concentration and effort.

As the subject controlled the joystick the computer noted the deviation from centre-screen of the intersection of the horizontal and vertical cursor lines at a rate of one hundred samples per second. The x-y coordinate RMS values for the 15-second period prior to the onset of a warning and for the 15-second period following warning onset were stored in data files. The pre-warning period was used as a control level for the period following warning onset. The post-warning period was sectioned into 5 periods of one-second duration followed with two periods of five-second duration. Previous work (Wheale et al., 1979) suggested that the performance consequences of reaction to a warning would persist for only a very short time.

The experimental task was maintained in an environment of cockpit noise (recorded during straight-and-level flight in a B-727) and recorded Air Traffic Control - Aircraft communications, which had been edited to produce continuous conversation. Inserted into the ATC tape were messages prefixed by a unique call-sign to which the subjects were required to respond verbally. These auditory inputs produced a background noise level of 71 db (linear), which is representative of the noise level in current transport aircraft. The voice messages and audio warnings were presented over loudspeakers giving intensities at the subjects' ears of 80 and 85 db (linear) respectively.

The experiment lasted for 80 minutes during which time 30 alerts were presented, six alerts being presented twice to maintain stimulus uncertainty. The order of the alerts was randomised. The separation time between alerts averaged 160 seconds, varying randomly between 60 and 260 seconds. The response to an alert was quite simple, requiring only the cancellation of the appropriate response button. The response buttons were located on a panel to the left of the subject, though they did not have the same spatial configuration as on the CWP, so that subjects could not respond on the basis of a transfer of positional sense from the CWP.

SUBJECTS

Thirty pilots took part in the experiment; fourteen completed conditions A and C and sixteen completed conditions B and D. The pilots were current on a wide variety of aircraft types and represented five airlines. The group consisted of 11 Captains and 19 First Officers. The average age was 36 years (range 23-54 years) and the average total flying hours was 6,213 (range 1,300-18,000 hours). All the pilots volunteered to take part in their own time; six pilots were drawn directly from British Airways with the remainder volunteering as a result of the British Air Line Pilots Association's co-operation in the study.

RESULTS

The performance decrements on the primary tracking task associated with reaction to different warning types for the four warning conditions are shown in Figures 1 to 4. There is an increase in tracking error following the onset of each warning. The amount of tracking error for each warning type initially increases reaching a maximum at a time which is roughly equivalent to the mean reaction time for that warning type, and subsequently decreases (see Figures 1 to 4). The performance consequences of the reaction to a warning are measurable fifteen seconds after warning onset, which is approximately ten seconds after the offset of the auditory component, if one was associated with the warning.

For the analysis of variance two measures of performance were derived, one (P_1) representing tracking error scores for the five-second period following warning onset and the other (P_2) for the fifteen-second period following warning onset. Tracking error was computed with reference to the fifteen-second control period before the onset of each individual warning. For both performance values the basic data were transformed for analysis. In the transformation a constant was added to the raw score (S) values of the tracking decrement in order to compensate for the few raw scores with a negative value, the latter being associated with tracking performance better than that achieved during the control period.

Hence, $P_1 = \log_{10} (S_5 - S_c + 150)$ and $P_2 = \log_{10} (S_{15} - S_c + 650)$

where S_5 and S_{15} are the raw scores for post-warning tracking performance and S_c are the equivalent tracking control scores.

There was no difference between the four warning conditions A, B, C and D in terms of performance decrement on the primary task. When the Amber and White alerts were analysed separately from the Red alerts no difference was observed between the voice warnings and the CWP warnings on tracking error scores (P_1 and P_2). This grouping was further subdivided into the Amber alerts (Numbers 7 to 16), which were signalled with voice messages using the key-word format, and the White alerts (Numbers 21 to 24) signalled by voice messages using a sentence context (see Table 3). For both types of voice message format no significant difference was observed for either P_1 or P_2 between the increase in tracking error induced by the voice warnings and that induced by the CWP warnings.

For the Red alerts (Numbers 1 to 6) there was no significant difference in the amount of tracking error by the voice and the audio warnings (P_1 and P_2). However, it was found that when the Flight Deviation warnings (Numbers 17 to 20) were signalled by voice messages there was less disruption on the primary task than when they were signalled by CWP indicators alone (P_2, $p < 0.06$; see Figure 5).

The tracking error data for each of the 24 warnings were tabulated across the four warning conditions and the warnings were rank ordered. Within the group of Red alerts the 'CONFIGURATION' warning induced the worst performance scores although it did not differ significantly from the remaining Red alerts. For the Amber and White alerts the 'ICE DETECTED' and 'ENGINE OVERSPEED' warnings induced the worst performance scores although they were not statistically discriminable from the remaining Amber and White alerts. When the individual alerts were ordered according to the amount of performance decrement they produced the order was similar to that reported for the RT data (Wheale, 1981) with those warnings that produced large reaction times being the warnings that induce high error scores. Consequently, a correlation between tracking error and RT for each warning across subjects and across conditions (698 data points) was calculated. Performance decrement (P_2) correlated significantly with the reaction time to a warning. For the between-subject data the relationship can be expressed as follows: $P_2 = 6.5515 + 0.2448 \ LOG_{10}RT$ ($r = 0.452$; $p < 0.001$). The relationship for the within-subject data is stronger and is expressed thus: $P_2 = 6.4535 + 0.31472 \ LOG_{10}RT$ ($r = 0.52$; $p < 0.001$). Both relationships are shown in Figure 6.

DISCUSSION

Although a decrement in performance was detectable on the primary task for up to ten seconds following the completion of the warning response, the results show that changes in performance accuracy on the primary task did not differentiate in a statistically significant manner between the four warning systems used in the study. It would appear, therefore, that a central warning system consisting of a small number of audio warnings dedicated to the Red alerts with CWP legends for the Amber and White alerts is essentially no different in human factors terms from a similar warning system in which the Amber and White alerts are additionally indicated by synthesized voice messages.

An identical conclusion was reached when the same four warning systems were evaluated in terms of the speed of response to a warning (Wheale, 1981). A significant correlation was observed between RT and performance decrement on the primary task which indicates that the longer the pilots took to respond to a warning the greater was the disruption of their main tracking activity. This result could be seen to favour the use of audio warnings for Red alerts as the audio warnings produced a significantly faster pilot response than did the voice warnings (Wheale, 1981). However, it is not possible to differentiate audio warnings from voice warnings on the basis of disruption to the primary task.

The findings of Kemmerling et al. (1969) indicate that voice warnings should cause less disruption than audio warnings to the primary task. But the study reported here differs from that of Kemmerling et al. in three important ways. First, this study used a synthesized voice as opposed to a tape-recorded female voice for the warning messages. Although the synthetic voice outputs of the Votrax were perfectly acceptable to the pilots prior to the testing phase of this study, in the debrief several pilots did offer the observation that the synthetic voice was difficult to understand whilst concentrating on the primary task. In addition, 95 per cent of the responses to voice warnings involved a visual cross-check of the CWP, which means that the pilots were not completely confident about this type of warning. It should be borne in mind, however, that the behaviour of cross-referring may also reflect the pilot's training and experience. Indeed, in a subsequent interview 57 per cent of the pilots maintained that they would always cross-check a voice warning with the CWP.

A particular example of the type of problem that can occur with synthetic voice is highlighted by the significantly high RT, and high performance decrement associated with the voice warning for CONFIGURATION. A high proportion of pilots noted that the pronounciation of the message was not normal. The elevated RT and the high performance decrement for the CONFIGURATION message was possibly due to the perceptual conflict generated by a clear and intelligible message which had an unusual rhythm and intonation. This evidence suggests that the difficulties associated with the use of a synthesized voice may be eliminated by the use of real voice messages which can be encoded and stored in digital form.

A second variable that may account for the discrepancy between results of the present experiment and that of Kemmerling et al. (1969) is that they used only three voice messages or three audio warnings, whereas this study used five audio warnings and six voice messages or more. However, in the one experimental condition where a small number of voice warnings was used in this study to signal the Flight Deviation warnings there was a significant gain in primary task performance when compared with the use of CWP legends alone. This latter condition is similar in principle to the current system of warnings on commercial transport aircraft, where the Ground Proximity Warning System voice messages add to the existing set of audio warnings. However, it is hypothesized that the strategy pilots adopt when dealing with an auditory warning depends on the total number of warnings in that set. If the set number exceeds four or five then the pilot's difficulty in identifying a voice message or an audio warning may show a disproportionately large increase (Patterson and Milroy, 1980). Given that the number of voice messages is greater than this small number, then pilots will adopt the strategy of cross-checking the CWP when they receive a voice message, just as they would with an audio warning, because they are not completely confident about which emergency it represents. This tendency to cross-refer voice messages will increase if the voice quality associated with the warning is not acceptable. However, no evidence was found in either the RT or the performance data to suggest that voice messages in a sentence format are easier for pilots to deal with than are voice messages in a key-word format. This is not consistent with the hypothesis of Hart and Simpson (1976), who maintained that voice messages in a sentence format are more effective.

The final factor that distinguishes the Kemmerling et al. (1969) study from the one reported here is the degree of visual task loading imposed on the pilots. Under high visual task loading it was absolutely essential for the pilots to keep their direction of gaze outside the cockpit and on the terrain display in order to complete the simulated military mission and this may have been sufficient to encourage the pilots to go straight from voice warning to corrective action. However, it should be noted, a behavioural difference between the response to voice and audio warnings was not observed with task loading at a low or medium level. In general, the requirement to look outside the aircraft is not so great for the pilots of commercial transport aircraft. The transfer to the simulated flying task of visual habits acquired in commercial operations could be the factor that made the pilots in this study cross-check voice warnings with the CWP legends. Whatever the reason for the differences in response to voice messages it would seem that a full account must be taken of operational requirements as they relate to pilot behaviour before statements can be made about the effectiveness of different warning types.

This experiment was carried out with the intention of using the results to establish guidelines for the design of an optimum warning system in which audio warnings and voice messages supplement the essential and basic display of the CWP. The results of the study have shown that neither speed of response to a warning nor the decrement produced by a warning on the primary task can be used to differentiate between the various warning combinations. However, sufficient evidence has been gathered to indicate that voice and audio warnings may be equally effective if limited in numbers. The fact that audio warnings can produce significantly faster responses is offset by the fact that voice warnings cause significantly less disruption to concurrent ATC activities (Wheale, 1981). In addition, there seems to be no advantage in using a large number of voice warnings because in commercial operations pilots would cross-refer to the CWP before responding. Thus the voice warning would serve merely as an attention-getter.

Because of the variety of factors influencing the effectiveness of a warning system it is prudent to advocate the design of relatively simple central warning systems. Any increase in their complexity by the use of additional voice messages and/or audio warnings is to be considered only when these offer demonstrable human factor advantages. Furthermore, because of the operational variables that can affect pilot response to warning systems, an effective evaluation can only be attempted in a full-mission simulation.

ACKNOWLEDGEMENT

I would like to thank all the pilots who gave generously of their free time to participate in this study and Mr Staples of BALPA who organised their time-table. Also I would like to thank Roy Patterson (MRC APU) who provided the audio warnings, Nigel Bevan (NPL) who provided the Votrax messages, John Wilson (British Aerospace) and John Rankin (British Airways) who helped design the experimental warning system.

REFERENCES

DU ROSS, S.H. (1978). Civil Aircraft Warning Systems - A survey of pilot opinion within British Airways. Royal Aircraft Establishment, Farnborough, Hampshire. Technical Report No 78056.

HART, S.G. and SIMPSON, C.A. (1976). Effects of linguistic redundancy on synthesized cockpit warning message comprehension and concurrent time estimation. Proceedings of the 12th Annual Conference on Manual Control, Champaign, Illinois. NASA TMX-73, 170, pp 294-308.

KEMMERLING, P., GEISELHART, R., THORBURN, D.E. and CRONBURG, J.G. (1969). A comparison of voice and tone warning systems as a function of task loading. USAF Technical Report ATD-TR-69-104.

KLASS, P.J. (1981). Aviation Week and Space Technology, May 11, pp 83-95.

PATTERSON, R.D. and MILROY, R. (1979). Existing and recommended levels for auditory warnings on civil aircraft. Civil Aviation Authority Contract Report 70/S/0142 R2.

PATTERSON, R.D. and MILROY, R. (1980). Auditory warnings on civil aircraft: the learning and retention of warnings. Civil Aviation Authority Contract Report 70/S/0142 R3.

SEXTON, G.A. and JONES, T.G. (1981). Voice command and response - new solutions to new problems. ICAO Bulletin, March, pp 24-28.

SIMPSON, C.A. and WILLIAMS, D.H. (1980). Response time effects for alerting tone and semantic context for synthesized voice cockpit warnings. Human Factors, 22(3), pp 319-330.

WHEALE, J.L. (1981). The speed of response to synthesized voice messages. In, Aural Communication in Aviation, AGARD Conf. Proc. No 311, 7, 1-11.

WHEALE, J.L., GOLDING, D. and DORÉ, C. (1979). Auditory warnings: signal variations and their effect on the operator. Paper presented at the 30th Annual Conference of the Ergonomics Society, St Catherines College, Oxford.

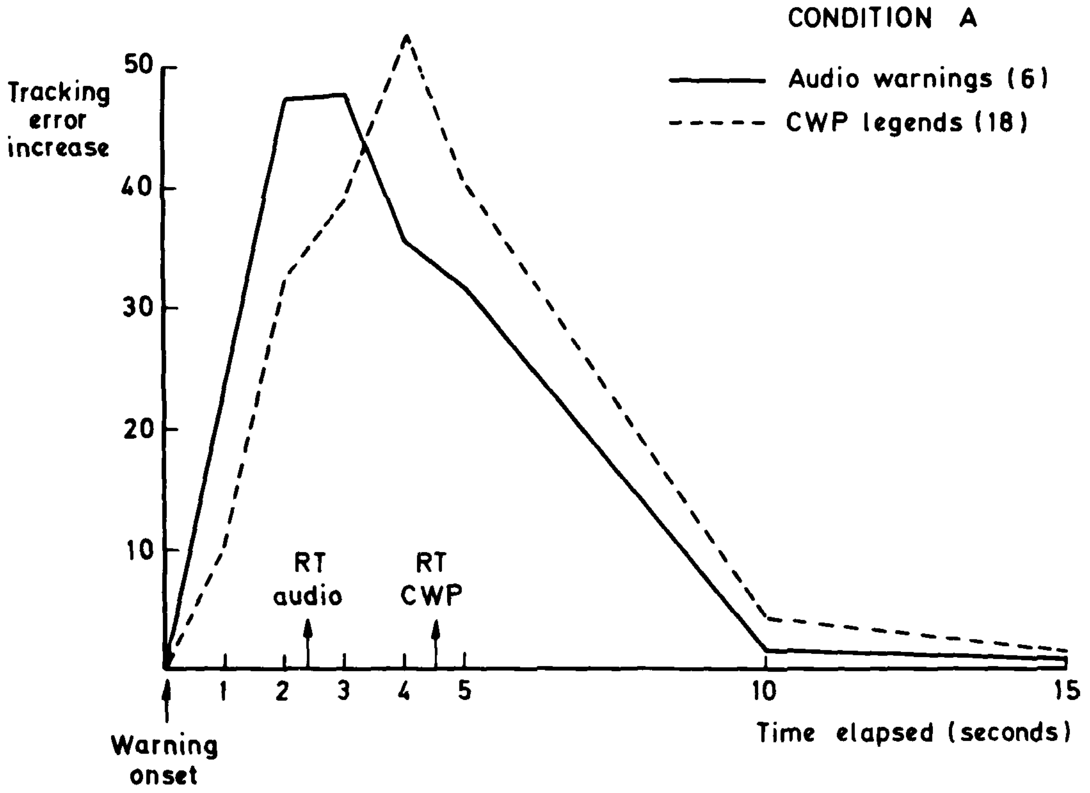


FIG 1 GRAPH SHOWING TRACKING ERROR INCREASE FOR THE 15 SECOND PERIOD FOLLOWING WARNING ONSET. IN THIS CONDITION RED ALERTS WERE SIGNALLED BY AUDIO WARNINGS AND THE AMBER AND WHITE ALERTS WERE SIGNALLED BY ILLUMINATED LEGENDS ON THE CENTRAL WARNING PANEL

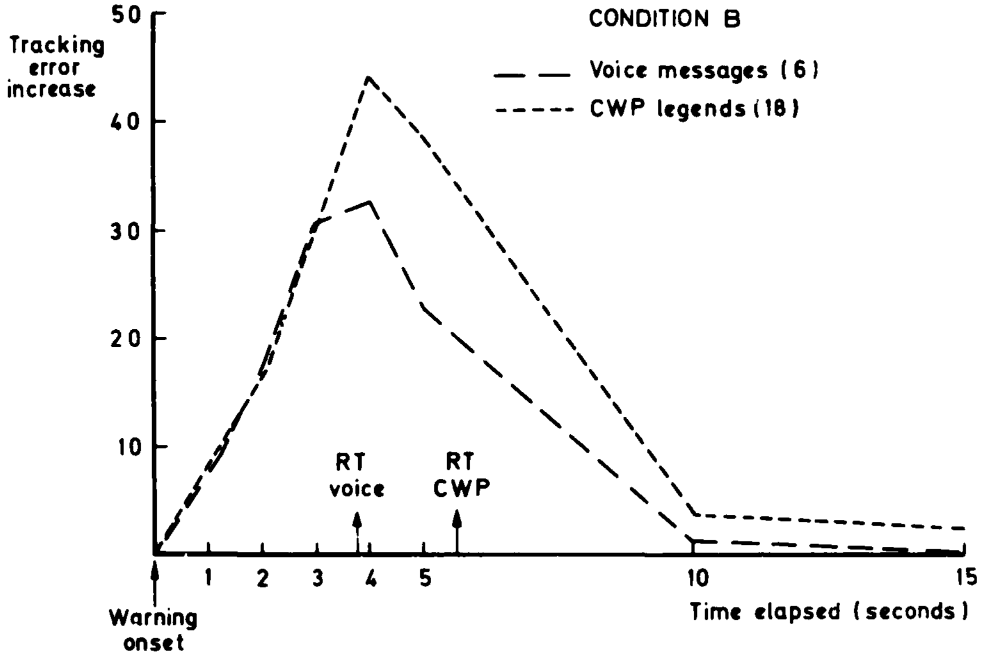


FIG 2 GRAPH SHOWING TRACKING ERROR INCREASE FOR THE 15 SECOND PERIOD FOLLOWING WARNING ONSET. IN THIS CONDITION RED ALERTS WERE SIGNALLED BY VOICE MESSAGES AND THE AMBER AND WHITE ALERTS WERE SIGNALLED BY ILLUMINATED LEGENDS ON THE CENTRAL WARNING PANEL

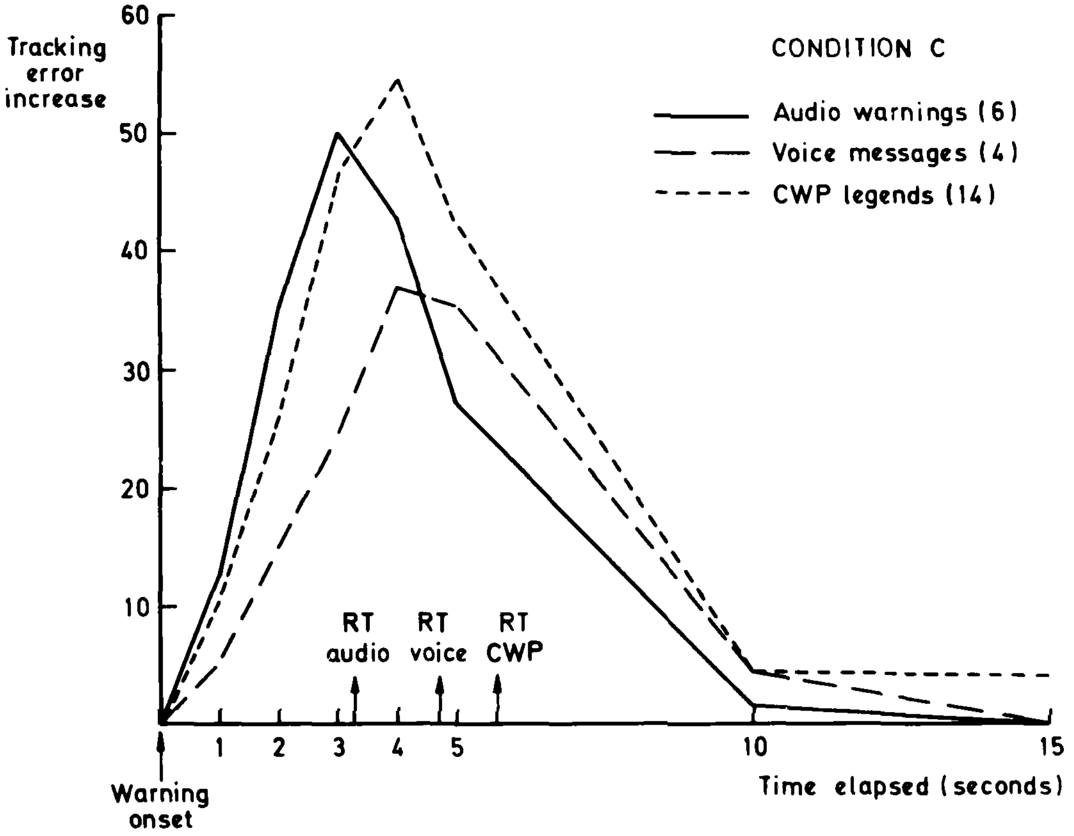


FIG 3 GRAPH SHOWING TRACKING ERROR INCREASE FOR THE 15 SECOND PERIOD FOLLOWING WARNING ONSET. IN THIS CONDITION RED ALERTS WERE SIGNALLED BY AUDIO WARNING AND THE AMBER AND WHITE ALERTS BY ILLUMINATED LEGENDS ON THE CENTRAL WARNING PANEL, ALTHOUGH FOUR AMBER ALERTS REPRESENTING FLIGHT DEVIATIONS WERE SIGNALLED BY VOICE MESSAGES

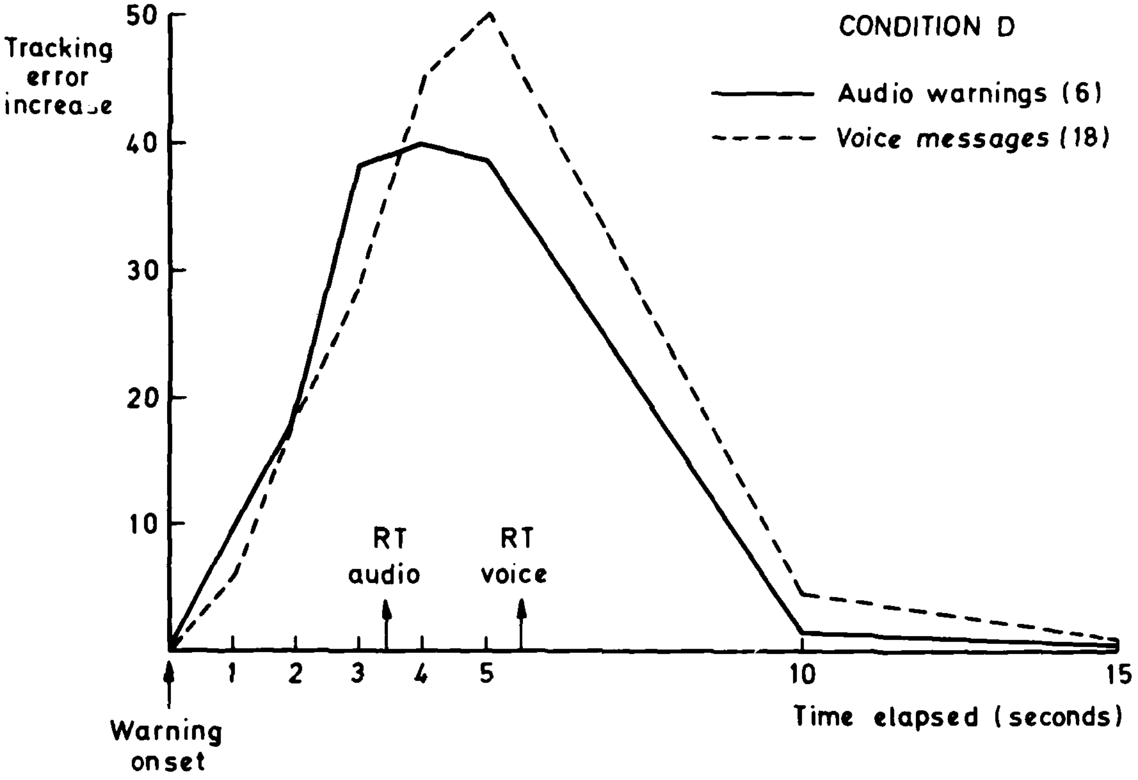


FIG 4 GRAPH SHOWING TRACKING ERROR INCREASE FOR THE 15 SECOND PERIOD FOLLOWING WARNING ONSET. IN THIS CONDITION RED ALERTS WERE SIGNALLED BY AUDIO WARNINGS AND THE AMBER AND WHITE ALERTS WERE SIGNALLED BY VOICE MESSAGES

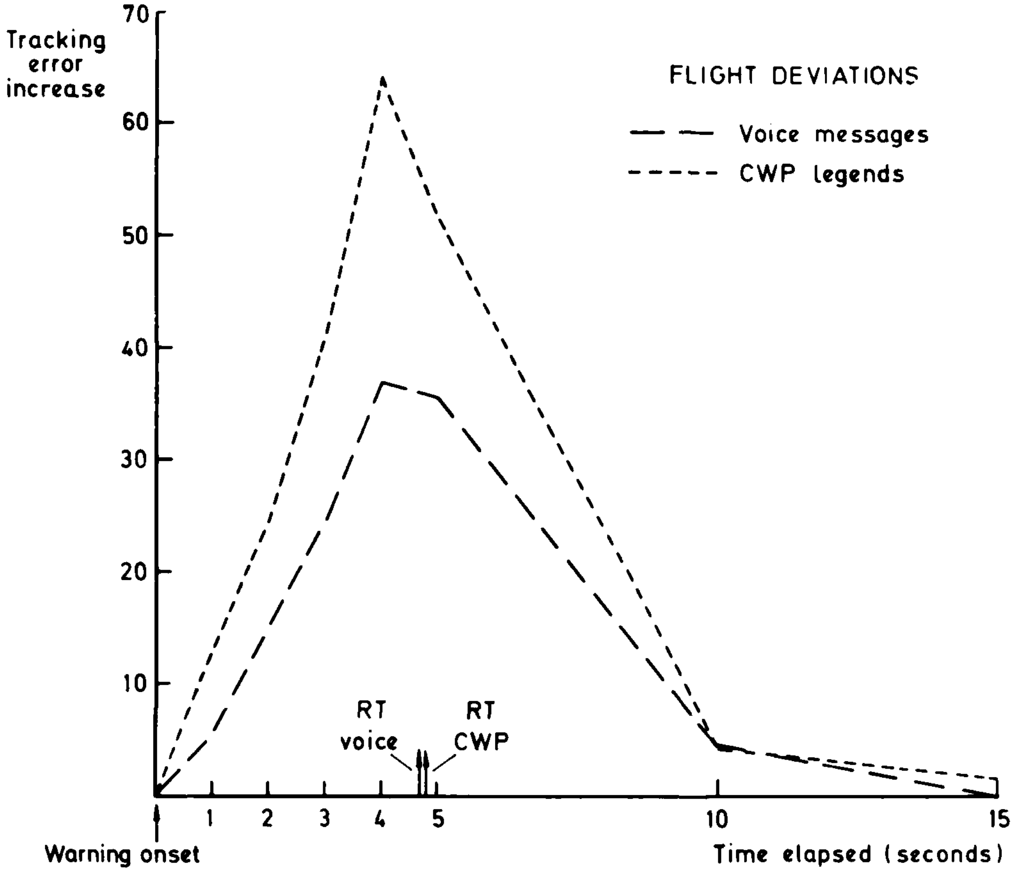


FIG 5 GRAPH SHOWING TRACKING ERROR INCREASE FOR THE GROUP OF FOUR AMBER ALERTS REPRESENTING FLIGHT DEVIATIONS. THE VOICE DATA IS TAKEN FROM CONDITION C; THE CWP DATA IS DERIVED FROM CONDITIONS A AND B

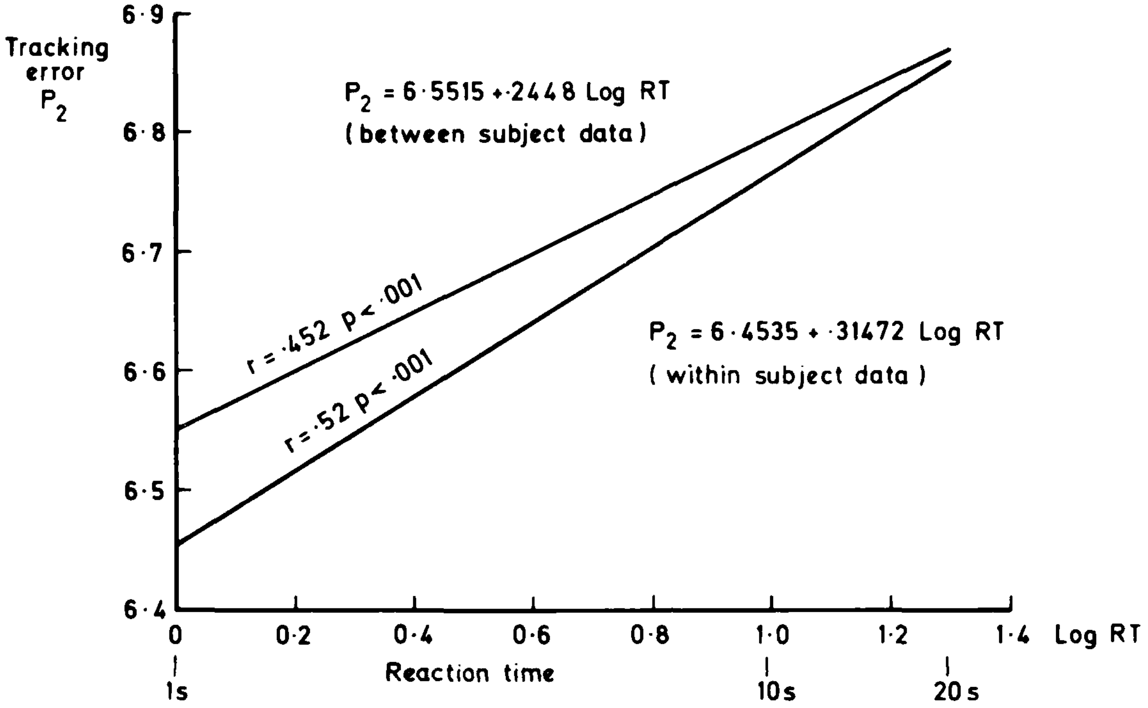


FIG 6 GRAPH SHOWING CORRELATION BETWEEN TRACKING ERROR IN THE 15 SECOND PERIOD FOLLOWING WARNING ONSET (P_2) AND THE REACTION TIME TO THE WARNING. BOTH CORRELATIONS SHOWN ARE TAKEN ACROSS ALL WARNING TYPES AND ARE BASED ON 698 DATA POINTS

DISCUSSION AVIONICS PANEL SPRING MEETING
On
ADVANCED AVIONICS AND THE MILITARY AIRCRAFT MAN/MACHINE INTERFACE
26-29 April, 1982

SESSION Nr. 3 VOICE INPUT & OUTPUT SYSTEMS-Chmn T. Sueta, US

Paper Nr. 9
Title : OVERVIEW OF STATE-OF-THE-ART, R & D NATO ACTIVITIES, AND POSSIBLE APPLICATIONS - VOICE PROCESSING TECHNOLOGY
Author : Dr B Beek
Speaker : W. E. Brierley
Comment : (a) Have investigations been made with voice characteristics in conjunction with noise, stress, physical change, with oxygen mask, etc.?
(b) What of involuntary utterances ?

Response : (a) Investigations have been performed on the changes of voice characteristics based upon g-force stress and microphone/oxygen mask utilization and their relationship to the performance of Automatic Speech Recognition (ASR). RADC & AFFDL performed a set of experiments using ASR in a centrifuge, with pilots using oxygen masks, to determine changes of speech characteristics and their influence on recognition performance. Also, multi-year experiments were conducted on Automatic Speaker Verification to determine the influence of colds, sinus and other physical changes on voice signals and their relationship to the performance accuracy. These changes did in fact increase the error rate slightly. RADC performed noise-stress measurement to determine the influence of high-noise background on Automatic Speaker Verification Equipment. However, I do not know of any definitive experiment where all factors were taken into account. It is my understanding that some of these measurements are now taking place at Wright-Patterson AFB in the US.

(b) Optimally, the ASR equipment would reject the utterance. Rejection, currently, is indicated by either a visual or audio alarm or both. Rejection alarms can also be caused by a word or phrase that cannot be properly recognized, so the alarm tells the individual to try again. Some designers of ASR systems have developed special software such as semantics/syntax modules to remove inconsistencies caused by involuntarily utterances Other attempts made to minimize confusion caused by involuntary utterances have been to design templates for these sounds/words to prevent misrecognition with valid vocabulary templates.

Paper Nr. 9
Title : OVERVIEW OF STATE-OF-THE-ART, R & D NATO ACTIVITIES, AND POSSIBLE APPLICATIONS - VOICE PROCESSING TECHNOLOGY
Author : Dr B Beek
Speaker : R. G. White
Comment : Dr. Beek said that an advantage of using speech to control machines was that the human operator did not have to be trained. To clarify this statement, I would like to ask whether he had observed any increase in recognition performance as operators gained experience of talking to the machine?

Response : Training as referred to in the paper meant operators did not have to acquire special skills (i.e., typing) as they all know how to speak. However, our experience in the Air Force, clearly has shown that as operators become familiar in the use of voice processing equipment and they are motivated to use it, their performance increases.

Paper Nr. 9
Title : OVERVIEW OF STATE-OF-THE-ART, R & D NATO ACTIVITIES, AND POSSIBLE APPLICATIONS VOICE PROCESSING TECHNOLOGY
Author : Dr B Beek
Speaker : R. Siefert
Comment : The error rate of speech recognition, if it is 2 % only, still is unacceptable, as Prof. Doetsch reported from the 1981 GCP conference - at least as far as aircraft application for "voice command" is concerned.

Response : I agree that error rate of 2 % for aircraft fighter pilot application may be unacceptable. However, for other voice data entry application (even aircraft applications), 2 % may be a very acceptable error rate. Also the type of error may be important, for example, a rejection error for a computer aided design application may be accepted, but a mis-recognition would be intolerable.

Paper Nr. 10
Title : CHARACTERISTICS OF THE HUMAN INFORMATION CHANNELS AND CONCLUSIONS FOR VOICE INPUT/OUTPUT
Author : Ing H Mutschler
Speaker : W. F. Brierley
Comment : (a) Is there any evidence that confirms or rejects theories that state that aural interface is degraded under stress?
(b) Is comparison of various modalities affected by type of voice employed?

Response : (a) I don't know.
(b) The detection of the physical characteristics of voice, e.g. its pitch, occurs during sensation i.e. in an early stage of the human information processing. Given no difference in intelligibility and rate, I would predict no influence of voice type, e.g. male-female, on the comparison with the visual modality.

Paper Nr. 10
Title : CHARACTERISTICS OF THE HUMAN INFORMATION CHANNELS AND CONCLUSIONS FOR VOICE INPUT/OUTPUT
Author : Ing H Mutschler

DISCUSSION

Speaker : J. C. Wanner
Comment : This is more a comment than a question. The voice channel cannot be used in order to increase the possible pilot workload capacity.
We have a good demonstration with the behavior of a car driver listening to news at the radio. When the work-load due to the traffic is low enough, it is possible to listen to the news; but when the workload increases suddenly at a crossing for instance, the experience shows that the driver concentrates his attention on his driving task and will miss the news, even if he is listening for something important.
So the information coming through the voice channel cannot be superimposed upon the information coming through the visual channel: This is a consequence of the single channel behavior of the human operator.

Response : I agree with you. It is correct that a human has a serial central system for just one difficult task, like traversing a crossing. But he has subsystems to work partially parallel especially if different modalities addresses and/or different types of information are used. So he can drive on a known road and listen to the radio.

Paper Nr. 11 ERGONOMIC REQUIREMENTS FOR VOICE PROCESSING SYSTEMS
Author : R. Seifert, P. Bubb
Speaker : R. W. MacPherson
Comment : The example phrases you analyzed were in English. Have you looked at other languages and if so is there any advantage to using say German or French or for that matter Russian? For example, some languages may not require the high octave bands to achieve the same level of intelligibility.
Response : Actually we did not and do not intend to. English is the "Aviation language". For other applications it would be necessary to investigate other languages; a task that should be done by any research institute, not by the aviation industry.

Paper Nr. 11 ERGONOMIC REQUIREMENTS FOR VOICE PROCESSING SYSTEMS
Author : R. Seifert, P. Bubb
Speaker : J. N. Holmes
Comment : I think Dr. Seifert has been unfair in dismissing synthesis from text. Although present day commercially available text synthesizers are not adequate for avionics applications, the best laboratory systems are already comparable with typical parametric storage systems and they are improving rapidly. Except for very low-cost consumer electronics applications, cost of equipment will not be a problem. Text systems have the advantage of simple message preparation, which means that a great variety of messages can be tried in human factors experiments, and the flexibility of very low data rate communications can be greatly increased when using a keyboard at the transmitter. I predict that it will be only a very few years before text systems have improved sufficiently for these advantages to cause stored human speech systems to be superseded for avionics applications.

Response : I did not intend to embarrass anyone working on speech synthesis. On the contrary, this method would be the "ultima ratio". Yet in the comment it is stated, that speech synthesis will take some years to reach the state of applicability in aircraft weapon systems.

Paper Nr. 12
Title : APPLICATION ASSESSMENT AND ENHANCEMENT OF SPEECH RECOGNITION FOR THE AIRCRAFT ENVIRONMENT
Author : R Vonusa, E Cupples, Capts. J Nelson, J Woodward, S Steigerwald, E. Cupples presented.
Speaker : L. Reed
Comment : Reference the Figure of test results of SEU:
(a) How many subjects were tested and how many tests were performed?
(b) Row 3 of the referenced figure with SEU off, indicates approximately 14 db SNR with 93% recognition accuracy.
While the third row from the bottom indicates approximately 15 db with the SEU on and a high level of noise; the recognition accuracy dropped to 52%. The SNR is greater in the latter case but the recognition accuracy is less. This would suggest that the SNR measure used is suspect in that it doesn't take into account the distortion of the signal by the SEU when high noise is present.

Comment : (a) The tests conducted were preliminary. Only one speaker was used who inputted the English isolated digits. A total of 600 utterances were inputted (300 with and 300 without the SEU). This does not include the training utterances which were done without the SEU at a S/N of approximately 40 db.

Response : (b) Your observation is correct. Since this investigation was very preliminary, it has not yet been determined as to why this result was obtained. Perhaps it is caused by the characteristics of the remaining noise after processing and the inter-state recognition characteristics or perhaps by distortion when high noise levels are processed. Whatever the case much more testing and experimentation is required to determine how much the SEU can help the recognition process. In spite of the fact that the results shown are conservative and that much more can be done that may improve the results (training through the SEU, use the SEU automatic gain control (AGC), process the signal multiple times, make algorithmic adjustments, etc.) the results are very encouraging.

Paper Nr. 12
Title : APPLICATION ASSESSMENT AND ENHANCEMENT OF SPEECH RECOGNITION FOR THE AIRCRAFT ENVIRONMENT
Author : R Vonusa, E Cupples, Capts. J Nelson, J Woodward, S Steigerwald, E. Cupples presented.

DISCUSSION

Speaker : Prof. D. Bosman
Comment : After the excellent audio demonstration of wide-noise rejection, can you tell us how the system reacts to non-stationary and transient type disturbing signals?
Response : The SEU removes transient or or impulse type interfering signals very effectively up to 35 milliseconds in length. The technique not only detects these impulses but blanks out the area of the impulse and fills the blanked area with data surrounding the area in a manner that insures that no discontinuities occur on either side of the defined impulse area. This is so effective that one cannot detect where the impulse was located after the process has been completed.
The ability of the SEU to handle non-stationary changes in wide-band and narrow-band noise is also very good. How quickly the SEU can react to step changes of wide-band noise is a function of the size of the step in level. The recovery rate is not a linear function. The SEU also allows the noise function to be held or frozen. This allows the SEU not to be concerned with changes in voice level that occur such cases as when receiving intermittent transmissions over communication channels.
The SEU can react to narrow-band noise changes very quickly. It responds quickly enough to reduce CW and FSK types of signals. I might also add that a reverse switch allows the rejection of speech signals while outputting CW and FSK signals.

Paper Nr. 12
Title : APPLICATION ASSESSMENT AND ENHANCEMENT OF SPEECH RECOGNITION FOR THE AIRCRAFT ENVIRONMENT
Author : R Vonusa, E Cupples, Capts. J Nelson, J Woodward, S Steigerwald, E. Cupples presented.
Speaker : J. S. Bridle
Comment : Does Mr. Cupples agree with me that it should be possible to improve performance by compensating for the presence of noise in the speech recognition process itself instead of feeding a processed signal to a standard speech recognition algorithm?

Response : Yes, but by using a separate noise reduction process we retain flexibility. Also utilization of parameters common to the SEU noise reduction process discussed in the paper and speech recognition or using a totally different noise reduction approach may provide a means of improving recognition performance but the noise reduction or recognition process may be compromised as each process may require different processing parameters such as block size, FFT size, etc. to achieve optimum performance.

Paper Nr. 13
Title : DIRECT VOICE INPUT FOR THE COCKPIT ENVIRONMENT
Author : R. Bell, M E Bennett, W E Brown
Speaker : L. Reed
Comment : Have there been any recognition accuracy tests performed on the DVI and if so, what are the results?

Response : Marconi Avionics have done a substantial amount of testing involving : laboratory environment; noise room; various microphones, masks and users; flight recordings and man-in-the-loop tests. The general findings were that commercial equipment is inadequate to cope with the military cockpit environment. Hence our equipment is designed to perform well in this environment and we see no insurmountable problems in meeting the required performance, but it would be inappropriate to disclose detailed test results until standard test procedures are established which make comparisons with other equipment valid.

Paper Nr. 13
Title : DIRECT VOICE INPUT FOR THE COCKPIT ENVIRONMENT
Author : R. Bell, M E Bennett, W E Brown
Speaker : D. Beevis
Comment : There is evidence from voice-ordered systems which are in use that operators, when under stress, do not always use commands which should be used, but say something else which means the same. There is an example of a destroyer which was involved in an accident because the Officer of the Watch, under stress, told the helmsman "Shift your rudder". The helmsman did hot move the wheel because "Shift your rudder" is not a correct command, although it is what the OOW meant. Similarly in tanks operators have used "shoot" instead of "fire", or even "get that bastard" again saying what was meant, but not what was correct.
This type of behavior, and its implications for the accuracy of voice recognition systems is of concern to me. The identity of a pushbutton does not change, whether the operator thinks of it as "shoot", "fire", or anything else. This does not seem to be so for voice recognition systems, and the problem is compounded by the habit some users have, of repeating the same phrase, only louder, when they are not understood. Is the speaker, or any others here, studying this problem, and what are they doing about it?

Response : There are two questions here.
First is the system response to unsolicited utterances. This is one of the major benefits of continuous speech systems because they can ignore utterances which do not make sense. This is also the reason why we are actively investigating verbal switch-on techniques.
Next is the question of using different words with the same meaning. So long as the speaker is consistent and feedback compatability is maintained then it is possible for an individual to use words of his own choice, and it is our experience that pilots are both capable and confortable within the apparent constraints of their existing structured language.

Paper Nr. 13
Title : DIRECT VOICE INPUT FOR THE COCKPIT ENVIRONMENT

Author : R. Bell, M E Bennett, W E Brown
Speaker : K. Coombes
Comment : Five years is not a long period in which to complete human factors trials, and gain user acceptance, and complete the required R&D and production processes for such a new technique. Various research, both US and UK, has shown that user acceptance for voice warnings (even when designed in co-operation with user groups) is not easily gained. Do you feel that user acceptance of DVI will be achieved within this timescale?

Response : First we must be careful not to equate DVI and verbal warning systems which have very different ergonomic and human factors aspects.
As far as DVI is concerned sufficient studies have been done to show the potential benefits and we will be ready for initial production within five years in order to meet anticipated requirements.

_Paper Nr. 14
Title : VOICE INTERACTIVE SYSTEM DEVELOPMENT PROGRAM
Author : Dr J C Ruth, A M Godwin, E B Werkowitz, presented by A. M. Godwin
Speaker : Wg Cdr. Schuller
Comment : The common component of all manned aircraft is the human pilot and if we could gain a better understanding of his workload allocation process our evaluation of cockpit controls and displays should be more valid. You showed a diagram outlining methodology for assessing the relative merits of different voice interactive systems, but I suggest we need to assess the pilot in an analogous manner. You described the very high workload you placed upon your subjects and added that in addition you had subjected them to various environmental factors, e.g. "g", to see the effect on their performance. Mental stress affects performance but is difficult to simulate. Did you consider using random imposition of disorientation as a means of inducing temporary mental stress? Spatial disorientation could for example be induced by Coriolis acceleration during simulated instrument flying.

Response : To date, we have not conducted experiments such as you have described. I agree that this kind of experimentation would potentially be very useful. However, it is also very costly, time-consuming and requires test facilities that we have not had at our disposal. This does not mean that we are unconcerned about the effects of emotional stress on the human voice and we will certainly investigate the practicability of any realistic suggested approach to determining the nature of these effects including yours.

_Paper Nr. 14
Title : VOICE INTERACTIVE SYSTEM DEVELOPMENT PROGRAM
Author : Dr J C Ruth, A M Godwin, E B Werkowitz, presented by A. M. Godwin
Speaker : L/Col. J. Catiller
Comment : Rhyming words was mentioned as a problem on one of your viewgraphs, but you did not mention it. Would you avoid problems with rhyming words, strictly by not having them in the vocabulary? If this is the case what about extraneous rhyming words which the system might pick up?

Response : Rhyming words can be avoided by careful control of vocabulary selection. Extraneous words of any kind will be prevented from entry into the recognizer through use of a push-to-talk button.

_Paper Nr. 14
Title : VOICE INTERACTIVE SYSTEM DEVELOPMENT PROGRAM
Author : Dr J C Ruth, A M Godwin, E B Werkowitz, presented by A. M. Godwin
Speaker : Gen. J. C. Wanner
Comment : I am not sure that we are dealing with realistic problems when speaking about the effect of a load factor of 8 g's, the effect of stress or the risk of confusing "start" and "stop". Have you ever tried to push a button under 3 g's? What pilot is able to fly correctly under stress with a conventional display? Why should confusing words be chosen in a set of 200 elements only; during the last war the pilots used conventional words like "Wilco" or "Roger" to avoid confusion; why should we not use special words like these if necessary.

Response : We do not expect that pilots will attempt to use voice inputs in the eight g's region any more than they would attempt to reach out and operate a switch under these conditions. For this reason it is not planned to conduct tests for such operations. We do however anticipate that a reasonably reliable level of operation can be achieved with voice inputs into the 5-6 g's region. Indeed, operation using voice may prove to be easier than with manual control actions in this area.
Relative to the use of special words, we cannot presently see any serious objection to such usage. Indeed, some special command words will undoubtedly be required. To the extent that it is practicable, however, we would propose to retain the pilot's normal vocabulary which by its very nature is quite robust.

Paper Nr. 15
Title : VOICE INTERACTIVE SYSTEMS TECHNOLOGY AVIONICS (VISTA) PROGRAM
Author : L W Reed
Speaker : W. E. Brierley
Comment : I have a comment on training in noise. I think one or two people when talking about noise have missed the point. The problem is not just the noise present at the microphone, but the noise that is present at the speaker's ears. The level of protection from the outside world, the ambient noise in the aircraft, for example, by the flying helmet is extremely inadequate. Apart from the level of noise appearing at the microphone, there is a level of noise appearing at the ears. Because the pilot only has a limited level available as side tone, he raises his voice. By raising his voice, he starts to strain his voice, the pitch of his voice changes, and the form of distribution changes. If the microphone and the amplifying system are slightly

non-linear, the combination of a high-level speech and the presence of noise will now contribute toward voice-noise inter-modulation products, so I am a little surprised that you say you do not need any training, I think it is in fact pretty essential that the person who is doing the training, does this in a realistic condition. I think this is quite important.

Response : Maybe I did not make myself clear, or I am not understanding your question. we performed our testing in the actual noise environment. When we did training not in the actual noise environment, I think you can notice from the charts that the recognition accuracy of the particular recognizer dropped significantly. Depending on the subject this was anywhere from 95%, when trained in the noise, down to approximately 50% in the same test condition when the subject was not trained in the noise. Now I should point out that all the testing was done in the noise, it was just the training that was not done in the noise. We only did this for the purposes of getting a system that may be usable in the environment. Clearly a 50% recognition accuracy is not usable for any kind of testing. We were getting up to around 80-90% accuracy when training in the noise was employed. However I do not believe training in the environment is what we want to do, because of the high ambient noise level. When a person is training now, the noise is going into his microphone just like his voice is, extremely loud at his ear. The reason why I say that is it actually can cause hearing damage in a very brief period of time. The levels are too high. However we prefer (at least as far as the recognizer is concerned) to filter out as much of that noise as possible and to eliminate this need to train. Now, I agree with you that there is a stress on the person's voice. As I mentioned one of the research areas is to actually subject the person to noise in the headset. He is in effect being stressed in a realistic manner as the noise is applied. I am sending this particular tape to some people in the Navy who will analyze it for me to see if there is a characteristic shift of the voice when it is trained while hearing the noise, as opposed to when it is in quiet. If we can determine some predictable characteristic change, we may be able to pre-process the person's voice also, so that when we do make future training patterns, this pre-processed voice pattern will be stored in a recognizer, and yet the person will not have to train in that noise environment..

Comment : I see a problem on two counts, first the levels of noise that you used were hardly representative. The sort of levels we are talking about in many modern aircraft approach 120-126 dba. This is quite a high level of signal.
The second thing is that the work we have actually done in noise-rooms etc., indicates that when the total person is actually subjected to total noise, the effect is quite different from when you simply inject noise into his headset alone. We have in fact noticed a considerable increase in the level of speech and an increase in the pitch of the voice. This is the reason for my concern.
The other point is that I am again rather surprised about the characteristics of your AGC, because techniques are quite easily available to insure that the type of thing you are talking about, does not in fact happen. I would be very, very disturbed to discover an AGC with a release time of ten seconds because I would be concerned about transmitter modulation characteristics, etc. Ideally, you should relate the performance in an AGC, to the long term RMS sensitivity and then the system itself should have at least a 10 db linear excursion for plus or minus short transients against the long term RMS. Unless you have this kind of exercise you will have considerable difficulty whenever you try to put speech containing noise into any kind of recognition system.

Response : In your first comment you were questioning the actual noise levels. The noise was measured in the UH-60 a real aircraft, and we measured 107 dba. That's the a weighted scale, on the linear scale that would come out to about 115 db. We do have a test library, and all these recordings were made with precision equipment, and are properly calibrated.
Now in response to your question regarding the AGC; unfortunately it is nothing we can control, it is in the intercom that is employed in the present aircraft systems. If we intend to install this recognizer in the aircraft, this is the environment we have to use, whether one likes the ten-second release time or not. However, I should point out that we have another program which is referred to as the digital multiplex audio system, which is for digitizing audio, putting it out on a common bus system. In this program we are looking at several techniques of digitizing, as well as questioning the need for an AGC. Several of the digitizing techniques have companding algorithms in them already, so therefore we have a predictable result and we can incorporate this as far as handling the function for the recognizer. We will eliminate that AGC problem. Also that threshhold can be set high enough so that in normal operation that AGC is not there, and for digitizing purposes it will only limit it so we do not exceed the digitization capability of the technique employed. But, as I said, getting back to our particular intercom system, that is the one that is in there presently, it has been there for several years, and we will have to interact with it when we put our system in the aircraft for the first several phases of our experimentation

Paper Nr. 17
Title : UTILISATION DES TECHNIQUES VOCALES DANS UN AVION DE COMBAT, PREMIERS ENSEIGNEMENTS
Author : J R Coste*
Speaker : Prof. Doetsch
Comment : (a) What are the present views on speech recognition time delay and its effect on flight performance? (Reference Statement in Paper No. 2)
(b) What are your views on the question of compatability between voice input systems and reversionary control?
(c) Do you envisage using voice control without reversion for such phases of flight as take-off, landing and simple cruise?

Response : (a) Such recognition time delay can be reduced by technological means (e. g. computing speed) to say 100 ms. It is of course incompatible with real-time effect commands (guns, coordinate update) but can be used for a lot of other controls. (b) Of course voice command of present reversionary controls is a problem - but there are other ways to manage it. For example, interceptions are performed in the Istres Simulator without being degraded by

in a significant way.
(c) We do not consider that different phases of flight such as takeoff can be performed without retaining feedback. The means we use are essentially visual.
I would like to point out that the task of analysis and reflection about operational procedures has not yet really begun; we are collecting data for this purpose.

Comment : (Prof. Doetsch) I would also like to have the reaction of the Marconi people who promised to have it in large-scale use in about ten years time. What are they envisioning on how they link up voice control and control systems? Are they equally optimistic?

Comment : (R. Bell) I think what we would say to that is we would largely agree that caution needs to be exrrted and certainly in the short term we would not go any way toward removing reversionary controls. Experience says that if you have something which is a central failure then it will go wrong when you least want it to, so until significant flight trials have shown manual reversion in its existing form to be unnecessary then we would want to see it kept there. But there is no doubt that if speech becomes the prime data entry, then benefits can be derived from taking advantage of the fact that the reversionary controls do not need to be so well engineered into the cockpit, into prime positions near to the primary flight controls, thus releasing some of that panel space for the real high integrity systems, for example weapons. But, I would like to think we would retain some sort of alternative.

Paper Nr. 18
Title : PERFORMANCE DECREMENTS ASSOCIATED WITH REACTION TO VOICE WARNING MESSAGES
Author : Dr J L Wheale
Speaker : C. Y. LaPorte
Comment : When using phonym synthesizers, subjects need training time in order to get used to this "robotic voice". Did you allow your pilots to listen to the speech synthesizer before the testing phase began?

Response : Yes, we allowed the pilots time to familiarize themselves with the VOTRAX synthesized voice messages. In fact, we adopted the strategy of having the pilots make three correct identifications in a row of the whole group of audio and voice messages that were to be used in their experimental condition. In addition to that familiarization process we assured the pilots that prior to the test phase of the experiment they could opt to hear the voice messages again. None of the pilots took up this option.

Paper Nr. 18
Title : PERFORMANCE DECREMENTS ASSOCIATED WITH REACTION TO VOICE WARNING MESSAGES
Author : Dr J L Wheale
Speaker : R. Seifert
Comment : Could it be that the performance decrement in the main task was partly due to the fact that both tasks, the tracking and the warning response required visual orientation? From the presentation of Herr Mutschler we know that parallel tasks loading one processing channel interfere.

Response : I would agree with your comment that performance decrement on the main was probably due in part to the fact that reaction to a warning involved visual processing essentially incompatible with visual processing on the main task. However, the decrement associated with cancelling the response button was constant for all responses and so we assume that the performance decrement we measured reflects this constant amount and the variable amount of decrement associated with the processing of the different types of warning. In addition I would also speculate that the decrement associated with the final button pressing is minimal since in a previous experiment where the subject did not have to look at his button pressing movement the decrement associated with warning reaction was similar in form to that observed in the study reported here.

Paper Nr. 18
Title : PERFORMANCE DECREMENTS ASSOCIATED WITH REACTION TO VOICE WARNING MESSAGES
Author : Dr J L Wheale
Speaker : R. A. Chorley
Comment : You mentioned that one probable reason why your experiment showed no significant reduction in response time when voice warnings were used was that the pilot always looked at the visual warning panel to confirm the warning message before making the response.
Although it would be an artificial situation, in that nobody would suggest removing the visual warning panel from a real aircraft, would it be useful to repeat the experiment with the panel covered up, to see whether that makes any significant difference to the time of response to voice warnings?

Response : The central warning panel was used in the experiments because it was envisaged that such a panel would always be present in transport aircraft although if an extensive system of voice warning messages were introduced the central warning panel might not have to be in prime panel space. However, I believe that your suggestion of covering up the panel information when pilots were responding to voice messages is a very useful one. I say this because the experiment was directed toward measuring the performance decrement associated with different types of warning and a stimulus arrangement along the lines you suggested would be a more accurate measure of performance decrement especially with respect to voice messages where the pilots were minimizing their difficulty of dealing with them by cross referring to the central warning panel for confirmation.

Paper Nr. 18
Title : PERFORMANCE DECREMENTS ASSOCIATED WITH REACTION TO VOICE WARNING MESSAGES
Author : Dr J L Wheale
Speaker : P. Orme

Comment : How do the results of your tests read across to fighter aircraft in the combat situation? In particular, it seems the pilot would like to know the level of the warning so that he can decide whether to react immediately to the warning or to continue the combat and deal with the warning later.

Response : In reading across from the results of this experiment to a fighter aircraft in a combat situation it is necessary to bear in mind differences in the ambient noise environment and the stress/workload placed upon the pilot. These two factors would make the use of a high quality voice in the presentation of voice warnings absolutely essential because the difficulties experienced by our subjects in the use of the synthesized voice messages would be exacerbated in fighter aircraft and the use of a virtually "normal" voice for warnings would make the use of an attention getting tone preceding the voice warnings essential. If a variety of attention getting tones were used then these would not only alert pilots as to the proximity of a voice message but they could also code the level of the warning, and this coding would be a supplement to the coding provided by master attention getting lights.

COMMUNICATIONS MANAGEMENT

A VITAL LINK

Author: W.E. Brierley

Marconi Avionics Limited,
Airadio Products Division,
Christopher Martin Road,
Basildon,
Essex. SS14 3EL

Telephone: Basildon (STD 0268) 22822
Telegrams: Expanse Basildon Telex
Telex: 99225

This paper was first presented at the 43rd Symposium of the Avionics Panel on the Advanced Avionics and the Military Aircraft Man/Machine Interface. April 1982.

SUMMARY

Effective Communications is of vital importance in any military airborne activity. The interface between the communications system and the pilot/operator can determine the efficiency of the total system and reflect considerably on workload.

The increasing complexity of communications has required additional communications equipment to be fitted to aircraft, often retrospectively, with controls located primarily by the availability of space. Consequently, the configuration can cause increased work load, be wasteful of panel area, and increase weight penalties or render the task of installing non-related equipment more difficult.

A study has been carried out on behalf of the Ministry of Defence to determine a method by which additional radio equipment can be fitted to light helicopters, preferably by reduction in the already allocated panel area, together with increased control facilties.

As a result of this study, a unit is being designed which will provide the required facilities within a panel area only 35% of that required for the controllers it replaces, whilst still providing all the functions required.

1 INTRODUCTION

What do we mean when we speak of a Communications Management System? In the broadest sense, it is the means by which effective communication is carried out between individual communicators.

In a large, complex aircraft, such a system may well include selection of optimum channels, multiple access, methods to combat jamming, and secure speech systems.

In a small aircraft, the requirements are, in general, to enable selection and display of desired channels, functions, control of transmission and presentation of incoming signals to the crew, possibly in conformance to a predetermined plan.

With the ever increasing complexity of modern aircraft, the communications management system is a vital interface between the crew, the aircraft, and the outside world.

The design of this system will therefore have considerable influence on the efficiency of the crew.

2 CURRENT METHODS OF CONTROL AND DISPLAY

The communication elements are:-

- Radio Equipments
- Audio Distribution
- Telephones and Microphones
- Crew

Current Radio equipments are usually each provided with a Control Function, remote from the main unit, and providing control of frequency or channel, together with discrete operating functions. The use of separate controllers usually requires a large number of control and signal lines to interface with the main units.

Where operational requirements demand the installation of a number of radios, the total panel area needed can be large and considerable cabling can be necessary.

In addition, when additional equipment is fitted to an already designed and in-service aircraft, considerable difficulty may be experienced in making available the necessary panel on which to mount the additional controls. The end result can be ergonomically unsatisfactory.

An example of the control panels required for a light military helicopter are shown in Figure 1. Five Radio Control panels, plus two audio control panels are shown. In practice these panels have been located in any space available.

The result of this is that panel area is not employed effectively, crew learning time is increased and access by one crew member is difficult.

3 OPERATIONAL ENVIRONMENT

The crew of the aircraft can be subjected to high levels of acoustic noise, there may be considerable vibration, and there will be a wide variation of lighting conditions. They may be wearing protective clothing; including gloves which reduce dexterity. One or both may be employing night vision equipment.

The combination of environmental conditions operational needs and weather conditions must be considered when designing the communications system.

Maintaining a helicopter in a hover at 50 feet, in high wind gusting, on an overcast night, wearing night vision goggles and bulky gloves, requires a high level of concentration. Operation of the communications system must not require such a high level of attention as to distract the crew unduly.

4 ALTERNATIVE METHODS

One method of providing communications management has been proposed, and in some instances adopted. This method incorporates the control and display requirement, (but not audio selection and control), into an integrated aircraft system, associated with navigation, cockpit management etc.

Such systems may employ CRT display, be controlled by keypads, and reduce substantially the total number of controls required.

With a number of operators, each with more or less identical facilities, and a relatively large aircraft, such a system may well be effective.

However, for a small military aircraft, a system of this kind suffers from a number of disadvantages.

Most important is that of system function selection. The integrated system must rely on some form of 'menu' paging, in that firstly the communications system must be selected for control and display, secondly the particular equipment must be selected, thirdly the particular features or functions must be selected, all before any attempt to address the system is made.

Considerable attention (head down time) is necessary to carry out these operations and with a complex system, and the possibility of operator error is increased.

Additionally in a small aircraft, there may be room for only one such display. There may well be a conflict in that communication control and display is required by one crew member, and for example, navigation display by the other crew member.

Finally, the possible failure rates and modes of the more complex system may reduce the reliability of the communications system.

In a small aircraft the use of a dedictated sub-system can offer a more cost effective solution, as the control and display can be specifically tailored for the purpose.

It must be pointed out that digital control methods, employing either ARINC 429 or MIL-1543B highways, can reduce the cabling required, but do not in themselves solve the control and display probems.

5 AN INTEGRATED CONTROL PANEL FOR COMMUNICATIONS MANAGEMENT

As a consequence of a study funded by MOD(PE) a communications management sub-system has been proposed for light military helicopters, and is currently being developed.

The study target was:

To examine methods of providing a centralised control system which would enable the number of radios to be increased, whilst:

- Not increasing, and preferably decreasing, the already existing panel area
- Interfacing directly with already installed equipment and cabling.
- Increasing certain facilities
- Not increasing work load
- Being compatible with night vision equipment

5.1 CONTROL AND DISPLAY REQUIREMENTS

It is obvious that all the controls and displays shown in Figure 1 cannot be compressed sufficiently to meet these objectives and that therefore, they must be presented in a form that involves selective sharing and multifunction selection.

The individual items must therefore be examined to determine the conditions under which certain display information is required and control functions are needed.

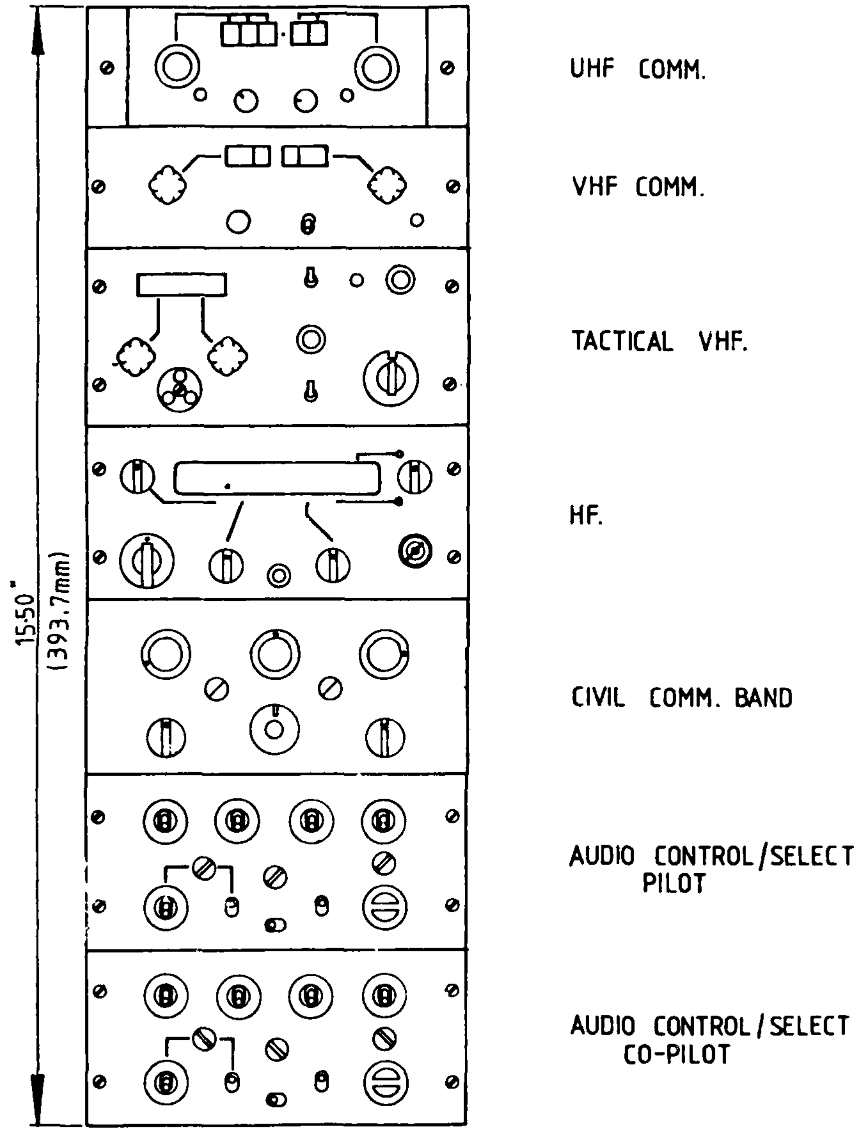
The first apparent problem is that of frequency display. A strong case can be made for continuous display of all frequencies of the radios. However, in practice, when a radio has been tuned to a given frequency, and the audio output selected, it is unlikely that any signal received on that particular radio will necessitate examination of its frequency. Only the lack of expected traffic will demand checking of the frequency.

Therefore shared displays are practicable. However, discussions with civil authorities, and military approval authorities, show that it can be essential that when transmission takes place, the frequency of the tranmission should be displayed.

Therefore, in the normal mode of operation, each pilot should have a display showing the frequency and/or channel on which he would transmit at that time.

It is logical, therefore, that a single frequency selector be provided in association with the display. The actual control for selection could take any one of several methods. In the past, rotary switches with linked mechanical digital read out have been employed. Increasing use has been made of Thumbwheel switches, stepping switches, and more recently, key pads.

FIGURE 1


15.50"
(393.7mm)
UHF COMM.
VHF COMM.
TACTICAL VHF.
HF.
CIVIL COMM. BAND
AUDIO CONTROL/SELECT PILOT
AUDIO CONTROL/SELECT CO-PILOT

Each of these switches may offer advantages for certain functions, but may not be suitable for others.

An experimental comparison between the various types of switch shows that in the conditions considered, rotary switches offer the best solution for frequency selectors.

A number of factors contribute to this conclusion. Firstly, rotary movement of the hand whilst gripping is a natural movement. When the switch is provided with a 'click' mechanism, incremental movement is simple and readily associated in the mind with changing display. This also applies with the rolling action of rotating a control with the fingers. When the convention of clockwise increase, anti-clockwise - decrease is also employed, this switch method is very effective.

Secondly, single digit changes require only one operation, as opposed to, for example, a keypad, where any change requires several operations to enter the new numbers.

Thirdly, when considering the possible adverse environmental and operational conditions, the probability of operating the incorrect control, or entering errors is considerably less.

In addition to the frequency displays and controls, each radio requires several functional mode controls. These are required to meet various operating conditions, but the number of operations for each flight are low. This being the case, common switches may be employed.

However, very few of the functions are common to each radio, and to provide controls for each would occupy considerable panel area. Some form of multifunction switch system is necessary. This again requires careful consideration if crew work load is not to be increased, or the probability of operator error raised.

A table of functions required for four of the radios is shown in Figure 2. The requirements for the fifth and sixth radios will be similar.

In addition, it is highly desirable to provide a number of preset channels, distributable across all the radios, and a means of selecting, and probably setting up, these channels.

The modulation of each transmitter must be selected and also the press to transmit line. For this purpose, again a rotary switch is preferred.

The audio output of each radio must be selectable, and capable of level adjustment. As each audio may be required when the particular transmitter is not selected, separate on/off switching is required. Limited panel area forces the use of combined controls. An alternate action push switch combined with a rotary control occupies the least panel area, the on/off state readily discernable in daylight, but may be more difficult to identify in low light levels.

As each audio service may be required with any or all of the others in various combination, these controls cannot be shared.

5.2 DERIVATION OF PRESENTATION

Any attempt to apply conventional analysis of time, motion, reaction time, etc., appears to be out of the question. This is due to:-

- Little or no order of operation is predictable.
- Operations are not repetitive
- Environment and operational conditions are subject to change
- The operating crew is not primarily trained as a communicator
- The distribution of existing equipment is not necessarily uniform, and some equipment may not yet be fitted.

It would appear, therefore, that the best approach is that of attempting to ensure that the operations necessary to control a particular radio are not increased beyond the minimum needed to control a single radio. The fact that all the facilities would be centrally grouped would, in itself reduce crew work load.

If the controls and displays were organized so as not only reduce the possibility of operator error, but as far as possible, prevent the opportunity of error, the problem would be at least partially resolved.

5.3 Proposed Solution

The proposed Communications Management System control panel is shown in Figure 3. It provides in one unit the facilities for two pilots to:-

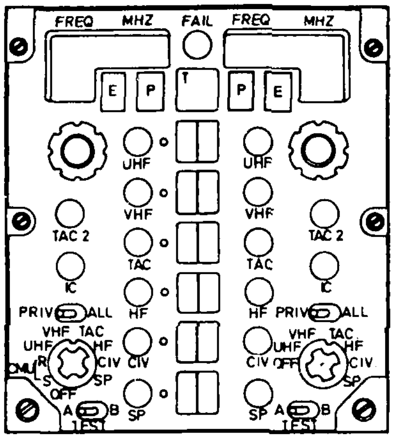
- Select control, and display any one of Six Transmitter-Receivers.
- Monitor and/or independently change the frequency or pre-set channel of the selected radio.
- Transmit/Receive on the selected radio
- Select and adjust any or all in any combination eight radio receiver outputs and other audios.

FIGURE 2.

FUNCTIONS REQUIRED

UHF —	ON-OFF	DC POWER
	T/R ONLY	MAIN TRANCEIVER
	T/R+G	MAIN PLUS GUARD RECEIVER
	SQ	SQUELCH OVERIDE
	H	UHF HOMING
	UP. AE	UPPER OR LOWER ANTENNA
	L AE	
	T	TEST (BITE)
VHF —	ON-OFF	DC POWER
	SQ	SQUELCH OVERIDE
TAC. VHF —	ON-OFF	DC POWER
	EM	EMERGENCY RF POWER
	CLN	BANDWIDTH COMPATABILITY WITH GROUND
	LKR	
	WBC	
	H	VHF HOMING
	T	TEST (BITE)
HF —	ON-OFF	DC POWER
	AM	DOUBLE SIDEBAND
	USB	UPPER SIDEBAND
	LSB	LOWER SIDEBAND
	SQ	SQUELCH OVERIDE
	T	TEST (BITE)

FIGURE 3



COMMUNICATIONS MANAGEMENT
TYPE AA 15601

- Either pilot to control the on/off and functions of each radio
- Monitor and adjust pre-set channels on the left hand display whilst maintaining normal operation on the right hand station.
- Direct emergency selection of guard channels for UHF, VHF, TAC VHF in the event of system failure.

The system is organised to ensure that when a radio is selected, the only frequencies that can be selected are within the particular radio band, or if a pre-set channel is selected, only channels applicable to the selected radio are available.

In addition the multifunction buttons are organised to ensure that when a given radio is selected, only those functions available on the radio are presented for selection.

The displays and annunciators are designed to be compatible with night vision equipment, and also to be readily readable in bright sunlight.

The operating methods are shown in the Appendix to this paper.

The panel described provides facilities for two crew, side by side. Obviously, smaller units for use by one crew only can be devised on the same principle.

6 AURAL INTERFACE

It is fair to say that until relatively recently, the direct link between the communicator and the system, the aural path, has not received the correct degree of attention.

Firstly, problems of high ambient acoustic noise combined with unsatisfactory specification of equipment performance, result in inefficient communications.

Secondly, even where these problems do not exist, the aural path is probably underemployed. Messages are received for only a fraction of any period. Advantage is often taken of this fact by presenting audible warning signals for flight conditions or other alerts. However, identification is normally either by specific tone combination, or by a general tone combined with visual annunciator. The multiple tone solution requires some degree of familiarisation, whilst the Audio/visual combination increases the already heavy visual load.

6.1 NOISE PROBLEMS

Historically, the audio bandwidth of communications equipment has been determined by the standards adopted for telephone systems, typically 300-3000Hz. As the maximum speech power is in the lower octaves (below 550Hz), but the formants are in the higher frequency [illegible], the traditional speech passband has been subjected to closer examination.

The relative inefficiency of aircrew personal equipment in high levels of low frequency ambient noise can cause masking of formants. The subjective adjustment of telephone levels by the crew is largely determined by the power of the lower frequencies. Such a level may appear to be more intelligable, but in practice can be considerably worse.

The criteria for the response of the system must be intelligability, not the classical concept of distortion or fidelity.

Trials of equipments incorporting frequency shaping to provide a response of -5dB at 300Hz to +5dB at 3000Hz relative to 1000Hz have shown that intelligibility in high levels of ambient noise is improved.

The use of 'hot' microphones to provide intercom with hands off operation can also inject excessive noise into the system. A voice operated switch will improve matters, but can 'hang up' in the presence of noise, or require a high level of speech in a quiet environment.

Circuits have been devised which provide 'ambient noise tracking' for a voice operated switch. The circuit enables normal levels of speech in the absence of noise, with an increase in level necessary at the noise is increased. Where sidetone is present, this indicates that the speech to noise ratio is correct.

There is often a requirement to listen to several communication channels simultaneously. The relative levels of the channels are determined by the requirements at any one time. If the mix is adjusted in quiet conditions, any increase in acoustic noise can necessitate re-adjusting each individually, a difficult task as the channels will not contain traffic for the greatest part of the flight.

If the ambient noise is sensed, it can be used to control the total level of the presented signal, without changing the mix. This reduces crew work load.

6.2 AURAL PRESENTATION OF INFORMATION

Speech synthesis has reached the stage where it should be considered for warning signals, confirmatory information, or standard message transmission.

Systems are available with sufficient vocabulary of 'normal' words to construct sentences covering a wide range of situations. For warnings, a voice signal to the ear does not require any familiarisation as with tone signals, or a visual search.

For communication, or for any other system, head down time can be decreased by providing an 'interrogate' button which causes an aural read-out of equipment state e.g.

"UHF, 235 Decimal 175, GUARD ON, HOMING OFF"

Alternatively, control change could automatically provide aural feed back of the actual change.

7 FUTURE POSSIBILITIES

The basic approach has been tailored to the original problem of extending the communications system in a light military helicopter. It is obvious, however, that the same approach applied to a larger and more complex aircraft could still give an overall increase in effeciency and cost effectiveness.

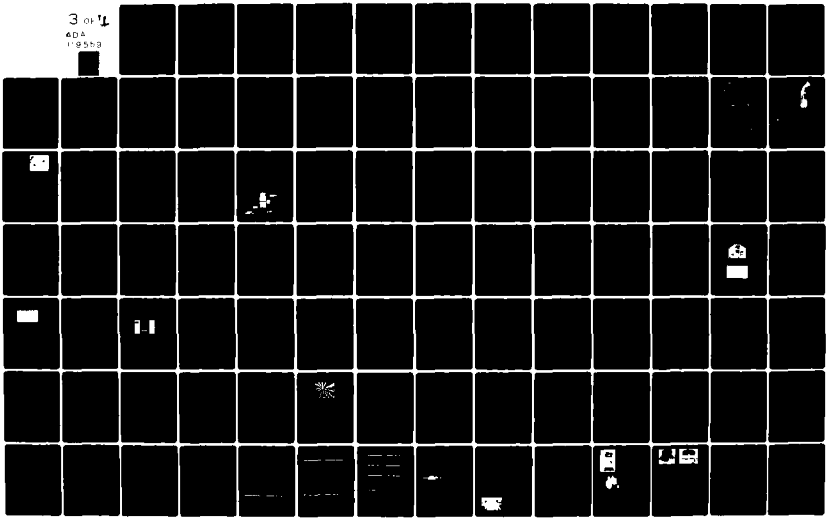
When problems associated with direct voice input in the presence of high ambient noise are refined to a suitable degree, the system can be further improved.

8 ACKNOWLEDGEMENT

The author wishes to express his thanks to the Ministry of Defence, Procurement Executive, A.Rad 12b, for permission to derive this paper from work carried out on their behalf.

AD-A119 559 ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT--ETC F/G 1/3
ADVANCED AVIONICS AND THE MILITARY AIRCRAFT MAN/MACHINE INTERFA--ETC(U)
JUL 82
UNCLASSIFIED AGARD-CP-329 NL

3 of 4
ADA
119559



APPENDIX

COMMUNICATION MANAGEMENT SYSTEM - CONTROL PANEL OPERATION

1 'OFF' State. Figure A.1.
Panel Engraving is visible. Panel engraving illuminated, controlled by main cockpit dimmer.

Legends E, P, T engraving visible, not illuminated

2 Select UHF, at left Station. Figure A.2
Rotate master selector to UHF.
Arrow pointing left at UHF will illuminate
CMU is now powered

3 Switch on UHF. Figure A.3

Repress button with arrow
ON legend on button will illuminate
Indicator by button will illuminate
Function annunciator will illuminate i.e. H (Homing) SQ (Squelch override) G (Guard) UAE (Upper antenna)
LAE (Lower Antenna) UAE ON.
Frequency Display will indicate lowest frequency of selected radio

4 Adjustment of UHF. Figure A.4

4.1 Select New Frequency

Set frequency by left frequency select knob below display.
Depress E.

4.2 Select Homing

Depress Button by H.
Button ON legend will illuminate
Next depression will deselect H.

4.3 Select Guard

Depress Button by G.
Button ON will illuminate
Next depression will deselect G.

4.4 Select Lower Antenna

Depress Button by LAE
Button illumination by UAE will extinguish, button illumination by LAE will illuminate.
Depression of button by UAE will cause change back to UAE.

5 Select Tactical VHF, Right Position

Rotate right master Selector to TAC.
Left display will remain indicting UHF frequency
Arrow by TAC will illuminate pointing right

5.1 Switch on TAC VHF. Figure A.5

Depress button with arrow.
ON legend on button will illuminate.
Indicator by button will illuminate
Annunciators CLN, LKR, WBC, EM, H will illuminate.
Button by CLN will indicate ON.
Right Frequency Display will indicate lowest frequency of TAC radio

5.2 Adjustment of TAC VHF Figure A.6

Adjust frequency of right display by means of selector. Press E button.
Radio will be on indicated frequency
Depress button by EM. (Emergency Power)
ON will illuminate
Second depression will deselect EM
Depress button by H.
ON will illuminate
Second depression will deselect H
Depress LKR
ON indication by CLN will extinguish
ON indication by LKR will illuminate
Depression of button by WBC will change function

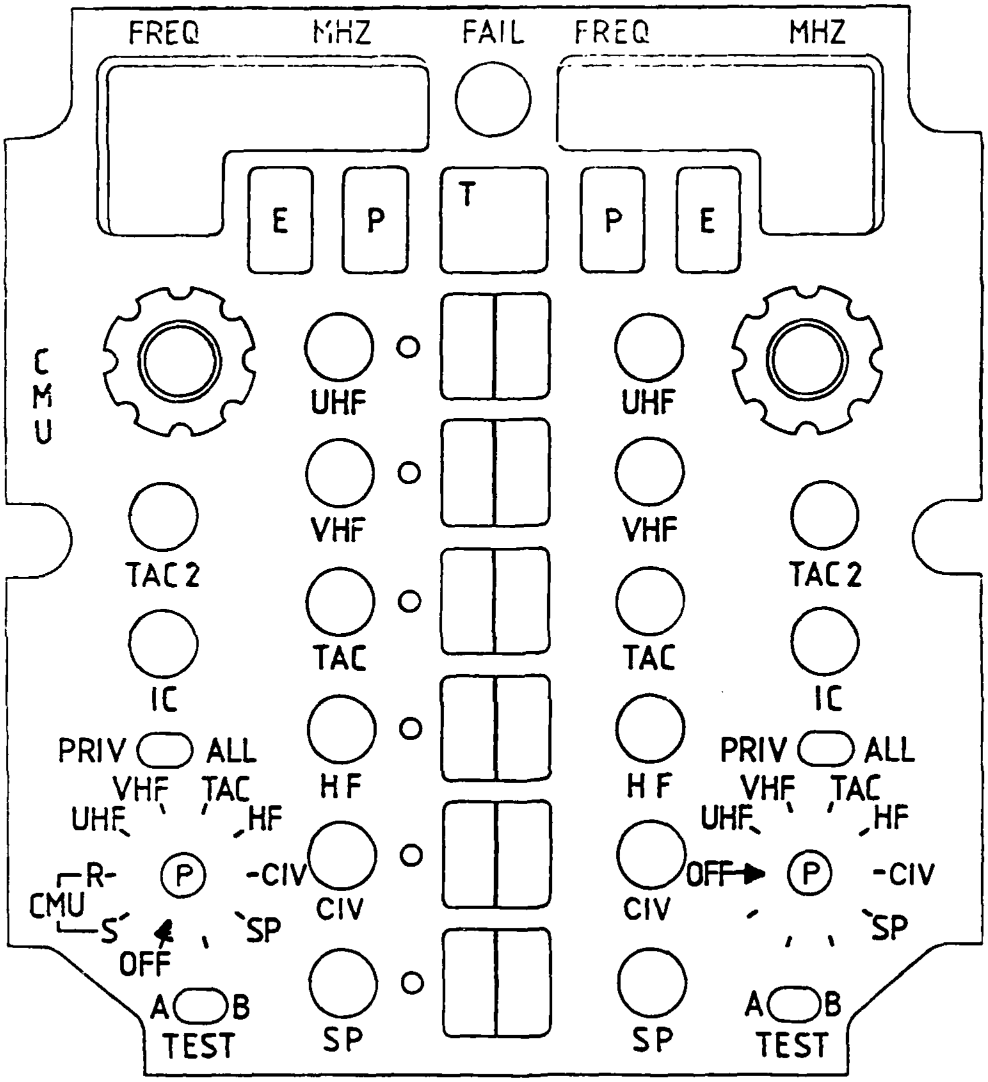


FIGURE A1 UNIT OFF - PANEL LIGHTING ONLY

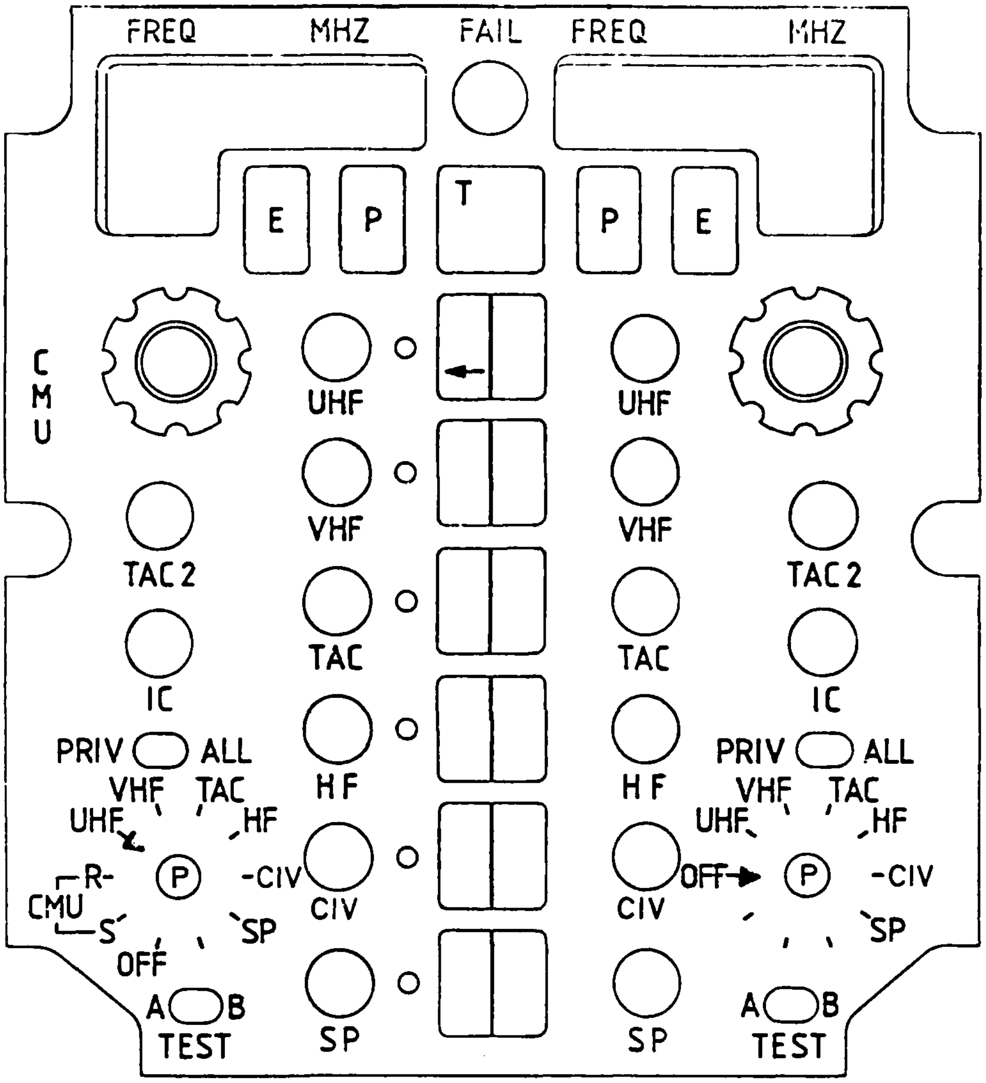


FIGURE A2 SELECT UHF LEFT POSITION

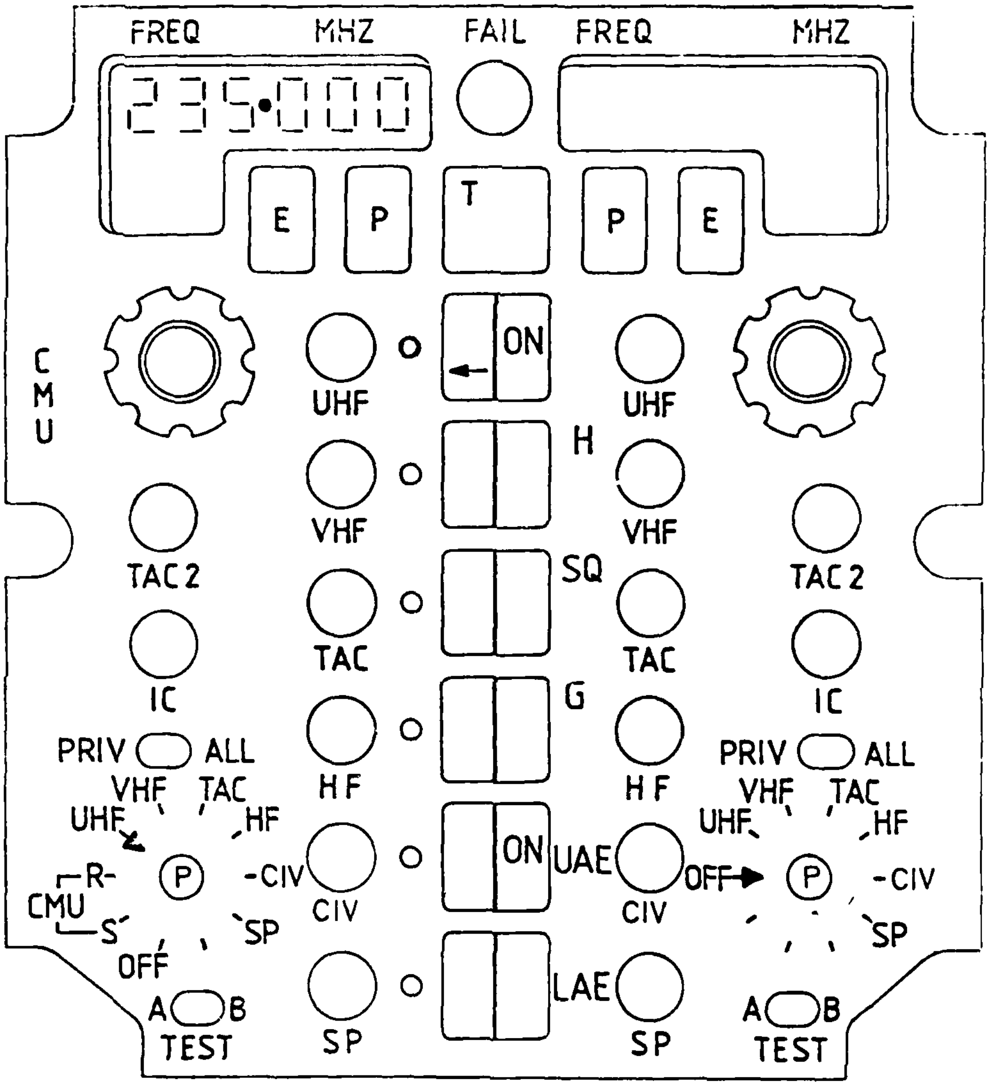


FIGURE A3 AFTER UHF POWER ON

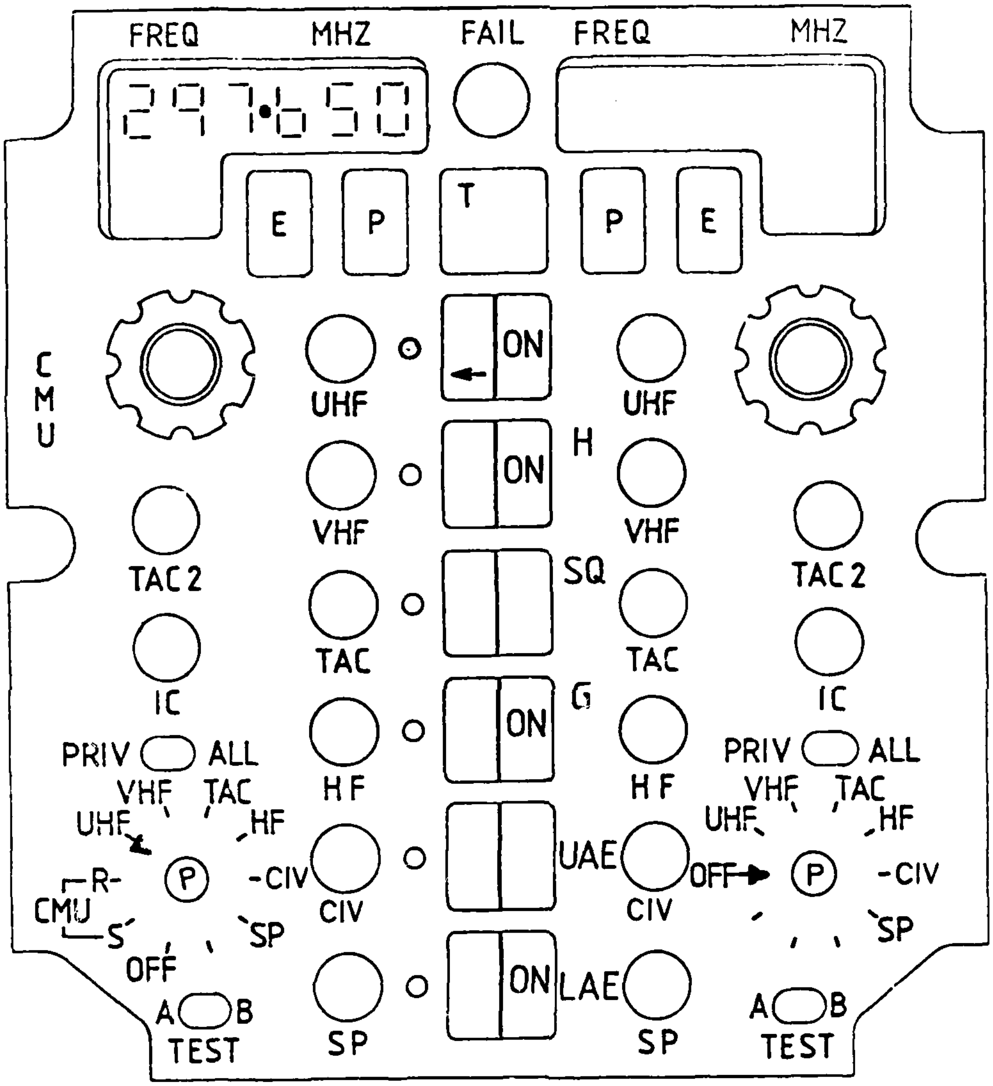


FIGURE A4
UHF ON 297·65 GUARD AND HOMING ON, LOWER AE

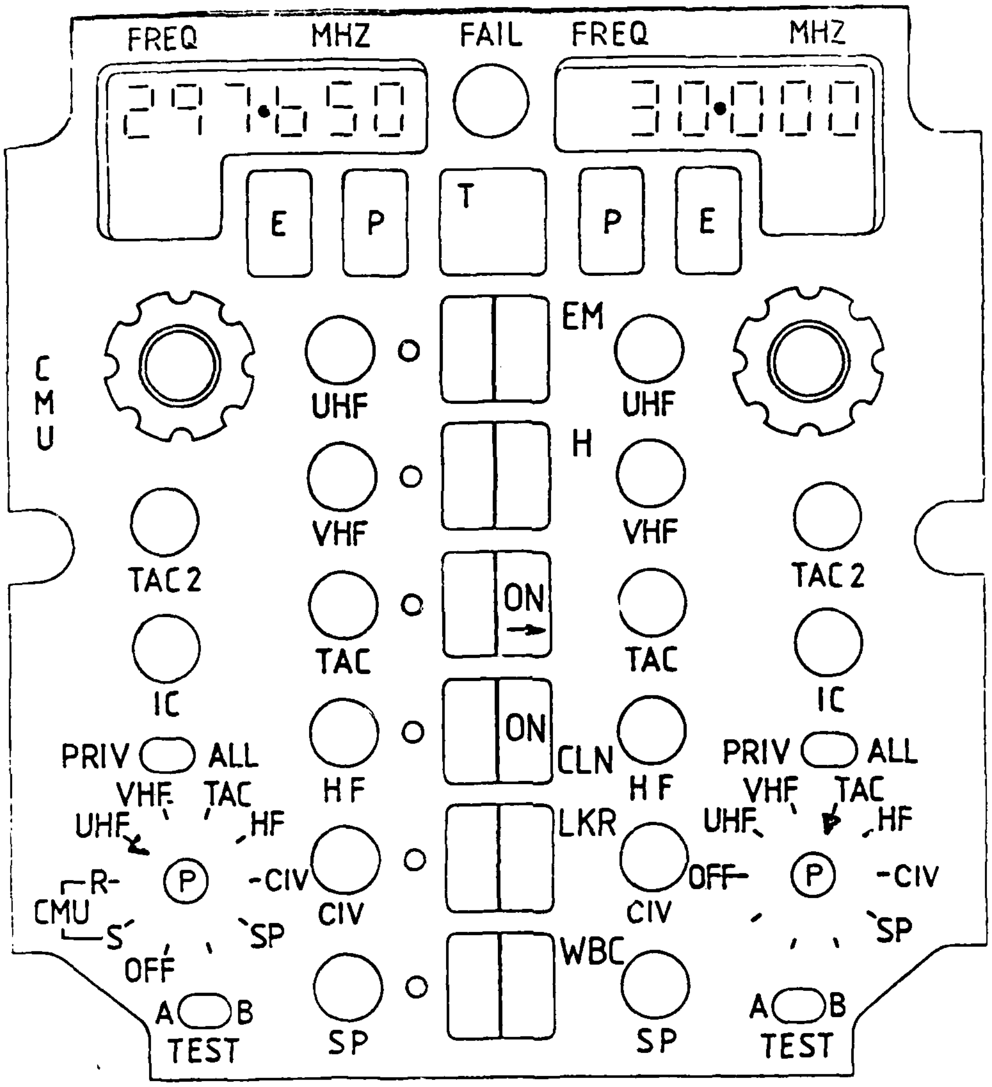


FIGURE A5 SELECT TAC RIGHT POSITION. POWER ON

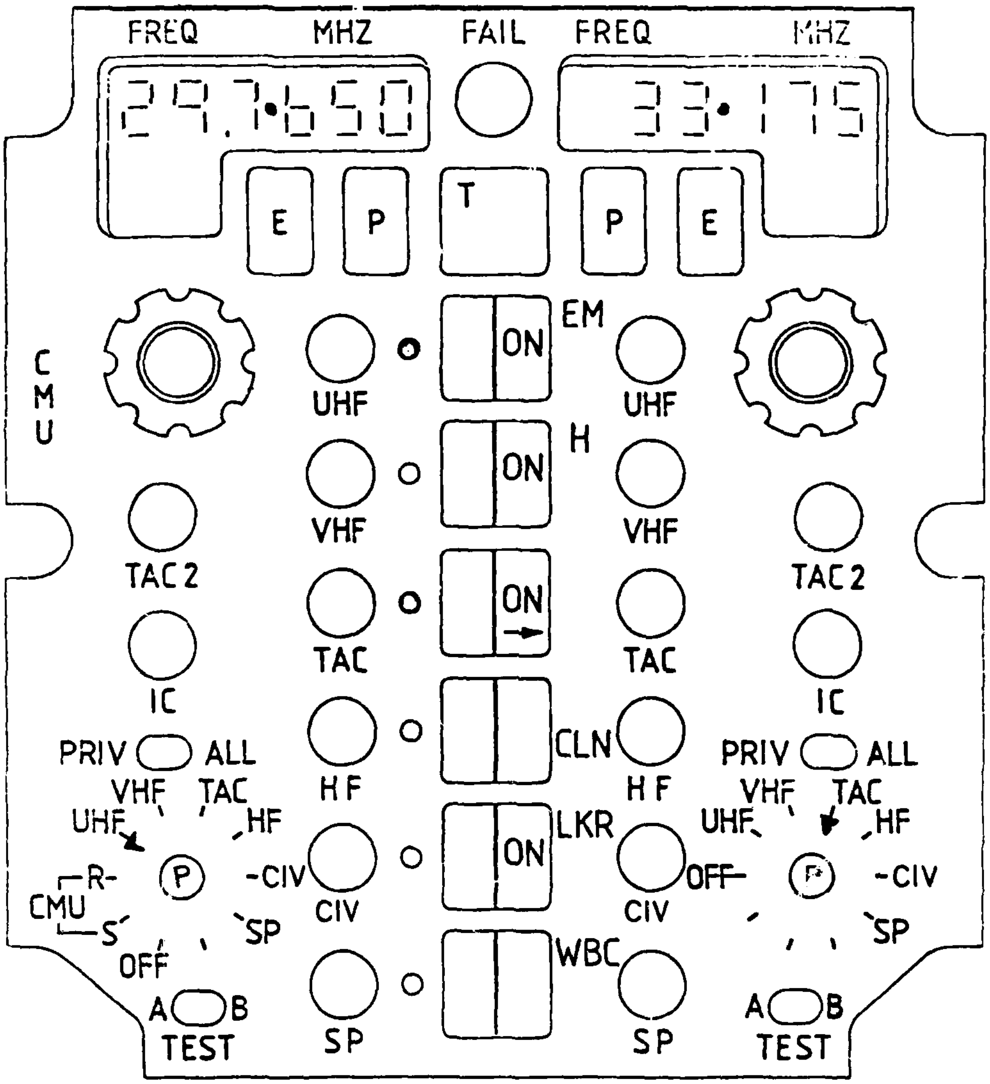


FIGURE A6
TAC. ON 33·175, HIGH POWER, HOMING ON, LARKSPUR

6 Select UHF Preset Channel. Left Position Figure A.7

With left master selector at UHF, depress P button.
P indication by UHF control will illuminate.
Channel number will appear in lower section of left display, with frequency displayed.
Rotate knob concentric with master selector to change channel.

NOTE: Only those channels set up within the UHF range will be displayed. The right display will remain in the TAC condition.

7 Select HF Right Position Figure A.8

Rotate master selector to HF, depress button with arrow.
ON will illuminate.
AM function will illuminate and indicate ON.
USB (upper sideband) and LSB (lower sideband) will be illuminated.
Frequency display will show lowest frequency of radio. Adjustment is carried out in a similar manner to UHF and TAC.

8 Other radios are operated in a similar fashion. The press to transmit lines are also selected by the master selectors.

9 Audio Service Select
Depression of the buttons UHF, VHF, TAC, I/C, etc, switches on the audio signals to the telephones. Rotation of the button will adjust the level of signal.
Selection of any radio by the master selectors will override the OFF state of the audio switch.

10 Pre-set Channel Read-Store

10.1 Read Store
Rotate left master selector to CMU.R.
(Radios need not be powered)
Rotate P control on master selector
All channels in store can be seleced and the frequency examined.

10.2 Enter Store

Select desired channel
Rotate master selector to CMU-S
Adjust frequency by control beneath display
Switching control between R and S enables new frequency to be compared to old.
With selector on CMU-S, depress E button
Selected channel is on new frequency

11 Time-Out Reversion

11.1 Normal Operation
Should any frequency be adjusted, failure to depress the E button within 10 seconds shall cause the display to revert to the original frequency. The frequency of the radio shall not be changed until the E button is operated, other than when pre-set is in use.

11.2 Pre-set Channel Store
With the master selector in the CMU.S. position, failure to operate the E button within 10 seonds of setting up new frequency on the display will cause the display to revert to the stored frequency.
The pre-set channel will not change frequency until the E button is operated.

12 Emergency Reversion
In the event of an emergency, or catastrophic failure, depression of the Fail button will cause the UHF radio to operate on 243MHz, the VHF radio on 121.5MHz, and the TAC VHF to revert to a predetermined frequency

13 BITE

The button engraved with T provides facilities for integrity monitoring and interuptive tests. Three secret numbers 1, 2, 3 are available within this button for diagnostic testing.

The T indicator is employed on TAC VHF to monitor correct operation, and depression of the button initiates the radio test cycle, correct operation indicated by T, 1, 2, 3.

The T indicator can be employed to indicate correct antenna tuning for h.f. The diagnostic self test for the CMU is currently being worked out. The audio system interlinked with this unit contains dual redundant channels, and each position is provided with a Test A-B switch for checking.

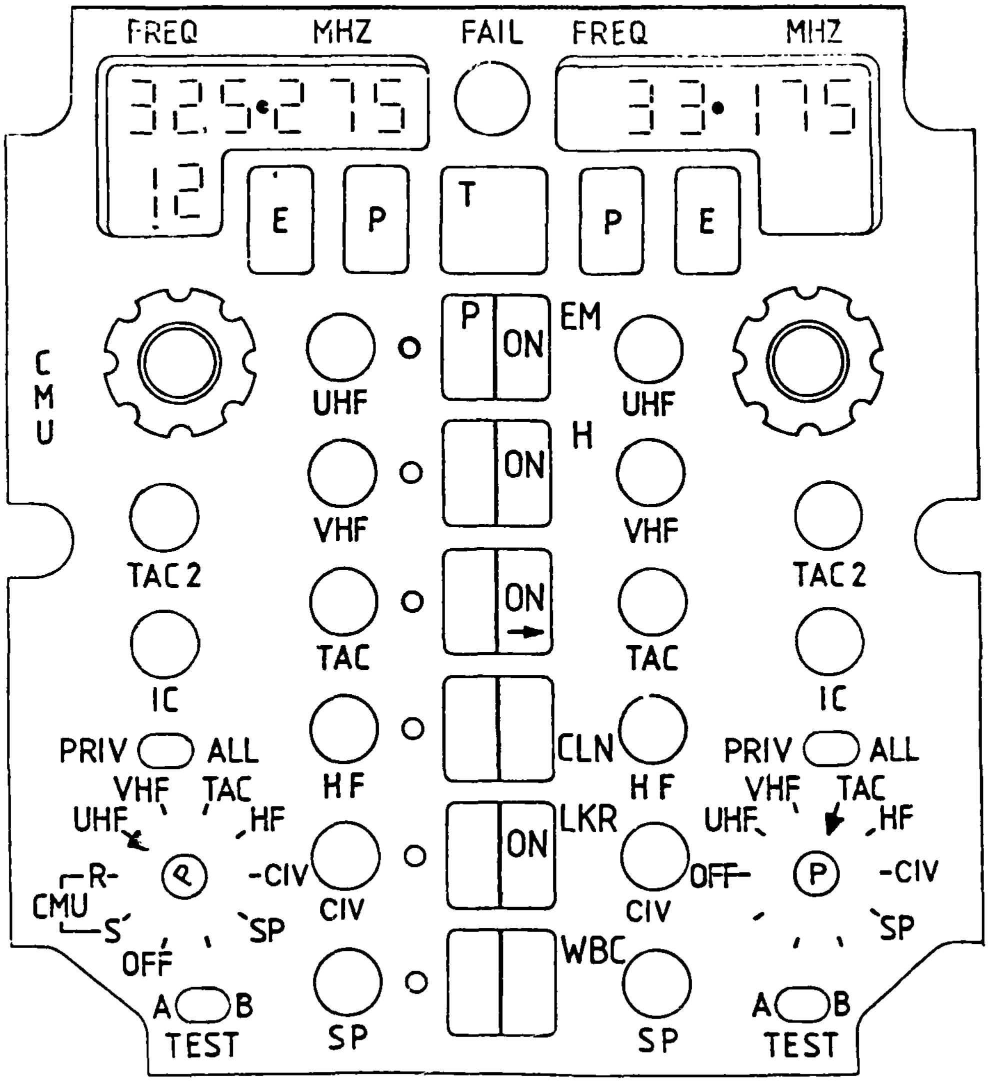


FIGURE A7 LEFT SELECT PRESET

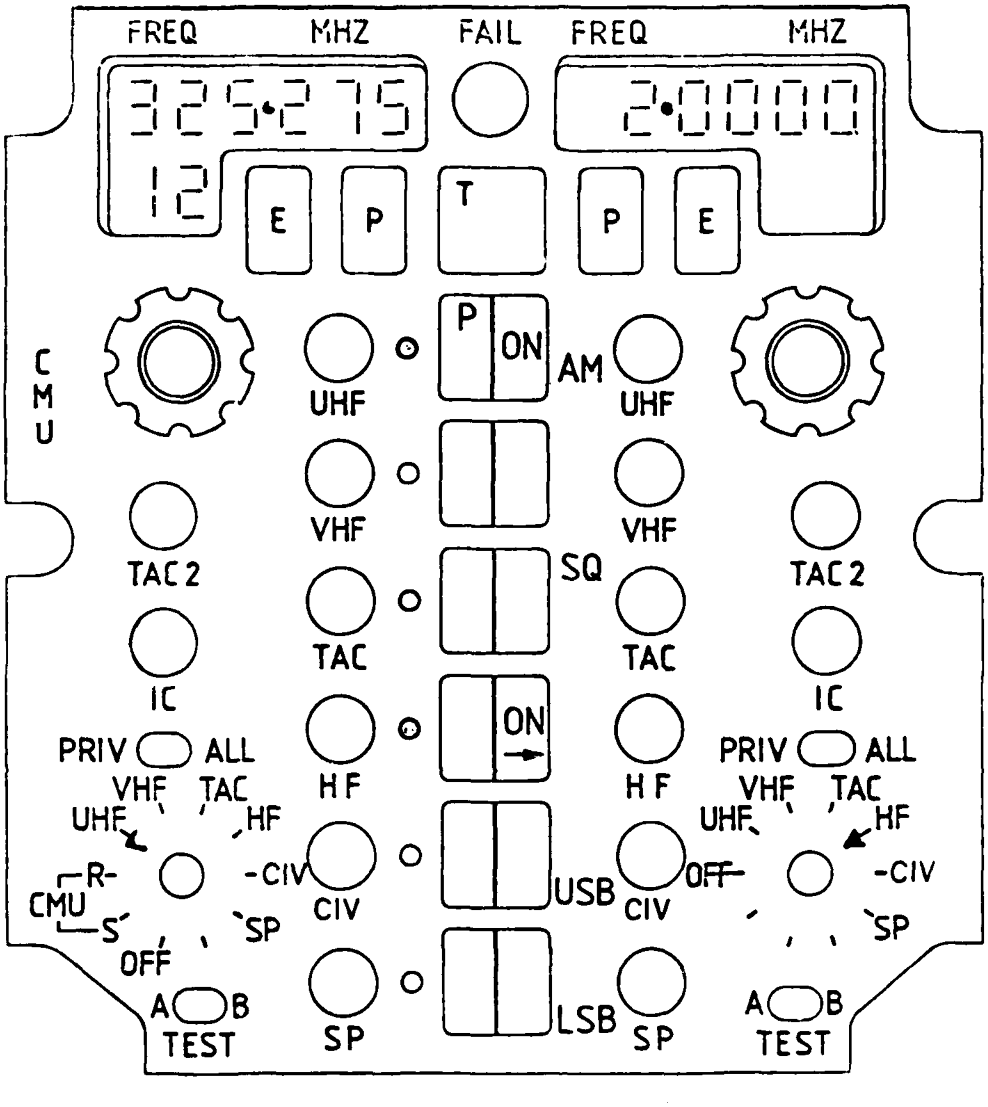


FIGURE A8 SELECT HF RIGHT, POWER ON

FACTORS AFFECTING THE ALLOCATION OF ATTENTION AND PERFORMANCE IN CROSSMONITORING FLIGHT INFORMATION DISPLAYS

by

V. P. Schmit
Human Factors Group,
Royal Aircraft Establishment,
Farnborough, Hants, UK

SUMMARY

The modern military cockpit possesses a variety of spatially separated displays which must be scanned. There is therefore a need for rapid and continuous visual attention switching. Results of two experiments relevant to this topic are presented and measures to facilitate scanning discussed.

Over the last 15 years, technological advances in microelectronics and display devices have revolutionized crew stations in aircraft. Electromechanical instruments and displays have been replaced and/or supplemented by CRTs, discrete switches with multifunction keys closely associated with displays and new sensors and onboard computers with considerable storage capacity have been introduced. These advances have resulted in an information explosion at the crew station, bearing with it the associated problems of information overload and the necessity for more serial sampling of information sources.

In spite of the effort going into voice input and output it is likely that, for the foreseeable future, the dominant modality for information exchange between man and machine in the cockpit will remain vision. The balance, with the introduction of Datalink devices, may even tip further towards vision. Therefore the continuous and rapid assimilation of visual information is, and will remain, a prerequisite for the operation of military aircraft. The amount of this information has increased with technical advances and changes in operational scenarios and this must be viewed in the light of the task of the single-seat fast jet pilot.

This task may be categorized, in broad terms, as an information-intensive, time-stressed divided attention task (achieved in the main by serial attentional focussing). In the extreme, the task is subject to breakdown under overload and exhibits changes of 'coping strategy' with different loadings (as shown by taskshedding and subtask fixation). Given this, any improvement in display design which will enable easier and more rapid information extraction will reduce pilot loading, relieve time stress and permit more rapid division of attention between subtasks.

Information is displayed over a relatively wide spatial angle in the cockpit and there is therefore a need to scan - an inherently serial process. Information sources are already densely packed and there is little or no room for the reduction of this serial aspect of monitoring. Some consolation can be drawn from the fact that, at present, the spatial position of specific information has remained constant and can thus be overlearned with experience (Senders 1966a and 1966b). In future cockpits, the availability of multifunction, multimoded displays may well result in a worsening of this position. The ability to direct information to different displays in the cockpit will tend to break up scanning patterns between displays by making the spatial position of specific information more indeterminate and rendering some information available only on request.

Taking a straightforward approach, we can ask whether there is a possibility of reducing the amount of information in the cockpit. But while specific cases can be argued, it is unfortunately true that, in general, the information presented is necessary to provide required operational performance and survival. In addition, with our current lack of knowledge of ways to effectively combine information there are significant dangers associated with the integration of information before display - we do not yet have an adequate body of knowledge on which to base such an approach, and any attempt to do so on an *ad hoc* basis carries with it potential flight safety hazards. In short, until avionic systems can be made considerably more reliable than at present, which will permit greater automation, one of the functions of the man will be to monitor system status, which can only be done by providing him with the necessary raw information.

The reduction of the amount of simultaneously displayed information through making some available only on request at some stages of flight will only be as good as the appropriateness of the rules used to define that required, and therefore has risks. A more reasonable and cost effective approach at present would seem to be the alleviation of the impact of increased information loading through the optimization of the design of display systems.

The information to be presented here relates to this approach - two areas are specifically related to flight information, while the third, a brief consideration of information coding conventions is equally applicable to all types of display.

Current cockpits have two main routine activities necessitating scanning between spatially separated information sources with a subtask:

(1) Crossreferring - where specific information is more clearly (or only) available on a display other than that currently being used.

(2) Crossmonitoring - this involves the crosschecking of aircraft status parameters derived from separate sources to ensure the correct function of display/information sources.

In addition there are breakpoints in such scanning resulting from either a change to a new subtask or reversion to a secondary display as a result of primary display failure.

Before dealing with the data to be presented, a brief review of what is known of attention will be useful to set the context for what follows. Human attention has been intensively studied since the Second World War, and the scope of this paper precludes a full review, so it will concentrate on one attentional model which fits a large part of the data, Broadbent's 1971 modified Filter Theory (see Fig 1). The central concepts in this are the limited information channel and the means by which the central nervous system restricts the loading on this channel and the output stages. Initially information arrives at the senses and is automatically processed or encoded. The results of this process are stored in a short term store with relatively rapid decay. Beyond this point, filtering takes place by which some elements of the input are differentially weighted in terms of current requirements, those having most relevance being passed to the central channel for further processing. Following processing, an analogous response weighting occurs through a process termed 'pigeon-holing' by Broadbent. This is a process whereby different responses are assigned and weighted by current task context.

To relate these processes to pilot activity, the operation of filtering may be demonstrated by such phenomena as subtask fixation and errors of omission, while pigeon-holing is shown by errors of commission. The apocryphal story of the Hunter pilot is an example of the class of error given by pigeon holing. During takeoff, a trainee pilot looked a little depressed to his instructor, who said "Cheer up" - due to the context of the situation, the trainee interpreted this as "Gear up" and raised the undercarriage while still on the takeoff run.

Given the serial nature of the cockpit scanning activities, with associated 'dwell times' on different sources, we can see where display system design parameters can assist in the reduction of 'dwell time' and increased information processing efficiency. The only place where display design can influence matters is during the early encoding phases of the process - once we reach the limited capacity channel, efficiency is determined by the man. Display system parameters can therefore only affect the encoding and filtering stages, everything beyond this can only be affected by task design.

Results coming from experiments not to be reported here suggest that, during the encoding phase, there is a spatio-temporal 'wave' of processing that spreads out from the point of interest. This is not under conscious control, and as it spreads, more and more peripheral information comes under processing and can interfere with the processing of the required information. The use of colour and intensity coding conventions can permit the early separation and processing of the item of interest before the full build-up of interference, and may permit gains of the order of 100 ms per fixation. Such gains in a scanning situation are considerable.

Considering the three types of activity, crossreferring, crossmonitoring and reversion, it is clear that the need for crossreferring implies some failure in the design process as the most efficient information extraction will occur when there is minimal scanning within a subtask. Crossmonitoring should not ideally be a human function in any situation involving high workload, as the heavy load on short term memory inherent in this activity will impose a heavy load on the limited capacity channel (Bradshaw 1968). Reversion cannot be eliminated, but should be made as easy as possible. At reversion, workload and arousal will be high and studies (*eg* Easterbrook 1959) suggest that a heightening of arousal restricts the range of cues used in the guidance of action: this may result therefore in the rejection of, or inattention to relevant information. There are also indications (Korchin 1964) that high arousal can lead to an increase in scanning behaviour together with increased distractibility. Reversion also involves a memory load. These factors may tend to disrupt performance during the course of reversion and could persist for a measurable time, while disruption may well be increased if the reversionary information is displayed in a different format to the primary information.

It is suggested that reversion is, in effect, an extreme form of crossmonitoring and that the effects of reversion on performance will be qualitatively, if not quantitatively, akin to those involved in flight information crossmonitoring. Thus, if noticeable performance decrements or time costs are exhibited in a reversionary situation, similar, though smaller, effects will be shown when crossmonitoring or crossreferring.

It was therefore necessary to assess any time or performance costs during reversion, and to see if these were affected in any way by the information being displayed in different formats. A subsidiary aim was to investigate performance as a function of duration of format use before reversion to look for any perseverence effects.

Six aircrew with HUD experience served in the experiment, which was run on a PDP11/34 programmed with a simple non-aerobatic aircraft model (Schmit 1981). This model presented and drove simulated head-up display (HUD) and head down instruments (HDI) on a CRT. Subjects were provided with throttle, aileron and elevator controls. Following familiarization with the properties of the model and the nature of the turbulence to be injected, subjects had to maintain 7000 ft, 500 kn and a heading of 090 against this turbulence. During the experiment, only one of the display formats was present at any one time and could be present for one of four durations (40, 60, 80 or 100 seconds). At the end of this time the display was failed and the screen blanked for a short time before the next display was presented. The subsequent display could be either the alternative display or a repeat of the display just failed, thus giving four transition types (HUD/HUD, HUD/HDI, HDI/HUD and HDI/HDI). There were two repetitions of each type of transition for each duration of the previous display.

When a display was failed and replaced by another, subjects were asked to press a button on the control stick when they felt they had a satisfactory appreciation of aircraft status. The time taken to press this button was recorded for each reversion and RMS errors on height, speed, heading, pitch and roll were continuously logged on a 2 second epoch.

Results were analysed using ANOVA and showed the following significant effects:

(1) Response time effects.

(a) Reversion to a HUD format was faster than to a HDI format irrespective of which format had been presented previously.

HUD mean reversion time = 3.48 seconds
HDI mean reversion time = 3.79 seconds.

(b) The time taken to revert was influenced by the length of time spent on the previous format; there was little difference between HUD and HDI formats when reversion occurred within 60 seconds, but beyond this point reversion from a HDI format was noticeably longer (see Fig 2).

(2) RMS tracking performance effects.

The RMS measures did not prove very sensitive, suggesting that the amount of turbulence inserted to make the task demanding served to mask any decrements. The analysis however did show significant and consistent effects for speed and altitude in the 10 seconds following reversion.

Speed:

(a) Speed was controlled more accurately with the HUD format.

(b) At reversion there was an error increase when going from HUD to HUD, while error decreased when reverting from HDI to HUD (see Fig 3).

Altitude:

(a) At reversion errors increased when going from HUD to HUD but decreased when reverting from HUD to HDI (see Fig 4).

From these results it can be concluded that:

(1) Reversion imposes a significant time cost (in this experiment 3.5 to 4 seconds) before full appreciation of aircraft status is restored. It should be noted that the situation used here involved no unusual attitudes and it is reasonable to expect a considerable lengthening of this period if unusual attitudes are present. This finding is of some importance when considered in the light of high speed low level flight.

(2) The HUD format gave more accurate flying performance than the HDI format. This performance was reduced at reversion, even when reversion was to another HUD format, indicating disruption.

(3) Reverting from a HDI format to a HUD format improved performance due to the inherently better display of information on the HUD for the type of flying imposed in this experiment.

(4) Reversion from a HDI format took longer when this display had been used for periods longer than 60 seconds - this may be interpreted as the time necessary to establish a scanning pattern and the interference resulting from its disturbance.

The HDI format inherently requires greater scanning and results appear to point to this lying at the root of slower reversion, duration effects and poorer performance overall. The results taken as a whole suggest that any reversionary flight display should exhibit:

(1) Minimum scanning requirements;

(2) Display integrality;

(3) The minimum readjustment required from the pilot at reversion.

A second experiment may serve to demonstrate what is meant by integrality - this experiment was actually concerned with ways of overcoming this for fault indication. The high integrality of the HUD shown in the previous experiment can also be a disadvantage when it is necessary to rapidly indicate failure, as the display tends to hang together and means that well integrated displays require grosser changes of format to give rapid perception of displayed faults.

The problem was to indicate attitude reference failure on a head up display, and failure formats proposed were as follows:

(1) Failure cross (occulted aircraft, horizon and pitch bars and VSI).

(2) Failure cross flashed.

(3) 'ATTITUDE FAIL' presented centrally (occulting as above).

(4) 'ATTITUDE FAIL' flashed.

(5) Occulted horizon and pitch bars and VSI, aircraft symbol central.

(6) As (5) but with aircraft symbol flashed.

(7) Blank centre (occulted as (1)).

(8) Blanked display.

The experiment was computer controlled with displays being presented on a graphics terminal with fast phosphor (P4). Twentyone subjects took part (twelve civilian and nine aircrew). Aircrew subjects all had some familiarity with HUDs and of the nine, seven had extensive experience of HUD usage.

Following instruction, the subjects' task was to press one of two buttons as rapidly as possible to indicate whether the display shown was a working or failed format. During the session, 160 displays were shown (80 working and 10 replications of each failure format). Each subject saw the same randomized sequence of display formats, but the display parameters (pitch, roll, altitude, speed, vertical speed and angle of attack) for each display was drawn randomly from a set of 10. Response times to the nearest millisecond were collected together with correct/incorrect response data.

Errors were very low (3% of all responses), so all findings were based on correct response times. Analysis of these showed (see Fig 5):

(1) No differences between formats 1, 2 and 3.

(2) Flashing the 'ATTITUDE FAIL' slightly impaired performance.

(3) Blank centre and formats involving the aircraft symbol result in long processing times.

(4) Blanking and display gives very long processing times.

There are differences between civilian and aircrew subjects; aircrew took longer overall, and were more disturbed by the failure formats involving the aircraft symbol. It is suggested that this is due to differing strategies among the two groups. While the civilians were using a pattern recognition strategy, the aircrew were using the displays as information sources which involved deeper processing. For present purposes the interesting feature is the necessity to use specific and gross failure symbology rather than partial removal of display elements in order to break through the tendency to perceive the display as a whole. With losses of some 200 ms in alerted subjects performing the task in isolation, the result in the multitask divided-attention situation in the cockpit is likely to be considerable.

Where then does this leave us? There are *a priori* grounds for regarding both crossreferring and crossmonitoring as activities to be avoided, but if present avionic reliability does not permit the total removal of crossmonitoring, then there are opportunities for the ameliorization of their effects in design criteria for displays and cockpit layout. Amongst these are:

(1) The necessity for crossreferring within a subtask should be kept to a minimum - this is achievable by task analysis during the design phase.

(2) The angle of scan required in a subtask should be kept as small as possible - this is one of the determining factors of display integrality. Sanders (1963) defined three functional visual field sizes - the stationary field (up to 20 degrees), the eye field (up to 80 degrees) and the head field (over 80 degrees) and showed that task performance dropped at the junctions of these fields due to indeterminacy of the appropriate strategy for scanning. Such field sizes are not fixed, but depend heavily on the complexity of the task and the discrimination required - it is reasonable to assume that reading a digitally presented altitude needs higher discrimination than counting dots (Sanders' task) and that field sizes for flight information would be smaller. For this reason, the advent of wide-angle HUDs should not tempt designers to spread flight information on this type of display.

(3) Primary and secondary flight information sources should have similar scan patterns and encodings. The availability of head down CRTs in the cockpit now permit the presentation of flight information similar to that of the HUD so this is now a technical possibility. This does not mean that there should be identical formats head up and head down, as the head down display (with the removal of the requirements for minimal outside world obscuration) could usefully show additional rate information for speed and altitude by counterpointer additions, while keeping the same spatial relationship between information head up and head down. This should allow very similar scan patterns for both displays.

(4) In order to reduce 'dwell time' in scanning, additional coding (apart from spatial position) should be seriously considered. The current availability of high brightness penetron tubes means that, for example, consistent colour coding can be carried on both head up and head down displays.

(5) The integral displays being advocated to minimize workload require more salient failure indications than scanned displays for rapid fault detection.

This is the current state of work on this topic, but, for the future, it is intended to establish Sanders-type field sizes for flight display and to extend the work on reversion to include unusual attitudes to see whether integral displays have any inherent vices in this situation. A more long term aim is to investigate the principles of combining information before display.

REFERENCES

J.L. Bradshaw: "Load and pipilliary changes in continuous processing tasks." British Journal of Psychology 59, 265-271, 1968

D.E. Broadbent: "Decision and stress." Academic Press, London, 1971

J.A. Easterbrook: "The effect of emotion on cue utilization and the organization of behaviour." Psychological Review 66(3), 183-201, 1959

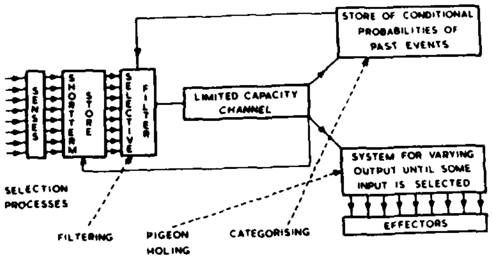
S.J. Korchin: "Anxiety and cognition." In Cognition: theory, research, promise. Ed. C. Sheerer Harper and Row; New York, 1964

A. Sanders: "The selective process in the functional visual field." PhD thesis, University of Utrecht, 1963

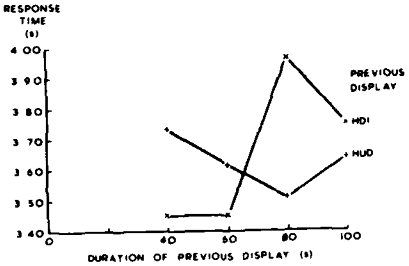
V.P. Schmit: "A simple computer based instrument flying simulator with CRT presentation." Royal Aircraft Establishment Technical Memorandum FS 428, 1981

J.W. Senders: "A reanalysis of pilot eye movements." IEEE Transactions on Human Factors in Electronics HFE-7, 103-106, 1966a

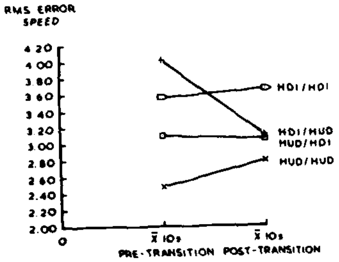
J.W. Senders: "The estimation of pilot workload." AGARD *ad hoc* Panel on Guidance and Control Symposium on 'The human operator and aircraft and missile control', Paris, 5&6 September, 1966b



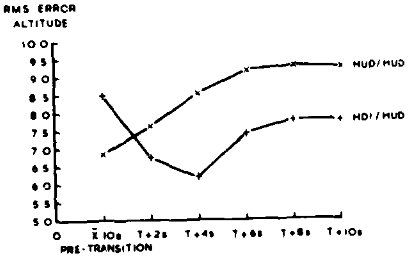
BROADBENTS 1971 FILTER THEORY
FIG 1



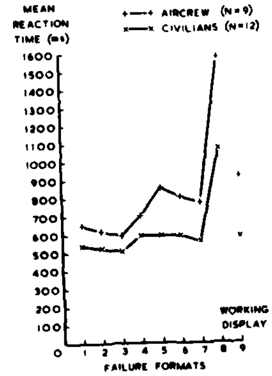
EFFECT OF PREVIOUS DISPLAY DURATION
ON RESPONSE TIMES
FIG 2



RMS ERROR FOR SPEED FOR DIFFERENT
REVERSION TRANSITIONS
FIG 3



RMS ERROR FOR ALTITUDE WITH HUD/HUD
AND HDI/HUD TRANSITIONS
FIG 4



MEAN REACTION TIMES TO
WORKING AND FAILURE
FORMATS FOR AIRCREW
AND CIVILIAN SUBJECTS
FIG 5

THE HEAD UP HANDS BACK CONTROL CONCEPT

Mr. G. Roe,
British Aerospace Public Limited Company
Aircraft Group
Kingston-Brough Division
Brough
North Humberside
U.K.

SUMMARY

The trend towards an ever increasing number of facilities in modern aircraft and the associated increase in the number of controls, switches and display surfaces has led to a self defeating situation in which the pilot has become severely inhibited in his ability to exploit the facilities provided. The development of the microprocessor and digital data transmission techniques provide the opportunity to reappraise the question of systems control. The rationale for a new control concept is developed in this paper by reviewing how current systems are controlled and what operational problems are experienced. Based upon this brief review, a discussion of the potential offered by digital data transmission, intelligent subsystems and a definition of the fundamental human factors requirements, a control concept is presented which requires little, if any head down activities. Results from human factors experiments reveal a consistent trend towards reduced times to complete various complex switch sequences while related errors are reduced.

1. INTRODUCTION

Every new combat aircraft which enters operational service is expected to out-fly its predecessors; this is usually achieved by a combination of flying lower, faster or further. These aircraft are also expected to have improved terminal navigation and deliver a much greater war load more accurately while in an extremely hostile battlefield environment. The sum of these enhanced capabilities is often attempted to be quantified by determining the improvements in what has been termed the "Mission Effectiveness" of the man-machine combination. A major, often limiting aspect of this, is the pilot's capability to adequately control all the basic offensive and defensive systems while still flying the aircraft. Despite this the traditional response for increased mission effectiveness has been the installation of more avionic systems each of which requires its own display and control facility. This trend has produced a near exponential growth rate in displays and control (Figure 1). This present paper describes an integrated control concept which allows the pilot to control all his aircraft systems by means of a greatly reduced number of selectors and with little or no internal head down viewing.

This paper initially reviews traditional control techniques identifying some problems these exhibit. The potential offered by recent technological developments in avionic systems to reduce or eliminate these will then be discussed. The control concept will then be described, specific attention being given to the influence of the pilot's visual and physical requirements on control types and layouts. The utility of this concept will be illustrated by the detailed description of control sequences associated with the communications system. Results from initial human factors evaluation programs will be presented. These provide justification for the claim that this concept has improved the man machine interface. Finally, the paper will discuss briefly a few speculative future concepts for systems control and management.

2. TRADITIONAL TECHNIQUES

The pilots of current aircraft are assumed to be adaptive enough to cope with an extremely complex data assimilation task within the cockpit and an ever more demanding basic flying task. This assumption is now however becoming questionable, as a number of recent aircraft losses have been attributed to the pilot being too occupied with head down console related tasks and as a consequence becoming disorientated and ultimately flying the aircraft into a fatal situation. To illustrate how these difficulties have arisen a current communication system and fuel system control task will be discussed. It must however, be noted that controls and displays cannot be easily considered in isolation as selections, particularly those associated with operational systems which require an indication of the action for pilot verification.

2.1 Communication System Control

The military pilot is expected to operate in both military and civilian airspace and has a basic need to communicate with airborne and ground based transceivers of both types on a selective basis. A typical and relatively simple current aircraft cockpit installation is shown in Figure 2; the obvious question to ask is, why are the various facilities in such diverse locations? Consider the forward panel mounted UHF transceiver; this location is very logical as this is the main radio and as such, requires extensive pilot interaction. The pilot will perform the selection tasks, typically selecting individual digits of a frequency by means of the rotary selectors with his left hand. This allows him to visually monitor the task and transfer attention to the outside world quickly while flying the aircraft with the right hand. The pilot control requirements were not the only motivation for this location; these units are bulky (typically 14.6 cms wide, 12.4 cms high and 6.5 cms deep) containing the transmitter and receiver circuits in addition to the controls and back connectors. A location therefore with ample volume for the basic box and the large connectors which additionally provided easy access for maintenance was essential. The VHF transceiver located on the forward end of the starboard console needs similar volume and access considerations, however, as it is principally for civil communications, its more awkward location which requires a change of hand to fly the aircraft and select data is acceptable. In an attempt to integrate these two radio systems a station box is included. This allows the transmission of the alternate frequencies (VHF and UHF) on a selective basis. The pilot may also select those receivers he wishes to monitor at their appropriate audio levels from this panel. Other facilities in this cockpit include the usual press-to-transmit selector on the throttle, while aerial selector switches are located on the starboard console. Also included are "pop-up" frequency cards which present the most commonly used frequency data in a head up location, in more advanced transceiver units this type of data may be stored and then selected by a simple multi position "Stud Selector". This apparently liberal attitude to control locations is further influenced by the traditional procurement procedure in which only functional groups (selectors, facilities and outputs) are marketed. Companies are justifiably reluctant to split systems to aid integration. Additionally, for fleet commonality, equipments are often Government supplied and therefore costly modifications would be required to other equipments if integration were to be attempted. This leads to the systems designer having to integrate these systems in a less than optimum solution affecting not only the pilots ability to adequately operate them but also wiring runs, weights, equipment location and costs.

2.2 Fuel System Control

The communication system represents what is termed an operational system, the next example, the control of an aircraft fuel system represents what may be termed a basic safety critical system, one without which the aircraft cannot fly. Each aircraft design imposes unique requirements on its fuel system, it is however possible to illustrate some common difficulties. The fuel systems function is to gauge tank contents and transfer fuel to the engine. The controls and displays which support a current aircraft fuel system are shown in Figure 3. The pilot has to control the transfer of fuel from the wing/wing tank combinations to ensure aircraft balance is maintained. To achieve this he needs to monitor a digital readout of total fuel and a gauge reading of internal fuel from the instrument located on the top of the forward console when the total fuel indication shows the two wing tanks are empty, i.e. the internal body and wing fuel remains; the pilot selects the wing tank transfer OFF by means of the selector on the left console behind the throttle, a vertigo inducing head down operation. These mental gymnastics are also required as each of the remaining tanks are emptied. The pilot has then the need to remember three or four values representing either actual tank contents which he may add to the internal contents or substract from the total contents or the actual total values as a consequence of the tanks emptying. This mundane control task becomes extremely demanding when undertaken at 600 knots, while flying 30 metres above the ground. The pilot has the added problem of reversing the whole procedure when in-flight refuelling occurs. Another extremely important feature of any safety critical system such as this is that the pilot has at all times a very good understanding of how the system is functioning. In this aircraft the only direct measure of the fuel system status is a clear warning panel. On this are various cautionary and emergency warning legends which illuminate when either a parameter is out of tolerance or a fault occurs. The pilot's response to this is to refer to hand flight reference cards for the appropriate corrective control procedures.

The two relatively simple examples illustrate the major control difficulties which presently face the combat pilot. These may be summarised as:-

- Functionally related controls (i.e. communications) are in diverse locations.
- Significant head down control panel activities are required which lead to vertigo and disorientation.
- Extensive mental effort required to control basic aircraft facilities.
- Insufficient readily available data on system failures.

3. RECENT TECHNOLOGICAL ADVANCES

Research and development programmes are now well advanced in many NATO countries into how all future aircraft may benefit from the technological advances made in avionics systems over the past five years. Two techniques - the microprocessor and the integrated system concept are seen to offer the potential to both improve overall system effectiveness and significantly improve the pilots ability to handle a multiplicity of control tasks.

3.1 The Microprocessor

The Microprocessor and Large Scale Integration of components is being investigated as facilities which may provide the basic aircraft system with sufficient intelligence to monitor and control its basic functions, removing these mundane tasks from the pilot. A simplified fuel system is shown in Figure 4 in which such a management function is included. This gathers data from all the tank contents gauges and valves while monitoring the aircraft heat load and the engine fuel demand. Utilising this data, fuel is transferred in a predefined manner possibly to suit flight conditions to maintain acceptable centre of gravity positions. Tanks may be isolated when empty or damaged and recirculation is possible in response to high heat demands or tank damage. This system offers the obvious benefits under normal operating conditions of only gross parameters such as total contents and percentage thrust levels being presented to the pilot. If an electronic display is considered this data may become a digital readout and an analogue display instead of a possible six instruments in a conventional cockpit, Figure 5. In the situation where the pilot has a system malfunction, he may select automatic corrective procedures and monitor these on the detailed display also shown in Figure 5 which presents much more data than ever before but in a concise and easily interpreted fashion. In the event of battle damage or power loss the management function would revert to a battery powered primitive capability ensuring fuel flows on demand to the engine. Such a concept as this, for the control of the basic aircraft systems, relies on very high reliability, availability and integrity levels being achieved if the pilot is to willingly rely upon and have confidence in them. Present studies are investigating whether or not such systems with these attributes may be economically achieved.

3.2 Integrated Systems

Most aircraft systems developed over the last ten years utilised a network/star archietecture in which a central computer is used to orchestrate all the data transfers from the effectively dumb aircraft systems. One contemporary system relies on a 50,000 word control programme, which required 300 man years of effort to produce, to control 1,000 data transfers. In such an architecture whenever a system is modified or a new one introduced the control programme must go through a costly and complex modification and revalidation program before flight. Recognising that proposed future systems were to be even more complex and that the pilot could only adequately control these if an unprecendented level of integration took place various investigations into total system integration were instigated.

The development of large scale integrated components small enough to be realistically located within aircraft systems, which can detect, interpret and respond to signals passed along the MIL-STD-1553B or DEF.STD.00-18 digital data highway is the major recent breakthrough in system integration techniques. What do the Data Bus based systems offer in the way of reduced pilot workload? A typical bus architecture is shown in Figure 6. The cockpit controls are now linked directly to the bus network. This now eliminates direct contact with the subsystem removing the need to switch large current, which in turn defines switch contact size. The use of small bodies selectors capable of switching only mill-amps is now made possible. Taking due consideration of the appropriate ergonomic standards relating to panel layout, these selectors may now be grouped into system related panels which in turn may be loaded with respect to their frequency of use. These remote control panels may also include some intelligence to ensure only valid switch sequencies are entered into the bus network.

Another important system to benefit from integrated components is the aircraft flight control system. The pilot presently is hampered in both his adaptive capabilities and his abilitiy to satisfactorily undertake a number of parallel tasks by the amount of effort he needs to apply to control the aircraft. The use of three or four flight control computers each monitoring the aircraft flight conditions and each others programme to control any undesirable dynamic aircraft responses will dramatically improve flying qualities. These fly-by-wire systems also provide the opportunity to reduce the dominance of the flight control inceptor on cockpit design. Flight and simulation studies of units such as the F16 unit, Figure 7, have provided confidence that this type of controller may now be located in a position best suited to the particular cockpit design requirements.

4. THE CONTROL CONCEPT

It was suggested at the start of this paper that it is extremely difficult to isolate the controls from the displays, particularly now that an integrated systems design approach is being considered. A very brief description of a proposed display system is therefore required. The display (Lyons, et al 1980; Roe, 1981) consists of four cathode ray tubes (CRT's) - Figure 8. The Head-Up Display (HUD) presents collimated flight and weapon aiming data, while the Head Level Display (HLD) provides attack sensor video and in an additional mode a full colour moving map on which navigation video data may be superimposed. The two displays of interest with respect to the control concept are the Multi Purpose Displays (MPD's) located either side of the HUD/HLD combination The display architecture which supports these display heads is such that data may be switched under pilot control to any surface, while upon display head failures or system malfunction automatic information reconfiguration is undertaken. The flexibility offered by such a system is obvious, the question is how and which control related tasks should be integrated with it?

4.1 Task Analysis

The overall objective of the present studies has been to produce an easily workable, highly flexible system. Essential steps in this however, was the need to develop an understanding of what the pilot's tasks are expected to be. This required the generation of formalised "missions" and segments of these missions, purely for the purposes of identifying essential facilities and the pilots actions. The initial stage was to develop functional flow diagrams from the missions, which transform requirements into functional terms, this technique is illustrated in Figure 9. It was then necessary to define what tasks the man and machine are best suited to undertake, the definitions used are presented in Table 1. This information in addition to a definition of acceptable levels of system automation, allowed an information and task analysis to be undertaken. In this the functional blocks are assessed to provide a definition of the information and task requirements to adequately fulfil the mission goals at that stage, the task requirements then being allocated to the portion of the system which is best suited to handling them based upon the Human Factors and system criterion previously defined. Having now developed an understanding of the relative split of actions it is possible to define candidate hardware concepts and overall operating sequences and procedures.

4.2 Layout Considerations

If these control tasks were considered in isolation it is obvious that within the guidelines all controls would at the time of operation need to be located in the same small easily accessible area of the cockpit at their time of use. The present approach was to assess the controls further, and attempt to define their frequency of use, the time the pilot dwells on them and the level of accuracy the particular control task requires.

When developing any control layout it is necessary to establish a number of basic physical and visual objectives. The modern combat pilot is exposed to high sustained 'g' forces and long periods of low frequency vibration. The 'g' forces restrict the pilots ability to reach around the cockpit and accurately control dynamic tasks. This has led to the development of the HOTAS (Hands on Throttle and Stick) concept, the control of weapon aiming and release systems during the attack phase. the vibration levels likely to be experienced require that control knobs and switches be large enough to grasp and hold during selection procedures. Vibration also requires reach distances to be minimised as the further away a control is the larger it needs to be if time is not to be sacrificed and more attention than necessary diverted to this simple task. Each cockpit layout imposes specific mobility and reach constraints. It is difficult to define exact requirements for the location of control types and tasks. It is however possible to generalise desirable reach/task volumes for layout purposes. It is considered that the primary reach volume should be that in which the pilot may reach all controls with both hands whilst fully restrained by shoulder and body harness. The secondary volume is that in which the pilot may operate any type of control easily using only one hand, while the tertiary volume should be that in which only limited types of controls may be operated easily.

In the control context two visual aspects need consideration. Firstly, the pilot's performance when reacting to visual stimuli such as warning data while he is viewing the outside world through the HUD. Various reported experiments (Haines R.F. et al 1975) have led us to develop a theoretical model based upon the Ovals of Cassini. The model shows (Figure 10) that warning indicators and any other visual displays may be positioned off the visual axis of the HUD with no real reduction in performance. The second consideration is that of gross head movements. It has been identified that gross downward and sideways head movements cause physiological problems, the most dangerous being vertigo. This indicates an obvious requirement that all displays and controls should be located in front of the pilot. This led us to a need to define visual areas. These developments have been derived from extensive visual studies and recommendations (Wulfeck J.W. 1958) and are also shown in Figure 10. These comprise the Primary visual area in which detail may be discriminated without effort, while maintaining a fixed head position viewing over the aircraft nose through the head up display. The secondary visual area is that which may be viewed while the eyes are fixed looking forward and the head moved, while the tertiary visual area is that which may be viewed without strain with a combination of head and eye movements.

4.4 Control Layout

During initial studies, techniques such as the Multi Function Display (MFD) concept embodied within the F18 Hornet avionics system were considered. The displays, Figure 11, provide the ability to select various control options written upon the screen from the adjacent peripheral key. These control options are organised in a hierarchical fashion, giving more detailed control features - the further into the tree structure the pilot ventures. In addition there is an integrated control panel (ICP) installed directly below the HUD combiner. The ICP provides hand up control of the communication system with an additional capability to update the navigation system by means of a keyboard and dedicated display panel. As integration proceeded however, a need arose for the area below the HUD combiner to contain an attack sensor (our HLD) thus allowing the pilot to transfer attention quickly from one display to the other and generally remain more aware of changes on each display. The need to reach forward was also a cause for concern in a cockpit which would be operated in a high speed low altitutde high vibration environment while in addition a reclined seat is being considered to relieve the effect of high acceleration.

The control layout developed and currently under evaluation is illustrated in Figure 12. The avionic system supporting this layout utilises all of those advanced technologies previously described (Data Transmission large scale systems integration, active flight controls etc.). The flight controller is located upon the starboard console in an attempt to improve dynamic tracking performance under high acceleration manoeuvres. The control handle contains all those facilities required by the pilot to select the appropriate sensor and its field of view during an attack along with the selectors for the enablement and release of the weapon. To minimise excursions off the flight controller during flight, although with an ACT system this is not a critical requirement, all the once-a-flight selectors were located outboard of this, these being arranged in order of frequency of use around the arm rest i.e. decreasing use forward and aft. At the forward end of this console is an Interactive Control Panel which in principle operates in the same manner as the F18 displays. However, this is primarily a control facility for sensor modes and role change equipment such as the RECCE pod.

Due to the desirability of all once-a-flight switches being located on the starboard console the major control panels need to be located on the port console. Traditionally this console has been dominated by the engine throttle box. It is proposed to use digital control techniques, similar to those proposed for flight control, the engine control, thus providing the opportunity to reconsider throttle design. The design developed for this cockpit is a sliding throttle incorporating all the usual gates and stops. A detailed description of a similar throttle mechanism has been reported elsewhere (Kaye A. 1981), the grip itself is the unique feature. This not only incorporates all aiming and flight modulation selectors but is shaped in such a way as to act as a wrist rest when the pilot enters or selects data from the keyboard at the forward end of the console. This keyboard, the Mission System Keyboard (MSK) may be considered at the heart of the control system. There are three basic facilities available at this location. The main mission keys, these select display formats related to specific tactical situations, the numeric keyboard which is utilised during data insertion into the communication, navigation and stores management systems may be used to select coded options related to other basic systems. While finally the systems keyboard may be used to access either detailed selection procedures or system monitor facilities. These systems-control facilities will be discussed in detail presently. The three major aircraft operational systems are controlled from integrated panels located outboard of the throttle again allowing control tasks to be undertaken with the minimum of arm movement. These panels consist predominantly of multi-position rotary selectors. Various control types were initially investigated, results from this assessment are summarised in Table 2. Rotary selectors with console legends were ultimately selected for the following major design reasons:-

- They offer an excellent space utilisation in a small cockpit.
- Provide an unambiguous indication of the option selected and a potential means of selection in the event of display and/or bus network failure.
- Provide a firm hand hold during selection in vibration conditions.
- The pilot is familiar with this type of control.

This type of selector however does require special system design considerations when used in conjunction with digital systems. In particular, switch contact bounce must be eliminated, this may be achieved by either hardware or software techniques.

In developing the actual layout of these integrated panels the task analysis functional requirements were again utilised. The total mission requirements for each system were evolved into logical switching sequences. Pilot logic diagrams were then developed using flow diagram techniques which describe each of the various system switching procedures. A portion of the logic diagram for the communication system is presented in Figure 15. This shows the control task, the location of the selector and the information required for presentation on the display screen.

To attempt to illustrate the utility of what are the major elements of the proposed control concept, the communication system control sequence will be discussed in some detail. If the pilot requires to select the frequency of a transceiver for transmission which is not part of his planned sequence he selects the 'COMMS' key on the systems keyboard. This presents the list of presently selected channels in the frequency bands available on the Display Screen (Figure 14), inverted video indicates the transceiver presently selected for transmission. If the channel required is one of those within the frequency bands presently selected for a second key press presents a list of channels, Figure 15, which were inserted into the system pre-flight by means of a "mass storage" briefing aid. If the channel is within another frequency band the frequency selector is operated, this presents the prebriefed channels for the new frequency band. The pilot may then inspect this list and by means of rotating the channel selector, obtain the required option. Depression of the accept key on the numeric keyboard acts as a task terminator and reverts the channel display to the master display which shows the data update and after a predefined time interval the main mission format is returned suitably modified. The initial reason for the pilot entering this selection procedure is likely to be the insertion of a new frequency/channel by means of the keyboard within the MSK. This task would be achieved by the pilot selecting the 'MAN' location on the channel selector, this "unlocks" the keyboard and informs the mainbus systems that the following keyboard insertion are to be routed to the Communication System. As the pilot inserts the digits for the new frequency these are presented on the display screen for verification at the location marked 'MAN'. Selection of ACCEPT again terminates the procedure and restores the mission displays. The side console processors during these tasks perform error checking ensuring that if the pilot misses visual verification of an invalid data insertion, this does not enter the system and an error is signified on the screen when he ultimately selects the accept key.

If the pilot interrupts the full task once initiated and selects another system option without the selection of the accept terminator, no system changes will take place and the system will continue transmitting on the last selected channel. Upon the subsequent selection of the Communications key and selection of the accept terminator the stored changes would be implemented. If the manual data insertion task were interrupted the same procedure occurs although the digits inserted to the point of interruption are saved. This allows on selection, the insertion procedure to be completed. However, if a new option is selected upon reselection of 'MAN' the new frequency procedures is implemented. This facility is again one of the attributes provided by the side console processor.

This procedure may be entered from any phase of flight and provides the full range of selection options. However, the system is configured to provide the selection of a new transmitting frequency/channel by simply rotating the relevant selector. For example, when requested to change from UHF 1 Channel 2 to UHF 1 Channel 3 a full data presentation is unnecessary as both the frequency channel selectors have their uniquely identified locations. The pilot action need only be to rotate the channel selector one step clockwise. Any action such as these would cause the current transmission status display to be modified for pilot verification. In addition these procedures do not require the Accept key to be selected as a terminator.

This technique of pages of data selected from systems keys and unique selectors to manipulate these data is utilised for the control of the other operational system facilities. The final control facility to be discussed is that termed the PAWS (the Pilot Alerting and Warning System). This system indicates to the pilot, by means of indicators mounted upon the coaming edge (refer back to Figure 8) that a quantity has exceeded a predefined tolerance or that an indicated value within tolerance is unreliable due to an associated subsystem failure. When an indicator is illuminated, the pilot depresses the key, this action, supercedes the mission mode data format on the display directly below with a presentation of the warning data and the appropriate corrective procedures, some of which may be automatically undertaken by the system with visual indication when complete. These presentations remain until either the pilot cancels the warning in which case a running list of warnings cancelled is presented on one display as part of the mission data, or the malfunctioning system is corrected.

5. HUMAN FACTOR STUDIES

The previous discussion has shown some of the present undesirable features of control systems and has discussed a control concept which is proposed to reduce, if not eliminate these problems. However, the question needs to be asked, how can such claims be justified and what techniques are available to assist in the validation?

5.1 Workload Discussion

It is necessary to briefly discuss what is meant by pilot workload to understand the foundations of the present studies. Those interested in a detailed discussion should consult Moray, 1979, AGARD, 1978. Workload may be considered as the relationship between operator performance and task load, Figure 16 illustrates this concept. The major problem for the system designer is that the well trained, highly motivated pilot tends to operate at the good high knee of the curve very close to the high workload slope. The every day understanding of this area is having too much to do with insufficient time for satisfactory completion. In the single seat aircraft if the pilot finds himself in a high load situation, what does he do? There are two hypotheses in general favour with respect to control tasks. Firstly, the pilot would shed the tasks he considered to be of least priority, thereafter concentrating on the high priority tasks. For example, during the attack sequence of aiming weapons the pilot may decide not to monitor his basic systems or communicate, concentrating upon the outside world and internal aiming cues. The second hypotheses is that the pilot is willing to accept a reduced level of accuracy for the completion of one task while undertaking another. The pilot may for example during cruise flight, set weapon release patterns, weapon fusing etc., into the stores management system while allowing the aircraft to deviate within broad tactical limits, from track and altitutde. From these hypotheses two basic assumptions may be drawn, firstly, the pilots activities may be measured as the fraction of time he is occupied in handling the multiplicity of tasks imposed on him. This includes both his mental processing and limb movement time. Secondly, the pilot allocates his attention in a sampling fashion, the dwell and sampling rates for a particular task being dependent on the information content and task demand. The present practical and theoretical studies are intended, while developing a practical affordable cockpit solution, to validate these hypotheses and assumptions.

5.2 Workload Evaluation

Workload Measurement Techniques may be conveniently split into Subjective (structured questionnaires, rating scales) and objective (secondary tasks, read times, physiological measures) techniques. The studies to be discussed use only objective techniques. It is considered vital however, that such tests are not conducted in isolation. It is hoped some form of test battery may ultimately be developed covering both techniques which will be universally adopted and applied.

In connection with the control layout it has been shown that reach times and hence distances between selectors are important factors. It would therefore prove extremely useful if predictive task time definition techniques could be developed for use during the design process before the mock-up stage. T techniques, Work Factor Time Standards (WFTS) and Index of Difficulty (IoD) have been studies. The initial requirement for both of these studies was the development of a reach distance matrix for the proposed controls layout. A simplified matrix showing the major functional selectors and groups is presented in Figure 17. The WFTS technique (Quick J.H. 1962) requires a detailed analysis to be made of particular tasks and actions with these being defined as a number of distinct and separate motions. The analysis defined the body member used, the type of motion and the distance travelled, the relevant sensory/mental process involved and the weight and dimensions of that target components. From these definitions, time values are established from comprehensive tables provided.

The IoD technique (Fitts P.M. 1973) uses a measure derived from information theory to specify the difficulty of a major task. This measure is Fitts expression of the ratio of accuracy of termination to amplitude of movement (e.g. distance). The results from this are given in terms of the number of 'bits' of response information per second passed by the subject, i.e. the higher the number of bits the more difficult the task. The major consideration with this technique is the development of realistic values for the target areas for the termination of a task. This is one area which is considered to require additional study.

To validate the results of these theoretical techniques a comprehensive slow motion video analysis was performed of specific control tasks. Against this data the WFT's predicted values exhibited a 74% correlation at + 15% least squares confidence limits. Whilst plotting the IoD for each selector against the actual reach and grasp time, Figure 18 shows a correlation coeffficient of 0.86 between the data. This supports the postulation that a small selector a long distance away requires longer to grasp and hence its index of movement difficulty is big.

This data by itself does little to tell us if pilot workload has been reduced. It is necessary to compare actual tasks undertaken in a conventional cockpit with the same task in our integrated cockpit. The communication task provides a useful example. The pilot switching sequence diagrams were used to define realistic pilot tasks. Theoretical times were defined for each discrete task, while well trained subjects performed these tasks in the cockpit where video recordings were obtained. The cockpit shown in Figure 2 was used for comparison purposes and the appropriate tasks defined. The example task is shown in Table 3 with the comparative results. Firstly, the advanced cockpit reach times show a typical 0.13 seconds increase from theoretical to observed times; it is believed this is caused by the inability to predict the time fraction associated wtih the decision making process. It is very tempting to say that the value experienced here is this fraction, however it is believed further studies are required to justify this. The initial high reach time value seen in the observed results is a consequence of the subject having no prior knowledge of the change required until briefed over the headset, this requires an interpretation and reaction phase, the definition of this is an area requiring further study. These comparative results show the obvious; that rationalisation reduces reach times and hence influences pilot workload. It should be noted, however, that not only has the control concept been validated with objective data a predictive technique has also been developed for reach times. This will have significant use as a control layout optimisation tool during future studies and present modification programmes. The techniques described here are being applied to the other major avionics systems control panels. The resultent data will supply a base line against which other control techniques and mission sequence schedules may be evaluated.

6. SOME FUTURE CONTROL PROSPECTS

The present paper has discussed a control concept which utilises control techniques of mature or advanced development status. There exists also a number of techniques presently considered medium to high risk which could significantly influence future control systems design.

The first such technique is Direct Voice Control (DVC) in which the pilot would verbally command the systems. The fundamental concepts and techniques associated with voice recognition have been extensively investigated and there are commercial voice control systems available. The main problems associated with aircraft applications of such systems are currently stated as high cost, weight and volume. There is also a belief to cope with environmentally induced voice changes. While investigating these problems, in-house studies using a simple system have shown that provided good R/T procedures are adopted 95%-98% is possible. If one considers that such a system would be used in conjunction with a display on which the data selection would be presented for visual verification this detection level appears quite acceptable considering the current development status. Present hardware limitations will be significantly reduced as Very High Speed Integrated Components (VHSIC) begin to be included in future systems. It should be noted however, that to exploit the full benefit of DVC it may be necessary to implement Synthetic Voice output as a verification facility and a means of systems monitoring.

The second technique is the Touch Sensitive display. The sensing techniques used vary - in one matrix of intersecting light beams and photodetectors are positioned around the edge of a suitable display screen. The intersections of the light beams are located above the selections available which are written upon the screen. When the pilot touches the screen at the selection he requires, the light beam is broken and the system recognises this as a selection. In the context of the present control configuration this type of device could replace the Interactive Control Panel, while on the Head Level Display, which is very close to the pilot such techniques are being considered for the selection of tactical data in the map mode. Use on the multi-function displays is considered unacceptable due to the reach distances.

7. SOME CONCLUDING REMARKS

This paper has sought to indicate how the pilot of the present combat aircraft is expected to monitor, interpret and reconcile often inadequate or insufficient data sources in an attempt to control his onboard systems. It was recognised a number of years ago that this situation was unacceptable and studies were implemented to investigate firstly, what the current limitations were and secondly how advances in various technologies could be put to use to enhance the pilot's obviously limited capabilities.

When new technologies and techniques are proposed to our military forces, they adopt the very justifiable attitude, after years of unfulfilled promises, that the burden of proof, that these advertised improvements offer an increase in operational effectiveness lies with the proposing group of engineers. This "burden of proof" not only covers an easily workable cockpit solution, but also presents a requirement to prove, to the satisfaction of the appropriate authorities, that the system solution, which inevitably is required to be of low cost, is reliable and maintainable, while achieving high levels of integrity and data availability. Our major efforts presently are attempting to provide a facility in which this apparently unresolvable set of problems may be addressed. To achieve this the current theoretical and practical human factors studies are supporting the detailed design and development of an integrated display and control system for this facility. To address the systems related problems a full digital bus orientated system is under development which will stimulate the cockpit systems. These studies have led to the development of fundamental control system design criteria. Those systems best suited for automation have been defined and practical studies are now well advanced into the practicability of the concepts. The example of fuel system control in this paper has shown that the pilot would have much more data readily available on which to make reasoned judgement than ever before, but this is on a selective basis. Evaluations have taken place into optimum control types, with rotary selectors presently offering the best compromise; while computing located within the side consoles has been shown to offer both the opportunity for extensive rationalisation/integration of controls and the ability to undertake error checking, cross monitoring, etc., of control selections, which potentially improves system integrity and availability.

It is believed the results presented of the control layout evaluation show that it is possible to develop predictive reach time techniques for use at the drawing board stage. It must be noted that until a comprehensive reach time data base pertaining to tasks performed in current aircraft is produced this technique is questionable. These techniques are however seen to be extremely useful in system modification programmes as optimisation/comparative measures.

From the preceeding discussion, it is obvious that the more effort expended on systems integration the deeper one's understanding needs to be of the human's capabilities as it is attempted to trade-off system complexity, against 'workload', and balance the displays and control requirements. The Avionics engineers need to become aware of workload measures and ergonomists of system design, could it be that an "Avionomist" is needed to ensure that the apparently limitless potential of future avionic systems techniques is exploited to the full.

8. ACKNOWLEDGEMENT

This paper presented by permission of British Aerospace Public Limited Company.

9. REFERENCES

1. OSTGAARD, M.A., 1981, "Multi Function Cockpit Design Considerations", AGARD-CP-312, Paper 1.
2. LYONS, J.W. et al, 1980, "The Influence of Visual Requirements on the Design of Military Cockpits", AGARD-AG 255 page 12-1 to 12-25.
3. ROE, G., April 1981, "Displays for Avionics", Display Applications and Technology, Volume 2, Number 2, IPC Press Pages 259-165.
4. WOODSON, W.E. et al, 1964, "Human Engineering Guide for Equipment Designers", Cambridge University Press.
5. HAINES, R.F. et al, March 1975, "Response Time to Coloured Stimuli in the Full Visual Field", NASA TN-D-7927.
6. WULFECK, J.W. et al, November 1958, "Vision in Military Aviation", WADC Technical Report 58-399.
7. KAYE, A., 1981, "The Development of a Miniaturised Digital Thrust Demand Unit", AGARD-CP-312, Pages 13-1 to 13-10.
8. MORAY, N., 1979, "Mental Workload - Its Theory and Measurement", NATO Conference Series Plenum Press.
9. 1978, "Assessing Pilot Workload", AGARDOGRAPH No.233.
10. QUICK, J.H. et al, 1962, "Work Factor Time Standards", McGraw Hill Book Company, New York.
11. FITTS F.M., et al, 1973, "Human Performance", Open University Press.

MAN GOOD AT	MACHINE GOOD AT
● DETECTING A WIDE VARIETY OF STIMULI	● LONG TERM MONITORING.
● PATTERN RECOGNITION	● CONTROL OF REPETITIVE LONG TERM TASKS.
● EXERCISE JUDGEMENT	● FAST RESPONSE
● REACT TO THE UNEXPECTED	● DOES NOT TIRE
● ORIGINALITY IN PROBLEM SOLVING	● RAPID COMPLEX COMPUTATION
● APPLY EXPERIENCE TO PROBLEM SOLVING	● PARALLEL MULTI TASK OPERATION
● FINE SHORT TERM CONTROL	● FAST RECALL AND STORAGE OF LARGE AMOUNTS OF DATA.
● NONE LINEAR CONTROL	● PRECISE, SMOOTH EXERTION OF GREAT FORCE
● GRACEFUL DEGRADATION UNDER OVERLOAD	
● INTUITIVE REASONING	

BASED UPON DATA FROM WOODSON W.E. 1964

Table 1 Distribution of Abilities

CRITERION \ CONTROL TYPE	ROTARY	INC DEC SWITCH	SINGLE KEY	MULTI FUNCTION KEY
SPACE REQUIREMENT FOR SINGLE FUNCTION	● ● ●	● ●	● ● ●	● ● ●
SPACE REQUIREMENT FOR 16 FUNCTIONS	● ●	● ●	● ● ● ●	● ●
KNOWLEDGE OF SELECTION AT SOURCE	● ● ● ●	●	● ● ● ●	● ● ● ●
POTENTIAL TACTILE CONFUSION	● ●	● ● ● ●	● ●	● ● ● ●
POTENTIAL MENTAL CONFUSION DURING TASK	● ●	● ● ●	● ●	● ● ● ●
HAND SUPPORT REQUIRED DURING OPERATION	●	●	● ● ● ●	● ● ● ●
OPERATING FORCES	● ● ● ●	● ● ●	● ●	● ●
ACCURACY TO REACH AND SELECT AT FIRST ATTEMPT	● ● ● ●	● ● ●	● ●	● ●
HARDWARE DEVELOPMENT	● ●	● ● ●	● ●	● ● ● ●
SOFTWARE SUPPORT	● ●	● ● ●	● ●	● ● ● ●
PILOT FAMILIARITY	● ● ● ●	● ●	● ● ● ●	●
POTENTIAL OPERATION IN EVENT OF BUS FAILURE	● ● ● ●	●	● ● ● ●	● ● ●
RELATIVE SYSTEM COMPLEXITY	● ●	● ● ●	● ●	● ● ● ●
BASIC CONCEPT RISK	●	● ● ●	● ●	● ● ● ●

KEY NONE ● LOW ● ● MEDIUM ● ● ● HIGH ● ● ● ●

DEFINITIONS

Rotary	a selector mounted on a centre spindle with mechanical latches on this which represent option
Increment/Decrement	a centre loaded off switch, forward motion moves, marker up a screen, backwards motion down. A display is essential for use of this selector
Single Option Key	a latched or unlatched push selector
Multi Function Key	an unlatched push selector, which after selection presents option on a display on the selector face

Table 2 Assessment of Control Types

ADVANCED COCKPIT					CONVENTIONAL COCKPIT			
ACTION NO	TASK DESCRIPTION	DISTANCE	PREDICTED TIMES	VIDEO TIMES	PREDICTED TIMES	DISTANCE	TASK DESCRIPTION	ACTION NO
1	HAND LEAVE THROTTLE & MOVES TO "COMM" SYSTEM KEY ON 'SK'	8.7	0.52	1.36	0.36	6.3	HAND FROM THROTTLE TO UHF CONTROL PANEL	1
2	HAND LEAVES KEY & MOVES TO FREQUENCY SELECTOR	10.8	0.53	0.67	N/A	N/A	VIEW FLIP PANEL AND ENTER REQUIRED CHANNEL ON FLIP SWITCHES	2
3	SELECT NEW FREQUENCY (COULD BE ANY OF 8)	N/A	N/A	0.48	0.50	9.8	LEFT HAND TO STICK (CHANGE HAND S)	3
4	HAND LEAVES FREQUENCY SELECTOR MOVES TO CHANNEL SELECTOR	1.9	0.27	0.39	0.71	17.3	RIGHT HAND TO VHF OFF UHF ON SWITCHES ON STATION BOX	4
5	SELECT NEW CHANNEL (COULD BE ANY OF 12)	N/A	N/A	0.75	0.71	17.3	RIGHT HAND BACK TO STICK (CHANGE HANDS)	5
6	HAND LEAVES CHANNEL SELECTOR MOVE TO ACCEPT KEY 'MSK'	7.9	0.53	0.66				
	TOTAL	32.3				50.17		

TASK

Change from VHF channel 6 to UHF channel appropriate to a divert airfield 6

Table 3 Results of Comparative Studies

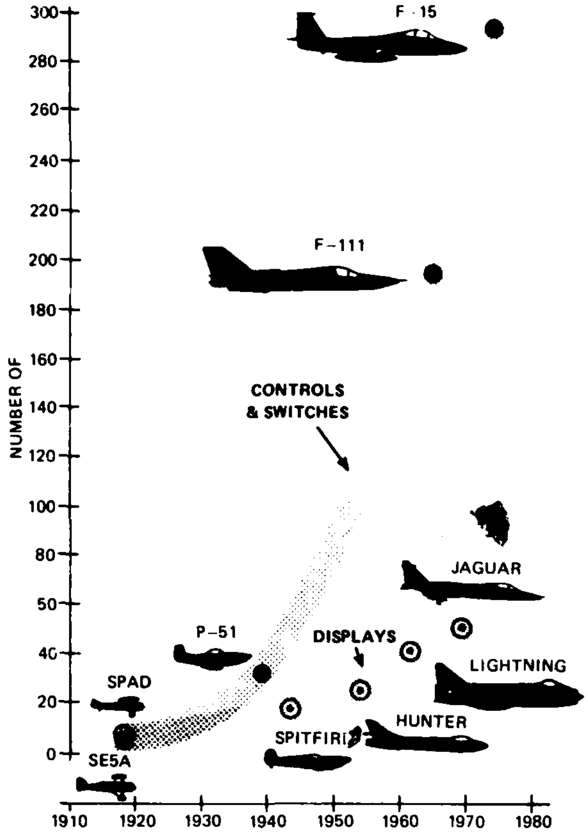


Figure 1 Cockpit Facilities Growth

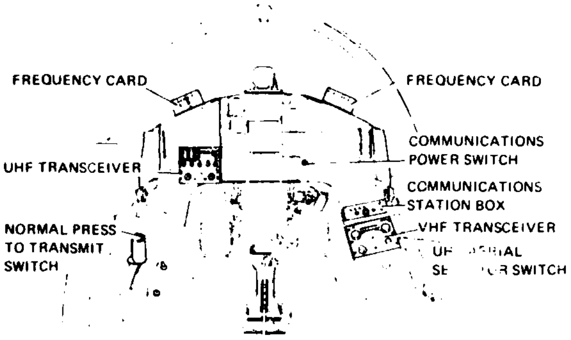


Figure 2 Communications Facilities

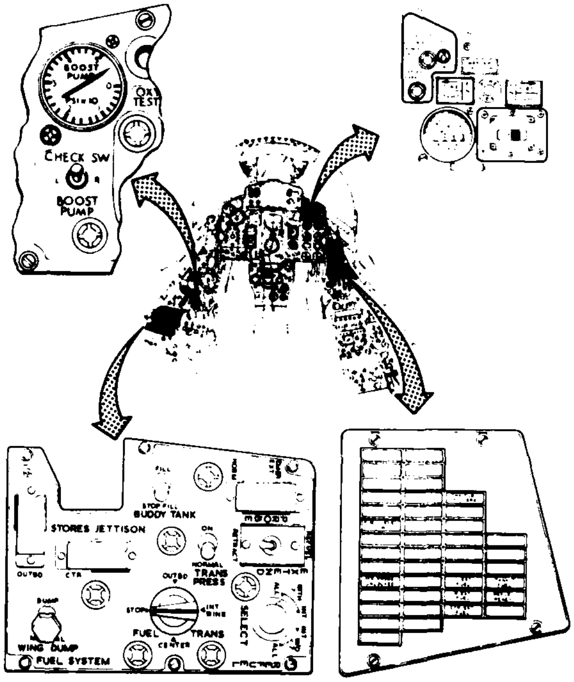


Figure 3 Current Aircraft Fuel System Control

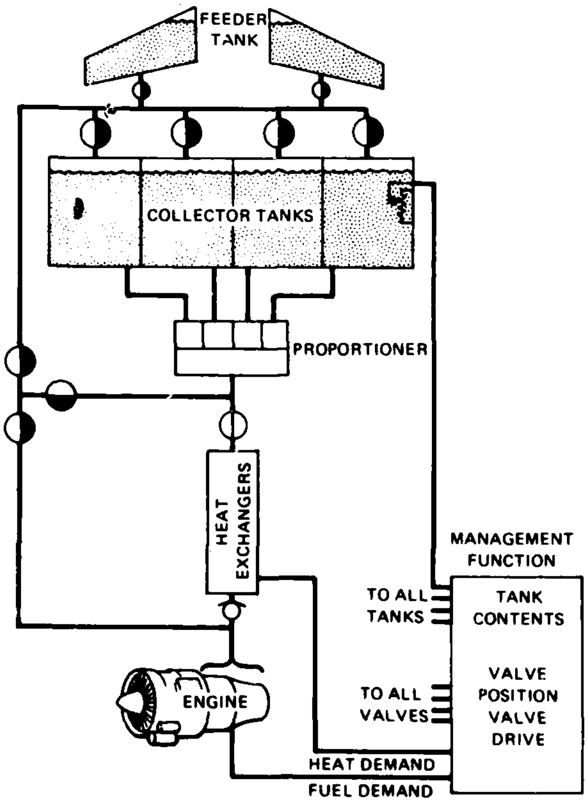


Figure 4 Conceptual Fuel System

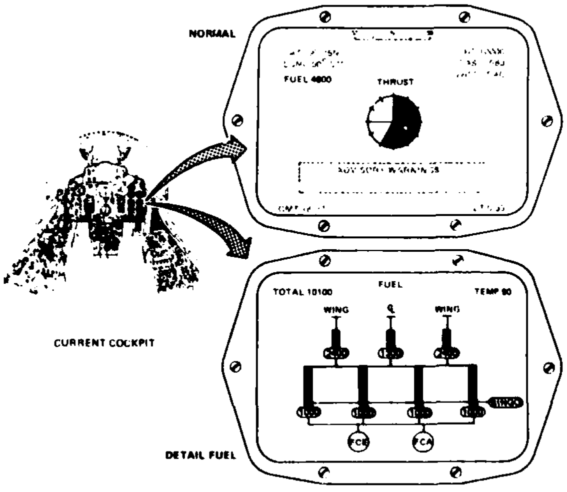


Figure 5 Advanced Engine System Pres[illegible]

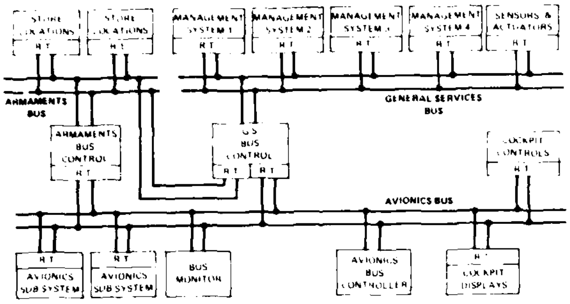


Figure 5 Data Bus System

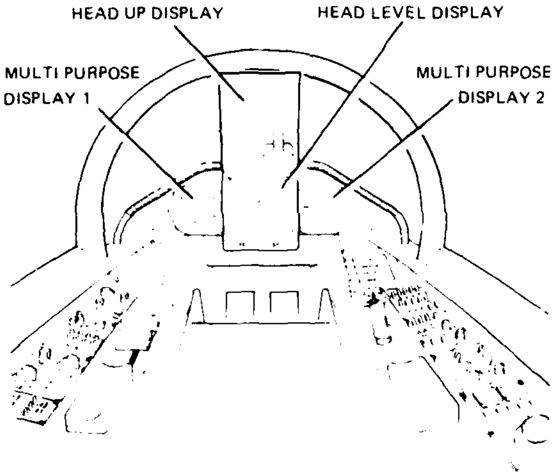


Figure 6 Display System Configuration

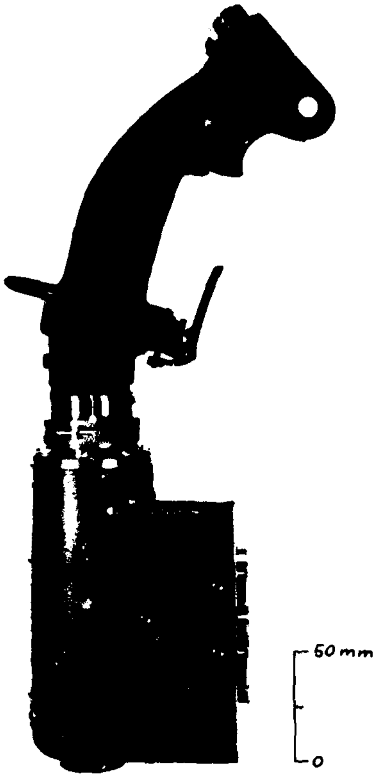


Figure 7 F-16 Flight Controller

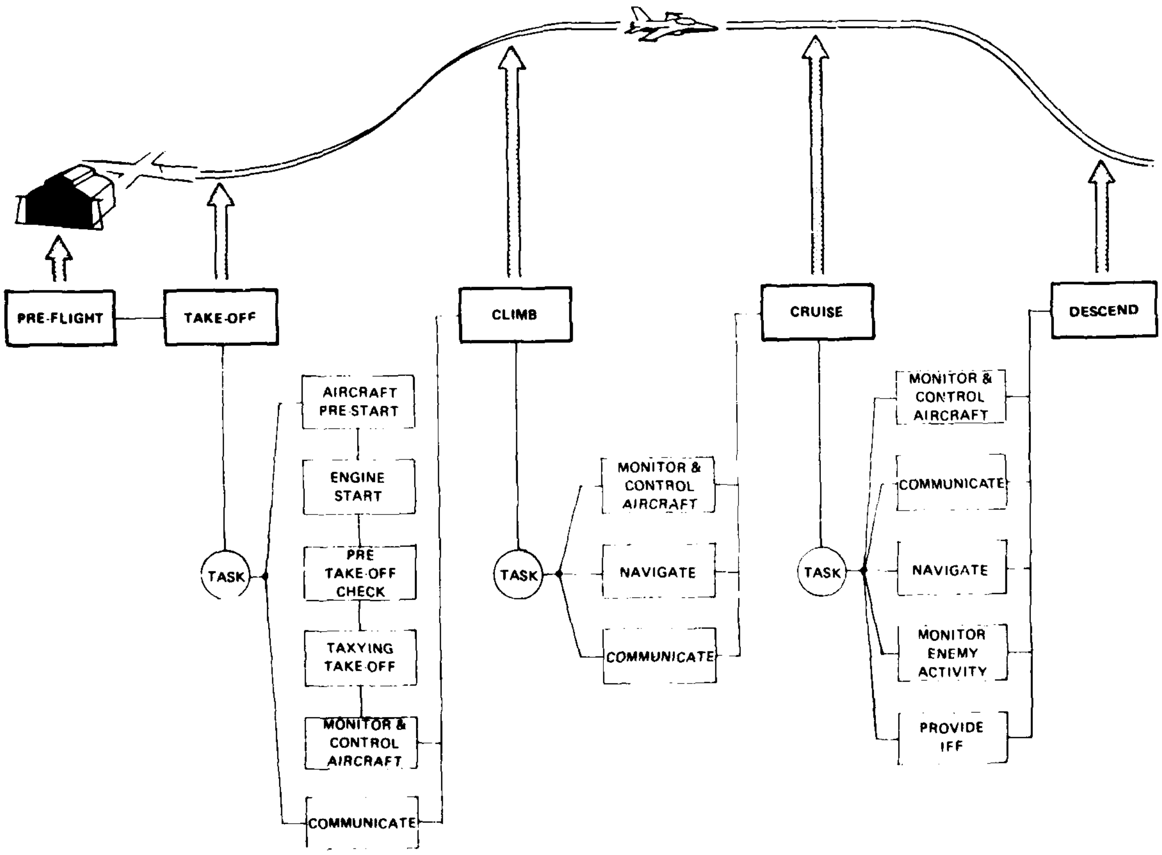


Figure 8 Task Analysis Technique

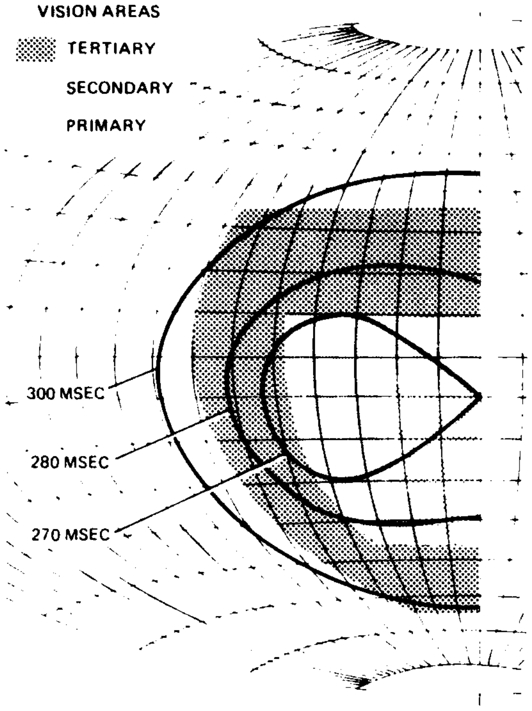


Figure 10 Vision Requirements

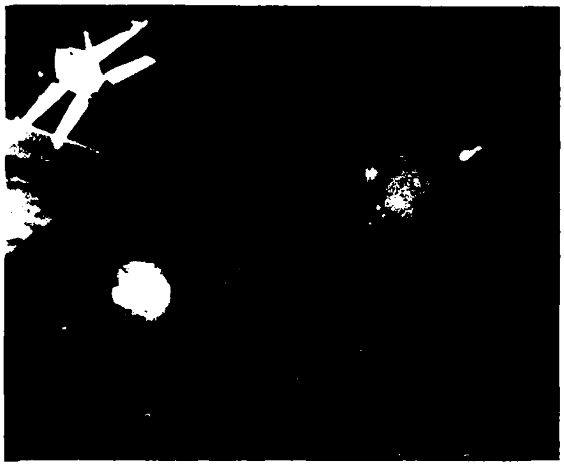


Figure 11 F-18 Hornet Cockpit

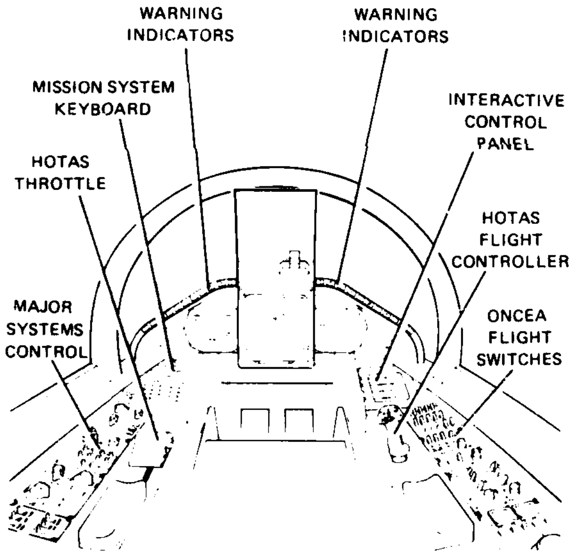


Figure 12 Advanced Cockpit Controls Layout

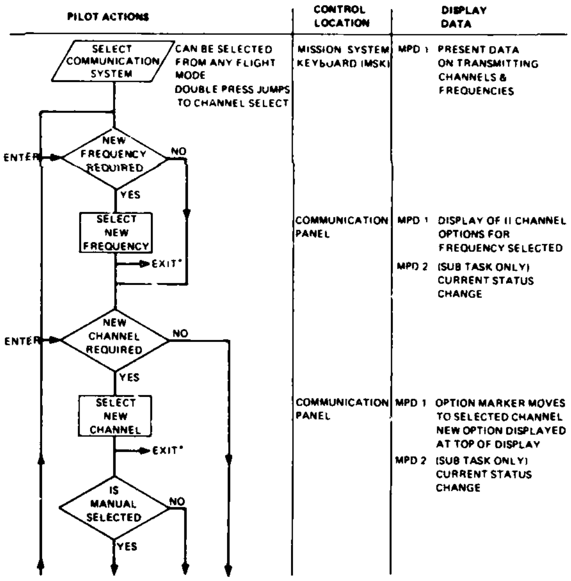


Figure 13 Control Logic Diagram

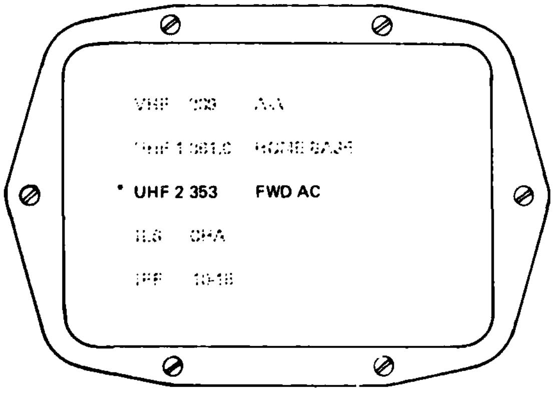
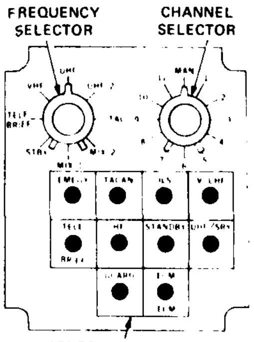
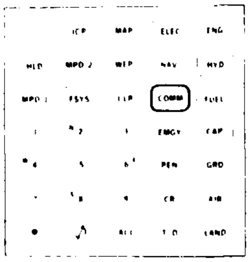


Figure 14 Present Frequencies



CENTRALISED AUDIO SELECTOR SYSTEM (C.A.S.S.)

CONTROL PANEL



MISSION SYSTEM KEYBOARD

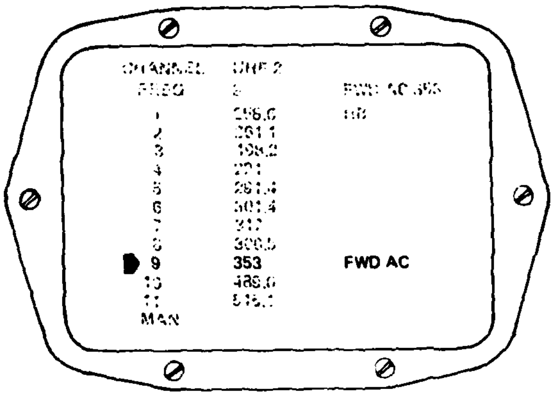


Figure 15 Available Channels

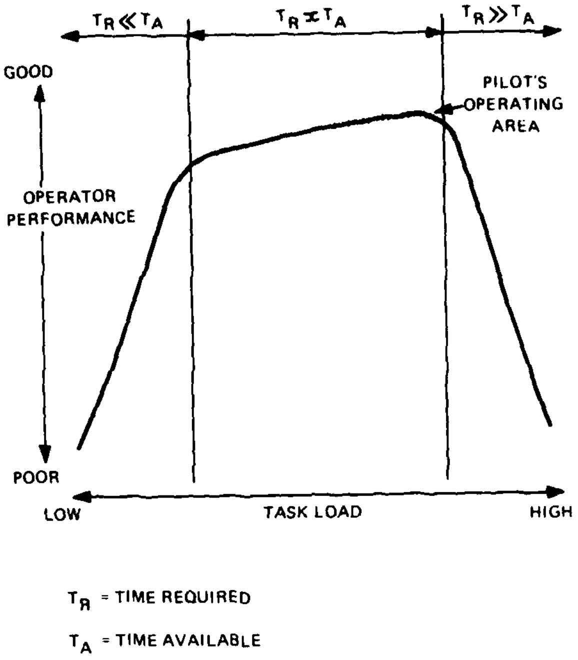
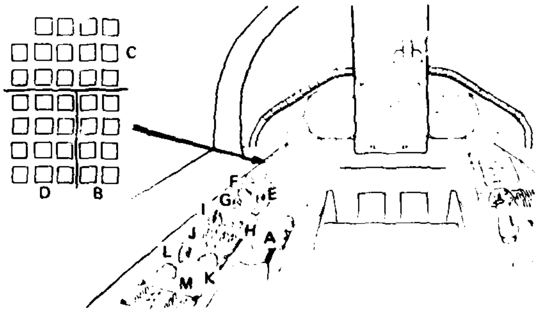


Figure 16 A Concept of Workload



REACH DISTANCE (IN)

	A	B	C	D	E	F	G	H	I	J	K	L	M
A		6.3	8.7	6.5	4.4	5.7	4.6	3.3	4.9	5.1	7.0	8.0	10.1
B			2.9	2.4	4.3	5.6	6.9	8.5	9.3	11.0	12.9	13.7	16.0
C				2.8	5.4	6.1	7.8	10.4	10.8	12.5	15.1	15.3	17.8
D					2.7	3.6	5.2	7.9	8.3	10.1	12.6	12.9	15.5
E						1.9	2.6	5.3	5.8	7.4	10.0	10.2	12.8
F							2.1	5.6	5.4	7.3	10.2	10.0	12.6
G								3.7	3.3	5.4	8.1	7.9	10.6
H									1.9	2.1	4.7	5.1	7.5
I										2.4	5.1	4.6	7.3
J											2.8	3.0	5.5
K												2.1	3.3
L													2.6
M													

Figure 17 Reach Distance Definition

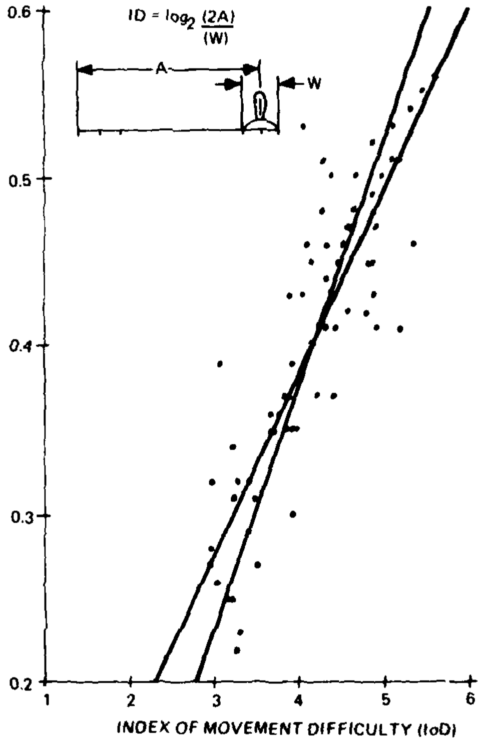


Figure 18 Comparison of Reach Time vs IoD

UNE INTEGRATION DE PLUS EN PLUS POUSSEE
POUR LES VISUALISATIONS DES AVIONS DE COMBAT

Mr. C. MAUREAU

THOMSON-CSF

Division AVS - Département AVG
52, rue Guynemer
92 132 - ISSY-LES-MOULINEAUX

GENERALITES

Un système intégré est, d'après les dictionnaires, un système "dont tous les éléments sont assemblés en un tout", et, un tout c'est - à contrario - un ensemble cohérent dont tous les éléments sont assemblés de façon positive vis-à-vis de la raison d'être de cet ensemble, comme par exemple dans un orchestre les instruments qui ont une partie à jouer dans la partition.

Lorsqu'on essaye de déterminer de quelle façon l'on peut espérer améliorer de façon significative les moyens de conduire les vols sur les avions de combat, on s'aperçoit que - pratiquement toujours - c'est "en poussant plus loin l'intégration des systèmes". Ceci est le plus souvent obtenu en utilisant de façon convenable des progrès technologiques, en particulier pour ce qui concerne les visualisations supports de l'information et les moyens mis à la disposition du pilote pour exploiter cette information.

Pour illustrer cette affirmation, il est proposé :

- d'abord une revue de certains aménagements modernes réalisés dans la cabine d'un avion entrant en service actuellement : le Mirage 2000,
- ensuite un examen analogue portant sur des projets d'aménagements de cabine pour un avion de combat de la prochaine génération.

Pour ce second exemple, il s'agit de projets élaborés à l'intérieur d'un groupe de travail réunissant équipementiers et avionneur ; des groupes qui ont été créés sur initiative de l'Administration française de façon à ce que les systèmes des avions futurs soient conçus, dès le début, pour s'intégrer de façon aussi cohérente et homogène que possible avec le pilote qui les utilisera.

-SYSTEMES D'AUJOURD'HUI

En France, le système de navigation attaque du Mirage 2000 marque de façon évidente la maîtrise des techniques liées à la digitalisation et à son utilisation à bord des avions. Il a succédé à des systèmes développés peu avant pour d'autres avions, à commencer par le Super Etendard - avion d'assaut embarquable de la Marine Nationale. Il va cependant plus loin dans le modernisme en ce qui concerne en particulier les visualisations et leur aménagement dans la cabine pilote. La planche de bord du Super Etendard est en effet encore assez traditionnelle avec une instrumentation électromécanique classique et un écran à tube cathodique pour une exploitation autonome du radar.

A bord du Mirage 2000 l'information digitalisée est canalisée dans une architecture moderne organisée autour d'un BUS central à grand débit et la présentation de l'information a été organisée de façon globale.

L'information n'est plus orientée seulement vers la visualisation électronique tête haute. Elle est aiguillée de façon cohérente et adaptée aux besoins du moment, entre cette visualisation tête haute et d'autres visualisations électroniques installées sur la planche de bord.

Il s'agit là, non pas de satisfaire un goût du modernisme pour le modernisme, mais, de s'adapter plus globalement au concept général de sélection de l'information, après sa centralisation sous forme numérisée, en pondérant au niveau de l'affichage dans la cabine les juxtapositions dans l'espace et les successions dans le temps.

Pour le Mirage 2000 il y a une combinaison des deux procédés avec une pondération qui vise à permettre une saisie de l'information de façon sûre, dans des délais courts, en prenant en compte une organisation générale de cabine qui permette au pilote de dialoguer chaque fois que nécessaire avec le système.

Un seul écran reste fonctionnellement spécialisé il est consacré à la présentation des éléments concernant la guerre électronique. Pour le restant on a choisi de ne pas disperser l'attention du pilote mais au contraire de lui permettre de se concentrer sur un écran capable de présenter de façon non ambigüe des synthèses de situations géographiques et tactiques, même lorsqu'elles sont complexes.

Cela est réalisé en utilisant un tube fonctionnant en multimode (cavalier et TV) et surtout en couleur de façon à ce que "l'essentiel" puisse être saisi très rapidement, même lorsque l'information présentée est "riche en contenu". Nous sommes tous conscients du fait que l'utilisation de la couleur n'est positive que si elle est faite judicieusement, mais après maintenant environ douze ans de travaux sur le sujet, THOMSON-CSF pense avoir trouvé des formules intéressantes.

A défaut d'avoir disposé d'une technique couleur valable, il eut fallu recourir à plusieurs écrans juxtaposés que l'on aurait consultés de façon séquentielle, une solution qui a aussi des avantages mais qui est, en tout état de cause, plus lourde.

- Deux techniques de présentation couleur ont été développées par THOMSON-CSF.

• La première utilise des tubes à pénétration à deux couches de phosphore, une verte et une rouge, sur lesquelles une modulation de la haute tension permet de donner à l'oeil la perception de trois couleurs : vert, rouge ou jaune.

Pour utiliser cette formule, le code retenu par l'Armée de l'Air française est approximativement le suivant :

- le rouge est associé aux informations en rapport direct avec des éléments mettant en cause la sécurité du vol,
- le vert est utilisé pour présenter les résultats des détections et/ou mesures effectivement faites à l'instant de la présentation,
- le jaune est utilisé pour présenter les données calculées par le système.

Ces différenciations chromatiques permettent une rapide corrélation comparative entre données mesurées et données calculées.

Par exemple, pour réajuster la trajectoire, le pilote peut utiliser des confrontations entre les valeurs instantanées des paramètres de vol et les valeurs calculées et conseillées par le système.

Cette introduction d'un codage facilitant le tri n'est en rien une "sophistication de luxe", mais une nécessité pour éviter que les performances globales du système MIRAGE 2000 ne soient dégradées, au niveau de l'interface pilote/avion, en introduisant à ce niveau des délais inacceptables dans l'exploitation du résultat des calculs faits par le système.

Il s'agit donc bien d'intégration et non seulement d'une intégration des différents modules de visualisation à l'intérieur d'un même système digital, mais aussi de l'intégration du pilote - avec ses capacités physiologiques - à l'intérieur d'un système plus large dont on essaye d'améliorer l'homogénéïté.

• La deuxième technique de visualisation couleur est arrivée plus tard dans le domaine des applications militaires. Elle utilise des tubes multichromes à masque et donne un choix plus large de coloris - leur utilité est surtout de permettre une présentation électronique de situations extrêmement riches en informations, comme par exemple les cartes géographiques.

De fait, en FRANCE, ces visualisations en version militarisée ont été, ces dernières années, développées, non pas seules, mais en parallèle d'un dispositif embarqué de stockage d'images de cartes capable de les alimenter en cartes vidéo. L'ensemble a été développé, sur demande de l'Administration française, pour la version pénétration du Mirage 2000 : le 2000 N qui arrive au stade des essais en vol. Les techniques développées pour lui apportent des possibilités nouvelles d'une souplesse exceptionnelle, permettant aussi bien de simplifier que de détailler et renseigner des synthèses de situation.

Cette version du Mirage 2000 est, il faut le remarquer, un biplace car il est apparu qu'en dépit des progrès indiqués ci-dessus un seul homme ne pourrait assurer à lui seul toutes les taches dans certaines phases de vol à très basse altitude, surtout si l'on prend en compte l'exécution de procédures armement ne souffrant pas l'improvisation.
C'est donc ici un équipage qu'il s'agit d'intégrer au système.

- SYSTEMES DE DEMAIN

Dans le domaine des visualisations et des commandes, est apparu le besoin d'essayer d'aller encore plus loin, pour prendre en compte les hypothèses actuellement faites concernant les conditions de combat vers lesquelles il semble que l'on s'oriente pour le futur. Elles tablent toutes sur des environnements de plus en plus menaçants pour les avions pilotés.

- Comme conséquence de cette évolution, on est conduit à rechercher pour un avion futur :

(a) - d'une part, une meilleure capacité pour des actions à des distances "*stand off*" qui seraient en général au-delà des portées visuelles.

(b) - d'autre part, une meilleure adaptation à la conduite de phases de vol :

. à grande vitesse,
. à basse altitude,
. avec de forts facteurs de charge
. avec des angles d'incidence élevés

et, en conjonction avec une multiplication des actions hors d'axe (*off boresight*).

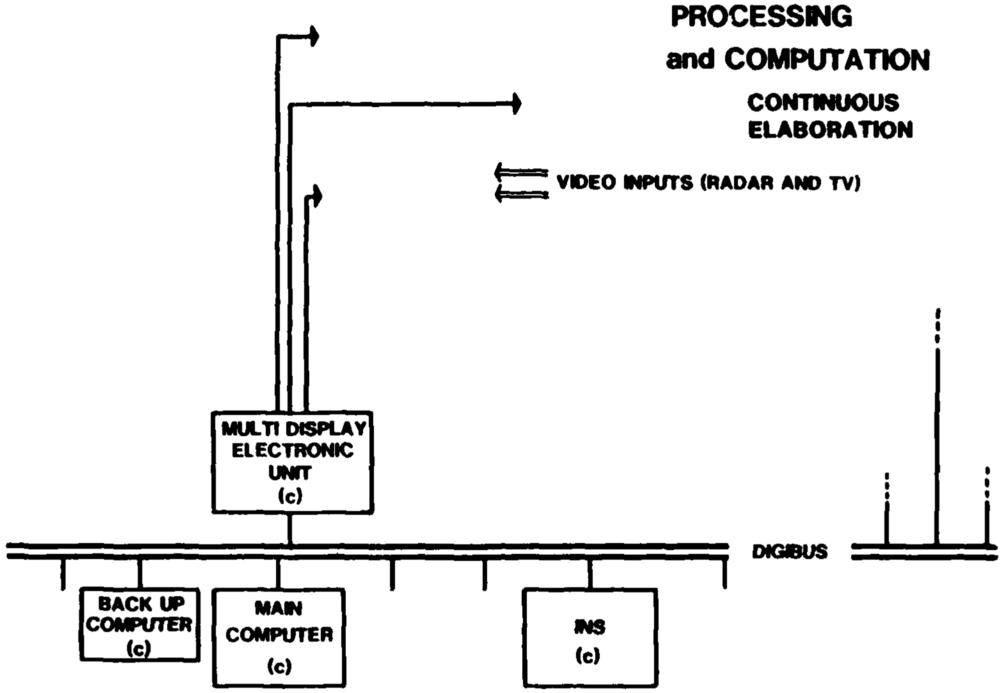
Pour ce qui concerne les visualisations :

- la première catégorie d'actions (a) pourra continuer à être traitée en utilisant des visualisations du type tête basse du genre de celles qui sont développées pour le Mirage 2000,
- la deuxième catégorie d'actions (b) demande, elle, une amélioration des visualisations du genre tête haute de façon à élargir très sensiblement le champ de leur ouverture vers l'extérieur.

THOMSON-CSF
DIVISION
EQUIPEMENTS AVIONIQUES

PROCESSING and COMPUTATION

CONTINUOUS ELABORATION



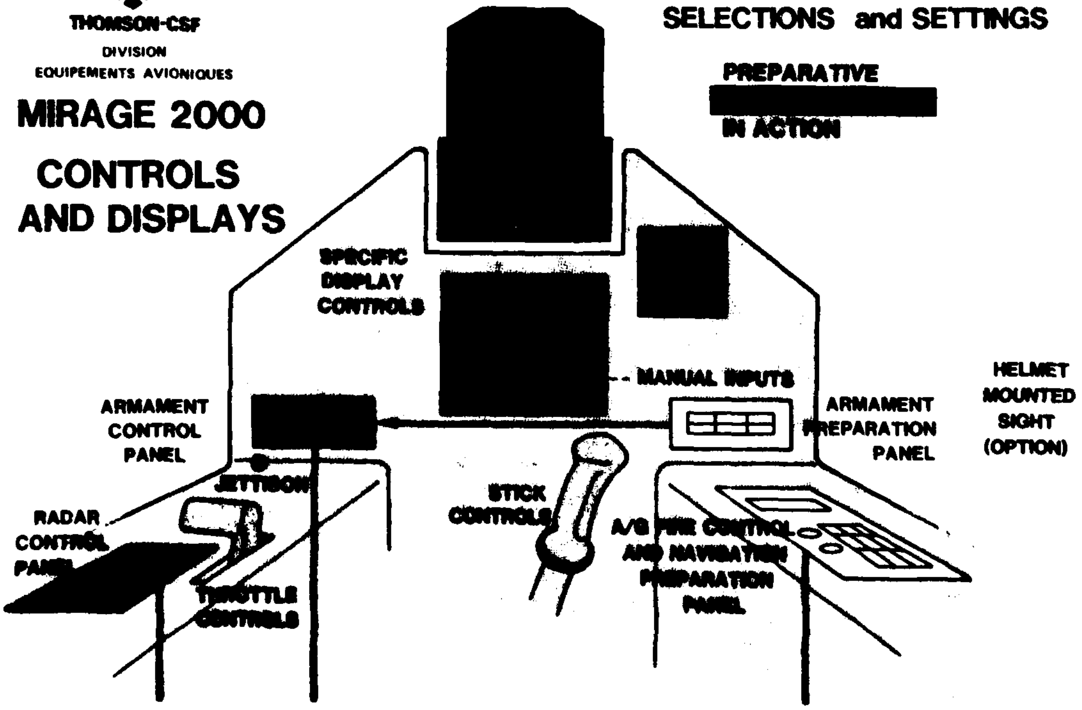
THOMSON-CSF
DIVISION
EQUIPEMENTS AVIONIQUES

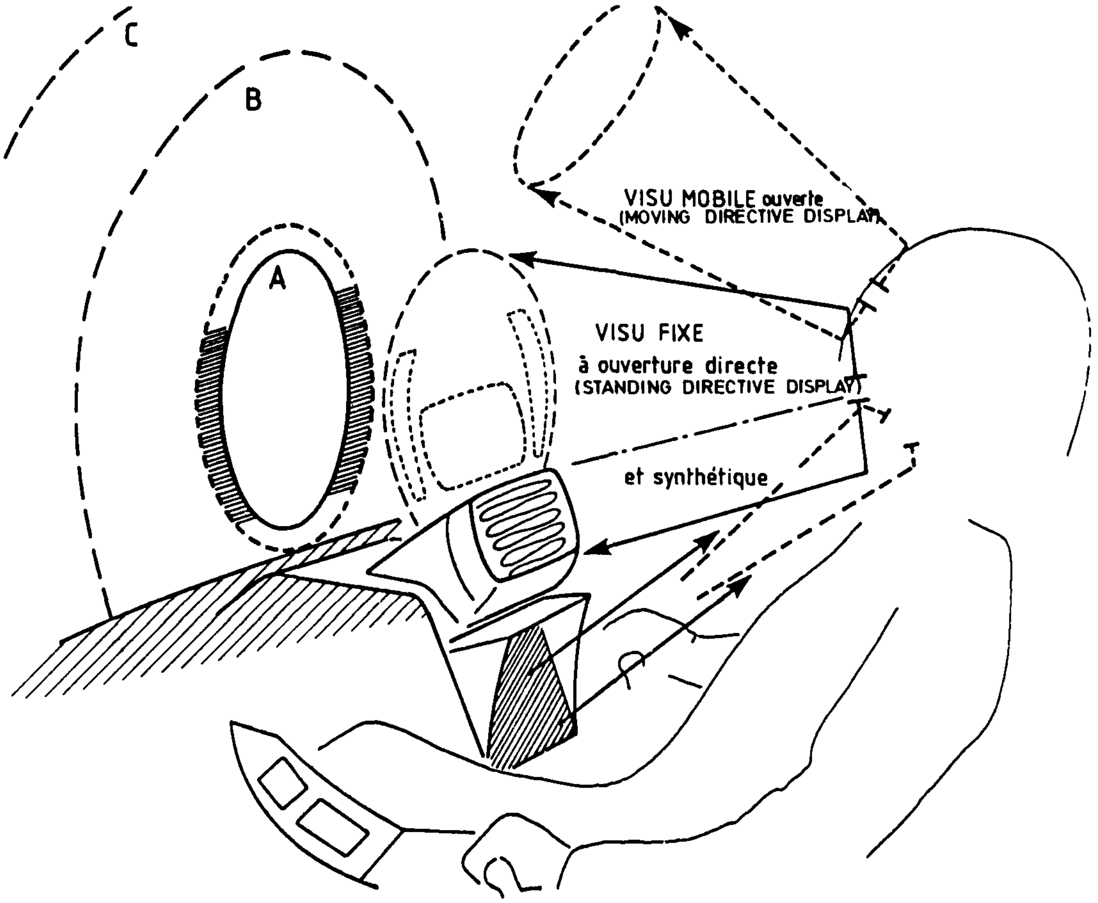
MIRAGE 2000

CONTROLS AND DISPLAYS

SELECTIONS and SETTINGS

PREPARATIVE
■
IN ACTION




C
B
A
VISU MOBILE ouverte
(MOVING DIRECTIVE DISPLAY)
VISU FIXE
à ouverture directe
(STANDING DIRECTIVE DISPLAY)
et synthétique

Face à ces perspectives, en France, la première certitude qui soit apparue a été que l'aménagement des cabines des avions futurs ne pouvait être étudié que par des groupes de travail réunissant avionneurs et équipementiers de façon à ce qu'une intégration profonde de l'ensemble soit recherchée dès le début de la conception de l'avion.

- L'un de ces groupes créés à l'initiative de l'Administration se consacre à l'étude des aménagements de postes d'équipage (OPE). Il a établi des projets pour un avion de combat de la prochaine génération. Le projet qui semble actuellement le mieux adapté aux besoins a été dessiné autour d'un pilote installé sur un siège très incliné et dont les yeux seraient cependant placés toujours dans une même zône de la cabine quelle que soit la taille des pilotes.

  - La quantité des informations présentées serait réduite en faisant "digérer davantage" les informations primaires par le système et en réduisant les actions pilote par l'utilisation d'automatismes. Outre la résolution du problème de présentation d'informations, ce choix contribuerait à la réduction de la charge de travail du pilote.

  - Les informations seraient, en face de lui, présentées en deux zones : une zone supérieure, "ouverte", cohérente avec le paysage extérieur, et une zone inférieure "fermée", non cohérente avec le paysage. La frontière entre les deux zones pourrait varier suivant les besoins, en changeant la façon dont serait utilisée une visualisation collimatée de niveau intermédiaire.

    Les solutions à proposer pour la zone fermée peuvent rester dans la ligne de celles qui sont développées pour la famille Mirage 2000.

    Par contre, pour la zone ouverte, il est nécessaire d'élargir considérablement l'angle solide couvert par l'intermédiaire d'un sous-ensemble réunissant une combinaison de visualisations collimatées. La collimation de toutes les visualisations ainsi associées est nécessaire pour deux raisons :

    . d'abord pour donner une valeur directionnelle à certaines informations essentielles,
    . ensuite, pour permettre la lecture dans un balayage continu du regard sans réadaptation en collimation des yeux.

- Comme indiqué à la précédente réunion AGARD tenue à FRANCFORT, deux formules sont en principe utilisables pour réaliser une association cohérente de visualisations ouvertes :

  . soit, à l'imitation de certains yeux d'insectes, utiliser une juxtaposition de modules collimatés en utilisant éventuellement une combinaison de miroirs holographiques ayant le pare-brise pour support,

  . soit, à l'imitation de l'oeil d'autre animaux, utiliser un module de visualisation à champ mobile.

  Compte tenu des difficultés techniques à résoudre respectivement, dans un cas et dans l'autre, la faisabilité de la seconde formule semble actuellement mieux assurée. L'élargissement serait donc réalisé par adjonction à la visualisation ouverte axiale d'une visualisation ouverte orientable.

- Au total est donc proposé un sous-ensemble de visualisations ouvertes essentiellement constitué d'une visualisation tête haute grand champ, pour la partie centrale du champ, et d'une visualisation de casque pour le champ périphérique ; cet ensemble fournirait une information collimatée, superposée au paysage extérieur. Dans certains cas, le champ de cet ensemble ouvert serait complété vers le bas par l'utilisation d'une visualisation tête basse collimatée, où serait présentée à l'échelle 1 une image du paysage prise par un capteur d'imagerie ou élaborée à partir d'une base de données.

  Ce sous-ensemble collimaté devrait fournir un champ global couvrant l'essentiel du besoin en donnant la possibilité de présenter devant l'oeil du pilote dans toutes ses orientations, une information qui devrait être suffisante pendant les actions en affrontement.

- Une portion de champ global au voisinage de l'axe avion serait couverte de façon probablement un peu plus précise et plus complète, c'est la part de champ laissée à la visualisation ouverte fixe (HUD) - c'est en effet dans son champ, et seulement là, que devraient figurer les informations d'aide directe au pilotage et celles qui concernent les conduites de tirs canon et roquettes.

  Dans ce champ prioritaire la visualisation de casque devrait normalement s'éteindre, sauf si elle était utilisée en fonction secours de la visualisation fixe.

  Est-ce que ce champ fixe serait par ailleurs utilisé pour présenter de l'imagerie pour pilotage de nuit ? C'est une question à laquelle il est encore difficile de donner une réponse ferme.

  Il faut en effet opposer à l'intérêt qui peut être porté à une présentation de ces images dans la direction exacte où elles devraient être, l'inconvénient qu'il y a "fermer la vue directe sur l'extérieur" par l'intermédiaire d'une trame TV interposée dans un angle solide d'intérêt prioritaire où, en effet, "réside l'essentiel du futur à court terme de l'avion".

  C'est bien seulement, me semble-t-il, par l'intermédiaire d'une telle approche globale des besoins qu'une optimisation du système de visualisation peut être obtenue, en justifiant ainsi pleinement le concept d'intégration qui a été retenu comme étant, sur la plan coût efficacité, le meilleur chemin vers le progrès.

On perçoit bien qu'il vaut mieux par exemple ne fixer la valeur à donner au champ de la visualisation tête haute centrale que lorsque aura été fixée la partie qui lui sera attribuée dans la partition que doit jouer le système.

Actuellement, dans un premier temps, THOMSON-CSF met en évaluation, avec le soutien de l'Administration française, des maquettes de visualisation avec des champs fixés à priori en fonction du savoir faire du moment, mais, dans la phase d'intégration, ces champs seront réappréciés. En particulier, une maquette de visualisation électronique tête haute à optique holographique,essayée actuellement, donne un champ d'environ 30° par 20° mais il ne faut pas considérer cette valeur comme un choix définitif pour l'avenir, d'autant que l'on saurait également faire un champ de 35° par 25°.

C'est notre conviction que les progrès dans le domaine des systèmes pour avions pilotés ne pourront être acquis qu'en essayant par de telles méthodes d'utiliser plus à fond le concept d'intégration.

HUMAN FACTORS IN AIRCRAFT KEYBOARD DESIGN: STANDARDS, ISSUES AND FURTHER EVIDENCE RELATING TO GLOVES AND KEY CHARACTERISTICS

by

R. M. Taylor
J. V. F. Berman
Royal Air Force Institute of Aviation Medicine,
Farnborough, Hampshire, UK.

SUMMARY

The aircraft pilot is increasingly required to interact with complex digital avionics systems. These systems often require data to be input in digital form. Keyboards provide a logical and convenient interface for performing this task. Current technology gives the aircraft designer almost unlimited scope for specifying the physical and functional characteristics of the keyboard. However, the designer has little information or guidance on which to base his decisions. Surveys of the literature reveal some human factors evidence relevant to aircraft keyboard design, but most of the work is based on the requirements of ground applications, and this is not readily generalised to aircraft environments. For these reasons, military standards for aircraft keyboards are brief and circumspect, and they have only limited influence on present and future aircraft keyboard installations. These problems have been highlighted by uncertainty over the effects of the requirements to operate keyboards with gloved hands. Keyboard factors affecting data entry performance include keyboard positioning and layout, key size, actuation force, pre- and post-actuation travel, visual and tactile feedback, key separation and barriers. Other factors include the effects of aircrew gloves on manipulative ability, tactility and hand/finger dimensions, operator comfort, fatigue and aircraft vibration, the level of skill of the operator, the cognitive and physical components of the data entry task and the interference between keyboard data entry and other tasks performed concurrently in the cockpit. The current status of human factors knowledge in these areas are reviewed and the results of recent experiments conducted at the RAF Institute of Aviation Medicine are discussed in relation to keyboard standardisation agreements and aircrew training.

1. INTRODUCTION

Keyboards are an increasingly common feature of modern aircraft cockpits where the pilot is required to interact with complex digital avionics systems. These systems often require data to be input in a digital form. Keyboards provide a logical and convenient interface for performing this task. They are generally more effective, in terms of speed and accuracy, than other discrete linear controls for high frequency momentary inputs, such as sequences of alphabetic, numeric or special function information (MINOR and REVESMAN, 1962; FENWICK and SCHWEIGHOFER, 1971; CHAPANIS and KINKADE, 1972; FENWICK and HICKOK, 1975). Voice data entry systems have advantages over keyboards when the amount of data to be entered is relatively small and when the frequency of data entry is low (SEIBEL, 1972). Voice data entry may also produce reduced interference with concurrent tasks, such as tracking, by utilising underloaded resources (MOUNTFORD and NORTH, 1980; COCHRAN and RILEY, 1980). But suitably robust voice data entry systems are still under development and they are unlikely to replace keyboards as the only means of cockpit data entry for reasons of reliability and redundancy.

Comprehensive reviews of ergonomics in keyboard design are available elsewhere (KLEMMER, 1971; ALDEN, DANIELS and KANARICK, 1972; SEIBEL, 1972; SPERANDIO and BISSERET, 1974). The purpose of the present paper is to summarise the outstanding issues and evidence pertinent to aircraft keyboard design, and to present the results of some recent experimental research at the RAF Institute of Aviation Medicine.

2. DESIGN STANDARDS

Current technology gives the aircraft designer almost unlimited scope for specifying the physical and functional characteristics of the keyboard. On the other hand, competition for cockpit panel space, miniaturisation, microtechnology and the availability of thin-panel keyboards produce trends towards smaller keys, with reduced tactile feedback, and for more multifunction keyboards, with remote legends and complex keying sequences (GRAHAM, 1974; SEIFERT, 1981). Also, aircrew glove assemblies are changing to provide increased protection in ways that seem likely to affect keying performance (TAYLOR, BERMAN and GILMORE, 1981). Faced with these problems, the keyboard designer has little or no information or guidance directly concerning aviation requirements on which to base his decisions.

Surveys of the literature reveal some ergonomic evidence relevant to aircraft keyboard design, but there are few definitive findings on which to base design standards (ALDEN, DANIELS and KANARICK, 1972; SEIBEL, 1972). Most of this work is based on ground applications, involving telephone key sets, office typewriters and skilled operators. This evidence is not readily generalised to aircraft environments where the data entry task is secondary and discontinuous, where the keyboard is panel-mounted rather than desk-mounted, and where keying is often carried out in vibration and turbulence, by aircrew wearing bulky glove assemblies. For these reasons, military standards for aircraft keyboards are brief and circumspect and they have only limited influence on present and future keyboard installations.

NATO Standardisation Agreement (STANAG) 3869 AI, Aircrew Station Control Panels, contains recommendations for the design, selection and arrangement of aircraft controls and displays, including pushbuttons and keyboards. The control characteristics recommended for pushbuttons in this standard are given in Table 1.

TABLE 1. STANAG 3869 AI Pushbutton Characterictics

	Size*	Displacement	Resistance***	Separation**
Minimum	10mm	2mm	2.8N	13mm
Maximum	25mm	13mm	5.6N	–
Preferred	–	–	–	–

* Major size dimension
** Between pushbuttons
*** 1N = 98.1 gmf or 3.59 ozf.

No distinction is made between the characteristics for pushbuttons and keyboards. It is recommended that keyboards are the preferred solution for selecting digits and entering alphanumeric data. The only other pertinent recommendations are that "pushbuttons should have visual or tactile feedback" and that the layout for numeric keyboards should be a 3x3 + 1 matrix, with keys 1, 2 and 3 on the top row.

One alternative and widely used source of ergonomic data, MIL-STD-1472B (Human Engineering Design Criteria for Military Systems Equipment and Facilities) contains recommendations for non-keyboard pushbuttons (Table 2), keyboards (Table 3), and legend switches (Table 4). According to this standard, pushbuttons should be used separately or in arrays for momentary contact (push-on, release off) or activating a locking circuit, particularly when frequent operation of the control is required. It is recommended that keyboards should be used when alphabetic, numeric or special function information has to be entered into the system. The applications of legend switches are not defined, but it can be assumed that they refer to alternate action (push-on, push-off) pushbuttons normally used for function and mode selection.

TABLE 2. MIL-STD-1472B Pushbutton Characteristics

	Size*		Resistance		Displacement
	Fingertip Operation	Thumb or Heel of Hand Operation	Fingertip Operation	Little Finger Operation	Thumb or Finger Operation
Minimum	10mm	19mm	2.8N	1.4N	3mm
Maximum	19mm	–	11.0N	5.6N	38mm
Preferred	–	–	–	–	–

	Separation**		
	Single Finger Operation	Single Finger Sequential Operation	Operation by Several Fingers
Minimum	13mm	8mm	13mm
Maximum	–	–	–
Preferred	50mm	25mm	13mm

* Major size dimension; ** Between adjacent pushbutton sides

TABLE 3. MIL-STD-1472B Keyboard Characteristics

	Size*		Resistance		
	Bare Handed	Arctic Mittens	Numeric	Alphanumeric	Dual
Minimum	10mm	19mm	1N	0.25N	0.25N
Maximum	19mm		4N	1.5N	1.5N
Preferred	13mm	19mm	–	–	–

	Displacement			Separation**
	Numeric	Alphanumeric	Dual	
Minimum	0.8mm	1.3mm	0.8mm	6.4mm
Maximum	4.3mm	6.3mm	4.8mm	
Preferred	–	–	–	6.4mm

* Major size dimension; ** Between adjacent key sides

TABLE 4. MIL-STD-1472B Legend Switches Characteristics

	Size*	Resistance	Displacement	Separation***	
				Vertical	Horizontal
Minimum	19mm	2.8N	3mm**	3mm	5mm
Maximum	38mm	11N	6mm	6mm	6mm
Preferred	–	–	–	–	–

* Major size dimension; ** 5mm for switches with two fixed positions; *** Widths of barriers between switch sides

The MIL-STD-1472B recommendations for non-keyboard pushbutton characteristics (Table 2) are derived from an earlier standard, MIL-STD-803A(USAF), used by [illegible] and KINKADE (1972) and now superceded by MIL-STD-1472. Data for keyboard characteristics first appeared in MIL-STD-1472B, issued 31 Dec 1974. In addition to the characteristics listed in Table 2-4, MIL-STD-1472B calls for non-keyboard pushbuttons with concave surfaces or a high degree of surface friction to prevent slipping; a positive indication of Activation (e.g. snap feel, audible click or integrated light); channel or cover guards when it is imperative to prevent accidental operation; and mechanical interlocks or barriers as an alternative to the requirements for pushbutton separation. For keyboards, the only additional requirements called for, over and above those in Table 2, are with regard to layout, configuration and slope. It is stated that numeric keyboards should conform to a 3x3+1 matrix, with the zero digit centred on the bottom row (N.B: STANAG 3869AI goes further by specifying the standard telephone layout with 1 2 3 on the top row). For alphanumeric keyboard layouts, the configurations in MIL-STD-1280 are recommended, with some separation of numeric keys, located to the right of the alphabetic keys, close to hand, if data entry is primarily numeric rather than alphabetic. Keyboard slopes of between 15 and 25 degrees are recommended, with the preferred slope at 16 to 17 degrees. A positive indication of switch action is called for on legend switches, but not on keyboards.

Whereas STANAG 3869AI is aimed at aircraft controls, MIL-STD-1472B is intended for military systems generally, and therefore covers a wider range of operational requirements, including some relatively benign working environments. Although the control characteristics specified in STANAG 3869AI fall within the boundaries set for switches, pushbuttons and keyboards in MIL-STD-1472B, they could not be considered to be close to the values that would normally be associated with the most difficult working conditions. On the other hand, the MIL-STD-1472B keyboard characteristics are relatively low, and for alphanumeric and dual keyboards, the resistances recommended (0.25 - 1.5N) are below the range laid down in STANAG 3869AI (2.8 - 5.6N).

A survey of RAF, RN and AAC aircraft keyboard resistance characteristics has shown that neither MIL-STD-1472B nor STANAG 3869AI reflect current design practice (TAYLOR, BERMAN and GILMORE, 1981). For instance, keyboard key resistances ranged from 0.6N (Alphabetic) to 4.7N (Numeric) on the Nimrod MR Mk 2 rear-crew stations, with pushbuttons and legend switches requiring operating forces of 6.1 - 15.9N. In a variety of helicopters and fixed wing aircraft, including Tornado, numeric keyboard actuation forces ranged from 4.9 - 9.8N, with pushbuttons up to 17.7N. These values are not limited by design restrictions. Manufacturers of aircraft pushbuttons produce momentary action keys with forces ranging from 2.0 to 26.7N. Also, it should be noted that the specifications for the F/A 18 and AV8b call for key forces between 5.6 - 7N for coaming-mounted numeric keyboards. Thus, it can be seen that whereas STANAG 3869AI key resistance characteristics are relatively high compared with those for keyboards in MIL-STD-1472B, they are low compared with key forces used on many aircraft pushbutton installations.

3. ERGONOMICS EVIDENCE AND OPERATIONAL REQUIREMENTS

Consideration of the operational requirements for keyboard data entry, the ergonomics evidence, and current design practice indicates that the aircraft designer needs information and guidance in several areas.

3.1. Operator Performance

The validity of any keyboard design standard will depend on the extent to which the standard takes account of the requirements for operator performance in terms of the speed and accuracy of data entry. With the exception of a few comparative studies of aircraft installations (e.g. FENWICK and HICKOK, 1975), most of the evidence for the advantages of pushbuttons over other discrete position controls, such as toggles, rotary selectors and thumbwheels, comes from studies of the high tapping rates and fast data entry speeds that can be achieved by skilled keyboard operators in ground environments (SEIBEL, 1972). For instance, performance data indicate that for short periods, experienced typists can achieve a rate of five or more key strokes per second (KLEMMER, 1971). It is known that speed versus accuracy trade-offs can be manipulated by instructions and differential pay-offs. In general, and particularly for inexperienced operators, low speeds tend to be associated with high error rates, but when not provided with a directional set, operators tend to set high standards for accuracy rather than speed (ALDEN, DANIELS and KANARICK, 1972).

In aircraft keyboard data entry, accuracy is of paramount importance since uncorrected errors can have serious consequences. Thus, factors affecting the frequency of undetected errors (RABBITT, 1967; 1973) and classes of errors (VAN NESS, 1976) are particularly important in aircraft keyboard design. Key actuation forces that are desirable in order to minimise unintended key pressing and to provide good tactile feedback are unlikely to produce fast data entry speeds and they may cause fatigue during periods of continuous data entry (KINKEAD and GONZALEZ, 1969). In the cockpit, the data entry task involves discrete rather than continuous sequences of inputs, with reduced redundancy in the input and sequence of movements, and hence slower key pressing rates (SEIBEL, 1972). Greater continuity and faster data entry rates may occur at rear-crew work stations, where the keyboard operation is often a primary rather than a secondary task. Also, in the cockpit, the positioning and tile of keyboards, on the coaming, centre and side consoles, are not optimised with regard to posture and they are unlikely to facilitate the acquisition of fast-keying skills (CREAMER and TRUMBO, 1960; KROEMER, 1972; FERGUSON and DUNCAN, 1974). Aircraft vibration and turbulence, and requirements for aircrew glove assemblies may also influence speed versus accuracy trade-offs.

In summary, the aircraft designer needs guidance on the speed versus accuracy trade-off for particular keyboard tasks, and he needs information on how operator performance is likely to be influenced by keying characteristics, by keyboard design and positioning, and by the operator's working environment.

3.2. Input Data Types

MIL-STD-1472B makes distinctions between the requirements for numeric, alphanumeric and dual keyboards, as well as between legend switches, keyboard pushbuttons and non-keyboard pushbuttons. These distinctions between input data types reflect differences in operator performance requirements for speed and accuracy in ground environments. Speed and fatigue tend to be more important factors with high frequency of use keyboards, involving continuous sequences of inputs, than with relatively infrequently operated functions and mode selection switches. Thus, in MIL-STD-1472B, relatively low key resistances are recommended for alphanumeric keyboards, compared with legend switches for which a positive indication of control activation is recommended. The need to distinguish between input data types for aircraft pushbuttons is less certain. For the reasons outlined in the previous section, there is a greater emphasis on accurate data entry in-flight. Hence, it is quite common to find higher key resistances in aircraft installations than those recommended for keyboards in MIL-STD-1472B.

Multi-function keyboards are an increasingly common feature of aircraft cockpits, and it is difficult to reconcile this trend with a design philosophy based solely on input data types. Considerable research effort has been directed towards the software configurations of multi-function keyboards (GRAHAM, 1974; REISING, BATEMAN, CALHOUN and HERRON, 1977; REISING, 1977; CALHOUN, 1978; HERRON, 1978; BATEMAN, REISING, HERRON and CALHOUN, 1978; CALHOUN, HERRON, REISING and BATEMAN, 1980; BUTTERBAUGH, 1981). However, operational experience with the Tornado multi-function keyboards indicates that the dissociation of the legends from the keys is a common source of data entry errors. Relatively little is known about the tactile and visual feedback requirements of multi-function keyboards.

In summary, further evidence is needed on operator performance requirements before a simple distinction between input data types can be applied to aircraft keyboard design standards, particularly for cockpit installations. Meanwhile, it may be advisable to use the recommendations in Table 2 (MIL-STD-1472B Pushbutton Characteristics) for aircraft keyboards, since these are based on the operator's method of data entry - thumb, single finger or different fingers - rather than on input data types. Indeed, the recommendations in Table 2 are closer to current design practice than those presented in either Table 1 or 3.

3.3. Feedback

Visual, auditory, kinaesthetic (amplitude of movement + resistance) and tactile (contact + pressure) information are sources of sensory feedback in keyboard data entry tasks. STANAG 3369AI states that pushbuttons should have visual or tactile feedback. This statement is misleading since it implies that the two forms of feedback are interchangeable. Research on the role of sensory feedback in motor skills indicates that there is a transition from dependence on visual feedback to a reliance on kinaesthetic or proprioceptive feedback in the acquisition of a complex motor skill (FLEISHMAN and RICH, 1963). Studies of deprived and delayed feedback during typing and key-tapping demonstrate the importance of kinaesthetic feedback, particularly in skilled keying. Visual feedback is important for aiming movements and error detection, particularly during training, whereas auditory feedback seems to have little importance during typing, irrespective of the level of skill of the operator (DEININGER, 1960); CHASE et al, 1961; DIEHL and SEIBEL, 1962; WEST 1967; KLEMMER, 1971; LONG, 1976; RABBITT, 1978; ROSINSKI, CHIESI and DEBONS, 1980).

In aircraft cockpits, where keyboard data entry is a continuing task and where accuracy is emphasised rather than speed, there is a strong argument for maximising error detection by providing kinaesthetic, tactile and visual feedback. Indeed visual feedback is usually provided by positioning the keyboard prominently, such as on the coaming, and by providing a 'scratch pad' display of the entered data. Some kinaesthetic and tactile feedback is always present in pushbutton keyboards, through surface contact, key resistance and displacement, and in many keys by a snap-action and hard-bottoming. These sources of feedback may be affected by vibration and turbulence, and by aircrew glove assemblies. Auditory feedback is usually masked by aircraft noise or attenuated by helmets and headsets.

The importance of visual feedback is supported by studies of aircraft keyboard location and display positioning (FENWICK and HICKOK, 1975; REISING, BATEMAN, CALHOUN and HERRON, 1977; REISING, 1977). It is conceivable that some experienced aircrew might find it possible to enter data by 'feel' alone. Indeed, some numeric keyboards have been designed with a small 'pimple' on the centre key (5) to facilitate orientation. However, this facility will be of little assistance to the inexperienced operator. Also, the possibility of 'feel-only' operation is further reduced by the wearing of bulky glove assemblies. A touch-sensitive aircraft keyboard has been proposed, lacking kinaesthetic and tactile feedback, but with auditory feedback provided by a tone on contact. Pilot reactions have been relatively favourable but there is a paucity of performance data and the study did not include an experimental control, i.e. touch display with no tone (BECKETT and SOUTHWORTH, 1981). DEININGER (1960) found no effects on performance of adding a tone to telephone keysets.

Further work is needed on the value of auditory feedback where kinaesthetic and tactile feedback is low. The case for visual feedback can be regarded as proven. The evidence for kinaesthetic and tactile feedback is equivocal and needs to be examined separately.

3.4. Force and Displacement

It seems difficult to demonstrate effects on operator performance of varying key force and displacement characteristics. DEININGER (1960) found no effects on operator performance with telephone keysets from adding a snap-action, from varying key resistance between 1-4N or from varying key displacement from 0.8-4.8mm. MIL-STD-1472B quotes these ranges for numeric keyboards. KINKEAD and GONZALEZ (1969) found snap-action keyboards produced more errors without affecting typing speed with experienced typists. Typing performance (throughput) was best when both key resistance and displacement were at relatively low levels, presumably because these minimised fatigue. The authors recommendations for key resistances (0.25-1.5N) and displacement (1.3-6.3mm) are quoted by MIL-STD-1472B for alphanumeric keyboards. Other studies rely heavily on preference judgements (e.g. BURGENTHAL, 1971; TAJIMA and NAKAZAWA, 1969). However, preferences for key characteristics tend to be inconsistent and have low correlations with keying performance ([illegible] and SNODGRASS, 1958; KINKEAD and GONZALEZ, 1969). Having reviewed the literature, ALDEN, DANIELS and KANARICK (1972) concluded that, in general, key resistance and displacement characteristics have little effect on the keying performance of experienced operators. Similarly, KLEMMER (1971) concluded that there was no evidence that enhanced internal feedback improves performance and that any kinaesthetic and tactile advantage may be offset by the increase in operating time and physical effort. However, he added that touch keyboards, with no displacement and resistance may be past the optimum compromise between kinaesthetic feedback and work. The same argument applies to the design of keyboards using thin-panel technology, where kinaesthetic feedback through key displacement can be as low as 1mm travel.

These conclusions and recommendations from the literature for telephone keysets and typewriter keyboards contrast with current aircraft keyboard design practice which uses relatively high key resistances, with snap-action and hard-bottoming, features which accord with aircrew preference for keys with positive "feel" In one of the few aircraft keyboard studies in which key characteristics have been systematically varied, FENWICK and HICKOK (1975) found reductions in key errors in turbulence without affecting keying rate when numeric key operating forces were increased from 2.2N through 4.4N to 6.7N. This is an important finding since accuracy tends to be more important with aircraft keyboards than speed. Evidence from studies of continuous adjustment linear controls is also equivocal with regard to the relative merits of force and amplitude cues. Whereas GIBBS (1954) found better tracking performance with a pressure joy stick compared with a free moving stick, other studies have indicated that amplitude of movement is a superior feedback cue to force (BAHRICK, BENNETT and FITTS, 1955). BRIGGS, FITTS and BAHRICK (1957) found that changes in amplitude of movement significantly affected performance only when force cues were high, and that changes in force cues affected performance only when amplitude was high McCORMICK (1964) concluded that there was no clear cut evidence regarding the relative merits of force and amplitude of movement feedback cues, and that they both have usefulness in control devices. Where distance of movement is limited, he concluded that pressure cues seem to be particularly useful, and in general, some 'feel' of control devices seems to be desirable. This would seem to support the use of tactile feedback in pushbuttons, particularly the thin-panel variety, where key displacement is low.

Further work is needed to determine the relationship between key force and displacement characteristics as they affect operator performance on aircraft keyboard tasks, including effects of snap-action, bottoming, and pre- and post actuation force and travel.

3.5. Layout, Tilt, and Size

The arrangement proposed for numeric keyboards in STANAG 3869AI conforms to the standard telephone layout (1 2 3 on top row) rather than the alternative more common layout on calculators (7 8 9 on top row) adopted as the British Standard (BS 1909, 1963). The telephone layout is supported by the literature on keyboard performance (DEININGER, 1960; MINOR and REVESMAN, 1962; PAUL, SALARNIS and BUCKLEY, 1965; CONRAD, 1967; CONRAD and HULL, 1968). Most aircraft use the telephone layout (SEIFERT, 1981; TAYLOR, BERMAN and GILMORE, 1981). However, this practice is likely to lead to transfer of training problems for operators familiar with the calculator format.

No arrangements are proposed in STANAG 3869AI for alphabetic or alphanumeric keyboards. Recommendations for QWERTY layouts are given in MIL-STD-1280 and MIL-STD-1472B. The choice of the QWERTY layout, as opposed to other simplified layouts based on letter occurrence frequencies or alphabetical sequence, is supported by the literature, even for unskilled operators (KLEMMER, 1971; ALDEN, DANIELS and KANARICK, 1972). Nevertheless, the lack of a military standard specifically for aircraft keyboard layouts is to be regretted since flight management computers have already demonstrated a wide range of formats which have been shown to affect operator performance (BUTTERBAUGH, 1981).

The evidence for a particular keyboard tilt or slope is weak. MIL-STD-1472B's recommendation that keyboards should have a slope between 15 and 25 degrees is probably based on operator performance data obtained by SCALES and CHAPANIS (1954). GALITZ (1965) found that a 21° slope was preferred. Neither study demonstrated performance effects over the ranges 0° to 40° and 9° to 33° respectively. Other evidence indicates that inclinations of 0° and 90° produce slower and more fatiguing performance (ALDEN, DANIELS and KANARICK, 1972). Most typewriters have a slope of 16° to 17°. These values are recommended by MIL-STD-1472B as the most preferred slopes. The relevance of this evidence to cockpit keyboard installations is questionable since it is based largely on preference judgements and considerations of fatigue during relatively continuous data entry.

As regards keyboard size, DEININGER's (1960) study of telephone keysets seems to have been particularly influential. Keying speed and accuracy were significantly affected by key size, with intermediate size pushbuttons (13mm) being superior to smaller (10mm) and larger (19mm) keys. MIL-STD-1472B uses these values for minimum, maximum and preferred pushbutton diameters. In cockpits fitted with coaming mounted keyboards, thumb rather than finger pressing may be preferred, particularly during vibration and turbulence. Table 2 recommends a 19mm key size for thumb operation, i.e. the maximum tested in DEININGER's (1960) study. This is considerably larger than most aircraft keyboard sizes. For instance, the F/A 18 and AV8b coaming keyboards use 13mm key sizes. In practice, key sizes tend to be a compromise between the limitations of panel space and the operator performance requirements. Where space is a serious limitation, the effects of small key sizes on data entry accuracy seem to have been offset by adding key barriers, recessing, and increased key resistance. In some aircraft installations, e.g. Tornado, relatively small key sizes are used with relatively large key separations, presumably to reduce inadvertent key pressing. However, there is a lack of published evidence on the effects of keyboard barriers, recessing and key size-separation on operator performance.

3.6. Turbulence, Vibration and Acceleration

Turbulence, vibration and acceleration affect the ability of aircrew to reach for and operate keyboards. The speed and accuracy of reaching movements is impaired as G increases: the detailed nature of the impairment will depend on the direction of the acceleration force, the positioning of the limbs within the acceleration environment, the location of the keyboard, and the direction of movement for pushbutton actuation (CHAMBERS, 1963).

DEAN, FARRELL and HITT (1969) compared performance on a numeric keyboard with toggles, rotary switches and thumbwheels, under static conditions and in random vertical vibration, simulating aircraft vibration conditions. The overall effect of vibration was to degrade performance, but no single device was best in terms of speed, accuracy and performance. The keyboard tended to be operated with the greatest speed but yielded the most errors. The slowest device (thumbwheels) tended to be the most accurate. However, subjects tended to prefer the faster device. The authors report that the outstanding feature of the vibration data was that subjects continued to perform in a coherent manner at all levels of vibration, even though the upper level ($3ms^{-2}$ RMS) was sufficient to cause intense discomfort.

The positioning of the keyboard was not reported in the DEAN, FARRELL and HITT (1969) study. In general, control operation is facilitated when the control is located in the direction of the acceleration force and requires control movements in the plane perpendicular to the acceleration force. Vertical (G_z) accelerations are predominant during flight in fixed-wing aircraft, particularly during turbulence and terrain avoidance manoeuvres. Transverse (G_x) accelerations occur mostly during take-off and landing. The helicopter acceleration environment is more complex. It follows that in flight, for fixed-wing aircraft at least, keyboards mounted vertically on the front panel or coaming will be difficult to reach during G_z accelerations (DOWDING and DAVIES, 1981), but if the operating hand can be stabilised, key operation should be relatively unaffected. Facilities should be provided for stabilising the hand when operating front panel and coaming mounted keyboards. Protruding keys, with high key resistances, are used on the Tornado TV Tab keyboard to provide stability without a high risk of inadvertent operation. Keyboards mounted on side consoles may be easier to reach during G_z accelerations, but there will be interference with key operation and feedback cues, which will increase the likelihood of keying errors. These effects could be reduced by tilting the keyboard out of the G_z plane. The likelihood of inadvertent key-pressing may be further reduced by recessing keys, increasing separation and resistance, and by providing barriers and cover guards (CHAPANIS and KINKADE, 1972). Little is known about how most of these design features affect keying speed but it seems likely that they will reduce data entry rates on continuous keying tasks. However, FENWICK and HICKOK, (1975) have demonstrated reduced errors without affecting numeric keyboard keying rate, in turbulence, by increasing key resistance up to 6.7N.

3.7. Motor Difficulty, Gloves and Stress

Motor difficulty leads to slow key pressing, more variable response times and more extensive changes in both time and variability as practice progresses (SEIBEL, 1972). Bulky glove assemblies can be expected to interfere with tactile feedback and to cause motor difficulty for keyboard data entry tasks, particularly if the gloves are worn only occasionally and habituation effects are not allowed to occur. In general, gloves are worn more frequently in the cockpit than at rear-crew stations, and the type of glove assembly will vary with the kind of protection required. BRADLEY (1961; 1969 a,b) has shown that glove tenacity (coefficient of kinetic friction) and snugness of fit are correlated with the time taken to reach for and to operate a pushbutton control using the thumb. Glove suppleness increased the rapidity of operation of adjustable controls, in the same way that suppleness might be expected to affect rapid key pressing by a skilled typewriter operator. Aircrew Cape leather glove assemblies are relatively close fitting and supple, compared with other more bulky glove assemblies. Indeed, it has been shown by MEREDITH (1973) that aircrew Cape leather gloves are only marginally inferior to bare hands on several standard tests of manual dexterity. Also, the gloves gave significantly improved grip (tenacity), which according to Bradley should facilitate key pressing. Wearing an additional layer of material beneath the Cape leather glove to increase protection causes further decrements in manual dexterity, and reduces the advantage for grip (TAYLOR, BERMAN and GILMORE, 1981). Factor analysis of tests of manual dexterity suggests that five factors can be involved in manipulation performance, i.e. finger dexterity, manual dexterity, wrist-finger speed, aiming and positioning (FLEISHMAN and HEMPEL 1954). Further work is needed to relate these factors to keyboard data entry tasks, and to determine the relative importance of reduced tactile feedback and restricted motor activity caused by aircrew glove assemblies.

Motor difficulty may also arise from environmental stress such as cold, when finger temperatures fall below 15°C (DUSEK, 1957), from the effects of vibration and acceleration, as discussed previously, and from increased muscular tension and tremor associated with anxiety (BADDELEY, 1966; BADDELEY and FLEMMING, 1967; BADDELEY, 1972; RUFF, 1963; WEYBREW, 1963). In practice, psychological and environmental stress may interact to produce either increased or decreased impairment of manual dexterity and tactility (BADDELEY and FLEMMING, 1967). The effects of stress on manipulative ability seem to have been largely ignored in recent trends towards miniaturisation and reduced tactile feedback in aircraft controls.

4. EXPERIMENTS

A number of experiments have been performed as part of the current programme of work on keyboard data entry. Some of these experiments have been designed to answer specific questions raised by the Royal Air Force, while others have sought to develop techniques or provide more generalisable data. The initial impetus for much of this work arose from RAF requirements for aircrew to operate wearing certain glove assemblies, and consequent concern over performance effects.

4.1. Experiment 1

Preliminary investigations revealed that the adaptability of the human operator tended to mask some of the performance effects which needed to be examined, although that is not to say that they were not important effects. These investigations indicated that a dual-task paradigm might be profitable, where performance decrements on some form of concurrent task would indicate changes in the data-entry task difficulty. There is some evidence that simple comparison of input media may not accurately reflect the effects found in a complex situation (PLUMMER, 1973). A structure-specific resources model was employed, which required that the two tasks utilised the same output modality. Different input modalities were chosen in order to reduce interference at the input stage, as processing and response demands were of more interest in this study.

4.1.1. Subjects

Six male subjects were employed, none of whom had any flying experience.

4.1.2. Task

The data-entry task required the subject to enter, via the keyboard, a seven digit number presented through headphones. The sequence would appear for verification, as it was entered, on a LED scratchpad indicator, and the subject would complete the keying sequence by pressing an 'ENTER' or 'ERROR' key depending on whether or not he had detected an error. He was not required to correct a detected error. White noise was also presented over the headphones to mask any external sounds.

The secondary task was a single axis compensatory tracking task which was chosen to represent a low flying task, although not in a rigorous sense. First order control was via a central joystick operated with the right hand, leaving the left hand free to perform the data-entry task. The tracking task was displayed on a monitor mounted in the same relative location to a cockpit head-up display. A cursor moving in a vertical direction had to be kept centred on a stationary marker. The task was controlled by a microcomputer utilising a pseudo-random forcing function. This task operated continuously throughout each experimental session.

4.1.3. Design

Six glove conditions were used, consisting of bare hands, neoprene inner gloves, Cape leather flying gloves, winter gloves with waterproof seal, and the last two each in conjunction with the inner glove. A Latin square was used to balance any order effects as a within subjects design was employed. Each subject performed on one condition per day, for six consecutive days excluding a weekend. For the data entry task, recordings were made of the time to press the 1st digit, time to press the 7th digit, and the time to press 'ENTER' or 'ERROR'. Accuracy and error detection were also recorded. The tracking task sampled the tracking error every half second with identification of when the data entry task was in progress.

4.1.4. Procedure

A seating rig was available which utilised a representative seat and was configured, in this instance, to the dimension of the Jaguar cockpit, in terms of seat angle, throttle, joystick, and rudder pedals positions, tracking display location, and coaming position. The keyboard was located on the coaming with the scratchpad display immediately above. The keyboard was in the telephone layout of 3x3+1 with 1, 2, 3, on top and 'ENTER' and 'ERROR' either side of, and lower than, the zero key. The subject was fitted with the appropriate gloves for that session. He was given a few minutes to practice the tracking task alone, and then a few minutes practising the data-entry task alone. Each session then consisted of 40 seven digit strings presented on a tape. Four different order sequences were available of these forty strings. A warning tone occurred 5 seconds before the string was presented, at which time the subject had to depress a button on the throttles. The timer for the data entry task was started when the subject released this button, after hearing the full sequence, thus controlling the hand location. The tracking task was stressed as being the primary task.

4.1.5. Results

No significant differences between glove conditions were found for data entry times, error rates, or error types. However significant effects of gloves were apparent for tracking impairment during data entry.

TABLE 5. Mean Tracking Errors

Condition	Interval Tracking Error	D-E Tracking Error	Impairment
Bare hands	17.99	22.99	1.28
Cape leather	18.23	28.94	1.58
Winter leather	17.34	27.23	1.53
Inner	17.46	24.26	1.39
Cape + Inner	17.36	28.02	1.61
Inner	17.14	27.52	1.61

TABLE 6. Tracking Error ANOVA

Source	SS	df	MS	F	P
Subjects	325.96	5	65.2		
Condition	172.94	5	34.6	2.6	< 0.05
Error	333.16	25	13.3		

4.1.6. Discussion

Other than those with the inner gloves alone, the impairment caused by each of the conditions was equivalent. This might imply that it was the tenacity of the gloves which was an important factor, as each condition involved a leather outer glove, and that the bulk and loss of dexterity were less important.

It was also possible that the tasks were not sensitive enough to detect the small performance differences. Various changes to the task were examined, involving changes in tracking difficulty, time between data-entry sequences, location of the keyboard and scratchpad in relation to each other and to the tracking display, and the physical characteristics of the keyboard. It became apparent that the experimental tasks were sensitive to all these changes, but that none of them increased the ability to discriminate between the different glove types.

Notwithstanding the advantages of a dual task paradigm, it was felt that some of the effects of gloves might be masked by the cognition and memory loads associated with these tasks. It was proposed, therefore, that the underlying processes might be more easily examined with a single keyboard task which eliminated a great portion of both the cognitive decision-making and short-term memory components of the previous task.

4.2. Experiment 2

A form of serial reaction time task was devised, utilising three keys, with the intention of examining the response factors alone of a data-entry task.

4.2.1. Subjects

Eight subjects aged between 20 and 30 were employed, none of whom had had experience of this type of task.

4.2.2. Task

The task was driven by a microcomputer, which also timed the responses and stored the data. In order to ensure that the subjects did not perform to some arbitrary self-imposed criterion, some form of machine pacing was necessary. A light cancelling task was chosen, where an LED positioned above each key indicated which key to press. As soon as the correct key had been pressed, the LED was extinguished and another LED was illuminated, in a pseudo random order. If the light was not cancelled within a certain period, initially 500 msecs, a miss was recorded, the light extinguished, and another light illuminated. The task was adaptive, and the period of time available for responding was decreased by 5 msec for each correct response. Incorrect responses, while not changing the status of the LEDs, caused the time period to be increased by 20 msec. Various algorithms were tried, with the one chosen producing reasonably consistent levels of performance, with approximately 10% errors. Although a subject could still improve his own rate, in practice this task appeared to prompt him into performing as fast as possible.

4.2.3. Design

Two conditions were employed in order to assess whether the test would be sensitive to gloves. These were bare hands, and the leather and neoprene glove assembly. Two further conditions were included, being the presence or absence of additional auditory feedback, in order to examine the role of feedback in such a task. The four conditions were balanced for order according to two 4x4 Latin squares. Each subject was tested on one condition per day for four consecutive days. The reaction time for every response was recorded along with the response made, plus any stimuli which went out of time.

4.2.4. Procedure

The subject was seated at a desk on which was placed the keyboard comprising three keys, with an LED above and in such a position as to not be obscured by the hand. Key size was 19mm x 13mm with a separation of 13mm. Travel was 3mm and resistance was 2.5N with a detent after half of the travel. He would be informed of the nature of the task and, if gloves were required for the condition they would be fitted. A flying helmet was worn with white noise provided over the headphones. The auditory feedback, if present, which was triggered by key actuation, would be superimposed on the white noise. Each session consisted of 200 trials, although incorrect responses could increase the number of key presses above this, and lasted approximately two minutes.

4.2.5. Results

No significant effects were apparent from the number or type of errors. The miss rate was somewhat dependent on the pacing algorithm, and needed to be considered in conjunction with the mean allowed time for responding. This also yielded no significant effects. Mean correct response times yielded a significant effect of gloves, but not of additional feedback.

TABLE 7. Mean Correct Response Time (msec)

Bare hands	No feedback	362.44
Bare hands	With feedback	373.20
Gloves	No feedback	381.90
Gloves	With feedback	385.39

TABLE 8. ANOVA Log Correct Response Time

Source	SS	df	MS	F	P
Subjects (S)	0.174	7	2.48 E-2		
Feedback (F)	1.889 E-3	1	1.889 E-3	2.447	NS
FxS	3.859 E-3	5	7.718 E-4		
Gloves (G)	1.675 E-2	1	1.675 E-2	16.180	<0.01
GxS	5.214 E-3	5	1.036		
FxG	3.465 E-4	1	3.465 E-4	0.231	NS
FxGxS	7.486 E-3	5	1.497 E-3		

4.2.5. Discussion

The task was sensitive to the effects of gloves, although the performance decrement, whilst significant, was small. However, no effect of additional auditory feedback was apparent. It is likely that additional feedback would only be of benefit if other forms of feedback were removed. Visual feedback was always present by virtue of the change in LED status and sight of the keyboard. Gloves probably did not mask the feel of the detent incorporated in these switches. While they may mask any tactile feedback, kinaesthetic feedback of movement and force would still be present. An alternative explanation could be that the subjects were making no use of feedback, but were operating in an open-loop mode. This is unlikely as they would then not detect when an incorrect key had been depressed. Such errors were detected as the subjects were often able to press the correct keys before the apparatus extinguished the light and presented the next trial. Even if the gloves did mask some of the feedback, then relatively short travel of the keys meant that subjects could depress the keys until no further movement occurred without incurring any great speed penalty. The relative contribution of mobility and tactility to keying performance could not be assessed because these were confounded variables. However, it seems likely for the reasons argued above, that the restrictions on movement caused by the glove assembly are an important factor in keying performance.

4.3. Experiment 3

Previous research has produced equivocal results regarding the effects of key characteristics on operator performance (Section 3.4.) The purpose of this experiment was to determine if the high compatibility key pressing task, used in the previous study, was sensitive to differences in key resistance and key displacement characteristics. Demonstration of a reliable effect for extreme practical key resistance and displacement values would justify further detailed study of the relationship between these and other independent key variables and operator speed/accuracy trade-offs.

4.3.1. Subjects

Sixteen male employees at the RAF Institute of Aviation Medicine were used as subjects. None were experienced typists.

4.3.2. Task

As in Experiment 2. Specially prepared, momentary keys were used on the keyboard. These allowed key resistances to be adjusted independent of key displacement. Key actuation occurred at [illegible] of the key travel for all settings. There was no snap-action or detent. Key size (15x15mm) and key separation (13mm) were held constant. Subjects performed the task with their dominant hand, with and without aircrew gloves, using one finger (1st digit) and using three fingers (1st, 2nd and 3rd digits) allocated one to each key.

4.3.3. Design

Four key settings were used: minimum travel (2mm), minimum force (1N); maximum travel (10mm), minimum force (1N); minimum travel (2mm), maximum force (15N). These were combined with hand conditions - bare hands and gloved hands (aircrew Cape leather + neoprene inner) - and keying method - 1 finger and 3 fingers and gloves conditions nested within a 4x4 Latin square for force and travel conditions. Each subject attended one session per day on four separate days. The same dependent variables were recorded as in Experiment 2.

4.3.4. Procedure

As in Experiment 2.

4.3.5. Results

A strong order effect dominated the data. This was taken out of each term in the analysis. No significant main effects on response times and errors were found between glove conditions. However, significant main effects and interactions were found for force, travel and finger conditions.

In this and all following analyses, interactions were examined by Tukey's range test. Correct response times (Tables 9 and 10) increased significantly with increased travel ($F=15.95$; $df=1,14$; $p<0.01$). A significant interaction between force and travel ($F=4.83$; $df=1,13$; $p<0.05$) was caused by particularly long times associated with the max force - max travel condition. Keying with 3 fingers was significantly slower than with 1 finger ($F=13.95$; $df=1,15$; $p<0.001$). A significant interaction between finger and force conditions ($F=5.08$; $df=1,15$; $p<0.05$) was caused by particularly long times associated with 3 finger keying at max force. A small but significant interaction between gloves and force conditions ($F=4.16$; $df=1,30$; $p<0.05$) was caused by increased times with increased force in the bare hands condition only.

TABLE 9. Mean Reaction Times for Correct Responses (msecs)

		Max Force		Min Force		
		Min Travel	Max Travel	Min Travel	Max Travel	Mean
With Gloves	3 fingers	380.94	412.48	381.92	392.27	391.90
	1 finger	363.65	382.44	372.27	378.13	374.12
Without Gloves	3 fingers	385.36	414.25	377.55	378.44	388.90
	1 finger	363.90	384.65	374.12	372.20	373.72
Mean		373.47	398.45	376.46	380.26	383.16

TABLE 10. Condensed ANOVA for Correct Reaction Times*

Source	SS	df	MS	F	P
Subjects (S)	1.3447	15	0.1229		
Hands (H)	0.1162	3	0.0387	12.248	< 0.001
HxS	0.1424	45	0.0031		
Keyboards (K)	0.1493	3	0.0497	6.801	< 0.001
KxS	0.3065	42	0.0073		
HxK	0.0467	9	0.0051	2.362	< 0.05
HxKxS	0.2966	135	0.0021		
Total	2.9036	252			

* Transform = log (1+x). Order effect between blocks was removed by covariance analysis.
Hands = Fingers + Gloves; Keyboard = Force + Travel.

TABLE 11. Mean Reaction Times for Errors (msecs)

		Max Force		Min Force		
		Min Travel	Max Travel	Min Travel	Max Travel	Mean
With Gloves	3 fingers	377.78	401.30	256.91	324.20	340.05
	1 finger	366.47	368.21	229.04	273.72	309.36
Without Gloves	3 fingers	378.26	413.39	264.47	306.85	340.74
	1 finger	354.35	375.48	246.74	274.65	312.80
Mean		369.22	389.59	249.29	294.85	315.74

TABLE 12. Condensed ANOVA for Error Reaction Times*

Source	SS	df	MS	F	P
Subjects (S)	108.08	15	7.2054		
Hands (H)	50.62	3	16.8757	8.412	<0.001
HxS	90.27	45	2.0060		
Keyboard (K)	677.07	3	225.6900	39.276	<0.001
KxS	241.34	42	5.7462		
HxK	11.14	9	1.2379	0.781	
HxKxS	214.06	135	1.5856		
Total	1392.60	252			

* Transform = $\sqrt{x + 3/8}$. Order effect between blocks was removed by covariance analysis.

In general, error responses tended to be faster than correct responses,,particularly in the minimum force conditions. Error response times (Tables 11 and 12) increased significantly with both increased travel ($F=9.54$; df=1,42; $p<0.01$) and increased force ($F=103.28$; df=1,42; $p<0.001$). Again, keying errors with 3 fingers were significantly slower than keying errors with 1 finger ($F=27.04$; df=1,15; $p<0.001$). Gloves had no effect on error response times.

TABLE 13. Number of Errors

		Max Force		Min Force		
		Min Travel	Max Travel	Min Travel	Max Travel	Mean
With Gloves	3 fingers	23.36	27.73	65.53	34.96	37.91
	1 finger	21.87	24.47	55.63	36.59	34.64
Without Gloves	3 fingers	24.22	26.63	[illegible]	37.31	36.20
	1 finger	22.79	26.21	57.53	38.86	36.36
Mean		23.06	26.26	58.36	36.93	36.28

TABLE 14. Condensed ANOVA for Number of Errors*

Source	SS	df	MS	F	P
Subjects (S)	7.1604	15	0.4773		
Hands (H)	0.2570	3	0.0856	1.500	
HxS	2.4564	43	0.0571		
Keyboard (K)	24.5636	3	8.1378	23.683	<0.001
KxS	14.5204	42	0.3457		
HxK	0.4231	9	0.0470	1.266	
HxKxS	4.8539	131	0.0370		
Total	54.2400	246			

* Transform = log (1+x). Order effect between blocks was removed by covariance analysis.

The number of errors (Tables 13 and 14) significantly increased with reduced travel ($F=7.17$; df 1,42, $p<0.05$) and reduced force ($F=45.59$; df=1,42; $p<0.001$). A significant interaction between force and travel ($F=14.79$; df=1,42; $p<0.001$) was caused by the particularly large number of errors associated with the min force - min travel condition, and to a lesser extent, the min force - max travel condition. Gloves and fingers conditions had no effects on the number of errors.

4.3.5. Discussion

In general, increasing key force and increasing key travel increase response times and reduce errors. However, it seems that across the ranges tested, key travel has the greater effect on response times, whereas key force has the greater effect on errors. These data would seem to indicate that reducing key travel is important for achieving fast keying rates, whereas increasing key force is important for reducing keying errors. Low travel combined with high force seems to be the best compromise if both keying rates and errors are important. Further work is needed to identify the speed-accuracy trade-off for intermediate force and travel values.

The aircrew glove assembly had no deleterious effect on keying performance, either in terms of speed or accuracy,,at any of the key settings used in this experiment. It can be concluded that the gloves do not cause any significant increase in motor difficulty at the rates of key pressing achieved by the subjects. However, it should be noted that these key pressing rates are relatively slow compared with those achieved by skilled typists, less than 200 msecs per key stroke, during continuous data entry, with high redundancy in the input and sequence of movements. The large order effect and the failure to achieve faster response times with 3 fingers than with 1 finger key pressing indicate that only relatively moderate levels of keying skill were achieved in the present experiment.

4.4. Experiment 4

The aim of this experiment was to determine the relative importance of reduced tactile feedback and restricted motor activity caused by aircrew glove assemblies on tests of manual dexterity, including the high compatibility keying task.

4.4.1. Subjects

Twelve employees at the RAF Institute of Aviation Medicine served as subjects. None of the subjects were experienced typists.

4.4.2. Tasks

The keying task was the same as in Experiment 2, with the difference that the key cueing light was illuminated for only 50 msec to reduce dependence on visual feedback. Subjects used their dominant for keying, and they were instructed to use three fingers (1st, 2nd and 3rd digits), allocating one each key. Mean RT for correct responses (MEANRT), Mean RT for error (MNER) and the number of errors (ERRORS) were recorded.

Six tests of manual dexterity and tactility were used, as listed below:

Washer Test (WASH) - Nine washers of varying depth and diameter to be placed on appropriate pegs. Completion time and errors (number remaining on board) were recorded.

Minnesota Block Test (MINN) - Sixty cylindrical blocks to be picked up in right hand, transferred inverted to left hand and replaced in slots. Completion time and errors (number un-turned) were recorded.

O'Connor Test (CONN) - Thirty thin metal pins to be removed from a metal pan and placed in slots in groups of three. Completion time and errors (number spilled and remaining in pan) were recorded.

Positioning Test (POS) - Ten shaped blocks to be picked up, rotated and repositioned in adjacent slots. Time to complete three circuits was recorded.

Purdue Assembly Test (PURDUE) - Construction of pin, washer, collar and washer assemblies in pin slots using both hands. Number of parts correctly assembled and errors (number of parts spilled on board) were recorded.

V Tactility Test (T) - Two 300mm perspex rulers, bolted together at one end, and separated by 5mm at the other end. The point at which the gap was just discriminable by touch, using the index finger, was recorded.

4.4.3. Design

The tasks were performed under the six glove conditions listed in Table 15.

TABLE 15. Glove Conditions and Associated Impairment of Mobility and Tactility

Glove Conditions		Impairment	
		Mobility	Tactility
C_1	No gloves	Normal	Normal
C_2	Complete Cape leather + neoprene glove assembly	Substantially reduced	Reduced
C_3	Glove assembly without fingertips	Substantially reduced	Normal
C_4	Glove assembly fingertips only	Normal	Reduced
C_5	Glove assembly without fingers	Partially reduced	Normal
C_6	Glove assembly fingers only	Partially reduced	Reduced

Edges of the dissected gloves were taped to the subjects' fingers using micropore tape.

The glove conditions were administered according to a 6x6 Latin square design, replicated twice. Test order was fixed within each glove condition.

4.4.4. Procedure

The procedure for the keying task was the same as in Experiment 2. Subjects completed the keying task first, followed by the dexterity/tactility tests, in the order listed in section 4.4.2. Typed instructions were given to the subject before each test, and the tasks were demonstrated, if necessary. All the tests and glove conditions were completed in a single experimental session, lasting approximately 60 mins.

4.4.5. Results

Analysis of variance was performed on the test results with glove conditions (C), subjects (S) and order (O) as main effects. The degrees of freedom for O were then split into linear and the remainder. Where the remainder were not important, these were pooled in with the residual for making specific comparisons. Comparisons among the individual means were made using the Newman-Keuls a posteriori procedure. Table 16 presents the means for all 9 variables, back transformed and corrected for transformation bias, where appropriate, with a posteriori comparisons where the F test for conditions was significant.

TABLE 16. Means for the Six Glove Conditions, with a Posteriori Comparison

Variate	C1 No Gloves	C2 Complete Assembly	C3 Less Fingertips	C4 Fingertips Only	C5 Less Fingers	C6 Fingers Only
Mean RT	354.27	351.60	359.96	367.98	363.39	354.27
MNER(Ln)	447.60	408.30	435.63	463.31	488.35	427.13
	C2, C6, C3, C1, C4, C5					
ERRORS	30.42	29.42	30.00	32.25	31.50	30.42
WASH(Ln)	20.98	27.62	22.67	26.31	22.23	28.70
	C1, C5, C3 < ** C4, C2, C6					
MINN(Ln)	46.70	56.39	52.69	55.46	48.47	54.22
	C1, C5 < ** C3, C6, C4, C2					
CONN(Ln)	50.53	73.28	60.02	70.07	50.53	70.59
	C1, C5 < ** C3 < * C4, C6, C2					
POS(Ln)	39.98	44.49	46.09	44.35	42.02	42.85
	C1, C5, C6, C4, C2, C3					
PURDUE (Parts)	37.75	14.00	32.67	17.58	35.75	17.17
	C2, C6, C4 < *** C3, C5, C1					
T	44.17	83.33	46.67	81.67	43.50	64.75
	C5, C1, C3 < * C6, C4, C2					

Ln indicates log transform of times.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

The correlation matrix for the six glove conditions means (C) is given in Table 17. Table 18 gives the correlation matrix for the residual term, after taking out the effects of subjects (S), conditions (C) and order (O).

TABLE 17. Correlation Matrix for Effect C (df = 5)

	Mean RT	MNER(Ln)	Errors	Wash(Ln)	Minn(Ln)	Conn(Ln)	Pos(Ln)	P	T
MEAN RT	1.00								
MNER(Ln)	0.83*	1.00							
ERRORS	0.39*	0.84*	1.00						
WASH(Ln)	-0.18	-0.52	-0.06	1.00					
MINN(Ln)	-0.04	-0.54	-0.11	0.88*	1.00				
CONN(Ln)	-0.21	-0.64	-0.17	0.95*	0.96*	1.00			
POS(Ln)	0.18	-0.35	-0.15	0.43	0.79	0.62	1.00		
PURDUE	0.20	0.56	0.08	-0.98***	-0.91*	-0.97**	-0.47	1.00	
T	-0.08	-0.46	0.03	0.86*	0.85*	0.90*	0.43	-0.95***	1.00

TABLE 18. Correlation Matrix for Residual Effect (df = 50)

	Mean RT	MNER(Ln)	Errors	Wash(Ln)	Minn(Ln)	Conn(Ln)	Pos(Ln)	Purdue	T
MEAN RT	1.00								
MNER(Ln)	0.80***	1.00							
ERRORS	0.29*	0.29*	1.00						
WASH(Ln)	0.11	-0.05	0.15	1.00					
MINN(Ln)	0.13	-0.05	0.07	0.13	1.00				
CONN(Ln)	0.26	0.15	0.08	-0.16	-0.03	1.00			
POS(Ln)	0.41**	0.32*	0.34*	0.34*	0.10	0.16	1.00		
PURDUE	-0.26	-0.26	-0.06	-0.37**	-0.09	-0.41**	-0.13	1.00	
T	0.09	-0.04	-0.10	0.13	-0.01	0.09	0.01	-0.29*	1.00

The keying task shows few clear cut differences between the six gloves conditions. The five manual dexterity tests performed in a similar manner, as indicated by the similar pattern of differences between individual means (Table 16) and the correlation matrix for the six conditions means (Table 17). However, it cannot be deduced that the tasks are generally measuring the same factors, since the correlation matrix for the residual term has very few large entries (Table 18). It is noteworthy that the correlation of the Positioning Test with the remainder of the dexterity tests is low.

The test results were re-examined for two explicit effects of mobility and tactility, defined as follows:

Tactility: C (1) (3) (5) vs C (2) (4) (6)

Mobility: C (1) (4) (5) vs C (2) (3) (6)

Analysis of variance was performed on the test results with subjects (S), order (LIN and Rem) and conditions (C) as main effects, with the conditions effect split into "Tactility", "Mobility" and "remaining effects".

Table 19 summarises the main effects.

TABLE 19. Effects of Mobility and Tactility

Variance	LIN Order	REM Order	Tactility (1df)	Mobility (1df)	Remainder (3df)
MEAN RT	*	*	-	-	-
MNER(Ln)	*	**	*	**	-
ERRORS	-	-	-	-	-
WASH(Ln)	-	-	***	-	-
MINN(Ln)	**	-	***	*	*
CONN(Ln)	-	-	***	**	-
POS(Ln)	**	-	-	*	*
PURDUE	**	-	***	**	-
T	-	-	***	-	-

This analysis confirms the dominant effect of "tactility" on the manual dexterity tests, with the exception of the Positioning Test, which seems to be more affected by "mobility". Keying error response times are the only keying variable affected by the conditions, and the effect seems to be more associated with "mobility" than "tactility", although both factors are involved to some degree.

It would seem that keying and performance on the Positioning Test are in some way related, as illustrated by the effects of "tactility" and "mobility" (Table 19, and the correlation matrix for the residual term (Table 18). However, the detailed nature of this relationship has yet to be determined.

4.4.6. Discussion

A preliminary analysis of the data provides some tentative evidence on the relative contribution of tactility and mobility to manipulative tasks wearing aircrew gloves. The reduction in tactility at the finger tips, seems to be the dominant factor influencing performance on the tests of manual dexterity. There is also evidence of an impairment of mobility caused by the gloves, on some of the tests. Keying performance seems to be affected by mobility, and to a lesser extent tactility, but with the possible exception of the Positioning Test, it seems that the dexterity tests measure different factors than those concerned with keying performance.

5. SUMMARY AND CONCLUSIONS

Operator requirements for aircraft keyboard design are likely to vary between keyboard installations, and will depend on factors such as task continuity and priority, the speed versus accuracy trade-off, the level of skill of the operator, and the operating environment. Current design standards are inadequate in many respects, but particularly with regard to the requirements for sensory feedback and the effects of aircrew glove assemblies. Four experiments are reported from the current programme of research at the IAM on aircraft keyboard design. The first two experiments indicated that aircrew glove assemblies could affect operator performance on data entry tasks. However, the effects were highly situation specific, and were more apparent during continuous data entry, with relatively high keying rates and a high compatibility keyboard task. Thus it seems that rear-crew keyboard tasks are more likely to be affected by aircrew gloves than cockpit data entry, and that the effects will be greater for experienced operators, who are able to achieve fast keying rates, than for the unskilled individual. Experiment 3 successfully illustrated the contributions of key displacement and resistance to the speed versus accuracy trade-off, and indicated that the optimal combination would vary, depending on different performance requirements. The methodology developed looks promising for further work on keyboard feedback requirements. Finally, the fourth experiment returned to the effects of aircrew gloves, and in particular to the relative contribution of glove tactility and mobility to manipulative performance. Whereas the aircrew glove assembly seems to be relatively benign in terms of its impairment of manipulative skills, compared with other more bulky glove assemblies, preliminary analysis of the results indicates that the reduction in tactility tends to be the more important factor on most tests of manual dexterity. However, the relationship with keying performance is less clear, and mobility may be of increased importance where fast finger-speeds are concerned. To summarise, different keys are probably justified for different keyboard tasks, but more evidence is needed to justify different gloves.

6. ACKNOWLEDGEMENTS

We wish to acknowledge the contributions of David Gilmore, Phillipa Wright, and Joan Butler (CBSCS placements at IAM) to the preparation and conduct of the experiments, and the assistance of Andy Belyavin and Mick Spencer (IAM Control and Data Division) in the statistical analysis of experimental results.

7. REFERENCES

ALDEN, D.G., DANIELS, R.W., and KANARICK, A.F., 1972, "Keyboard Design and Operation: A Review of the Major Issues", Human Factors, 14(4): 275-293.

BADDELEY, A.D., 1966, "Influence of Depth on the Manual Dexterity of Free Divers. A Comparison Between Open Sea and Pressure Chamber Testing", Journal of Applied Psychology, 50(1): 81-85.

BADDELEY, A.D., 1972, Selective Attention and Performance in Dangerous Environments", British Journal of Psychology, 63: 537-546.

BADDELEY, A.D., and FLEMMING, N.C., 1967, "The Efficiency of Divers Breathing Oxy-Helium", Ergonomics, 10(3): 311-319.

BAHRICK, H.P., BENNETT, W.F., and FITTS, P.M., 1955, "Accuracy of Positioning Responses as a Function of Spring Loading in a Control", Journal of Experimental Psychology, 49: 437-444.

BATEMAN, R.P., REISING, J.M., HERRON, E.L., and CALHOUN, G.L., 1978, "Multi-Function Keyboard Implementation Study", AFFDL-TR-78-197, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio, December.

BECKETT, P., and SOUTHWORTH, M.R., 1981, "Future Cockpit Displays". Ministry of Defence Contract A7a/327, Final Report, British Aerospace Aircraft Group, Warton Division, Preston, Lancs.

BERGENTHAL, J., 1971, "Preferred Pushbutton Switch Operating Forces", IEE Transactions, Systems, Man and Cybernetics, SMC-1(4): 385-7.

BRADLEY, J.V., 1961, "A Methodology for Glove Evaluation". Perceptual and Motor Skills, 12: 373-374.

BRADLEY, J.V., 1969, "Glove Characteristics Influencing Control Manipulability", Human Factors, 11(1): 21-36.

BRADLEY, J.V., 1969, "Effect of Gloves on Control Operation Time", Human Factors, 11(1): 13-20.

BRIGGS, G.E., FITTS, P.M., and BAHRICK, H.P., 1957, "Effects of Force and Amplitude Cues on Learning and Performance in a Complex Tracking Task", Journal of Experimental Psychology, 54: 262-268.

BUTTERBAUGH, L.C., 1981, "A Performance based Evaluation of Keying Logics for Alphanumeric Keyboards", AFWAL-TR-81-3104, Flight Dynamics Laboratory (AFWAL/FI), Wright-Patterson Air Force Base, Ohio, November 1981.

CALHOUN, G.L., 1978, "Control Logic Design Criteria for Multifunction Switching Devices", Proceedings of the Human Factors Society 22nd Annual Meeting, p.383-387.

CALHOUN, G.L., HERRON, E.L., REISING, J.M., and BATEMAN, R.P., 1980, "Evaluation of Factors Unique to Multifunction Controls/Displays Devices", AFWAL-TR-80-3131, Flight Dynamics Laboratory (AFWAL/FIGR), Wright-Patterson Air Force Base, Ohio, November 1980.

CHAMBERS, R.M., 1963, "Operator Performance in Acceleration Environments. In: 'Unusual Environments and Human Behaviour', BURNS, N.M., CHAMBERS, R.M., and HENDLER, E., (Eds), New York: Free Press of Glencoe.

CHAPANIS, A., and KINKADE, R.G., 1972, "Design of Controls", In: 'Human Engineering Guide to Equipment Design', VAN COTT, H.P., and KINKADE, R.G., (Eds), Chapter 8: 345-379, Washington DC: US Government Printing Office.

CHASE, R.A., RAPID, I., GILDEN, L., SUTTON, S., and GUILFOYLE, G., 1961, "Studies on Sensory Feedback", II. "Sensory Feedback Influences Key Tapping Motor Tasks", Quarterly Journal of Experimental Psychology, 13(3): 153-167.

COCHRAN, D.J., and RILEY, M.W., 1980, "An Evaluation of the Strengths, Weaknesses and Uses of Voice Input Devices", Proceedings of the Human Factors Society 24th Annual Meeting, p.190-193.

CONRAD, R., 1967, "Performance with Different Pushbutton Arrangements", HET. PTT-BEDRIJF DEEL, 15: 110-113.

CONRAD, R., and HULL, A.J., 1968, "The Preferred Layout for Numeral Data-Entry Keysets", Ergonomics, 11(2): 165-174.

CREAMER, L.R., and TRUMBO, D.A., 1960, "Multi-Finger Tapping Performance as a Function of the Direction of Tapping Movements", Journal of Applied Psychology, 44: 376-380.

DEAN, R.D., FARRELL, R.J., and HITT, J.D., 1969, "Effect of Vibration on the Operation of Decimal Input Devices", Human Factors, 11(3): 257-272.

DEININGER, R.L., 1960, "Human Factors Engineering Studies of the Design and Use of Pushbutton Telephone Sets", The Bell System Technical Journal, 39: 995-1012.
Also in: IRE Transactions on Human Factors in Electronics, March 1960: 24-30.

DIEHL, M.J., and SEIBEL, R., 1962, "The Relative Importance of Visual and Auditory Feedback on Speed Typewriting", Journal of Applied Psychology, 46(5): 365-369.

DOWDING, F.J., and DAVIES, E.B., 1981, "Evaluation of Digilux Touch-Sensing Equipment under Whole-Body Random Vibration Conditions", RAE-TR-81036, Royal Aircraft Establishment, Farnborough, Hants.

DUSEK, E.R., 1957, "Effects of Temperature on Manual Performance", In: 'Protection and Functions of the Hand in Cold Climates', Washington DC: Nat. Acad. Science, National Res. Council.

FENWICK, C.A., and HICKOK, C.W., 1975, "Keyboard Data Entry in Avionics", Society of Automotive Engineers 750522, Business Aircraft Meeting, Wichita, Kansas, April 8-11, 1975.

FENWICK, C.A., and SCHWEIGHOFER, H.M., 1971, "Human Factors Study of Keyboards for Cockpit Data Entry", Journal of Aircraft, 8: 935-938.

FERGUSON, D., and DUNCAN, J., 1974, "Keyboard Design and Operating Posture", Ergonomics, 17(6): 731-744

FLEISHMAN, E.A., and HEMPEL, W.F., 1954, "A Factor Analysis of Dexterity Tests", Personnel Psychology, 7: 15-32.

FLEISHMAN, E.A., and RICH, S., 1963, "Role of Kinaesthetic and Spatial-Visual Abilities in Perceptual-Motor Learning", Journal of Experimental Psychology, 66: 6-11.

GALITZ, W.O., 1965, "CRT Keyboard Human Factors Evaluation", Systems Application Engineering, Roseville, DPD, March 1965.

GIBBS, C.B., 1954, "The Continuous Regulation of Skilled Response by Kinaesthetic Feedback", British Journal of Psychology", 45: 24-39.

GRAHAM, D.K., 1974, "A Procedure for the Design of Multi-Function Switching Controls", JANAIR Report 740702, Office of Naval Research, Arlington, Virginia.

HERRON, E.L., 1978, "Two Types of System Control with an Interactive Display Device", SID 78, Digest, 84-85.

KINKEAD, R.D., and GONZALEZ, B.K., 1969, "Human Factors Design Recommendations for Touch Operated Keyboards", Final Report, Document 12091-FR, Minneapolis: Honeywell Inc.

KLEMMER, E.T., 1971, "Keyboard Entry", Applied Ergonomics, 2(1): 2-6.

KROEMER, K.H.E., 1972, "Human Engineering the Keyboard", Human Factors, 14(1): 51-63.

LEE, W.A., and SNODGRASS, J.G., 1958, "On the Relation Between Numbering Preferences and Performance on a Ten-Button Keyboard", Abstract in American Psychologist, 13: 425.

LONG, J., 1976, "Effects of Delayed Irregular Feedback on Unskilled and Slilled Keying Performance", Ergonomics, 19(2): 183-202.

McCORMICK, E.J., 1964, "Human Factors Engineering", Second Edition, New York: McGraw-Hill.

MEREDITH, A.E., 1978, "Manual Dexterity Tests and Real Military Tasks. A Validation Study Comparing Bare Hands, NBC Gloves, Pilots' Gloves and Arctic Mitts", APRE Report No. 20/77. Army Personnel Research Establishment, Farnborough, Hants.

MIL-STD-1280, "Military Standard Keyboard Arrangements", Department of Defense, Washington DC, 28 January 1969.

MIL-STD-1472B, "Human Engineering Design Criteria for Military Systems, Equipment and Facilities", Department of Defense, Washington DC, 31 December 1974.

MINOR, F.J., and REVESMAN, S.L., 1962, "Evaluation of Input Devices for a Data Setting Task", Journal of Applied Psychology, 46: 332-336.

MOUNTFORD, S.J., and NORTH, R.A., 1980, "Voice Entry for Reducing Pilot Workload", Proceedings of the Human Factors Society 24th Annual Meeting", p.185-189.

RABBITT, P.M.A., 1967, "Time to Detect Errors as a Function of Factors Affecting Choice-Response Times", Acta Psychologica, 27: 131-142.

RABBITT, P.M.A., 1978, "Detection of Errors by Skilled Typists", Ergonomics, 21: 945-958.

REISING, J.M., 1977, "Multi-Function Keyboard Configurations for Single-Seat, Air-to-Ground Fighter Cockpits", Proceedings of the Human Factors Society 21st Annual Meeting, p.363-366.

REISING, J.M., BATEMAN, R.P., CALHOUN, G.L., and HERRON, E.L., 1977, "The Use of Multi-Function Keyboards in Single-Seat Air Force Cockpits", AFFDL-TR-77-9, Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio, April 1977.

ROSINSKI, R.R., CHIESI, H., and DEBONS, A., 1980, "Effects of Amount of Visual Feedback on Typing Performance", Proceedings of the Human Factors Society 24th Annual Meeting.

RUFF, G.E., 1963, "Psychological and Psychophysiological Indices of Stress", In: 'Unusual Environments and Human Behaviour', BURNS, N.M., CHAMBERS, R.M., and HENDLER, (Eds), London: Free Press.

SCALES, E.M., and CHAPANIS, A., 1954, "The Effect on Performance on Tilting the Toll-Operator's Keyset", Journal of Applied Psychology, 38: 452-456.

SEIBEL, R., 1972, "Data Entry Devices and Procedures", In: 'Human Engineering Guide to Equipment Design', VAN COTT, H.P., and KINKADE, R.G. (Eds), 311-344, Washington DC: US Government Printing Office.

SEIFERT, R., 1981, "Analysis of Pilot Input Concepts and Devices into Integrated Display/Control Systems", Paper presented at AGARD 32rd GCP Symposium, Stuttgart, May 5-8, 1981.

SPERANDIO, J.C., and BISSERET, A., 1974, "Human Factors in the Study of Information Input Devices", RAE Translation No. 1728, Royal Aircraft Establishment, Farnborough, Hants, March 1974.

TAYLOR, R.M., BERMAN, J.V.F., and GILMORE, D., 1981, "Human Factors in Aircraft Keyboard Design: Report on Work on Air Staff Task 031 for the Period Sep 80 - Aug 81", Report No. 613, Royal Air Force Institute of Aviation Medicine, Farnborough, Hants, December 1981.

TAJIMA, K., and NAKAZAWA, H., 1969, "Human Factors Studies in the Design of Pushbutton Dial Telephone Sets", Review of the Electrical Communication Laboratory, 17(12): 1455-1471.

VAN NES, F.L., 1976, "Analysis of Keying Errors", Ergonomics, 19(2): 165-174.

WEST, L., 1967, "Vision and Kinaesthesis in the Acquisition of Typewriting Skill", Journal of Applied Psychology, 51: 161-166.

WEYBREW, B.B., 1963, "Psychological Problems of Prolonged Marine Submergence", In: 'Unusual Environments and Human Behaviour', BURNS, N.M., CHAMBERS, R.M., and HENDLER, E., (Eds), London: Free Press,

PILOT-MACHINE INTERFACE CONSIDERATIONS FOR ADVANCED AIRCRAFT AVIONICS SYSTEMS

Gloria L. Calhoun
Systems Research Laboratories, Inc.
2800 Indian Ripple Road
Dayton, Ohio 45440

Emmett L. Herron
General Dynamics, Fort Worth Division
MZ 2660, P.O. Box 748
Fort Worth, Texas 76101

SUMMARY

Control technology is undergoing dramatic change as a result of the development of digital avionics information systems. Aircrew acceptance of computer-driven controls depends largely on the successful establishment of the pilot-machine interface. Research was conducted to determine pilot acceptability and usability of one type of interface device--a multifunction control which integrates many aircraft functions onto a single, easily reached control panel. In each study, pilots completed communications, navigation, and weapons tasks on the control while flying simulated missions. This paper discusses some of the design guidelines identified during the studies as critical to the design of the interface. Topics addressed include how to identify functions to implement on a multifunction control, maximize accessibility of frequently used functions, optimize switch/function assignment, label switches, verify selections, and minimize hand motion and errors.

1. INTRODUCTION

The evolution of compact digital computers has resulted in an increase in the amount of information that can be presented to the pilot. If dedicated, single purpose instruments and switches are used to display and control this information, it is likely that locations outside the pilot's primary reach and vision envelope would have to be used. One means of solving this problem is through the use of multifunction displays and controls, which integrate a great deal of information and functions onto a few surfaces. Besides solving the physical packaging problem, multifunction devices prevent the pilot from becoming overloaded by restricting the information, through the use of time sharing, so that only that which is relevant to the pilot's current task is available. However, this time sharing concept, in which the computer changes the meaning of both displays and switches as a function of the pilot's current requirements, may also complicate information design. In order to ensure that pilot performance is not degraded, a fresh system design approach is required which uses an intelligent integration of optimally designed computer-driven displays and controls.

One of the key aspects in designing effective computerized aircrew systems is the successful establishment of the pilot-machine interface. This paper will address one type of interface device--a multifunction control. Unlike traditional dedicated controls in which each switch has only one function, a multifunction control consists of several computer-controlled switches which perform different functions at different times. An example of these two concepts is shown in Figure 1. A control panel consisting of 12 dedicated switches is illustrated in Figure 1a; each switch is associated with one system or function used during flight. All of these functions can be integrated on a few multifunction switches so that the functions or options available to the pilot are just the options likely to be used during that portion of the flight. For example, when the pilot is in a cruise mode with the "CRUISE MODE" dedicated switch selected, only 5 of these functions are available instead of 12: UHF, TACAN, IFF, WAYPOINT, and AUTO HEADING (Figure 1b). During a bombing mode, the same 5 switches have new legends or functions: UHF and WEAPON TYPE, QUANTITY, INTERVAL, and FUZING.

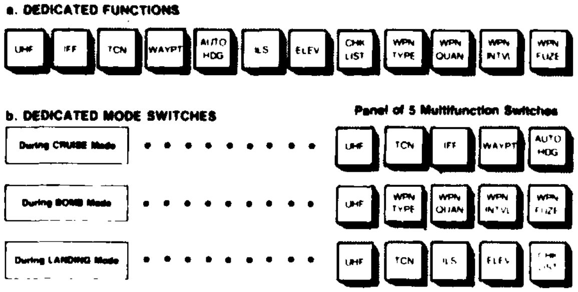


Figure 1. Illustration of Dedicated Controls and a Multifunction Control

Such an interface device can reduce workload and enhance mission success since a large number of functions, formerly performed by conventional, dedicated switches, can be consolidated in an optimal location on relatively few multifunction switches. In addition, the computer can restrict the information or options available to the pilot at any given time to just those possibilities which are relevant to the current task.

Since many questions relative to the design of multifunction controls have not been encountered in the design of control panels using single purpose switches, it is necessary that the designer base many decisions on common sense guesses or intuitive hunches. Therefore, the design of multifunction controls must, for the most part, be conceived intuitively and refined by an iterative process of test and redesign (Smith, 1980). This was the case in several studies conducted at the Flight Dynamics Laboratory to determine pilot acceptability and usability of such controls for aircraft applications (Reising, Bateman, Calhoun, and Herron, 1977; Bateman, Reising, Herron, and Calhoun, 1978; Calhoun, Herron, Reising, and Bateman, 1980; Kopala, Reising, Herron, and Calhoun, in press; Herron, Calhoun, Reising, and Kopala, in press; and Aretz, Reising, Kopala, Calhoun, and Herron, in press). A multifunction control which integrates most of the switching requirements for a fighter aircraft onto a single panel was designed and mounted on the lower left front panel of a cockpit simulator (Figures 2 and 3). The computer presented lists of mutually exclusive options on the display surface in alignment with the multifunction switches on the left and right sides of the panel. The pilot controlled the pages to be displayed and accessed the functions by either selecting the dedicated switches across the top or the multifunction switches. To operate the multifunction control, the pilot selected the desired function and then entered the data. Such a procedure corresponds to the thought sequences used during data entry (Fenwick and Hickok, 1975).

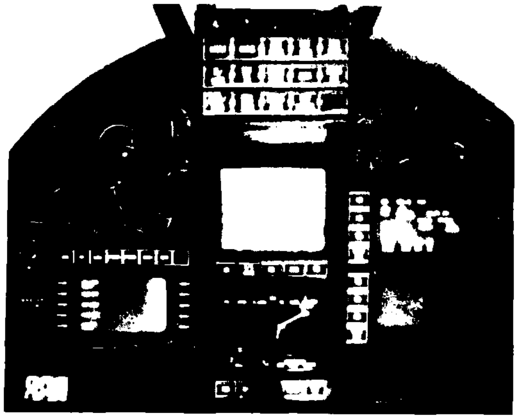


Figure 2. Cockpit Simulator Used in Multifunction Control Evaluations

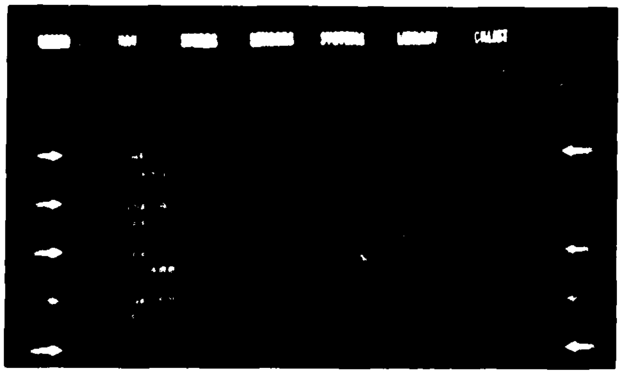


Figure 3. A Multifunction Control Page with Options for the Communications System Displayed

A series of studies were run to examine several aspects of multifunction control implementation. In each study, operational pilots (mean number equaled 15) completed communications, navigation, and weapons tasks on the multifunction control while flying missions. Control logic revisions and hardware changes were made after each evaluation, based on multivariate analysis of variance of performance data (flight control deviations, task completion times, and errors in switch selection) and nonparametric statistical analysis of subjective questionnaire data.

The purpose of this paper is to serve as a starting point for the multifunction control designer by providing insight into areas in which little documented factual data exist. First, the "lessons learned" by the authors in their multifunction control evaluations over the past 7 years are summarized. In order to serve as a general overview, only a brief report of results is made. The reader is encouraged to obtain information pertaining to the methodology and basis for data interpretation from the cited references. In addition, a few general design criteria documented in the human engineering literature which are applicable to multifunction control design and which were found to be especially pertinent during the evaluations are presented. Although this paper is not a definitive or exhaustive guide, it can assist the designer in identifying factors to be considered in the design of multifunction controls and provide initial design specifications from which the designer, through evaluation, can refine for a specific application. However, it is only after the guidelines are verified through extended research in a broad range of applications that they can be considered for inclusion in a quantitative design handbook for human-machine interfaces.

2. MULTIFUNCTION CONTROL DESIGN GUIDELINES

2.1 Identify Functions to Implement on a Multifunction Control

In order to determine which control functions to implement on the multifunction control, a systematic task analysis should be conducted early in the design process. The results of such an analysis will help determine the systems to be utilized and the functions to be accomplished by the pilot (Graham, 1974). Functions identified as "critical," however, should not be assigned to a multifunction control since several switch selections may be required to call them up. Rather, critical functions should be assigned to immediately available dedicated switches which serve a single function all the time. Examples include emergency functions which must operate when the system is degraded and functions which could endanger the pilot-computer system if erroneously activated (Willich and Edwards, 1975; and Nevins and Johnson, 1972). In addition, selection of some functions may be more efficient on dedicated switches. The results of one study indicated that digit entries should be completed on a separate panel made up of dedicated switches (Reising et al., 1977).

2.2 Maximize the Accessibility of Frequently Used Functions

One of the most critical design considerations is how the control logic is programmed. Perhaps the most commonly used design procedure is to program the control logic so that it is in parallel with system operation--the pilot chooses one of the systems such as communications or navigation, and then functions of that system. For example, to change the frequency of an UHF radio might require that the pilot progress through four steps or logic levels. First, a dedicated switch labeled communications is selected to display all of the radios on the aircraft (Figure 3). Further activation of the control would cause various sublevels for the applicable system to appear and the selected functions of the first page (set of options) to disappear. To complete the UHF change the pilot selects UHF to call up that particular radio (Figure 4) and then UHF CHNG to activate a separate digit entry keyboard (dedicated switches in 4 rows x 3 columns telephone layout) on the left console. With this type of control logic, it may take as many as four steps to access frequently used functions Tailoring the logic to a flight mode, however, eliminates some of the levels or steps. For example, page shown in Figure 5 presents the options most frequently used in a bombing mode. Different opt would be presented in a landing mode, etc.

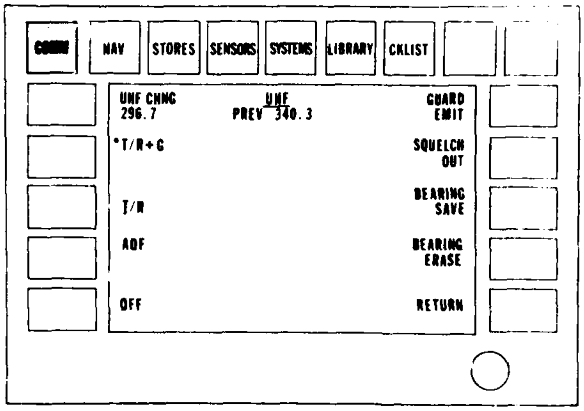


Figure 4. A Multifunction Control Page with Options for the UHF Radio Displayed

In the simulation evaluations conducted, it was shown that pilot performance can be enhanced when the logic is not programmed according to systems but rather tailored to the functions most likely to be used in the current flight mode (Calhoun et al., 1980). Using tailored logic as the primary interface reduces the number of switch hits and levels of indenture the pilot must progress through to complete common tasks. It was also found that concurrent implementation of the two alternate control logics is very beneficial (Herron et al., in press). The logic tailored to a flight mode provides access to frequently used functions. The logic programmed by systems provides access to functions not on the tailored logic page since they are not required by the pilot on a frequent basis. In implementing the latter logic type for the evaluations, it was found that having each system function less than four steps removed from the first page was very effectual (Bateman et al., 1978; and Reising et al., 1977).

Another means of keeping frequently used functions accessible and reducing the number of required switch hits, is having the computer automatically return the control logic to the first tailored logic page for the current flight mode when a task is completed. A logic return mechanism is required when a pilot is required to progress through pages of the control logic to access a function. In order to return to the first logic page the pilot must select a return switch (Figure 4). However, the pilot can be relieved from making this additional switch hit by having the computer-driven system automatically return the logic when no switch hits have been made during a certain length of time. Pilots indicated on evaluation debriefing questionnaires that they are in favor of an automatic logic return and that they prefer a 10 second time period before return rather than a 5 or 15 second period (Herron et al., in press).

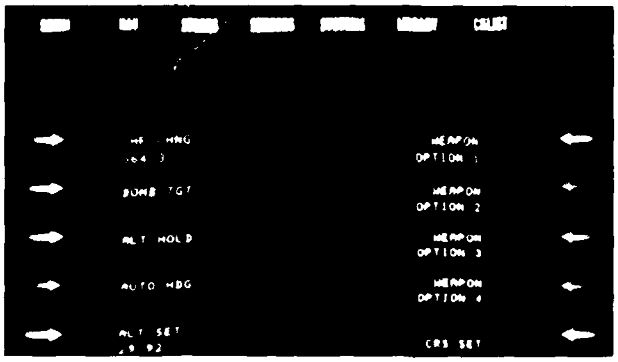


Figure 5. A Multifunction Control Page with Options for a Bombing Phase Displayed

2.3 Optimize Switch/Function Assignment

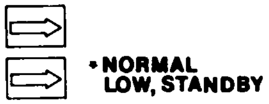
Once the functions to appear on each logic page are identified, the next step is to assign the functions to the switches. Function assignment should be based on how frequently they are used, how quickly they must be used, and how important they are to system operation. Important and frequently used functions should have the most favorable positions, e.g., those switches most easily differentiated from the other switches, such as the top switch of a column of switches. For instance, on the control used during the evaluations, it was felt that the top left switch was the most convenient switch. Since the UHF radio is an important function very frequency used, it was assigned to that switch (Figure 3; Graham, 1974; and Calhoun et al., 1980). Graham (1974) developed a design procedure which should facilitate making optimized switch/function assignments such as one just described. The procedure involves functional task analysis and quantitative classification of control functions according to their operational need.

Another consideration for assigning functions to switches is that once a function is assigned to a switch, it should, if possible, always appear on the same switch in any operating mode or on any other control panel used to accomplish similar functions (United States MIL-STD-1472B). Additionally, related functions should be assigned to adjacent switches rather than be scattered on the panel (United States MIL-STD-883A-1, 1964). Using this rule, weapon option functions should appear on adjacent switches rather than interspersed on the control panel with other functions (Figure 5). If only one of several related functions can be operational at a time, it may be possible to implement all these functions on one switch with rotating legends. For example, there are three mutually exclusive states of the Identification Friend or Foe (IFF) communication system: STANDBY, NORMAL, and LOW. The three functions could appear on a display surface next to <u>one</u> switch as shown in Figure 6a. In Figure 6a, the IFF system is in the STANDBY mode as indicated by the asterisk and location of the label "STANDBY" on the first line. Selection of the switch would activate the first function of the second line, and the legends would rotate clockwise and be displayed as shown in Figure 6b. The IFF system is now in the NORMAL mode. With such a switch mechanization, all the possible functions of the switch are displayed to the pilot, and the current function is identified by the asterisk and the top location of the legend. Not only can multifunction control operation be enhanced when several related functions are assigned to a "rotary switch" in this manner, but more switches are then available for other functions (Calhoun et al., 1980; and Aretz et al., in press).

2.4 Minimize Hand Motion During Multifunction Control Operation

Sequential operations should, if possible, require repeated selection of the same switch rather than selection of different multifunction switches (Bateman et al., 1978). For example, in control logic programmed parallel to system operation, the frequently used UHF radio function is located on the top left switch of a multifunction control (Figure 3). The most commonly selected function within the UHF radio subsystem, i.e., UHF change, is also located on the same switch (Figure 4) so that most of the pilots' communication operations involve two successive pushes of the <u>same</u> top left switch. Pilot comments indicated that locating the most commonly selected function <u>of a</u> page on the same switch that called up that page makes operation of a multifunction control much more efficient for two reasons: (1) hand motion is reduced and (2) the pilot soon learns to give the switch a double push without waiting to read the legend associated with the intervening step. If the mechanization described above is not possible, then the functions should be assigned, preferably on adjacent switches, such that sequential operations proceed left to right or top to bottom on the panel (United States MIL-STD-1472B).

a. IFF system is in the STANDBY mode



b. IFF system is in the NORMAL mode

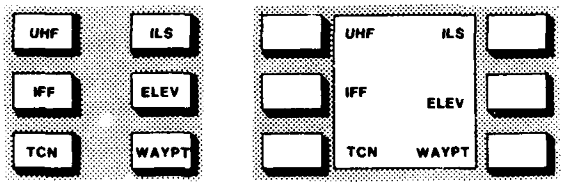
Figure 6. Illustration of Three IFF Functions Implemented on One "Rotary Switch"

2.5 Use Informative Legends to Identify Switch Functions

Each multifunction switch legend should provide sufficient information for proper identification and activation by the pilot (Engel and Granda, 1975). It should be obvious to the pilot what function is associated with each switch. For example, rather than label fixed options as "OPTION 1" and "OPTION 2," names or abbreviations describing the functions such as "SAVE" and "ACTIVATE" should be used. In addition, highly similar names for different functions should be avoided. Navigation functions labeled "DATA ENTRY" and "NAV UPDATE" may be confused, for instance.

2.6 Ensure Switch/Legend Association Unambiguous

Two methods of associating the legends to multifunction switches were evaluated in a simulation (Bateman et al., 1978). In one, the legends were on the switches, and in the other, the legends were adjacent to the switches (Figure 7). The results showed that pilot performance was better when the legends were displayed on the switch faces (Figure 7a). With this mechanization, it is clear what functions are assigned to each switch--the pilot pushes the legend for the desired function. Controls which require an association of the switches with the corresponding legends (Figure 7b) are less than optimal. If the latter type is used, the legends on the display surface must be aligned with the switches for the appropriate pilot viewing angle and seat adjustment. An additional problem with this type of mechanization is the added search time required to associate the switch with its proper legend--the pilot must locate the desired legend on the display surface, associate the legend with the corresponding switch, and then push the switch.



a. LEGENDS ON THE SWITCHES

b. LEGENDS ADJACENT TO THE SWITCHES

Figure 7. Two Methods of Implementing Multifunction Switch Legends

2.7 Eliminate Error Prone Design Features

If the pilot knows where he is in a multifunction control operation, what input has been made, and how the computer interpreted the input, then the number of errors likely to be committed is less (Engel and Granda, 1975). For example, if the pilot realizes that an incorrect digit or wrong multifunction switch has been selected, then the pilot can immediately correct the error before making further selections which would eventually have to be redone.

To reduce the entry of erroneous digit selections, each selected number should be displayed to the pilot on or near the control panel. The following procedure was used in several evaluations and was found to be very efficient (Reising et al., 1977; Bateman et al., 1978; and Aretz et al., in press). The current digit entry was displayed until the first number of the new entry was selected. Then the current readout disappeared and the new selections were displayed. If the new selections were cleared before selection of an ENTER switch, then the current digits reappeared. The readout was presented, in most cases, next to the function's legend. This location helped minimize eye movement between the active function and the scratch pad (Fenwick and Hickok, 1975).

Feedback or confirmation that a multifunction switch is active and that selection is acknowledged by the system can be accomplished through a visual indication [color change, intensity change, field reversal (Figure 8), blinking, display of additional symbol, etc.], audible click, or tactile snap feel (Engel and Granda, 1975; and Graham, 1974). Several visual indications were evaluated in a flight simulation (Aretz et al., in press). In addition, the use of different codes for switches which activate a separate digit keyboard such as UHF CHNG and switches which engage a function, like IFF NORMAL/LOW/STANDBY, was evaluated. The results indicated that the pilots preferred having different codes for the two types of switches. Of the methods evaluated as feedback for switches which activate a digit panel, they significantly preferred a combination of the color change and field reversal indications (black legend on a green field from a white legend on a black field) compared to a black legend on a white field (Figure 8) and a green cursor by a white legend. For switches which activate a function, their preferences appeared to be equal for a color change indication (green legend) and a symbol indication (white box around a white legend). Both these indications were better than a black legend on a white field. Such feedback cues reassure the pilot that a switch selection is acknowledged by the computer and assist the pilot in determining where he is in the logic, should he get interrupted or confused.

Another method of reducing pilot errors and enhancing smooth operation on a multifunction control is to ensure that no sequential operations are restricted, solely for the convenience of the software designer. Once the pilot initiates an operation, it should be possible to finish it without having to stop and complete a prerequisite operation. For example, the pilot should be able to set the altimeter without having to first set the course. In addition, restrictions on data input should be minimized as much as possible--input of leading zeros, unneccessary symbols, or special placement of decimal points should not be required (Obermayer, 1977). For example, it is unnecessary to require the operator to include the latitude and longitude symbols (degree, minute, etc.) since the software is capable of placing these symbols once the digit string is entered.

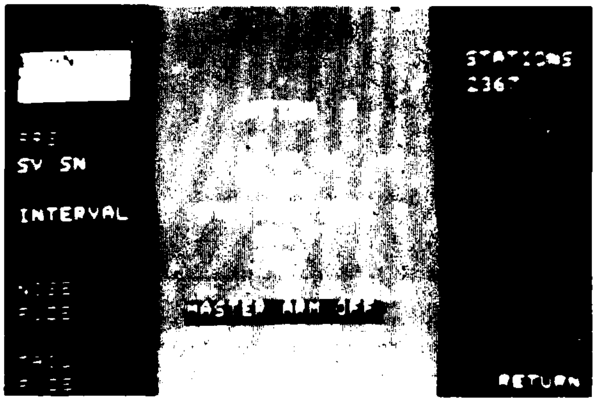


Figure 8. A Multifunction Control Page with "Quantity" Selected as Shown by the Field Reversal Feedback Indication

2.8 Implement Automatic Verification of Selections

The computer-driven control should be programmed to anticipate selection errors that are likely to be made (Obermayer, 1977; and Fenwick and Hickok, 1975). When an error in switch selection is identified, the selection should be rejected from the system and a message should be presented to the pilot. In a recent evaluation, the pilots indicated that displaying the error message in color was better than using monochrome messages and that the messages should specify the required remedial action (Aretz et al., in press).

Some types of verifications are described below.

A. Ensure data selections are correct in length and format. Computer edits can be performed for alpha, numeric, special characters, and total character counts. For instance, IFF Mode 3 entries can be checked to ensure that the input is four digits in length and that none of the digits is greater than seven.

B. Ensure selection is valid. For example, a VHF communications frequency (118.0-135.9 MHz) is an invalid input for a VHF navigation receiver (108.0-117.9 MHz) and the system should recognize this.

C. Ensure number of selections is sufficient for an operation. Verifying that enough parameters are specified for a weapon option is one example.

D. Ensure selection is logically consistent with other selections. An inconsistent entry would be for a pilot to select a type of weapon which cannot be delivered in the bombing mode previously selected.

2.9 Provide Efficient Correction Mechanisms

Corrective operations on the multifunction control should be easy for the pilot to perform. If the desired function is on the currently displayed multifunction control page, the pilot should be able to select it without other intervening switch hits. If it is not available on the same page, the pilot must restore the control through switch activation to the previous page or else to the first page for that phase of operation. Such a return or backstep mechanism also enables the pilot to look at previous pages during all operations. In addition, it should be noted that selection of any multifunction switch should not trap the pilot so that it is impossible to return to the previous or first page (Graham, 1974).

To correct errors made in digit entries, a CLEAR switch should be employed. Implementation of the CLEAR switch in the following manner has proved to be very helpful to the user in the evaluations: one push of the CLEAR switch erased the last selected digit and two pushes of the CLEAR switch erased all the digits for that particular entry (Reising et al., 1977; and Bateman et al., 1978). In addition, the pilot should not have to reenter long digit strings to correct an error (Engel and Granda, 1975). For example, latitude and longitude waypoint designators should be considered as two entries so that the pilot does not have to select the digits for both when an error is made.

3. CONCLUSION

The advent of time-sharing controls and displays poses an extraordinary challenge to human factors specialists during the next decade. Because the pilot-machine interface can serve both as a link and as a barrier to effective communication, there is an urgent need to examine how the interactive sequences are implemented in computer-driven controls. The guidelines just presented should be of benefit to the development of multifunction switching controls. It is only, however, by subsequent testing of a candidate control, that one can determine whether human factors as well as hardware and software design objectives have been met. Design and evaluation must continue, for the use of an optimally designed interface between the aircrew and advanced avionics equipment should tremendously enhance mission success.

ACKNOWLEDGEMENT

The research was conducted while the authors were with the Bunker Ramo Corporation, supporting the Air Force Wright Aeronautical Laboratories, Flight Dynamics Laboratory under Contract Numbers F33615-73-C-0391 and F33615-76-C-0013. The efforts were also performed in support of the Air Force's Digital Avionics Information System Program. The authors are grateful to the Air Force Aerospace Medical Research Laboratory for supporting the preparation of this paper under Contract Number F33615-79-C-0503 with Systems Research Laboratories, Inc.

REFERENCES

Aretz, A. J., Reising, J. M., Kopala, C. J., Calhoun, G. L., and Herron, E. L., in press, Evaluation of Stores Formats and Switch Status Methods, Wright-Patterson Air Force Base, Ohio: Air Force Wright Aeronautical Laboratories, Technical Report AFWAL-TR-in press.

Bateman, R. P., Reising, J. M., Herron, E. L., and Calhoun, G. L., 1978, Keyboard Implementation Study, Wright-Patterson Air Force Base, Ohio: Air Force Flight Dynamics Laboratory, Technical Report AFFDL-TR-78-197.

Calhoun, G. L., Herron, E. L., Reising, J. M., and Bateman, R. P., 1980, Evaluation of Factors Unique to Multifunction Controls/Displays Devices, Wright-Patterson Air Force Base, Ohio: Air Force Wright Aeronautical Laboratories, Technical Report AFWAL-TR-80-3131.

Engel, S. E. and Granda, R. E., 1975, Guidelines for Man/Display Interfaces, Poughkeepsie, New York: IBM Technical Report TR00.2720.

Fenwick, C. A. and Hickok, C. W., 1975, Keyboard Data Entry in Avionics, Society of Automotive Engineers, Technical Report 750522.

Graham, D. K., 1974, A Procedure for the Design of Multifunction Switching Controls, Joint Army-Navy Aircraft Instrumentation Research Program, Technical Report JANAIR 740702, AD-A000 532.

Herron, E. L., Calhoun, G. L., Reising, J. M., and Kopala, C. J., in press, Study of Logic and Engine Displays, Wright-Patterson Air Force Base, Ohio: Air Force Wright Aeronautical Laboratories, Technical Report AFWAL-TR-in press.

Kopala, C. J., Reising, J. M., Herron, E. L., and Calhoun, G. L., in press, Symbology Verification Study, Wright-Patterson Air Force Base, Ohio: Air Force Wright Aeronautical Laboratories, Technical Report AFWAL-TR-in press.

Nevins, J. L. and Johnson, I. S., 1972, Man's Role in Integrated Control and Information Management Systems, Cambridge, Massachusetts: Massachusetts Institute of Technology, Technical Report E-2695.

Obermayer, R. W., 1977, Accuracy and Timeliness in Large-Scale Data-Entry Subsystems, Proceedings of the Human Factors Society 21st Annual Meeting, 173-177.

Reising, J. M., Bateman, R. P., Calhoun, G. L., and Herron, E. L., 1977, The Use of Multifunction Keyboards in Single-Seat Air Force Cockpits, Wright-Patterson Air Force Base, Ohio: Air Force Flight Dynamics Laboratory, Technical Report AFFDL-TR-77-9.

Smith, S. L., 1980, Requirements Definition and Design Guidelines for the Man-Machine Interface in C^3 System Acquisition, Bedford, Massachusetts: MITRE Technical Report M80-10.

United States Military Standards, 1964, Human Engineering Design Criteria for Aerospace Systems and Equipment Part 1, MIL-STD-803 A-1.

United States Military Standards, 1974, Human Engineering Design Criteria for Military Systems and Equipment and Facilities, MIL-STD-1472B.

Willich, W. and Edwards, R. E., 1975, Analysis and Flight Simulator Evaluation of an Advanced Fighter Cockpit Configuration, Wright-Patterson Air Force Base, Ohio: Air Force Avionics Laboratory, Technical Report AFWAL-TR-75-36.

DISCUSSION AVIONICS PANEL SPRING MEETING
On
ADVANCED AVIONICS AND THE MILITARY AIRCRAFT MAN/MACHINE INTERFACE
26-29 April, 1982

SESSION Nr. 4 AIRCREW INTERACTION WITH COMPLEX SYSTEMS-Chmn Y. Brault, FR

Paper Nr. 19
Title : COMMUNICATIONS MANAGEMENT CONTROL - A VITAL INTERFACE
Author : W. E. Brierley
Speaker : Y. Brault
Comment : (a) Did you consider the case of night operations? If so do you feel that the pilots who will certainly use night vision goggles will be able to operate the control panel?

(b) Don't you think that voice control and command techniques are the right answer to the problem?

Response : (a) The spectral emmision of the display has been closely specified. In normal operation, only one crew-member wears Night Vision Goggles. The second crew member would normally operate the control panel. By far the greater problem is meeting bright sunlight conditions for secret legends while still maintaining Night Vision Goggle capability.

(b) Voice input would take longer, as some form of aural menu selection is required. In the battlefield command mode aural channels would be occupied at a high level.

Paper Nr. 19
Title : COMMUNICATIONS MANAGEMENT CONTROL - A VITAL INTERFACE
Author : W. E. Brierley
Speaker : W. H. McKinlay
Comment : In view of the reduced panel size that had been achieved, could the author comment on the compatibility of the resulting controls spacing with NBC glove assemblies?

Response : The spacing of controls is little different from that existing on current equipment. Some work has been carried out with NBC gloves, but final evaluation awaits the engineering and flight trials models.

Paper Nr. 19
Title : COMMUNICATIONS MANAGEMENT CONTROL - A VITAL INTERFACE
Author : W. E. Brierley
Speaker : J. Laycock
Comment : What influenced the decision to make the two radios have a panel which was laterally symmetrical rather than laterally displaced, as the pilot now has to learn a new pattern for each seat?

Response : (a) The right hand pilot uses left hand for selector, left pilot employs right hand.

(b) The angular placing of panel in only available space required consideration of possible operation of displays by knobs and hands.

(c) The central common function buttons form natural barriers between the two positions.

(d) The audio controls are located near the function buttons to enable use as selected radio indicators.

(e) Some preference was expressed by user elements of the RAF for this layout.

Paper Nr. 19
Title : COMMUNICATIONS MANAGEMENT CONTROL - A VITAL INTERFACE
Author : W. E. Brierley
Speaker : W. H. McKinlay
Comment : (a) Would it be better to have distributed controllers rather than a central unit to cover the battlefield damage case?

(b) Would more automation reduce the number of functions to be covered?

Response : (a) The existing installations with present controller plus proposed additions require excessive area that is needed for other purposes.

(b) Irrespective of any automation, the pilot must have override authority. Function is determined to a high degree by external compatibility requirements.

(c) The direct presentation of functions requires fewer operations than via central control.

Paper Nr. 19
Title : COMMUNICATIONS MANAGEMENT CONTROL - A VITAL INTERFACE
Author : W. E. Brierley
Speaker : F. S. Stringer
Comment : Has an ergonomic study been made to detect the possibility of an increase in the wrong selection of switches due to congestion of controls - particularly when aircrew are fatigued?

Response : Yes, as far as practicable. Control congestion is no worse than on existing controls. Area reduction is due to control combination, i.e. use of less controls. The configuration is intended to present no opportunity for invalid entry, over and above those that can be made on an existing controller.

Paper Nr. 20
Title : FACTORS AFFECTING THE ALLOCATION OF ATTENTION AND PERFORMANCE IN CROSS-MONITORING FLIGHT INFORMATION DISPLAYS
Author : V. P. Schmit

DISCUSSION

Speaker : Y. Brault
Comment : If my understanding is correct you said that flight information could be displayed both on the H.U.D. and H.D.I. and that the spatial relationship must be the same on both displays. It seems to me that such a statement will lead to concentrating the flight information in the center of the H.U.D., and in the case of wide angle H.U.D. you are losing the advantage of a large field of view, which gives the possibility to spread the flight information, and have a better view of the outside world.
Response : I think there might be a slight misunderstanding here, what I was advocating was that specific information should be placed in equivalent portions both head-up and head-down. There are however strong reasons to present greater information elaboration head down, to give for instance, rate information for flight parameters. At RAE preliminary investigations with wide angle HUD's has supported my reservations on the inadvisability of spreading flight information. The advantages of wide angle HUD's would seem to be more those of permitting weapons symbology (for example that associated with agile missiles) to move over a wider area of the real world.

Paper Nr. 20
Title : FACTORS AFFECTING THE ALLOCATION OF ATTENTION AND PERFORMANCE IN CROSS-MONITORING FLIGHT INFORMATION DISPLAYS
Author : V. P. Schmit
Speaker : Dr. G. Hunt
Comment : For the types of displays used in real combat aircraft the head-up display is collimated and therefore the pilot has to re-focus and to translate his point-of-regard in order to visually acquire a H.U.D. from a H.D.I. and vice-versa. What difference will this make to the times which you measured in your experiments?

Response : In the experiment, HUD and HDI formats were presented on the same, non-collimated display. The times found in the experiment therefore did not take account of the necessity to make a head movement or re-focus the eyes when moving between displays. I have no specific data myself, relating to this, but it seems most unlikely (from the literature) that this would add more than 1 second to the times reported assuming that both flight information display suites are satisfactorily viewable without major position changes on the part of the pilot.

Paper Nr. 21
Title : THE HEAD UP HANDS BACK CONTROL CONCEPT
Author : G. Roe
Speaker : Y. Brault
Comment : I am a little bit confused by your Table 1 - The multifunction key appears to be very poor, regarding the possibility of confusion between tasks, for example. I do not understand the difference between your multi-function key and the keyboard. Can you comment?

Response : A functional definition of a multi-function key would be: a push selector which after initial selection subsequently presents functionally related selections either upon the key face or upon a display surface beside the key. Potential mental confusion exists during selection tasks if the operator is called upon to transfer attention for a period of time away from the selection task then needs to rapidly return to complete the task.

Paper Nr. 21
Title : THE HEAD UP HANDS BACK CONTROL CONCEPT
Author : G. Roe
Speaker : R. G. White
Comment : One characteristic of your system architecture is that displayed information and display surfaces would be reconfigured automatically following display system failures. Have you performed any trials to assess the pilot acceptability of this philosophy or to measure pilot adaptation times following such reconfiguration? The reason for my question is the paucity of such data in the literature.

Response : The system architecture to undertake the studies into pilot reaction times and response to display head failures will be available in mid-summer 1982. It is hoped that the studies proposed for this system will provide some literature to assist future design activities. The current work has only been able to solicit pilot reaction to the concept which in general is favorable and study the pilot's information needs during display head failures.

Paper Nr. 22
Title : UNE INTEGRATION DE PLUS EN PLUS POUSSEE POUR LES VISUALISATIONS DES AVIONS DE COMBAT
Author : C. Maureau
Comments : No questions.

Paper Nr. 23
Title : HUMAN FACTORS IN AIRCRAFT KEYBOARD DESIGN
Author : R M Taylor, J V F Berman
Speaker : Y. Brault
Comment : It is my understanding that you have conducted your experiments without simulating high "g" conditions. In experiment 3 your conclusions are that increasing key force reduces the errors. What will happen in high "g" conditions as the pilot will experience difficulties in asserting force?

Response : (J. V. F. Berman) We have not yet examined high "g" or vibration in our experiments, and would hope to do so before we conclude our work in this area. What we have shown, so far, is that for aircraft operations the range of forces quoted in the various standards are too generous and that high forces have a measurable performance benefit associated with them. In a

DISCUSSION

high "g" environment it is necessary to have a high enough spring force to prevent inadvertent operation, and the location and orientation of the keyboard will be important in order to reconcile the axis of switch operation with the axis of increased "g" force.

Paper Nr. 23
Title : HUMAN FACTORS IN AIRCRAFT KEYBOARD DESIGN
Author : R M Taylor, J V F Berman
Speaker : R. G. White
Comment : With changing fashions in NBC glove assemblies, were the authors intending to re-run their experiments for other assemblies before recommending changes to the standards?

Response : (J. V. F. Berman) We have, in fact, examined all of the current and proposed glove assemblies, including those to which I believe you are referring. Also, our first experiment showed no significant differences between glove types, although some performance decrement was associated with them all.

Paper Nr. 24
Title : TACTILE MAN-MACHINE INTERFACE CONSIDERATIONS FOR ADVANCED AIRCRAFT AVIONICS SYSTEMS
Author : Ms. G. L. Calhoun, E. L. Herron - presented by Dr. Reising
Speaker : M. Reinecke
Comment : You pointed out that one function should always appear in just one position or on just one key. Why is it then that in your display, when you showed the different selection modes for IFF, that is low, high, and so on, that you changed the position of the words? Did you make tests on that?

Response : What I was referring to was the use of a legend such as UHF, if you start it on the upper left, you should keep it there and for example, you would not bring up a TACAN radio. Now with a rotary selector you are in effect locating a cluster of legends all referring to the same system. So as long as we kept those three legends on the same switch we had no problems with the pilots using the same system. What we did not want to do was move around the position for UHF, for example.

LIMITING PERFORMANCE OF THE EYE/DISPLAY SYSTEM

D. Bosman, F.W. Umbach
Twente University of Technology
Enschede, Netherlands

26.1 INTRODUCTION

The performance and its limits of the CRT as used in both the recreational sector (television, e.g. Ref. 1) and professional applications such as aircraft displays, Refs. 2, 3, have been extensively researched and described. The new generation of flat panel display devices (Refs. 4, 5, 6) have image generation properties which are sufficiently different from those of the CRT to require additional ergonomic investigations.
In particular, the structural information (spatial domain) does not allow such operations as analogue low pass filtering based on partial overlap of pixels: the image remains tesselated because of the display technology involved, wherein pixels are formed by reticulation of the light modulating or emitting display surface. Also a wide dimming range is necessary to ensure good legibility over the whole ambient luminance range as encountered in cockpit environments. These aspects will be given attention with the human visual characteristics as a reference; recommended display specifications are derived.

26.2 CHARACTERISTICS OF RETICULATED, FLAT PANEL DISPLAYS

26.2.1 SAMPLING AND RECONSTRUCTION OF IMAGES

Images are two dimensional distributions of luminance $L(x,y)$ wherein x and y are the spatial (distance) coordinates of the local luminance L. The spatial resolution required for faithful reproduction of the image is determined by very steep luminance gradients and small radii in curvature of contours, and by just noticeable differences (JND's) in low gradients. The required luminance resolution is determined by discernible luminance contrasts. In digital sequential image scanners each line consists of a number of consecutively acquired samples, each frame of a number of subsequently formed lines. The samples are converted to digital format in an ADC, processed, and stored for further handling and display.
In a theoretical model of sampled images, (Ref. 7) the original or object image $L_0(x,y)$ is multiplied by a matrix $D(x,y)$ of Dirac (delta) functions located at the nodes (n,m) of a lattice or grid with spacing $(\Delta x_1,\Delta y_1)$, Fig. 1.a. The area $dA_1 = \Delta x_1.\Delta y_1$ centered around each node (Fig. 1.b) is a picture element (pixel, pel) of the object image. The grid spacing $(\Delta x_1,\Delta y_1)$ is chosen such that details of interest in the image are resolved <u>after</u> processing and display. The multiplication of $L_0(x,y)$ and $D(x,y)$ transforms into a convolution in the spatial frequency domain. The transform of the matrix $D(x,y)$ happens to be again a matrix of delta functions in the spatial frequency domain (f_1,f_2): each delta function located at the nodes of a grid with coordinates if_x,jf_y; $i,j = 0,1,2...$ The spacing of the nodes thus is $f_x = \frac{1}{\Delta x_1}$, $f_y = \frac{1}{\Delta y_1}$. Around each node a section is centered with area $f_x f_y$; each section carries an alias of the transform of the object image (Fig. 2), thus is representative for the whole of image data. The central section has node $i = 0$, $j = 0$: the (0,0) alias.

In practice, the sampling function $S(x,y)$ does not consist of delta functions, but can be considered as the convolution of the matrix $D(x,y)$ and a point spread function (PSF): $F_s(x,y)$ of the actual sample, see Fig. 3.
The expression of the acquired sampled image, before(!) measurement, becomes

$$L_a(x,y) = L_0(x,y).\left[D(x,y)*F_s(x,y)\right]$$

Each sample magnitude is obtained by performing the spatial integration over the area covered around each sample by the PSF: $F_s(x,y)$. In one-sample-at-a-time systems only one sample exists during measurement, so that

$$L_a(n\Delta x_1, m\Delta y_1) = \sum_n \sum_m \int_x \int_y L_o(x,y).F_s(x-n\Delta x_1, y-m\Delta y_1)dxdy$$

or: the image sample value at each sample point is determined separately.
By the sampling operation with practical pulses $F_s\ (x,y)$ one has obtained a matrix of numbers $L_a(n\Delta x_1, m\Delta y_1)$. The pixels must be made visible in a number to luminance transducer: a display. The display pixel distances are Δx_2 and Δy_2; the display grid spacing is chosen such that details of interest in the image are resolved by the eye at the given viewing distance. The display is k pixels wide and ℓ pixels high. The relation between the object image parameters n,m, and the display parameters k,ℓ, are $n \leq k$, $m \leq \ell$. Predisplay processing may be required: the processed image $L_p(n\Delta x_1, m\Delta y_1)$ is transformed into the display input $L_p(k\Delta x_2, \ell\Delta y_2)$. The displayed image $L_d(x,y)$ is the result of convolving $L_p(k\Delta x_2, \ell\Delta y_2)$ with the display PSF: $F_r(x,y)$:

$$L_d(x,y) = \sum_k \sum_\ell L_p(k\Delta x_2, \ell\Delta y_2).F_r(x-k\Delta x_2, y-\ell\Delta y_2)$$

$$= L_p(k\Delta x_2, \ell\Delta y_2) * F_r(x,y)$$

26.2.2 THE DISPLAY PSF AND MTF

In Fig. 4.a the luminance profiles, of comparable size, of a CRT spot and of a square pixel in x-direction of a flat panel display (such as thin film electro luminescence, TFEL, display) are depicted. The width of the pixel equals the matrix distance Δx_2 (in m), its luminance is L cd m^{-2}. The display sample frequency f_d is $(\Delta x_2)^{-1}$; for reasons of comparison it is assumed that the CRT spot is switched off and on, to coincide with the locations k of the square pixel matrix. The maximum display sample frequency is determined by the max. retinal frequency resolved by the eye (26.3.3): at 70 cm (28") viewing distance this translates into 10 pixels per mm, diagonal.

In Fig. 4.b the cross section of the modulation transfer functions (MTF) in the $M\text{-}f_1$ plane of both the CRT spot (A) and the square pixel (B) are shown, but only for the (0,0) alias. The intersection between the (0,0) alias and the first aliases takes place at the Nyquist frequency $f_N = \frac{1}{2} f_d$. If $L_p(k\Delta x_2, \ell\Delta y_2)$ does not contain power in the interval $[f_N, f_d]$, then the power of the 1st aliases folded back into the interval $[-f_N, +f_N]$ is also zero. However, this is frequently not the case, so that interference occurs between frequency components of the same frequency originating from the first and the zero'th alias or: interference between image structure and matrix grid structure (aliasing error, Kell effect, Ref. 8). In Fig. 5, both the analogue and square pixel representations of radial sectors illustrate aliasing. Straight lines e.g. are approximated by combinations of shifted pixels and line pieces. Especially when the object image contains periodic components with a main direction rotationally displaced with respect to the grid coordinates, interference fringes become visible which, in optics, are known as moiré patterns. But also (seemingly) stochastic image parts can interfere with the grid pattern to produce visibly different components, because the sensitivity of the visual channel for displacements perpendicular to a dominant orientation in the image is greater than for displacements parallel to that orientation.

It must be realized that there exists no inverse operation to reduce the aliasing error. Its effect can only be mollified at the expense of (more) blur, or by exploiting the prior information about the grid structure in combination with available quantization redundancy. In two level displays the experience of granularity caused by aliasing (Fig. 5) can be reduced by softening the visibility of protruding pixels, i.e. through weighting their luminance as a function of the lateral distance error (Refs. 9, 10).

However, the effect is purely cosmetic, no increase in image bandwidth is obtained. A good example is e.g. the technique described in Ref. 10, applied to continuous raster display (CRT-TV), wherein use is made of the spatial electron density distribution of the CRT beam in order to create diffuse transitions in slanted lines. Each line piece of the slanted line is preceded and followed by a slowly increasing and decreasing intensity which has the appearance of modulating the line width because of the electron density distribution of the beam; thus producing the illusion of less distorsion. Of course, the rate of increase/decrease must be computed for each line piece to match the local slant angle, being zero for horizontal and vertical lines

In order to obtain a measure which describes the cause and the amount of error introduced by every operation in the image processing system, one should adopt a quantity which, preferably, can be mapped onto a ratioscale; i.e. a scale which is divided into equal intervals and where 'zero' is well defined. Such a measure is too simple to account for all relations between display signal to noise ratio and operator performance. One may take the normalized RMS value of the difference between the power of the object image $L_o(x,y)$ and the power of the displayed image $L_d(x,y)$ as a fidelity parameter. In the following, noise power is assumed to be additive, whether resulting from filtering, sampling or reconstruction; and also closely connected to image quality, as determined in psycho-physical experiments (Refs. 11, 12, section 26.3).

26.2.3 THE SAMPLING OPERATION, ALIASING ERROR

The normalized aliasing error ε_a adds noise by interference of the original image with image power, which is shifted to higher frequencies (aliases) through convolution with the delta functions (see Fig. 2) situated at nodes other than the (0,0) node. Let $M_o(f_1,f_2)$ be the magnitude spectral distribution (MSD) of the object image. Assume that the power spectral density (PSD): $M_o^2(f_1,f_2)$ of the zero'th alias (located around node 0,0) is decomposed into its individual contributions as they extend over all sections, See Fig. 6. Only the image power located in the central section (0,0) is desired, all other contributions are considered lost since the reconstruction operation must be limited to the area bounded by $\left[-\frac{1}{2}f_x,\frac{1}{2}f_x\right],\left[-\frac{1}{2}f_y,\frac{1}{2}f_y\right]$. The sum of these other contributions thus represents the minimal reconstruction error, which is realized when the reconstruction operation has an MTF with the shape of a box with uniform height and area (f_x,f_y). However, the square pixel display has a $\frac{\sin u}{u}$ response in the spatial frequency domain, its first zero response located at $f_x = f_d$ for $m = k$, as shown in Fig. 4. Thus considerable power of the first alias $(f_N < f_1 < f_d)$ is transmitted.

Moreover, the image power shifted to other nodes than 0,0 by the convolution operation associated with sampling, extends into the central section as shown in Fig. 6. Unwanted power is added to the desired power: aliasing error. By reciprocity (Fig. 6), the power of the original image (zero'th alias) which extends into other sections is equal to the power which extends from the first alias sections (i,j): (0,1; 0,-1; 1,0; 1,0) into the central (0,0) section; be it that the spectral contents are different.

26.2.4 RECONSTRUCTION BY UNIFORM PSF; PREDISPLAY FILTERING

The actual display luminance distribution $L_d(x,y)$ is the convolution product of the prefiltered, sampled and processed image $L_p(k\Delta x_2,\ell\Delta y_2)$ and the reconstruction filter PSF: $F_r(x,y)$:

$$L_d(x,y) = \sum_n \sum_m L_p(k\Delta x_2,\ell\Delta y_2).F_r(x-k\Delta x_2,y-\ell\Delta y_2)$$

The spectral distribution $O\{L_p(k\Delta x_2,\ell\Delta y_2)\}$ is multiplied by the MTF of the reconstruction filter (Fig. 4). The PSF of this filter usually is symmetrical so that $\Phi_r(f_1,f_2) = 0$ and the MTF: $M_r(f_1,f_2)$ is real. Consequently the power transmitted by the reconstruction filter is given by the product of the PSD: $M_p^2(f_1,f_2)$ and the $(MTF)^2$: $M_r^2(f_1,f_2)$, of the processed image and the displayed image respectively:

$$M_d^2(f_1,f_2) = M_p^2(f_1,f_2).M_r^2(f_1,f_2)$$

Referring back to Fig. 4 one may observe that, especially for the square pixel display, the power contributions of $L_p(n\Delta x_1,m\Delta y_1)$ greater than 0.5 f_d must be removed by a predisplay filter. In the use of a CRT display this low-pass function is performed by the spot luminance distribution. There is one difference: the CRT spot performs an analogue weighting operation, the predisplay filter is purely digital so that its MTF also is folded about 0.5 f_x and 0.5 f_y. To be effective, its cut-off frequency must be farther removed from $\frac{1}{2}$ f_d than in the case of analogue (optical) filtering, causing more omission of high frequency information. This can be very severe when $k = m$, $\ell = n$ ($f_x = f_d$). A predisplay filter with sufficient attenuation at $\frac{1}{2}$ f_d, has a PSF which is wide compared to Δx_2: i.e. for $k = m$, $\ell = n$, at least 5 samples are combined in both the x and y directions (convolving a 5 x 5 matrix with $L_p(n\Delta x_1,m\Delta y_1)$). In Fig. 7.a the effect of a sampled Gaussian filter (in x direction only) is shown:

$$M(f_1)_{f_2} = \exp -18\frac{f_1^2}{f_x^2}$$

A predisplay and optical filter may be combined. For technological display realizations which support non-addressed pixels in-between the addressed pixels, with a linearly interpolated response of the luminance of their addressed immediate neighbours, $k = 2m$, $\ell = 2n$; the predisplay PSF base can be smaller in terms of $(\Delta x_1,\Delta y_1)$, e.g. $4\Delta x_1 = 8\Delta x_2$, requiring a 3 x 3 matrix. In Fig. 7.b the resulting spatial frequency characteristic is depicted for a linearly interpolating 3 x 3 predisplay filter:

$$M(f_1)_{f_2} = \left[\frac{\sin 2\pi\ f_1/fx}{2\pi\ f_1/fx}\right]^2$$

26.3 CHARACTERISTICS OF THE VISUAL CHANNEL

26.3.1 GENERAL

By proper design of the acquisition and processing of the image the combined effects of filter error and aliasing can be made acceptable. The presented image still contains high frequencies, some correlated with, others completely foreign to the image but associated with the display technology. Changing environmental conditions make the interface between display and cognition very variable. In the following we restrict ourselves to some aspects of image quality (Refs. 3, 12, 13) of the orthogonal grid, square pixel display, with some emphasis on perception of artificial images.

26.3.2 THE PERIODIC STRUCTURE OF THE DISPLAY

The orthogonal grid display is very well suited to coding schemes wherein the x and y directions are preferred orientations such as block diagrams, text and tables. For oblique angles a hexagonal grid has advantages; in the orthogonal grid the combination of aliasing and pixel form causes raggedness at edges. This effect tends to increase the increment threshold of small spots in grey-tone images. Also, the gradual desensitization for the apparent periodicity in the display surface may induce a masking effect of patterns with the same periodicity even though the spatial frequency content (MSD) is very different (Ref. 14). However, for systems with suitable anti-aliasing filters this problem cannot arise. According to some experiments reported in Ref. 15, the display's periodic structure will be masked by the average grey-tone image in areas where its modulation depth is smaller than 2%. The periodic components of the grid can be attenuated by using covers with optical filter characteristics; the simplest being a low pass filter such as ground glass with controlled blurring property.

26.3.3 THE CONTRAST SENSITIVITY OF THE VISUAL CHANNEL FOR PERIODIC COMPONENTS IN THE IMAGE

The contrast sensitivity (CS) is, among others, a function of spatial frequency and luminance. Displays are normally read under good contrast and illumination conditions (the experienced luminance controls the adaptation state of the eye), which are far above threshold: supra-threshold (ST) condition. As displays must also be observable under threshold (TH) conditions, the latter is a worst case contrast design guideline; but without automatic contrast and luminance control a light emitting display designed for worst case becomes unreadable at normal and high ambient lighting.

The threshold of contrast sensitivity is measured by presenting sinusoidal or bar gratings of different modulation depth ($MD = CS^{-1}$) and observing at what MD the grating is just noticeable. Supra-threshold is measured at higher contrasts in matching experiments, comparing perceived contrast of a sample with that of a reference. Also contrast estimation without a reference: free modulus magnitude estimation, gives surprisingly good results (Ref. 16). The curves so obtained with harmonic gratings are shown in Fig. 8; the curves for bar gratings have 25% higher CS at high frequencies, diverge at lower frequencies (Ref. 17). In this paper we are mainly concerned with high frequencies.

It has been shown that, for periodic image structures, the maximum retinal frequency perceived is about 60 cycles per degree (cpd). The contrast sensitivity at contrasts higher than threshold (ST), can be obtained by $C_{ST}(f) = 0.14\{C_A - C_{TH}(f)\}$ (Ref. 18) wherein C_{ST} is perceived contrast at supra threshold, C_{TH} is perceived contrast at threshold, and C_A is the actual, physically measurable contrast. The expression is validated between 1 and 12 cpd. The limit of 60 cpd causes the ST curves to fall progressively steeper with increasing luminance. Thus, at grid frequencies lower than 20 cpd, the third harmonics of the tesselated image become better visible at higher luminances. The reticulated display surface may also show very small magnitude second harmonics due to manufacturing imperfections (e.g. 2 seconds of arc); but at ST level the CS may be very high for this frequency. Consequently one is inclined to design pixel size such that in the viewing distance range of 33 to 70 cm (13" to 28"), the second and higher harmonics of the pixel form have frequencies higher than 60 cpd. The pixel diagonal then must be smaller than 0.2 mm (compare Fig. 4).

Under TH conditions (Fig. 8) the contrast sensitivity is much lower: higher contrasts are required to maintain just noticeable difference levels. Also the contrast sensitivity curve shifts to lower frequencies at lower luminances. It can be argued that for good legibility the contrast in the high frequency region should be controlled (Ref. 19): the blurring effect at low luminance is stronger for letters which have PSD's with the power mostly concentrated in the high frequency region (such as the letter E).

The above is in agreement with ergonomic experiments (Refs. 3, 20, 21) in which it has been determined that at normal ambient lighting and high contrast the performance score of letter identification increases with the number of scan lines per letter height (diminishing aliasing error), saturating at 16 to 20. With the pixel diagonal of 0.2 mm, the pixel frequency becomes 7 per mm so that 20 pixels high letters are 2.8 mm: close to the recommended size of noncritical markings and critical fixed legends, numerals on fixed scales etc. However, the cost in pixels per letter is much higher than with the now current Huddleston and Lincoln-Mitre fonts and a breakthrough in matrix display technology is required to attain this desired image quality.

26.3.4 VISUAL ACUITY; CONTROL CONTRAST

A skeletal display depicts lines and symbols. For the description of viewing thresholds of such images the concept of visual acuity VA (separability of local edges in minutes^{-1} of arc) is better suited than contrast sensitivity of harmonic gratings. Visual acuity is, just like CS, a function of contrast and luminance level.

For patches large compared to the VA, over a wide range of adaptation luminance level ($1\text{-}10^3$ cd m^{-2}), the perceived luminance (brightness) difference is proportional to contrast $\Delta L/L$. This relation is known as the law of Weber-Fechner. For low luminances, relatively higher contrast are required; also for extremely high levels.
However, the criterion for legibility is not constant brightness difference but constant satisfaction of visual acuity. Fig. 9 is a curve adapted from Refs. 22, 23. For a round target of size Δx_2 (e.g. a pixel) it shows the relation between the required threshold contrast $(L_f\text{-}L_b)/L_b$ and the background luminance level L_b.L_f is foreground luminance. Note that the relation is valid for the unaided average, healthy, young human eye and makes no allowance for surround and veiling luminance, visual fatigue, age and pathologies. The curve is adequately modelled by (in the range $1<\Delta x_2<5$)

$$(\Delta x_2)^2 \frac{L_f-L_b}{L_b} - 0.18 = L_b^{-0.67};$$

it was experimentally determined for 50% probability of seeing a patch of size Δx_2. To raise this probability to better than 99%, contrast must be 3 times higher; in Ref. 23 a total factor of 15 is recommended for comfortable viewing and short reaction time (Fig. 9).

$$\frac{L_f-L_b}{L_b} = (2.7+15.L_b^{-0.67}).(\Delta x_2)^{-2}$$

the factor 2.7 being dominant in the high background luminance range $10^4 - 1$ cd m^{-2}, the factor $15.L_b^{-0.67}$ in the low luminance range $1 - 10^{-5}$ cd m^{-2}; see Table I.

Table I

L_b[cd m^{-2}]	$(L_f-L_b)/L_b$	$2.7+15L^{-0.67}$	$L_f(\Delta x_2=1)$[cd m^{-2}]
$(10.000)^{-1}$	450	7200	0.7
$(1.000)^{-1}$	120	1500	1 5
$(100)^{-1}$	20	330	3.3
10^{-1}	3.2	73	7.4
1	0.9	18	19
10	0.42	5.9	70
100	0.22	3.4	440
1000	0.18	2.9	3.900
10.000	0.16	2.7	37.000

The expression describes the desired supra threshold contrast factor, and determines the modulation of the driving voltage u of the pixel. Assume a driving characteristic $L = C_1.u^\gamma$, then $\Delta L/L = \gamma.\Delta u/u$. Let the luminance of the driven pixel be $L_f = L_p+L_b$; so that $L_p = L_f-L_b$; of the non-addressed pixel L_b — the emitted light flux is zero, u_b a constant bias voltage. Thus $L_p = \Delta L$ and the relation becomes

$$\frac{\Delta L}{L} = \frac{L_p}{L_b} = \gamma\frac{\Delta u}{u} = (2.7+15L_b^{-0.67})(\Delta x_2)^{-2}$$

For a pixel size of 1 minute of arc, over the luminance range of office equipment (10-1000 cd m^2) the driving voltage Δu can be proportional to L_b provided the display $\gamma = 2.7$: Δu is obtained by hard-switching of $u_b = C_2.L_b$

The γ of many phosphors used in VDT-CRT's comes remarkably close: $\gamma = 2.2$. The VDT with background luminance corrected CRT driving voltage has a fairly good ST contrast factor (4 decades) as compared to the VDT with constant CRT driving voltage (1 decade) as shown for $\Delta x_2 = 1$ in Table II.

Table II

L_b [cd m^{-2}]	10^4	10^3	10^2	10^1	10^0
$\frac{L_f - L_b}{L_b}$ at threshold = a.	0.16	0.18	0.22	0.42	0.9
contrast factor:					
- ST controlled = $\frac{2.2}{a}$	14	12	10	5.2	2.4
- not controlled:	0.06	0.56	4.5	24	111

26.3.5 CONTRAST ENHANCEMENT

From Table I it follows that for constant legibility, dimming range of the display must be 40.000 to 1 for aircraft displays, 450 to 1 for office type VDT. At low to intermediate light levels the L_f-L_b does not decrease as much as L_b; the still high light output of the display may adversely affect the adaptation state of the eye. The use of an external contrast enhancing cover decreases the required foreground luminance for given legibility of the display. For the display light spectral distribution the cover has a transmission factor T_p, for the environmental light T_b. Thus the contrast increases by the factor T_p/T_b^2 which is a multiplier similar to the factor $(\Delta x)^{-2}$. However, such covers do not materially help to reduce the dimming range, unless the transmission factor of the cover can be controlled as function of the background luminance level (photochromic, electrochromic materials). But at very low light levels, where the display surface hardly reflects any light, a low transmission factor of the cover reduces L_p without contrast enhancement. Since visual acuity (or high frequency CS) deteriorates rapidly with low light level, wider lines and higher letters (zoom facility) seem to be the only real alternative to maintain legibility in the complete dark without (partially) blinding the pilot. This is also in agreement with existing specifications for size of marks and numerals on aircraft instruments to be read under low luminance conditions: the 0.3 inch wide marking is 3.7 minutes of arc or 3 to 4 pixels wide.

In the cover with controlled transmission, the transmission factor should again become low at the high end of the L_b range to reduce the background luminance so as to enable the designer to cut the power requirement of the CRT (lower L_p) to advantage.

26.4 CONCLUSION

In 26.2.4 it was shown that the aliasing error can be kept sufficiently small (for statistically defineable images such LLTV, FLIR, SLAR) when the Nyquist frequency of the display is about two to three times higher than the image cut-off frequency (Fig. 7). If one may assume that the contrast control law as obtained for dots (26.3.4) is also valid for images as a whole, then, under normal ambient conditions, the visual cut-off frequency can be matched to the display cut-off frequency.

In 26.3.3 the pixel diagonal was determined to be 0.2 mm so that the display frequency is 7 pixels mm^{-1} (pmm). At 70 cm viewing distance this equals 0.2 mrad or 88 cpd which is well above the max. retinal frequency of 60 cpd: but at 33 cm: 48 cpd, still sufficient to suppress the second harmonic. The upper limit of spatial frequencies of interest in the displayed image is the Nyquist frequency: 3.5 pmm. Using the Gaussian characteristic (26.2 4) as a model for the image magnitude spectral density, then its - 3dB point must be located at 0.28 f_N = 1 cycle per mm or 12 cpd. Remains to be determined the ratio between the cut-off frequencies of the acquired and the displayed image; this ratio, of course, depends highly upon the application of the imaging system

From the economic point of view it may seem wasteful to design a display with pixel frequency of 7 ppm when the cut-off frequency of the displayed image is 7 times lower; or when the minimum line width in a skeletal display is two to three pixels wide (1.4 to 2 minutes of arc) under normal ambient conditions and possibly even 10 pixels wide at very low or extremely high light levels. Of course, one may put up with more aliasing, with the consequence of a higher probability that a small object is not properly and/or timely seen and identified. The limits calculated in this paper define an ergonomically justified display with good legibility over the whole ambient light range encountered in the cockpit.

1. Pearson, D.E. Transmission and Display of Pictorial Information. Pentech Press, London, 1975.
2. Hunt, G.H. Airborne Electronic Displays, IEE Proc , vol 128, Pt.A., no 4, May 1981.
3. Clarke, A.A. Opto Electronic Systems: Perceptual Limitations and Display Enhancement. AGARD Lecture Series 76 on Electro Optical Systems, 1975.
4. Tannas, L.E. Flat Panel Displays, Van Nostrand Reinhold Company, New York, 1981.
5. Hollister, W.M. (ed.) Advancement on Visualization Techniques, AGARDograph no 255, 1980.
6. Bosman, D. (ed.) *Modern Display Technologies and Applications.* Report of AGARD AvP-WG11, to be published 1982.
7. Andrews, H.C. Pratt, W.K. Caspari, K. Computer Techniques in Image Processing. Academic Press, New York and London, 1970.
8. Kell, R.D. Bedford, A.V. Trainer, M.A. An Experimental Television System, Proc. IRE, 22, pp 1246-1265, 1934.
9. Craggs, Mitchell, Raster scan Overlay Generation Techniques for High Quality Displays. In preparation. Marconi Aviation Ltd.
10. Negroponte, N. Soft Fonts. SID intern., San Diego, Ca., USA 1980.
11. Snyder, H.L. Human Visual Performance and Flat Panel Display Image *Quality. Human Factors Laboratory, Virginia Polytechnic* Institute and State University, Blacksburg, VA. Available NTIS, AD-A 092685.
12. Laycock, J. Chorley, R.A. The Electro Optical Display/Visual System Interface. Human Factors Considerations. In: AGARDograph 255, Advancement on Visualization Techniques. Ed.: W.M. Hollister, 1980.
13. Bosman, D. The Human Visual System. In: AGARD Lecture Series 119. Image Processing Techniques. Ed.: L.A. Gerhardt, 1982.
14. Henning, G.B. Hertz, B.G. Broadbent, D.E. Some Experiments Bearing on the Hypothesis that the Visual System Analyzes Spatial Patterns in Independent Bands of Spatial Frequency. Vision Res., 15, pp 887-897. 1975.
15. Carlson, C.R. Masking of Periodic Luminance Flaws by Pictorial Information. SID Digest 1980, pp 182-183.
16. Stevens, J.C. Stevens, S.S. Brightness function: effects of adaptation. J. Opt. Soc. Am., 53, pp 375-385, 1963.
17. Campbell, F.W. Robson, J.G. Application of Fourier Analysis to the Visibility of Gratings. J. Physiol., 197, pp 551-566, 1968.
18. Cannon Jr., M.W. Contrast Sensation: a Linear Function of Stimulus Contrast. Vision Research, 19, pp 1045-1052, 1979.

19. Ginsburg, A.P. Visual Information Processing Based on Spatial Filters Constrained by Biological Data Aerospace Medical Research Laboratory Report AMRL-TR-76-129, vol I & II. Wright Patterson Air Force Base, Ohio, USA, 1978.

20. Buckler, A.T. A Review of the Literature on the Legibility of Alpha Numerics on Electronic Displays. Techn. Memorandum 16-77, U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, Md., USA 1977.

21. Shurtleff, D.A. Legibility Research. Proc. SID, 15, no 2, pp 41-52, 1974.

22. Blackwell, H.R. Contrast Thresholds of the Human Eye. J. Opt. Soc. Am., 36, no 11, pp 624-643, 1946.

23. Carel, W.L. Pictorial Displays for Flight. Prepared for JANAIR; ONR 4468(00). Hughes Aircraft Company, CA., USA 1965.

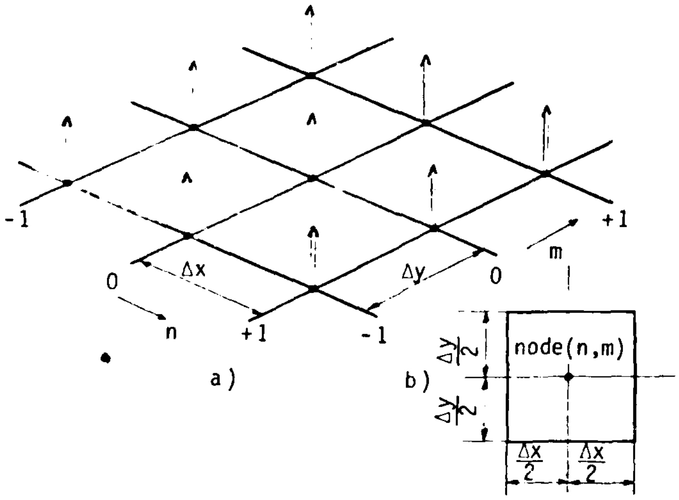


Fig. 1 Sampling matrix D(x,y).

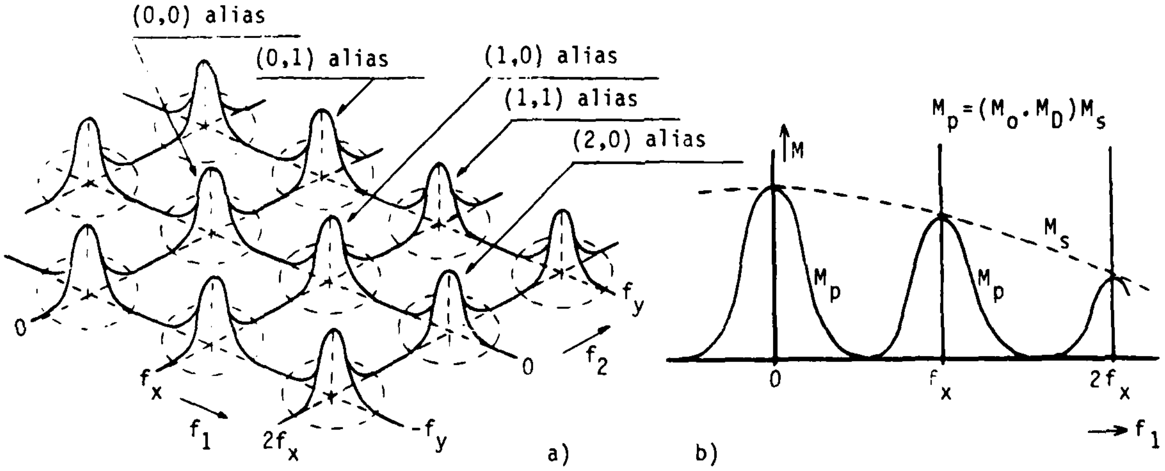


Fig. 2 a) Fourier transform of the sampled image;
b) Cross section, $f_2 = 0$; effect of practical sample pulse on alias amplitudes.

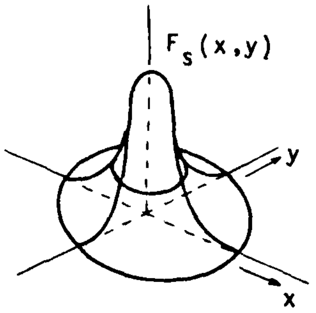


Fig. 3 Point Spread Function of actual sampler.

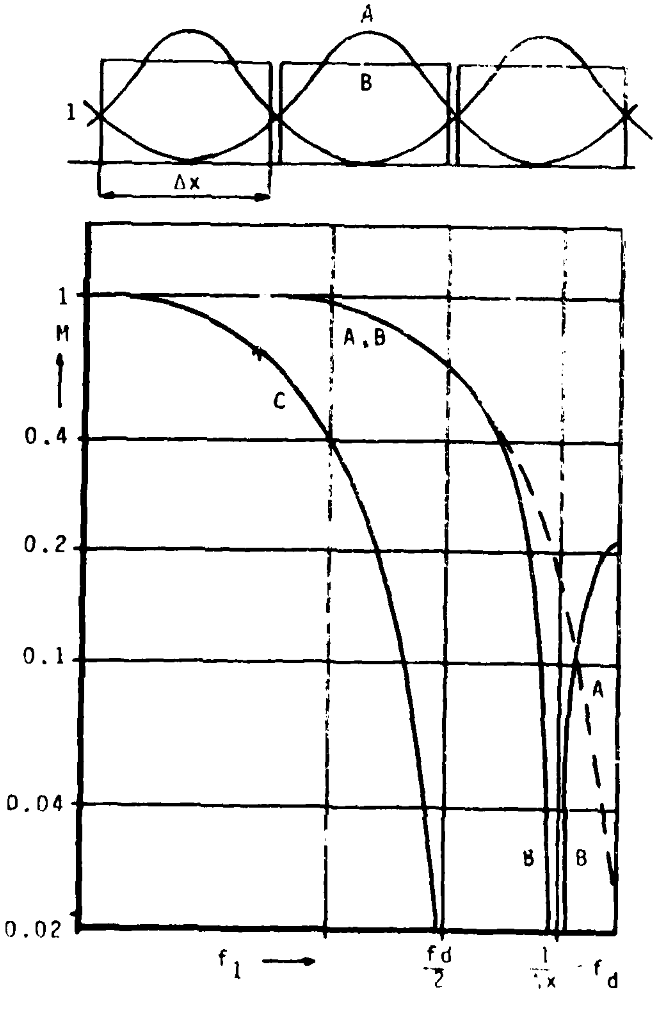


Fig. 4 a) PSF'f of CRT and matrix display;
b) MTF's to the PSF's of 4.a.

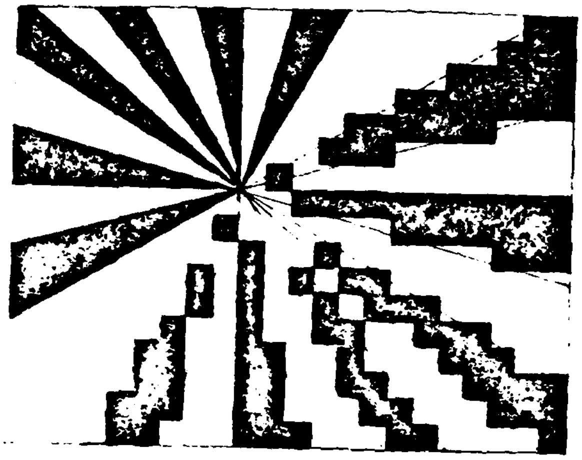


Fig. 5 Square pixel display compared to analogue display of radial sectors.

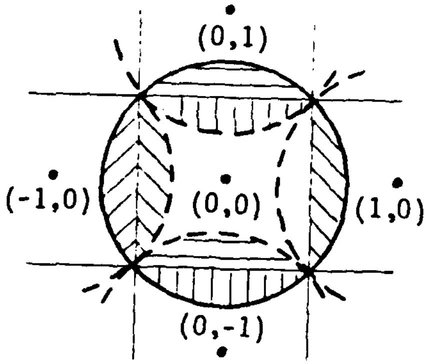


Fig. 6 Reciprocity of overlapping power.

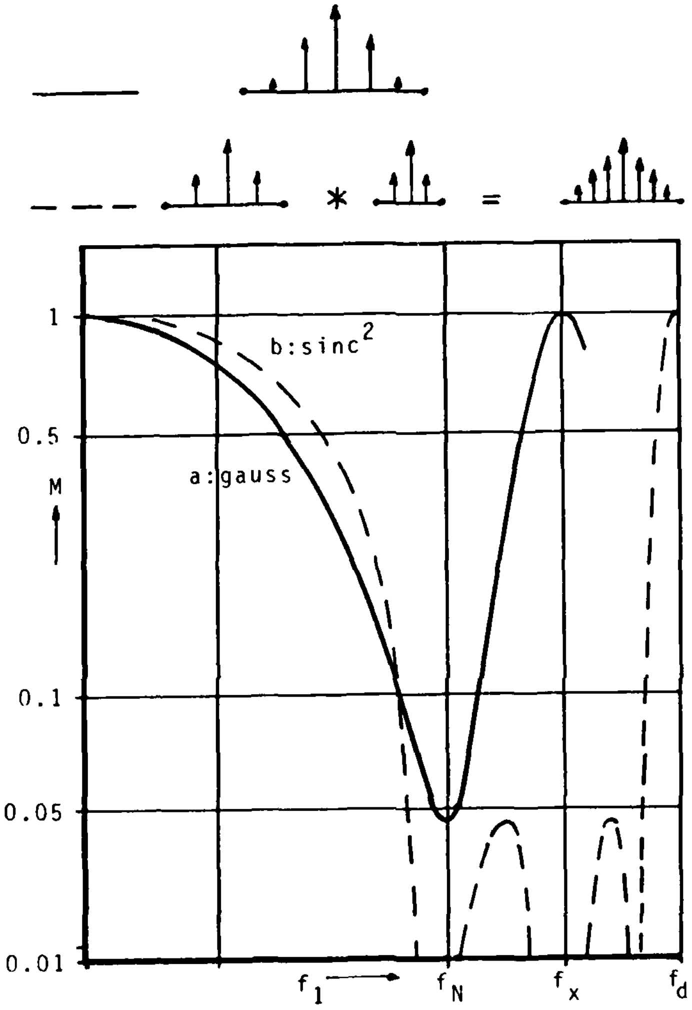


Fig. 7 Two types of display filters.
a) gauss, base $6\Delta x_1$. predisplay filter;
b) sinc^2, base $4\Delta x_1$, predisplay and optical filter combined.

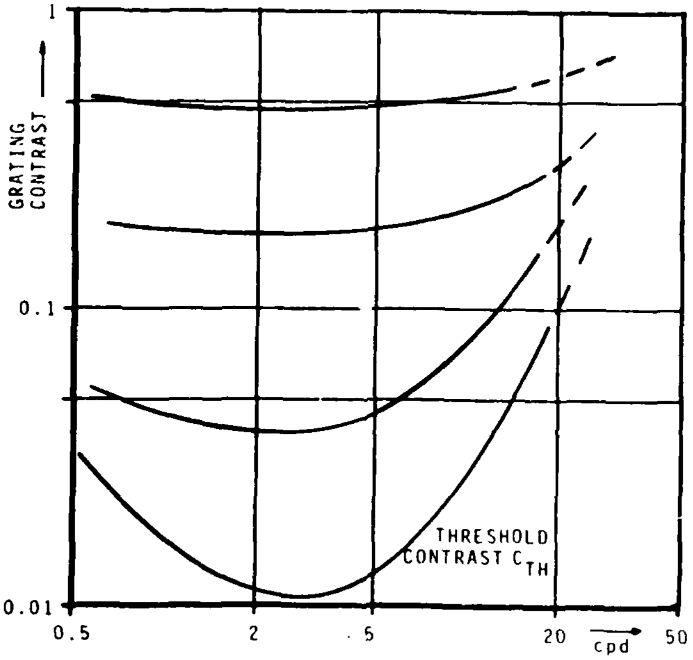


Fig. 8 Contours of constant contrast sensation (after Ref. 18).

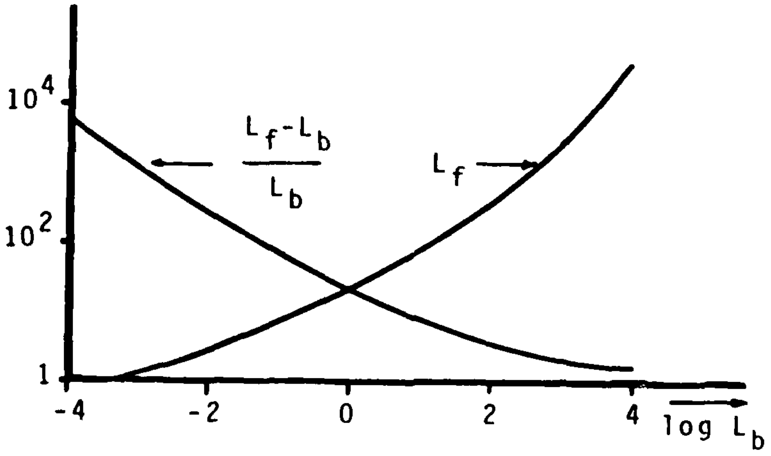


Fig. 9 Required absolute pixel contrast and foreground luminance for VA=1, as function of background luminance (after Ref. 22).

ARCHITECTURE FOR HIGH INTEGRITY DISPLAY SYSTEMS IN FUTURE COMBAT AIRCRAFT

J. A. Grice
EASAMS Limited
Lyon Way, Frimley Road,
Frimley, Camberley,
Surrey, England

SUMMARY

Present indications are that the next generation of combat aircraft will require both Air Defence and Ground Attack capabilities leading to a complex Avionic system. Three different System Architectures have been considered for this complex system with a trend towards a hierarchical system. A Mil-Std-1553B Data Bus has been assumed as the interface standard for the Avionics Bus. Problems of Bus traffic loading, reversionary capability and software location have been investigated.

Particular attention has been paid to the Displays subsystem and the architecture of processors, Waveform Generators and display surfaces. Display requirements in terms of number and type of display surfaces and the different display formats are suggested.

Some of the implications of giving the pilot flexibility to allocate display formats to different displays are increases in Bus traffic, bus control logic and software. The reliability of the different displays configurations is discussed.

1. ASSUMPTIONS

This paper considers Advanced Avionics Systems for a future Combat Aircraft.

Present indications are that the next generation of Combat Aircraft for European operations must have both Air Combat and Ground Attack capabilities. If Survival in the European conflict environment is also considered this leads to a complex Avionic system. So a complex advanced Avionic system has been assumed with accurate reliable Navigation, sophisticated Weapon Aiming and Target detection (A/A and A/G), low altitude flying and a complete futuristic threat assessment subsystem.

The aircraft will be a single seat fighter.

The interface standard has been assumed to be a Mil-Std-1553B Dual Multiplex Data Bus for the Main Avionics Bus.

The layout of the main cockpit displays is shown in Fig. 1 and includes Helmet Mounted Display System (HMDS), Head Up Display (HUD), Combined Radar Map and Electronic Display (CRMED) and 4 Multi Function Displays (MFDS). This is the most complex displays configuration considered and some simple options with only 2 or 3 MFDS and without the HMDS are discussed later.

Particular assumptions relating to subsystems and equipments are defined in Section 2. These represent the system solutions investigated and are not neccesarily the only solutions.

2. SYSTEM ARCHITECTURE

Initial work concentrated on the overall systems architecture and various architectures were investigated some federated and some more centralised.

In order to describe the different architectures and their associated problems and advantages, a brief description of the subsystems and major equipments included in the system is necessary.

The navigation subsystem includes a navigation (or mission) processor, 2 INs, Radar Altimeter, Tacan and Microwave Landing Aid.

The Weapon Aiming subsystem includes a Weapon Aiming (or mission) processor, Radar, Electro-Optical Sensors and Visual Augmentation system.

The Threat Assessment or Defensive Aids subsystem includes Radar Warning, IR Warning, Active ECM and IFF

A JTIDS has also been included.

The displays subsystem has already been defined to include seven Electronic Displays (HMDS, HUD, CRMED and 4 MFDs) but also includes Multi Function Keyboards and Numerous mode control switches which all interface via 2 interface units (one for each side of the cockpit)

The Flight Control system is largely self contained and includes Air Data and Rate gyro sensors.

The Armament subsystem controls all weapons and will probably have its own data bus.

The General A/C subsystem includes Electrics, Hydraulics, Environmental, Fuel and Engine Data management.

The Communications subsystem has a processor and the usual equipments.

There will be a Bus Monitoring or Recording system. There will also be a device for loading Mission Data into the various subsystems at the start of the mission.

All these major subsystems have at least one duplex interface with the Main Avionics Bus, and depending on the Systems Architecture may have more. In some Architectures individual equipment have their own separate interface e. g. IN)

2.1 Centralised System

The centralised element of this system is the two Mission Computers which perform all the mission orientated software calculations including Navigation and Weapon Aiming. Even with this system some processing is distributed into other subsystems and equipments (e. g. FCS, Armament and General A/C subsystems).

This system was configured so that the following subsystems and equipments have one interface with the Main Avionics bus (see Fig. 2). One interface means the ability of that equipment to transmit and receive on both of the 1553B Dual Data Buses. The Flight Control System; the General A/C System; the Armament System; 2 INs; a Navigation Terminal for Tacan, Rad. Alt. and Microwave Landing System (MLS); Communications Processor; Threat Assessment Processor; Radar; Electro-Optical Sensor Package; Visual Augmentation System; HMDS; CRMED; 3 Waveform Generators driving the 4 Multi-Function Displays and the HUD; a Mission Data Input equipment; a Bus Monitoring equipment; the 2 Mission Computers; Left and Right IFUs for interfacing cockpit controls and MFKS. This means that in this Architectural configuration there are 23 systems connected to the Main Avionics Bus. This leads to certain problems notably Bus Traffic loading (see Para. 3 and Table 2) if the 1 mega bit maximum limit of Mil-Std-1553B is assumed.

2.2. Semi Federated System

The Semi-Federeated systems architecture is shown in Fig. 3

In order to reduce the complexity level and therefore the bus traffic a more federated system was considered. This is done by grouping equipments and sensors into subsystems by functional partitioning so that they are as self contained as possible and only have one direct interface with the Main Avionics Bus. This reduces the complexity of the Main Avionics Bus and the Bus Traffic loading but some problems have been passed into the subsystem making some of the subsystems more complex. Some subsystems as a result may have to have their own data bus.

The major new features are: the creation of a Navigation subsystem with the 2 INs, Rad. Alt., Tacan and MLS connected to the bus only via the Nav. processor

A Weapon Aiming subsystem so that the Radar, E-O sensors and VAS only interface via the Weapon Aiming processor.

The Threat subsystem has been expanded to include JTIDS

CRMED is now driven by the WFGs instead of its own WFG.

The HMDS interface is via the Left IFU.

This has reduced the systems connected to the Avionics bus to 14; 7 subsystems, 5 for Displays and Controls, a Bus Monitor (BMON) and Mission Data Input (MDI). This reduces the bus traffic loading (see Table 2) mainly because some of the complex interfaces (e. g. Radar, E-O-Sensors, JTIDS, IN) are kept off the Avionics Bus and only processed paramenters required by other subsystems need to be transmitted.

2.3 Fully Federated

The philosophy of creating large subsystems is extended even further with this system (see Fig. 4) A displays subsystem has been formed by putting all the displays and controls interfaces into a displays processor which has the only direct connection to the Avionics bus.

The communications subsystem has been combined with the Navigation subsystem.

The effect of this is to reduce the number of processors/terminals on the Main Avionics Bus down to nine with the consequent further reduction in Bus Traffic loading (see Para. 3.3 and- Table 2). The system now consists of seven major subsystems plus the Bus Monitor and Mission Data Input system; and BMON and MDI contribute virtually nothing to the Bus Traffic loading in flight.

These major subsystem processors are nodes between the subsystem and the Avionics Bus and are shown as Duplex in most cases to solve this integrity problem. Integrity and Reliability are discussed in Para. 5.

2.4 Displays Subsystem Architecture

The Displays and Controls subsystem will now be discussed in more detail.

The systems design has accepted the trend towards more electronic displays by including 4 Multi-Function Displays and only small stand-by instruments.

It may be that the real systems that are developed will only have 2 or 3 MFDS and also may not have the HMDS. However the investigation here only considers the complex system with 7 displays.

A simple solution to the system architecture is shown in Fig. 5A giving each display its own WFG. If 2 or 3 displays were removed the configuration would be very similar to certain existing systems. This has certain obvious disadvantages; 9 terminals on the Avionics Bus for the Displays and Controls subsystem alone, too many WFGs, a WFG failure means that display also fails. This particular display system architecture was not considered any further.

The next solution is Fig. 5B and this shows the Displays and Controls subsystem as configured in the Centralised System Architecture. The number of WFGs has been reduced and the number of terminals on the Avionics Bus has been reduced to 7. WFGs 1, 2 and 3 have to drive 4 MFDs and the HUD but this does give a reversionary capability if one WFG fails.

Fig. 5C indicates the Displays and Controls configuration in the Semi-Federated Architecture. The HMDS interface is now via the LIFU and the CRMED has been added to those displays driven by WFGs 1, 2 and 3. This reduces the interfaces on the Main Avionics Bus to 5 for Displays and controls. WFGs 1, 2 and 3 now have to drive 6 Displays which means 2 each and 3 each if one WFG fails. This could be organised as in the following table so that with one WFG failure there is no degradation as far as the displays are concerned

WFG1	WFG2	WFG3
HUD	CRMED	MFD2
MFD1	MFD3	MFD4
CRMED Reversion	HUD Reversion	MFD3 Reversion
MFD2 Reversion	MFD4 Reversion	MFD1 Reversion

Table 1 WFG Interface

The reversionary case assumes that one WFG can drive 3 Displays and this may mean that WFGs will have to be produced which have greater capacity and operate faster. This logic assumes one reversion only; if there are two failures then some facilities are lost

Fig. 5D shows the Displays and Controls configuration for the fully federated system architecture. This has given the Displays and Controls subsystem the same hierarchical structure as other sub-systems by introducing the Duplex Displays processors as the only interface with the Main Avionics Bus. Duplex processors are necessary otherwise the whole of the Displays and Controls subsystem could stop with only the one failure of a simplex Display processor. The Displays and Controls interface with the Displays processor using a separate Displays Data Bus has a similar configuration to Fig. 5C

3. BUS TRAFFIC LOADING

As a result of preliminary investigations and because of the complexity of the system the centralised system was found to have a bus overload. Thus Bus Traffic Loading becomes an important system parameter when judging the suitability of the different system architectures for this particular system.

In order to calculate Bus Traffic the data messages between all equipments using the Main Avionics Bus have to be defined in terms of the number of parmeters and their update rate. This in turn means allocating software functions to particular processors, defining reversionary philosophy and defining the use of the displays. The following table gives the display formats considered for CRMED and the 4 MFDs. Initially only a primary display surface and one reversion was considered, the possibilities and implications for more flexibility than this are discussed in Para. 4.

MFD 1 FORMATS	CRMED	MFD 4 FORMATS
1. E-O Picture 2. Weapon package data 3. VAS 4. A/A Weapon Status 5. Rev. attitude recovery 6. Rev. status 7. Rev. comms.	Map Radar Map Radar (El + Az) Threats (Electronic Mkrs + Data superimposed)	1. Attitude recovery (Attitude, Speed,) (V_vAlt, Hdg. A of A) 2. Rev. VAS
MFD 2 FORMATS	**MFD 3 FORMATS**	
1. System status (inc. fuel + eng) 2. Comms. 3. Rev. E-O 4. Rev. Plan 5. Rev. NAV 6. Rev. weapon data	1. NAV + HSI 2. Plan	

Table 2 Display Formats

Familiarity with Mil-Std-1553B protocol is assumed in most cases a rigid interface structure has been assumed with the same Bus Control logic all the time, however change of Bus Control logic to react to failures and Display Format changes has been investigated. The use of Broadcast mode and Dynamic Bus Control have been exlcluded.

As a way of presenting the interface data an N^2 chart type of diagram was drawn for every case. An example for the Fully Federated system is shown in Fig. 6. The N^2 chart is a method of representing Command, Control and Communications (C^3) systems and is described in Ref. 1. The numbers in the boxes have been evaluated by determining what parameters each subsystem needs, defining display formats and using available experience and knowledge of current A/C systems (e. g. Ref. 2). Obviously these numbers are not exact but were considered accurate enough to illustrate the effect of the different system Architectures and Reversionary philosophies.

The current standard of Mil-Std-1553B was assumed and not some futuristic improvement. This means maximum capacity of 1 M bit per second is 100% loading. Terminal response delays and inter-message gaps were not included.

The bus loading for the different systems is shown in Table 3 as a percentage of the maximum (1 M bit/sec). The bus loading is also quoted for the Displays and Controls interface as well as the overall system to indicate the high proportion of data on the bus for this subsystem alone.

3.1 Centralised

In Version 1 of this system it has been assumed that all reversionary interface is sent all the time in a rigid interface structure which results in an inflexible but simpler Bus Control Logic. This means that all Navigation and Weapon Aiming interface is sent to both the central mission computers since one is the reversion for the other.

This version gives a very high bus loading and is included mainly as an illustration of the effect of this particular interface structure. It is obviously inefficient to send Reversionary interface continuously when no failure exists.

Version 2 assumes that both Navigation and Weapon Aiming Mission Computers are functioning correctly and software tasks are not duplicated. The bus control logic is assumed to be flexible and change the interface if the Navigation or Weapon Aiming processor fails. All other reversionary interface (e. g. 2 INs and reversionary display surfaces) is still being sent in this version.

In Version 3 all reversionary interface has been removed. The bus control logic must be even more flexible and obtain interface from the redundant equipment if the primary equipment fails. For example the Bus Loading calculation assumes IN2 has no interface and reversionary display functions are not driven.

3.2 Semi Federated System

In Version A reversionary interface is not provided to the reversionary bus controller. If the bus controller (the Navigation processor) fails the reversionary bus controller must initiate new bus control logic to change the interface as appropriate. Reversionary interface is included for sensors and displays (e. g. Display formats are sent to at least 2 WFGs to allow for WFG failure).

Version B is the same as Version A except that data is no longer sent to a reversionary WFG. The Bus controller will have to react to WFG failure and change the interface to the reversionary WFG. However data for each display format on the MFDs is still being sent to both the primary display and one reversionary display.

In Version C the Bus loading has been calculated assuming that each format is only displayed on its primary display surface; otherwise Version C is the same as Version B. This means that either the pilot loses flexibility and can only select each display format on its primary display surface or the bus control logic has to change interfaces when the pilot requests a format on an MFD other than the primary MFD. This is making the Bus Control logic very complex which is undesirable because the Bus Control logic has to be proved correct with a high level of confidence to ensure correct interfacing all the time. Apart from this version of the Semi-Federated system the interface logic does not change with changes in system moding unless there is a failure.

3.3. Fully Federated System

The bus traffic loading for this system was calculated with the same assumptions as Version A of the Semi Federated System i. e. Reversionary interface provided except for Bus Controller failure.

However since equipment reversions and display format reversions are now all organised within their respective subsystems the bus traffic loading on the Avionics Bus does not change for equipment failures or to provide more display format flexibility. With this hierarchical type of system architecture additional reversionary interface will only increase Bus traffic on the subsystem bus (if there is one).

3.4 Displays and Controls Bus Loading

The colums in Table 3 for Displays and Controls Bus Loading gives the Bus Loading of the Displays and Controls subsystem interface as a percentage of 1 M bit/sec. This was included to demonstrate the large amount of data on the Avionics Bus needed to drive the displays. This is particularly noticable in the semi-federated system where the Displays Bus loading represents 53% to 66% of the total Bus loading. Even in the Fully Federated system it is nearly 50%

Current system philosophies indicate that all this display data is necessary and that the pilot should at least have access to all system status and mission data; not necessarily all continuously displayed but selectable.

What should be remembered is that this creates a large amount of Bus traffic and requires additional software.

	System Assumptions	Disp. & Cont. (%)	Overall System (%)	Disp. as a % of Total
Centralised System	Version 1 Full Reversionary Interface	82	191	43
	Version 2 Reversionary Interface except for Bus Controller Failure	55	128	43
	Version 3 No Reversionary Interface	30	95	32
Semi-Federated System	Version A Reversionary Interface except for Bus Controller Failure	49	74	66
	Version B No Reversionary Interface for equipment Failure but with Display Format Reversion	33	57	58
	Version C No Reversionary Interface for Equipment Failure or Display Formats	28	53	53
Fully Federated System	Reversionary Interface except for Bus Controller Failure	21	44	47
	No Reversionary Interface for Equipment Failure or Display Formats	21	44	47

Table 3 Bus Traffic Loading

3.5 Summary of Bus Traffic Loading

Table 3 demonstrates that most of the systems have a Bus Traffic loading problem.

These Bus Traffic loading figures do not include reponse time delays, inter message gaps or the time needed by the Bus Controller to perform housekeeping tasks such as internal bite and rechecking terminals failing to respond. Also, if expansion and future development are to be allowed for, the recommeded maximum bus loading at first design freeze should be kept down to between 40 and 50%.

Only the federated system with its 44% Bus Loading meets this design requirement.

It is the Bus Traffic loading problem which is dictating in this particular case that a more hierarchical type of system architecture is necessary.

If the system was slightly less complex or the capacity of the Bus was increased, Bus Traffic loading would not be such an important criteria in determing system architecture.

4. GREATER FLEXIBILITY OF DISPLAY FORMATS

The assumption in the bus loading calculations for the Semi-Federated system that Display formats only have a primary display surface and one reversion may be unnecessarily restrictive. This is a brief description of some of the implications of giving the pilot complete flexibility of choice as to where he puts each format.

If the HUD and HMDS are excluded since they are superimposed against the outside world and have specialised formats there are 5 Electronic Displays remaining. In the Bus loading assumptions there was no reversion for CRMED formats if CRMED failed. However apart from the MAP there is no overriding reason why the other formats should not be displayed on an MFD. For flexibility with a MAP display it would have to be digitised (rather than film as at present) but this is already happening in other systems and only presumes powerful enough digital processing to be available.

The likely display formats for the two major types of mission are therefore:

Air to Ground Mission	Air to Air Mission
1. E-O Sensor Video	1. Radar El + Az
2. GM Radar Video	2. VAS Video (Visident)
3. MAP	3. A/A Weapon Status
4. Threat Display	4. Threat Display
5. Weapon Package Data	5. Attitude Recovery
6. Attitude Recovery	6. System Status
7. System Status	7. Comms Frequencies
8. Comms Frequencies	8. Navigation + HSI
9. Navigation & HSI	9. PLAN
10. PLAN	

Table 4 A/G and A/A Display Formats

These 9 or 10 formats are not an exhaustive list there are other formats which could be added (e. g. The system status format will have a sub-format for each subsystem).

But even this minimum list of formats presents considerable complication if any format is displayed on any of the 5 Head Down Displays. For A/G mission this is more than 30 thousand permutations and for the A/A mission more than 15 thousand. This represents a considerable volume and complexity of software and an even greater effort to test and prove it.

If the system assumptions are similar to Version A of the Semi Federated system the Display Format data will have to be sent to all WFGs instead of only 2 (Primary and one reversionary). This leads to an increase in Bus Traffic loading of 11% of 1 M bit/sec. The general effect of reversionary interface being continuously sent in the Semi Federated system is illustrated in Table 5.

	Version C No Reversion	Version A 1 Reversion	Full Flexibility 2 Reversions
Displays + Controls (%)	28	49	60
Overall System (%)	53	74	85

Table 5 Semi Federated System Bus Loading

The alternative to increasing the Bus Traffic is to have the flexibility in the Bus Control logic as explained previously but for full flexibility this would be very complex.

In the Fully Federated system the Main Avionics Bus traffic is not effected because all necessary data is sent to the displays processor. The additional complexity necessary for flexibility of display formats appears as additional software logic in the displays processor and increased interface on the displays subsystem bus.

5. DISPLAY INTEGRITY AND RELIABILITY

The integrity and reliability of the different display configurations is only briefly investigated here.

5.1 Equipment Reliability

The major equipments involved are processors, Waveform Generators (WFGs), and Electronic Displays. The reliability of these equipments in terms of MTBF currently achieved and likely future values is indicated in this table.

Equipment	Current (MTBF hrs)	Future (MTBF hrs)
Processors	1,000 to 2,000	20,000
WFGs	500 to 1,000	10,000 to 20,000
Displays (CRTs)	250 to 500	500 to 1,000

Table 6 Equipment Reliability

Processors and WFGs are largely similar being basically computers. The future high reliability of processors is based on the Very High Speed Integrated Circuit (VHSIC) technology being developed in the US in which the reliability requirement is 10 to 100 times current values (Ref. 3). However this does not apply to the display surfaces which involve CRTs and are not likely to improve much.

5.2 Display Subsystem Reliability

The reliability of the simplex type of system in Fig. 5A with one WFG per display is limited by the display reliability. The MTBF could be as low as 300 hrs and unlikely to exceed 1000 hrs. Failure of either WFG or display prevents any function being displayed. The only reversion is to display that function where possible on another display surface via another WFG. This also applies to HMDS and CRMED in the Centralised Architecture (see Fig. 5B)

The Duplex displays structure in the Semi-Federated system is obviously much more reliable with its built in redundancy. The assumptions of one reversionary WFG for each display and a reversionary display surface for each display format (excluding HUD and HMDS formats) mean that either 2 WFGs or 2 display surfaces have to fail to prevent a particular format being displayed. This Displays system Architecture gives an MTBF of between 50,000 and 250,000 hrs. Even with VHSIC technology applied to the WFGs it cannot be increased with only 2 displays and the reliability of CRTs.

In the fully federated system the architecture of the displays and WFGs is similar but the Displays Processor has been added between WFGs and Avionics Bus. If this was a current processor with MTBF of 1000 hrs and only one processor is used (no redundancy) the reliability of the Displays formats being displayed comes down to an MTBF of just under 1000 hrs. If there are 2 Displays processors (Duplex) both with an MTBF of 1000 hrs the reliability of displaying the display formats goes up to more than 160,000 hrs. If a simplex VHSIC processor with MTBF of 20,000 hrs is used the reliability is greater than 18,000 hrs and Duplex VHSIC processors gives better than 200,000 hrs

5.3 Functional Redundancy

It is necessary to determine what this means for particular functions.

HUD formats are particular to the HUD and although the HMDS (if fitted) might be a good reversion for most HUD functions less data can be displayed at any one time. Even current HUDS now have fixed combiners and so with no mechanical moving parts may become more reliable.

CRMED currently still uses film for the MAP and so has moving mechanical map projection. If the MAP was digitised, as previously suggested, it would remove the need for this display to have moving parts (and it could therefore be more reliable) as well as giving increased flexibility to where the MAP is displayed.

High Reliability for MFD functions is obtained effectively by having more than one display surface i.e. redundancy. The number of CRT failures can be reduced by regular replacement as part of scheduled maintenance.

5.4 Operational Requirement

The question arises as to how reliable should the system be? Major A/C components are lifed at 3,000 to 6,000 hours and this represents the maximum number of flying hours.

If the fully federated system is considered with only a simplex but future highly reliable Display processor (20,000 hrs) the display format reliability of 18,000 hours would seem to be sufficient. This would allow displays and processors to operate for 3 hours for every flying hour of the A/C and there is only going to be an average one failure in the whole life of the A/C up to 6000 flying hours. Or two failures if the amount of Ground Testing means Display + Processors are operated 6 hrs for every flying hour. The amount of ground testing is likely to be less if the equipment is more reliable in any case.

If processors become as reliable as VHSIC technology suggests is there a need to have duplex processors in a displays subsystem architecture of this type? If any Display functions are safety critical to the A/C then failure rates of less than 10^{-7} or 10^{-8} should be considered. Another possible reason for having Duplex processors would be battle damage although future processors are going to be quite small.

If a highly reliable displays subsystem is necessary then the fully federated system with Duplex VHSIC processor and full flexibility of Display formats will give an MTBF of better than 10^{5} hrs. Any more redundancy or integrity than this in a Displays subsystem would seem to be superfluous.

With reliabilities of this order it is likely that other problems will require more attention. There will be a higher probability of software errors in the large and complex amount of software required.

How good is the internal self-check in determining when a processor has failed and so organising a smooth handover to the reversionary processor. The rules for this handover need to be thoroughly established otherwise the theoretical reliability of a Duplex processor system would never be achieved.

6. CONCLUSIONS

With the complex system that was investigated Bus traffic loading on the Avionics Data Bus was a particular problem. This would not be such a problem if the system was simpler or the capacity of the Mil-Std-1553B data bus was greater.

The Bus traffic loading problem forces the Architecture design towards the hierarchical structure of the fully federated system described here. More complex reactive bus controller logic can also be used to reduce the bus traffic.

The data necessary to drive and control all the display formats is a large proportion of the total data flowing on the data bus; too large a proportion for some configurations. The question as to whether all this data and electronic displays are necessary for a single crew aircraft has not been answered.

With advanced technology a systems architecture has been suggested which could give great flexibility and high integrity for display functions if the penalties of Duplex displays processors, more complex software logic and the large number of displays are accepted.

REFERENCES

1. TMSA and TTS State of the Art Seminars on Command Control and Communication (C^3) Oct. 8/9 1979 - part 13 The N^2 Chart

2. 2nd AFSC Multiplex Data Bus Conference 10-12 Oct. 1978 - at Dayton, Ohio

3. AGARD Short Course "Applications of Microprocessors to Guidance and Control Systems" 5/6 Oct. 1981 London

GLOSSARY

A/A	Air to Air
A/G	Air to Ground
Az	Azimuth
BMON	Bus Monitor
C^3	Command, Control and Communication
CRMED	Combined Radar Map and Electronic Display
CRT	Cathcode Ray Tube
El	Elevation
ECM	Electronic Counter Measures or Defensive Aids Subsystem
E-O	Electro Optics
FCS	Flight Control System
HMDS	Helmet Mounted Display System
HSI	Horizontal Situation Indicator
HUD	Head Up Display
IFF	Identification Freind or Foe
IFU	Interface Unit
IN	Inertial Navigation
IR	Infra Red
JTIDS	Joint Tactical Information Distribution System
LIFU	Left Interface Unit
MFD	Multi Function Display
MFK	Multi Function Keyboard
MDI	Mission Data Input
MLS	Microwave Landing System
MTBF	Meantime Between Failures
NART	Navigation Remote Terminal
NAV	Navigation Processor
Rev.	Reversionary
RIFU	Right Interface Unit
SMS	Stores Management System
VAS	Visual Augmentation System
VHSIC	Very High Speed Integrated Circuits
WA	Weapon Aiming
WFG	Waveform Generator

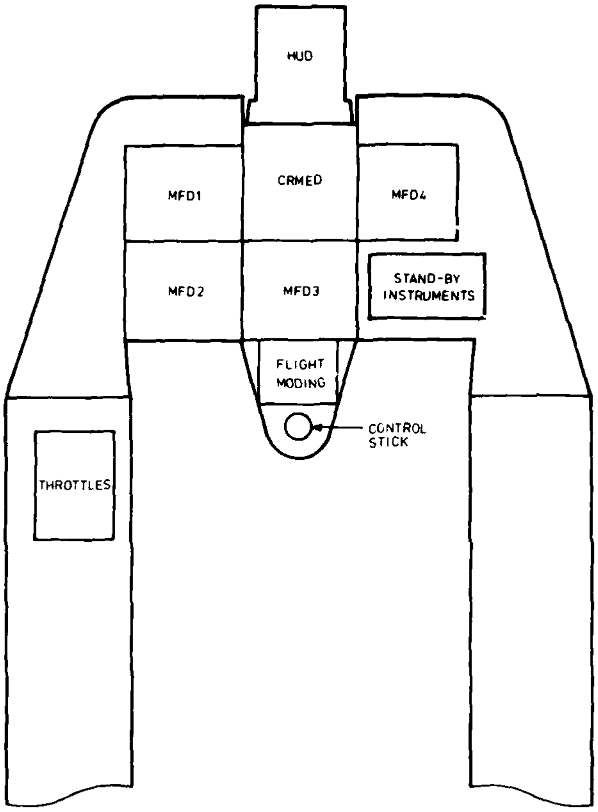


Fig.1 COCKPIT LAYOUT

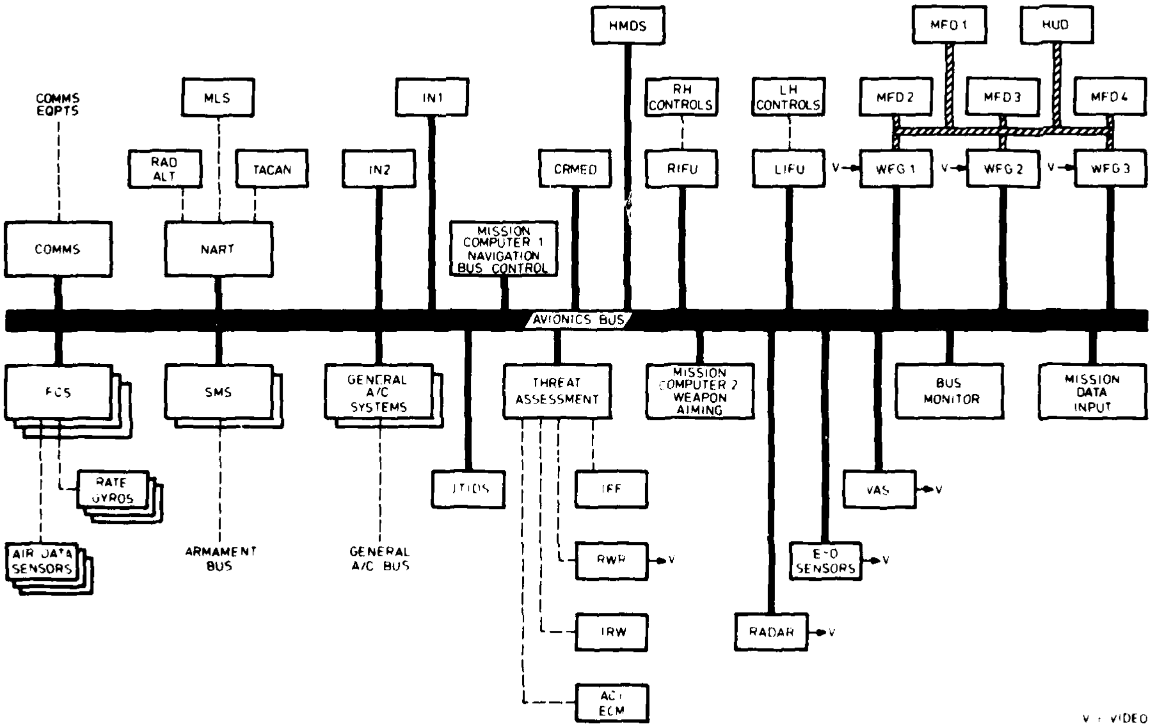


Fig. 2 CENTRALISED SYSTEM ARCHITECTURE

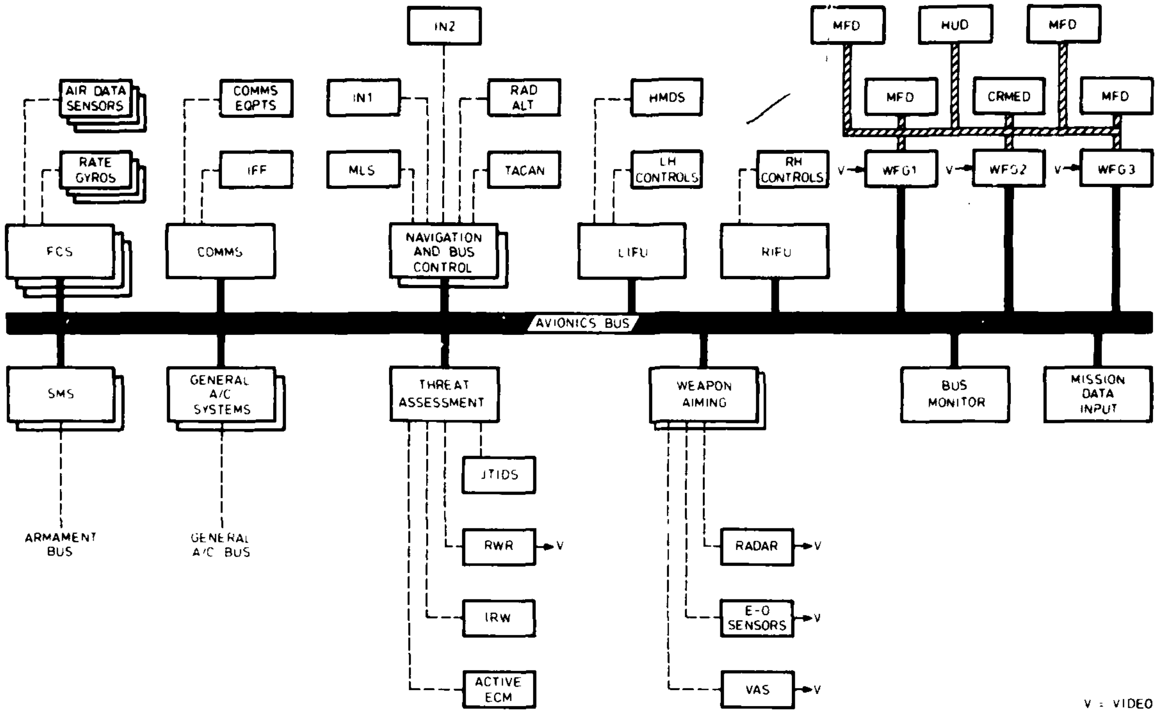


Fig. 3 SEMI FEDERATED SYSTEM ARCHITECTURE

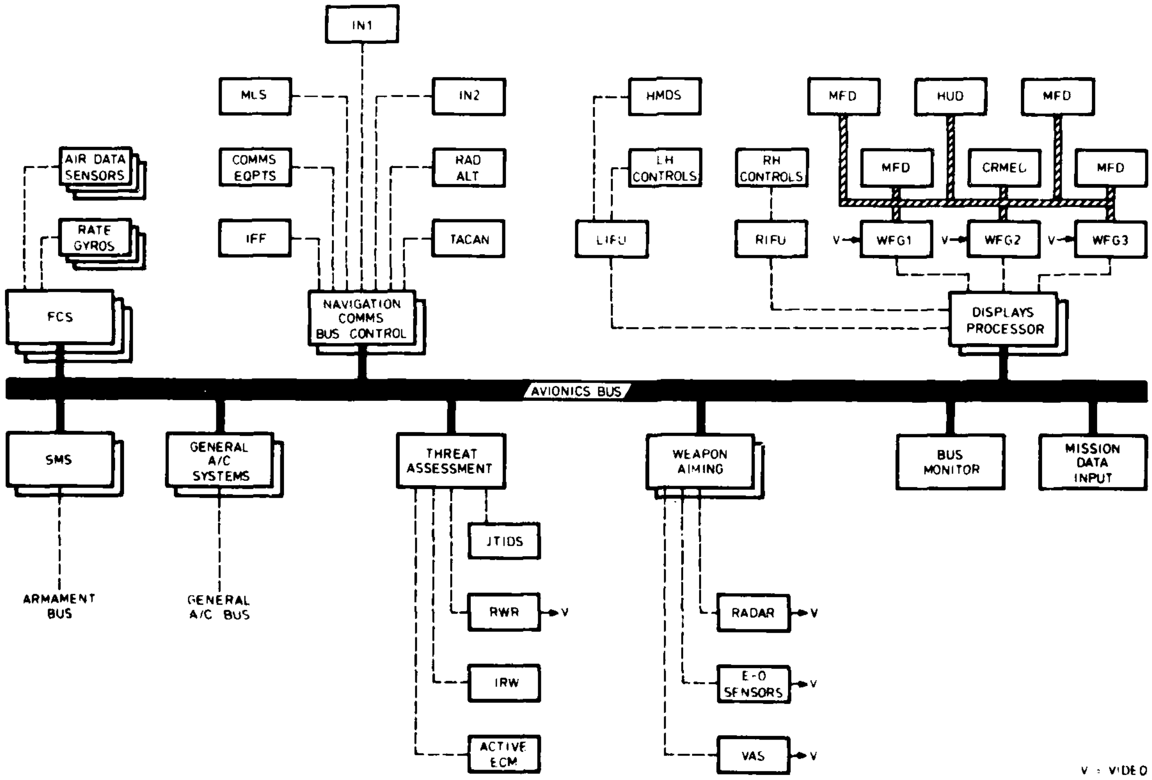


Fig.4 FULLY FEDERATED SYSTEM ARCHITECTURE

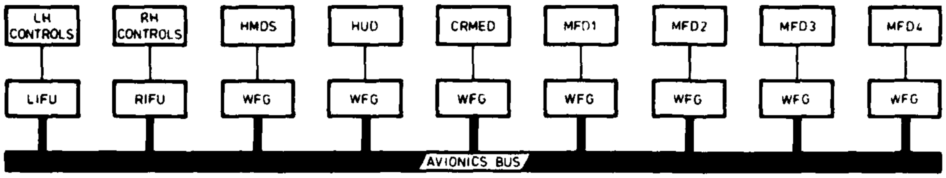


Fig.5A

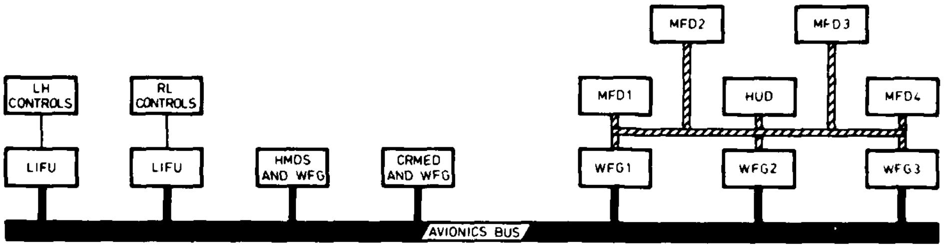


Fig.5B

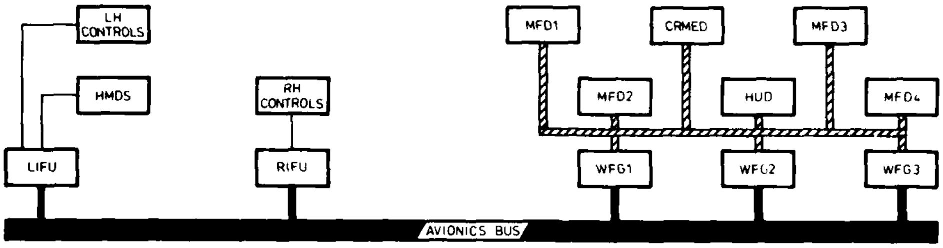


Fig.5C

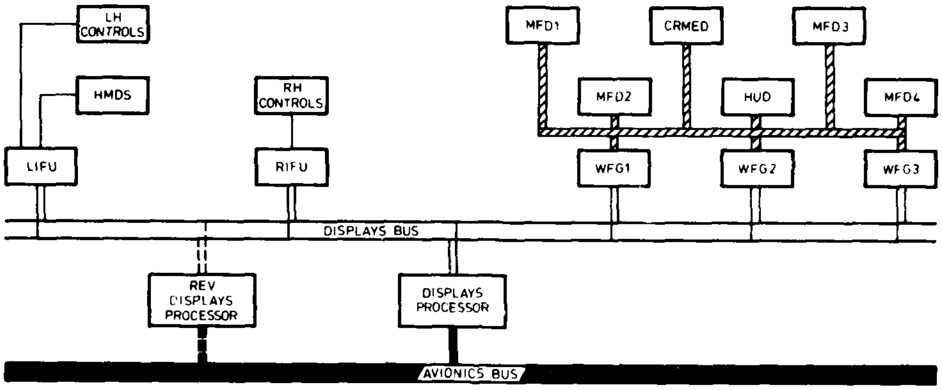


Fig.5D

FCS	17		14				(14)	
22	NAV	34	39 59 @ 10 27 @ 5 86 @ 1	22	14 @ 10		(34)	
	34	WA	90 13 @ 10 34 @ 5	34		8	(34)	
5 @ 10	11 @ 10 3 @ 5	11 6 @ 10 5 @ 5	DISP	10 @ 10		5 @ 10	(6)	
	16	34	34 @ 10	ECM			(34 @ 10)	
			26 @ 10		A/C		(14)	
		24 @ 5	10	12		SMS	(10)	
							BMON	
	BEFORE TAKE-OFF	BEFORE TAKE OFF	BEFORE TAKE-OF-	BEFORE TAKE OFF	BEFORE TAKE OFF	BEFORE TAKE OFF		MDI

FOR NUMBERS WITHOUT A DATA RATE ASSUME 50 Hz
IF SQUARE IS LEFT BLANK THERE IS NO INTERFACE

Fig 6 FULLY FEDERATED SYSTEM INTERFACE CHART

ELECTROLUMINESCENT LIGHTING AND OTHER TECHNIQUES FOR IMPROVING NIGHT VISION GOGGLES COMPATIBILITY WITH COCKPIT DISPLAYS

By

H. L. Task, Ph.D.
L. L. Griffin
AFAMRL/HEF
Wright-Patterson AFB
Dayton, OH 45433
USA

SUMMARY

Standard night lighting for most aircraft cockpits results in a lighting configuration that is not compatible with the use of night vision goggles. One specific example discussed in this paper is the US Air Force PAVE LOW III helicopter; a modified version of the HH-53H. Both wavelength and geometric light control techniques were developed and applied to this cockpit to make it compatible with the night vision goggles. A combination of light control film (3-M micro-louvre), color filters, infra-red blocking filters, electroluminescent light and anti-flare baffles were used to successfully retrofit the cockpit for night vision goggle use. In addition, some of the techniques are applicable to reducing windscreen reflection, thus, improving unaided night vision through the windscreen.

1. INTRODUCTION

The work described in this paper was done in support of the US Air Force PAVE LOW III helicopter. The PAVE LOW III is a modified version of the HH-53H helicopter (see Figure 1). The modifications included a moveable infra-red imaging sensor mounted to the forward nose section and a radar altimeter to allow night and adverse weather low level flight. These and other modifications were done to facilitate the helicopter's night/day air rescue mission. After delivery of the initial aircraft, a decision was made to use night vision goggles to obtain lower night flying capability. Unfortunately, the cockpit lighting and displays were not originally designed for night vision goggle compatibility. The authors were requested to assist in developing techniques to reconfigure the cockpit lighting to alleviate this problem. The desired night flying configuration was for the pilot to wear the night vision goggles for piloting the aircraft while the copilot did not wear goggles so that he could monitor the aircraft instruments and the infra-red video display. In this configuration it was impossible to achieve sufficient lighting for the copilot to do his job while allowing the pilot to also do his job of viewing outside with the night vision goggles. Infra-red light from the incandescent lighting system and console displays caused reflections in the windscreen and other scattered light that made it impossible for the pilot to see outside with the goggles, even when the lights were turned so low that the copilot could barely see to do his job. The objective of this effort was to develop light control techniques that could be easily retrofit to the cockpit and would allow both crew members to do their assigned jobs.

Figure 1. PAVE LOW III helicopter

2. LIGHT CONTROL TECHNIQUES

Basically, the light control techniques that were employed fell into two general categories: wavelength control and geometric control. The wavelength control techniques involve the judicious use of various filters to separate the visual sensitivity spectrum from the night vision goggle sensitivity spectrum. The geometric control involves the use of techniques to direct the light so that it only goes in desired directions.

2.1 Wavelength Control Techniques

The US Army AN/PVS-5 night vision goggles (NVGs) are sensitive to light in the spectral region from about 350nm to 900nm. This includes the visible wavelength region of 400nm to 700nm as well as a small portion of the near infra-red. Incandescent lighting normally used in aircraft cockpits for night operations emits considerable energy in this near infra-red band from 700nm to 900nm. The result is that reflections in the aircraft windscreen of instrument lights, that are annoying to the unaided eye, render the NVG's nearly useless.

The approach taken by the authors was to use electroluminescent lighting and color filters to separate the night lighting required for unaided vision from the sensitivity region of the modified NVGs. This was done by turning off all possible incandescent lamps and floodlighting the instrument panels with blue-green filtered electroluminescent light. Infra-red transmissive red filters were placed over the NVGs to reduce their sensitivity to the blue-green light. Since the electroluminescent light emits essentially no energy in the infra-red, it makes an ideal light source for the NVG compatibility. Figure 2 shows the emission spectrum of the electroluminescent light used before filtering (upper curve) and after a blue-green filter was used to "shape" its wavelength output. Similarly, Figure 3 shows the sensitivity of the so-called second generation NVGs before (upper curve) and after wavelength filtering. The result (see Figure 4) is that the two wavelength distributions have very little overlap.

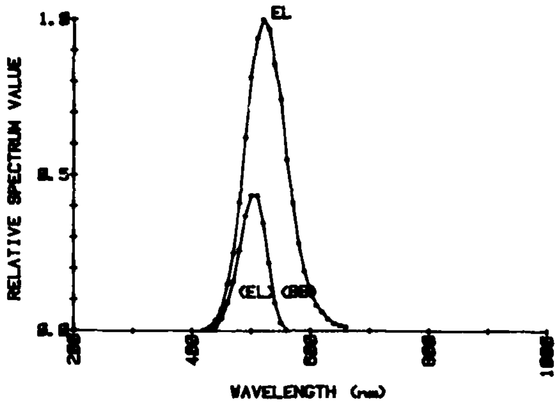


Figure 2. Emission spectrum of the yellow-green electroluminescent lights without blue-green filter (EL-upper curve) and with filter (EL-BB-lower curve).

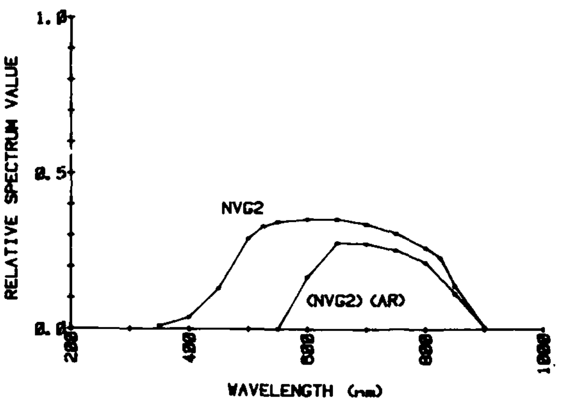


Figure 3. Relative sensitivity spectrum of the US Army second generation night vision goggles without filter (NVG2-upper curve) and with a red/infra-red transmissive filter (NVG2-AR-lower curve).

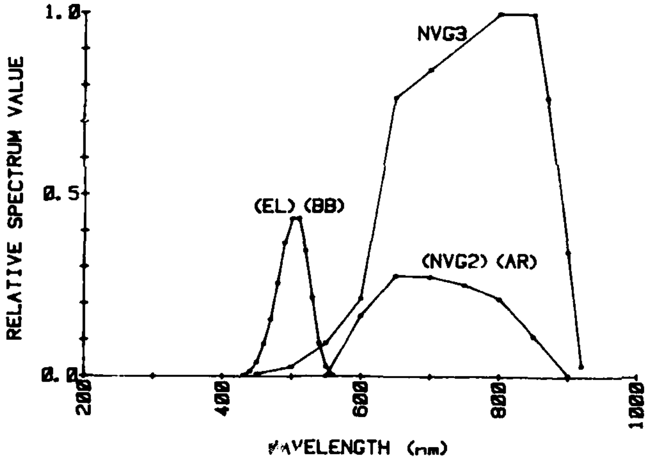


Figure 4. Comparison of emission and sensitivity spectra for the electroluminescent light with blue-green filter (EL-BB), the US Army second generation night vision goggles with red/infra-red filter (NVG2-AR) and the US Army third generation night vision goggles without filters (NVG3). Note that the spectra for the filtered EL light and the filtered NVG2s barely overlap.

This means that the NVGs can easily "see through" any spurious windscreen reflections that occur from the electroluminescent lighting.

The PAVE LOW III cockpit has two 5" by 7" video displays for presenting infra-red imagery (see Figure 5).

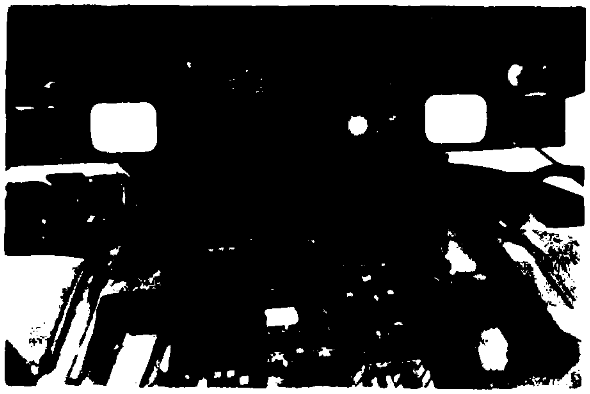


Figure 5. Front instrument panel and center console of the PAVE LOW III helicopter. Note the video displays located in front of the copilot seats. Light switches and instruments on the center console are a major source of windscreen reflections.

These displays use a P-4 white phosphor and are normally covered with a red filter for night flying. This results in incompatibility with the use of the NVG's since the red filtered displays are filling the cockpit with red light to which the NVGs are sensitive. Figure 6 shows the overlap with wavelength distributions for the display (P-4) and the unfiltered NVGs. By using the same combination of blue-green filters described previously, it is possible to separate these two wavelength distributions as shown in Figure 7.

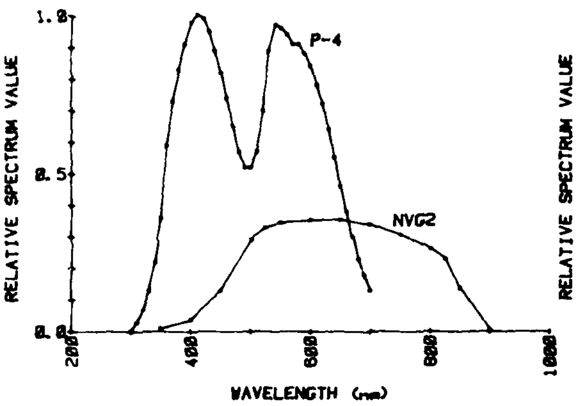


Figure 6. Comparison of the emission spectrum of the P-4 phosphor on the video displays and the sensitivity spectrum of the night vision goggles (NVG2). Note the considerable overlap of these two curves out to and including the red region of the spectrum (600-700nm) used for conventional red light lighting.

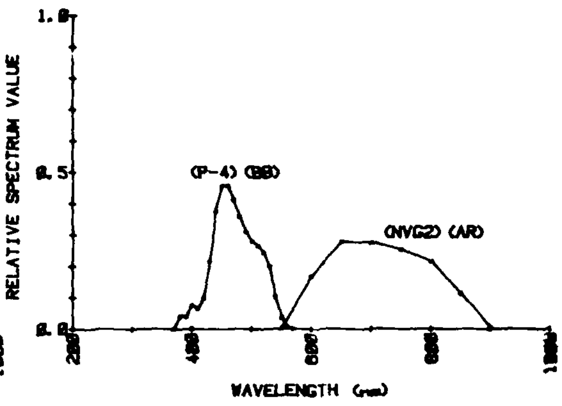


Figure 7. Comparison of the same two spectra described in Figure 6 but with appropriate filters placed over the display and the NVGs. Note that there is very little overlap between the two distributions.

There has been some concern expressed about using blue-green lighting and blue-green filters over the display from the standpoint of its effect on the dark adaptation state of the crew members. It should be noted that the crew members that are not wearing the goggles are focussing their attention on the displays and instruments inside the cockpit. It is, therefore, not necesaary for them to be absolutely dark adapted.

Some instrument lights in the cockpit cannot be turned off. The incandescent infra-red light from several of these lights located in the center console (see Figure 5) resulted in direct reflections in the windscreens. To reduce this adverse effect, these lights were covered with an infra-red blocking material that transmitted most of the visible light. This thin plastic material was originally developed for laser safety goggles but worked very well for this application.

2.2 Geometric Control Techniques

Geometric control was accomplished by simply devising means to direct the instrument lighting in desired directions and blocking it from going in undesired directions.

Many instrument lights consist of an incandescent lamp with a diffusing (sometimes colored) filter over the top with a printed legend on it. This diffusing filter distributes the light in all directions, including toward the windscreen. This results in unwanted reflections of these lights in the windscreen. To combat this problem, a product developed by 3-M Corporation called micro-louvre was used to direct the light away from the windscreen. The micro-louvre is a relatively thin plastic material with extremely small slats or louvres imbedded within. It is available with different slat spacing and orientation. It acts very similarly to a miniature venetian blind.

By selecting the appropriate angle of micro-louvre, it is possible to direct the instrument lights toward the aircrew members and away from the windscreen. This allows full viewability of the instruments and displays by the aircrew members but prevents the light from reaching the windscreen and causing a reflection. Figure 8 shows a laboratory example of this effect for visible light. A back illuminated lettered text in the lower portion of Figure 8 was positioned so that a reflection of it could be seen in a thin piece of clear plastic (windscreen) in the upper portion of Figure 8. A small section of micro-louvre set for a 30° angle was placed on the lettered text so that it directs the light toward the louvres and away from the windscreen. Note that it is difficult to see through the windscreen in the area of the reflection except for the rectangular area covered by the micro-louvre. This technique was used considerably throughout the PAVE LOW III cockpit.

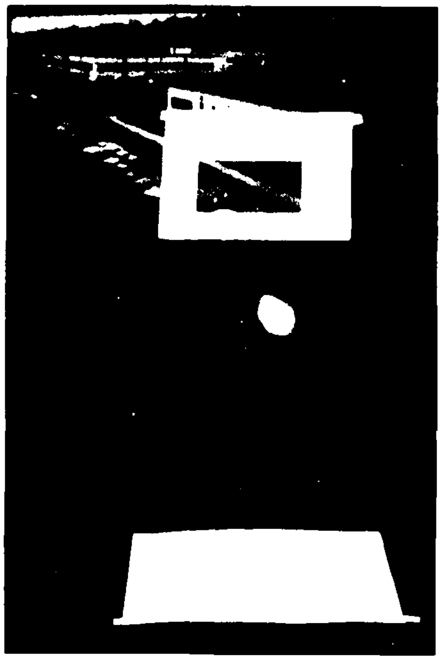


Figure 8. Laboratory example of the effectiveness of the 3-M Corporation micro-louvre in directing the light from display screens. The lower part of the photograph shows a back illuminated screen with a rectangular piece of micro-louvre placed over the center of the text. The upper part of the photograph shows the reflection of the text in a sheet of plastic simulating a windscreen. A background scene consisting of buildings and cars in a parking area is easily visible except for where the display reflection washes it out. But the area of the text display covered by the micro-louvre does not reflect in the windscreen, permitting easy visibility of the outside scene. Note also that there is no detrimental effect caused by the micro-louvre in reading the text display in the lower portion of the photograph.

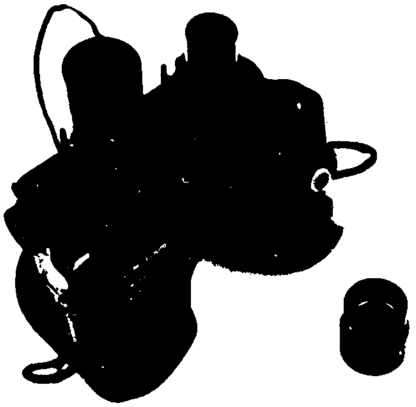


Figure 9. US Army second generation night vision goggles with anti-flare baffle (lower right).

A second geometric control technique was to attach a small flare baffle to the objective lens housing of the night vision goggles. These baffles (see Figure 9) reduced the flare produced in the objective lens caused by relatively bright light sources outside of the field of view of the goggles. The baffles also made a convenient mounting location for the red/infra-red filters previously mentioned.

The final light control technique was a recommendation that the flight crews wear black or dark infra-red absorbing clothing and, to a maximum degree, the interior of the cockpit be painted with a black matte finish. The geometry of the cockpit was such that the pilot and copilot could see a reflection of their knees in the windscreen. In other cockpit configurations, i.e., C-130 aircraft, many of which have a cream colored control column, the light colored objects are clearly reflected in the windscreen at low (one quarter foot Lambert) ambient light conditions. By reducing the stray light in the cockpit and minimizing the reflectance coefficient of the clothing, this reflection source was considerably reduced.

EVALUATION OF LIGHT CONTROL TECHNIQUES IN THE PAVE LOW III HELICOPTER COCKPIT

All of the previously discussed light control techniques were installed in the cockpit of a PAVE LOW III helicopter for evaluation. Several instructor pilots viewed the modified cockpit and provided a critical assessment. In general, the comments concerning the modifications were extremely positive. Reflections in the windscreen were greatly reduced, even for the visible spectrum, which improved outside visibility for both the copilot (without the goggles) and the pilot (with the goggles). It was not possible to make photometric measurements of the improvements because of the relatively low light levels involved. However, photographs were taken to document the improvement. Figure 10 shows a picture taken through the night vision goggles of the forward field of view of an unmodified cockpit. The lower row of lights are runway [illegible] [illegible]. The [illegible] reflections of lights in the upper portion of the picture are from reflections [illegible]

Figure 10. Photograph taken through the night vision goggles of the forward field of view seen from an unmodified PAVE LOW III cockpit. The lower row of lights are runway lights from a nearby airstrip The upper secton of lights are reflections in the windscreen from the center console. Note that some of the reflections are as intense as some of the runway lights.

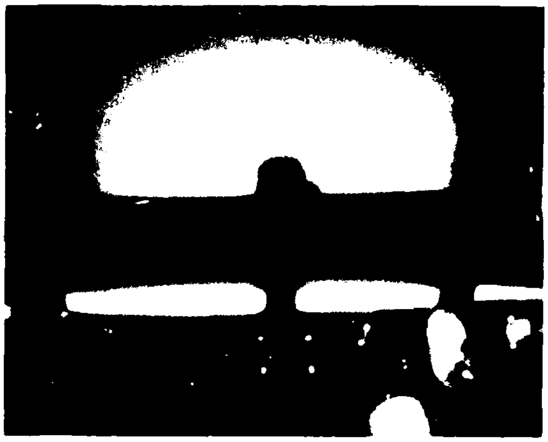


Figure 11. Photograph taken through the night vision goggles of the light control modified cockpit Note the absence of reflections except for two minor light leaks reflected from the center console. The rectangular strips of light toward the lower part of the photograph are the electroluminescent lights mounted under the glare shield to illuminate the forward instrument panel.

of center console instruments in the windscreen. Note that the intensity of some of these reflections is comparable to the outside runway lights. For comparison, Figure 11 shows the forward view out of a helicopter cockpit that was modified with the light control techniques. Except for two small reflections caused by inadequately covered instrument lights, the view is clear of unwanted reflections. With the reflections gone, the night vision goggles' gain was increased to a level that it was possible to see the sky glow of a nearby city that was masked in the view from the unmodified cockpit

4.0 CONCLUSIONS AND RECOMMENDATIONS

The light control concepts discussed in this paper were quite successful in providing lighting conditions compatible with the use of night vision goggles. However, several problems still exist in developing materials and installation techniques that will be suitable for aircraft retrofit. It is extremely difficult to locate electroluminescent floodlighting to adequately illuminate all areas requiring illumination without involving expensive modifications to the cockpit lighting. It is considerably easier to provide for electroluminescent lighting when designing the original cockpit than to devise acceptable ways to retrofit this lighting in the cockpit. The micro-louvre does an excellent job of directing the light as desired but it is unfortunately cast in a relatively soft plastic that is susceptible to both warping from heat and loss of effectiveness from scratching and wear. It would be highly desirable to develop a tougher version of the micro-louvre, but as of this writing, there are no known efforts in effect to do this. The laser safety material used for blocking the infra-red radiation from critical incandescent instrument lights needs to be improved to pass more visible light in the red region (630nm) and to block the light better toward the far red and infra-red region (650nm to 900nm). Use of the material over red warning lights reduced the visible level to a degree which rendered them unsatisfactory for daytime use in the helicopter. With the indicated needed improvements, this problem should be alleviated.

Even with these shortcomings from the materials standpoint, interest and work in this light control area for night vision goggle compatibility is progressing rapidly. Other USAF aircraft that have been modified and tested with these light control techniques are the UH-1N and HH-53C rotary wing aircraft for MAC/AARS (Air Rescue and Recovery Service) and two special mission C-130E/H fixed wing aircraft for TAC. In all cases, the wavelength separation and light control techniques were pursued, as appropriate to the individual cockpit configuration and aircraft mission, with very good to excellent results through ground evaluation and flight test.

Yet to be tested is an all electroluminescent lighting system for the interior and exterior of six A-10 single seat attack aircraft for TAC. NVG compatibility is not a requirement with these ten aircraft, rather, a complete emphasis on unaided night visibility inside the cockpit and through the transparencies and improved lighting for formation flying and night refueling is needed.

5.0 BIBLIOGRAPHY

Electroluminescence: Lamps and Panels, Grimes Division, Midland Ross Corporation report EL95 3/72, Urbana, Ohio.

Lees, Michael A.; Glick, David D.; Kimball, Kent A.; and Show, Allen C. Jr., In-Flight Performance with Night Vision Goggles During Reduced Illumination, US Army Aeromedical Research Laboratory Report No. 76-27, Fort Rucker, Alabama, August 1976.

Sanders, Michael G.; Kimball, Kent A.; Frezell, Thomas L.; and Hofmann, Mark A., Aviator Performance Measurement During Low Altitude Rotary Wind Flight with the AN/PVS-5 Night Vision Goggles, US Army Aeromedical Research Laboratory Report No. 76-10, Fort Rucker, Alabama, December 1975.

Task, H. L. and Griffin, L. L., "Pave Low III Interior Lighting Reconfiguration for Night Lighting and Night Vision Goggle Compatibility", presentation at First Conference on Aviation Psychology, Ohio State University, Columbus, OH, April 1981.

Task, Harry L. and Griffin, Leonard L., Matched Filter Technique for Improving Visibility Through Windscreens Using Night Vision Goggles, AF Invention #14,043, March 1980.

THE HELMET-MOUNTED HUD: A CHANGE IN DESIGN AND APPLICATIONS APPROACH FOR HELMET-MOUNTED DISPLAYS

John Bridenbaugh
William Kama
H. Lee Task, Ph.D.
Air Force Aerospace Medical Research Laboratory
Crew Systems Effectiveness Branch
Wright-Patterson Air Force Base, Ohio 45433
U.S.A.

SUMMARY

In the past much of the effort expended in the development of Helmet-Mounted Displays (HMD) was directed toward the goal of displaying high resolution video over a wide angular field of view. These systems were not entirely acceptable from an operational standpoint due to excessive weight, size and a number of adverse visual effects related to viewing two competing, high resolution images.

Recent studies at the USAF Aerospace Medical Research Laboratory (AFAMRL) have been *directed at the introduction of a flexible fiber optics bundle (FFOB) to relay* alphanumeric/symbolic information from a Cathode Ray Tube (CRT) located off the helmet in order to provide Head-Up Display (HUD) equivalent display information. This approach results in less weight and size, the potential for increased brightness and the removal of high voltage from the helmet. In addition to these improved hardware characteristics several visual problems are avoided by this simple configuration. This paper will examine the rationale for such a design approach as well as present results of laboratory studies to assess the effect of FFOB fiber density on symbol legibility for a Helmet-Mounted Head-Up Display (HMHUD).

1. INTRODUCTION

Over the years a great deal of research time, effort and money have gone into the study and development of Helmet-Mounted Displays without reaching the ultimate objective — an operational system. Many factors have contributed to these results, not the least of which has been the failure of technology to overcome the many diverse human engineering problems involved. This paper discusses a conceptual approach that is successful in avoiding many of the confounding elements of traditional HMD design in favor of a simple, useful, less objectionable system with higher potential for operational acceptance.

The term Helmet-Mounted, Head-Up Display is a rather clumsy, although quite appropriate and descriptive, title for an item of display hardware in that such a device falls under the general category of Helmet-Mounted Displays but takes on some of the attributes and operating characteristics of a Head-Up Display. For those not familiar with these and related display devices a few brief descriptions follow.

1.1 Head-Up Display

The HUD is a large electro-optical instrument that is accurately affixed (boresighted) to the aircraft structure in front of the pilot to provide a sophisticated gunsight capability. Information derived from various aircraft flight instrument and weapon delivery sensors is presented in symbolic form on a very high intensity CRT located within the instrument. This information is projected through an optical system and reflected from a beamsplitter or combining element located in the pilot's forward field of view (see Fig. 1). The symbology is seen focused at optical infinity, superimposed upon the view of the real world scene. This allows the pilot to accommodate the video information and real world information together, and therefore monitor essential flight and weapon delivery data without having to look down into the cockpit as he flies the aircraft, thus the term "head-up" display.

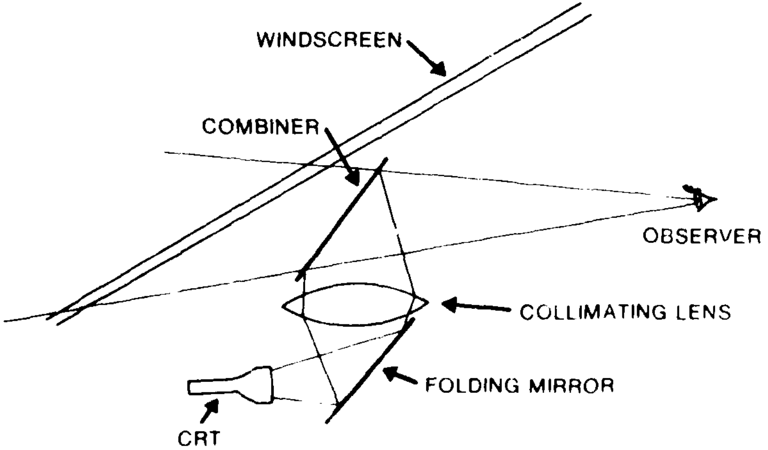


FIG. 1. HEAD-UP DISPLAY (HUD) CONCEPT

AD-A119 559   ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT--ETC   F/G 1/3
ADVANCED AVIONICS AND THE MILITARY AIRCRAFT MAN/MACHINE INTERFA--ETC(U)
JUL 82
UNCLASSIFIED   AGARD-CP-329   NL

4 OF 4
ADA
119559

END
DATE
FILMED
11-82
DTIC

1.2 Helmet-Mounted Display

The HMD is a device that makes use of a miniature CRT or other such small, controlled image source mounted on the pilot's helmet to provide an information display. The image source, again, is not viewed directly but through an optical link that presents a virtual image, focused at optical infinity and reflected from a transparent combining element in front of the pilot's eye (see Fig. 2). In some designs the helmet visor is used for this purpose (Kocian and Pratt, 1973). Two visual fields of information are therefore seen simultaneously, the virtual image superimposed upon the real world scene. A wiring bundle must be routed to the helmet from a remote location to supply electrical excitation for the image source. In the case of a CRT approach high voltages (7 to 7.5 Kilovolts) are present and special precautions must be taken to permit separation of the bundle during emergency egress, without introducing potentially dangerous sparks.

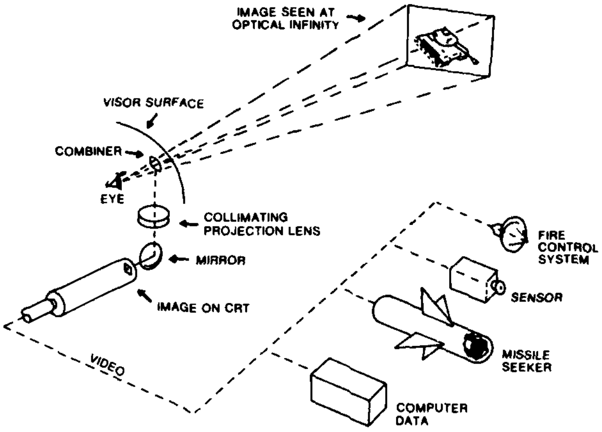


FIG. 2. HELMET-MOUNTED DISPLAY (HMD) CONCEPT

A few important distinctions are worth noting in comparing the HUD and HMD. The HUD requires nothing on the pilot's head. Both eyes view the information presented through the same aperture with restricted head positioning but very stable boresight accuracies can be achieved. In utilizing the HMD the pilot sees the entire video field constantly, regardless of head motion but usually only in one eye. Also, some visual obstructions are usually present due to the proximity of the hardware and boresight does not have significance.

1.3 Helmet-Mounted Sight

A third type of device that is important to this discussion is the Helmet-Mounted Sight (HMS). The HMS measures the pilot's line of sight in relation to the aircraft by sensing helmet orientation. It then provides that information for use in controlling weapon delivery systems and external sensors. A small reticle display reflected from the pilot's visor is used for positioning reference. The pilot overlays the reticle on a target and the system then calculates helmet angle referenced to the airframe, and hence line of sight relative to the target (see Fig. 3). Several techniques have been developed to sense helmet orientation in the cockpit. Such physical phenomena as infra-red radiation, magnetic fields, and ultrasonic waves have been employed for detection. More specific technical detail on this subject can be found in Birt and Task (1973).

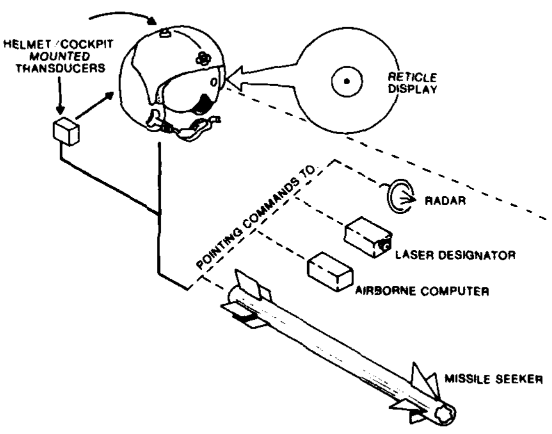


FIG. 3. HELMET-MOUNTED SIGHT (HMS) CONCEPT

THE HELMET-MOUNTED HUD: A CHANGE IN DESIGN AND APPLICATIONS APPROACH FOR HELMET-MOUNTED DISPLAYS

John Bridenbaugh
William Kama
H. Lee Task, Ph.D.
Air Force Aerospace Medical Research Laboratory
Crew Systems Effectiveness Branch
Wright-Patterson Air Force Base, Ohio 45433
U.S.A.

SUMMARY

In the past much of the effort expended in the development of Helmet-Mounted Displays (HMD) was directed toward the goal of displaying high resolution video over a wide angular field of view. These systems were not entirely acceptable from an operational standpoint due to excessive weight, size and a number of adverse visual effects related to viewing two competing, high resolution images.

Recent studies at the USAF Aerospace Medical Research Laboratory (AFAMRL) have been directed at the introduction of a flexible fiber optics bundle (FFOB) to relay alphanumeric/symbolic information from a Cathode Ray Tube (CRT) located off the helmet in order to provide Head-Up Display (HUD) equivalent display information. This approach results in less weight and size, the potential for increased brightness and the removal of high voltage from the helmet. In addition to these improved hardware characteristics several visual problems are avoided by this simple configuration. This paper will examine the rationale for such a design approach as well as present results of laboratory studies to assess the effect of FFOB fiber density on symbol legibility for a Helmet-Mounted Head-Up Display (HMHUD).

1. INTRODUCTION

Over the years a great deal of research time, effort and money have gone into the study and development of Helmet-Mounted Displays without reaching the ultimate objective — an operational system. Many factors have contributed to these results, not the least of which has been the failure of technology to overcome the many diverse human engineering problems involved. This paper discusses a conceptual approach that is successful in avoiding many of the confounding elements of traditional HMD design in favor of a simple, useful, less objectionable system with higher potential for operational acceptance.

The term Helmet-Mounted, Head-Up Display is a rather clumsy, although quite appropriate and descriptive, title for an item of display hardware in that such a device falls under the general category of Helmet-Mounted Displays but takes on some of the attributes and operating characteristics of a Head-Up Display. For those not familiar with these and related display devices a few brief descriptions follow.

1.1 Head-Up Display

The HUD is a large electro-optical instrument that is accurately affixed (boresighted) to the aircraft structure in front of the pilot to provide a sophisticated gunsight capability. Information derived from various aircraft flight instrument and weapon delivery sensors is presented in symbolic form on a very high intensity CRT located within the instrument. This information is projected through an optical system and reflected from a beamsplitter or combining element located in the pilot's forward field of view (see Fig. 1). The symbology is seen focused at optical infinity, superimposed upon the view of the real world scene. This allows the pilot to accommodate the video information and real world information together, and therefore monitor essential flight and weapon delivery data without having to look down into the cockpit as he flies the aircraft, thus the term "head-up" display.

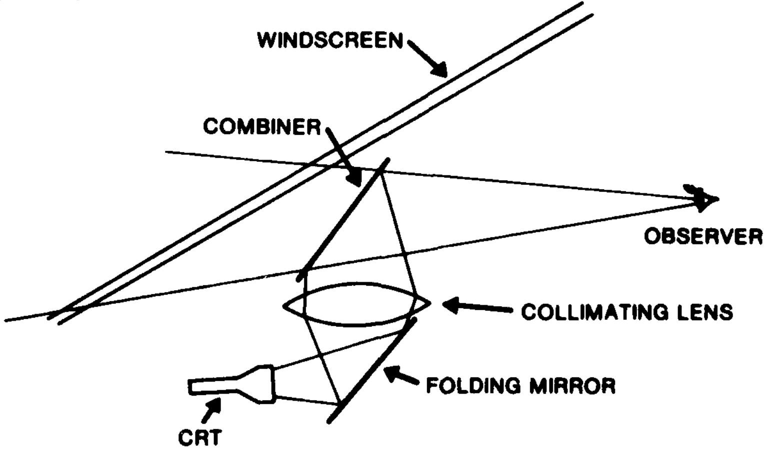


FIG. 1. HEAD-UP DISPLAY (HUD) CONCEPT

1.4 Visually-Coupled Systems

The concurrent use of an HMD with an HMS results in a configuration that has been defined as a Visually-Coupled System (VCS). The HMS determines the operator's line of sight directing video sensors to coincide such that imagery from the observed field of regard is displayed in real time. This powerful technique gives the operator instantaneous visual feedback so that he can introduce corrections and manipulate directional systems (Fig. 4). Additional information on VCS can also be found in Birt and Task (1973).

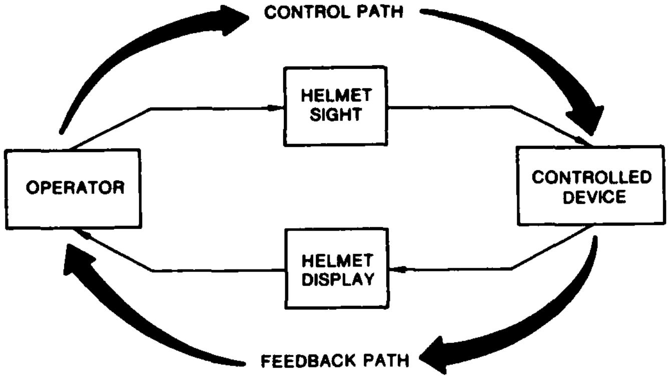


FIG. 4. VISUALLY-COUPLED SYSTEM (VCS) CONCEPT

2. BACKGROUND

Head-Up Displays, although not technically perfected in terms of man-machine interface, have been in operational use in fighter and attack aircraft for the last few decades (Gard, 1978). The Helmet-Mounted Sight, although not so extensively employed, has also undergone production and field service. Helmet-Mounted Displays have languished in the laboratory. The primary reason for this is that every HMD system designed to date has imposed upon the operator more physiological and psychological hardships than could be counterbalanced by the benefits that such systems are capable of providing. This is not to say that HMDs do not offer the potential for significant increases in performance and reductions in pilot workload. It does, however, give some indication of the rather substantial human engineering problems encountered in the design of helmet mounted systems.

There are many complex and interacting parameters involved in the design of a given HMD (Task, Kocian and Brindle, 1980) making trade-offs very difficult. Typically, improving field of view, exit pupil or eye relief results in a larger optical system and unwanted extra weight. The potential solutions are geometrically limited. More detailed discussion on the subject of optical constraints can be found in Larkin (1980). Adverse visual effects are also difficult to avoid. These include such phenomena as distortions, occlusions, brightness inadequacies and binocular rivalry to name only a few. Binocular rivalry has been examined in some depth and documented in Hershberger and Guerin, (1975).

Finally, the physical properties of weight, size and balance (center-of-gravity) complicate the design task even further. Ultimately, the most objectionable feature of an HMD system is added helmet weight. Generally speaking the problems discussed herein increase with system sophistication.

Historically much of the significant HMD development transpired in the late 1960's and early 1970's (Birt and Task, 1973). A large portion of this work included optimization of miniature CRTs in terms of size, brightness and resolution and in the manipulation of various helmet and optical design configurations to reduce weight, improve center-of-gravity and provide for satisfactory viewing characteristics. As one might expect with a fresh technology, design goals were quite high and not knowing the true design limits, researchers emphasized systems with large fields of view, high resolution imagery, binocular viewing capability, color, etc. As discussed earlier the complexity of the systems led to their unacceptability.

3. HELMET-MOUNTED HEAD-UP DISPLAY

A much simpler HMD configuration has been suggested that has fewer physiological disadvantages and the potential for operational usefulness. A Flexible Fiber Optics Bundle can be used to relay the image from a CRT located off the helmet to the helmet optics. Several advantages can be seen with this approach (see Fig. 5). Removing the CRT not only gives a significant weight reduction but does away with high voltage on the helmet. This permits a simple optical decoupling mechanism that the pilot can easily separate in an emergency. Increased flexibility in CRT choice permits the use of larger devices exhibiting higher brightness, ruggedness and even the option of color. Tailoring the design for a symbology-only capability has additional advantages. The lower resolution required to generate recognizable symbols permits a fairly flexible and lightweight bundle, since fewer fiber elements are required. The durability of such a bundle would be quite good. Excellent viewing characteristics result from being able to display a singular, high level of brightness as opposed to several levels of brightness as would be required for imagery. A monocular display presenting symbology only would not be susceptible to binocular rivalry as studies have indicated (Jacobs, Triggs and Aldrich, 1970). In addition, symbolic information is readily interpreted and understood.

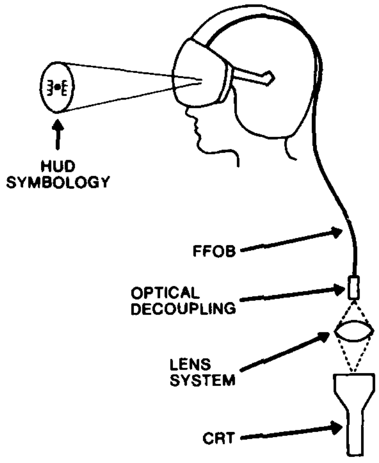


FIG. 5. HELMET-MOUNTED, HEAD-UP DISPLAY (HMHUD) CONCEPT

The overall capability would be similar to that of a HUD although boresight would be lacking. Use of a HMHUD with an HMS would provide the advantages of off-boresight target designation, weapon lock-on and navigation update. Warning and caution information would always be within the view of the operator. The display would be very convenient for input/output interaction with on board computers. Retrofit of course would be relatively simple, giving HUD capability to aircraft that were not originally so equipped.

4. HMHUD PROTOTYPE

With this concept in mind, an in-house effort was undertaken to demonstrate the HMHUD. A Honeywell Mod 7A HMD was chosen to be modified (see Fig. 6). This particular HMD design originally made use of a short non-flexible fiber optics bundle to relay the image from a miniature CRT located on the back of the helmet to the optical system used to project the image onto the helmet visor. The unit shown in Fig. 6 includes Helmet-Mounted Sight sensors and cabling. It was a simple task to replace the CRT and original FFOB with a one meter long, off-the-shelf FFOB. The completed prototype unit is pictured in Fig. 7.

FIG. 6. HONEYWELL MOD 7A HMD

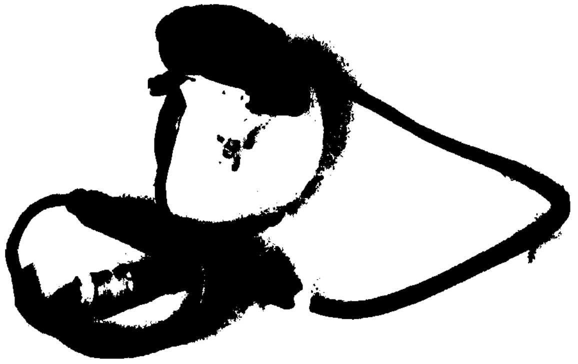


FIG. 7. HMHUD PROTOTYPE

A lens was used to optically couple the image from a miniature CRT to the end of the bundle. Work is presently in progress to couple the miniature CRT to a micro-computer for generating appropriate symbology. The entire system will be used as a research tool to develop a symbology set best suited for HMHUD use.

To determine whether or not a flexible fiber optics bundle of reasonable size could support the image quality required for HUD symbology some test situations were set up and photographed. Figure 8 shows a photograph of a 35 mm slide with a sample of HUD symbology. This slide was then imaged through a 50,000 element, hexagonally formatted FFOB composed of 50 micron fibers. Fig. 9 shows the resulting image at the other end of the FFOB. The FFOB selected for the research prototype is a 350,000 element bundle in a rectangular format composed of 10 micron fibers in 6x6 element subbundles. This FFOB should provide slightly better resolution, depending on the misregistration and fiber breakage of the particular bundle acquired.

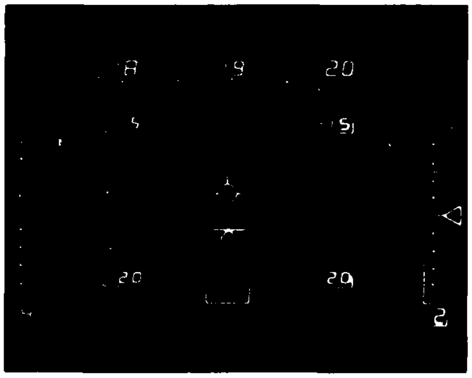


FIG. 8. HUD SYMBOLOGY (35mm SLIDE)

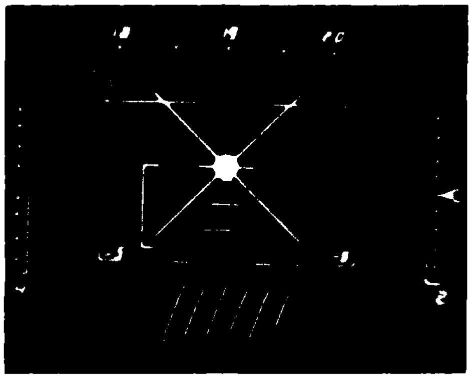


FIG. 9. HUD SYMBOLOGY ON FFOB IMAGE PLANE

5. FFOB STUDIES

Since resolution is directly related to the number of fibers and since weight and flexibility are improved with fewer fibers, it becomes desirable to know how many fibers across a given symbol are required for easy recognition. Studies are being conducted at AFAMRL to define limits such as these. One study, already completed, varied both the number of fibers across alphanumeric characters and the angular subtense of the characters themselves. Subjects were scored on response time and number of correct responses. Two different bundles were used, one having a rectangular format (Fig. 10) and one having a hexagonal format (Fig. 11). Major findings of the study indicated that performance with the hexagonal bundle was superior to that with the rectangular bundle and optimal performance occurred at approximately 8.7 elements or more per character height and with character angular subtenses greater than 18 minutes of arc. This data will serve to define the lower limit of symbol sizes for a Helmet-Mounted Head-Up Display.

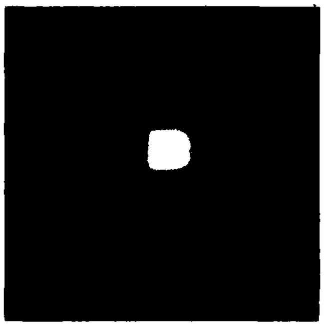


FIG. 10. RECTANGULAR FORMAT FFOB

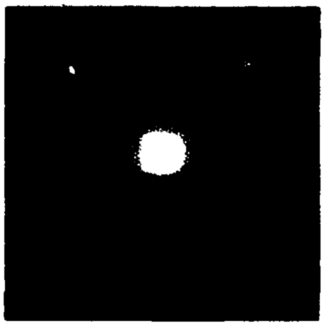


FIG. 11. HEXAGONAL FORMAT FFOB

There are a few FFOB disadvantages worth discussing. Imperfections are present in every bundle to some degree. Fibers are not always registered perfectly from end to end although this is not a severe problem. Misregistration displaces a pixel of information slightly from its original physical location. Broken fibers and sub-bundles result in small, dark inactive areas (see Fig. 10). This problem becomes worse with time and use as more fibers break. Light transmission is attenuated by approximately ten percent per foot in a typical FFOB. A sufficiently bright source would compensate for this effect. Since each end surface of the bundle is an image plane, debris and scratches on these surfaces can interfere with any image being projected. Extra care must be taken to insure that the imaging surfaces are kept isolated from foreign material and abuse. The bundle structure itself results in a fixed pattern that is superimposed on the image plane. This can be a mild distraction. There are two techniques that can be employed to limit fixed pattern effects, if this is desirable. A small specially designed prism set properly at each end of the bundle breaks up and recombines the transmitted light according to wavelength eliminating the image of the pattern. This technique is called "wavelength multiplexing". Wavelength multiplexing results in additional complexity, size and added weight. Another method to effectively eliminate the pattern image utilizes synchronized vibration at each end of the bundle. It is not a simple task to control vibration with the accuracy necessary to eliminate the fixed pattern noise without blurring the image due to unsynchronized vibration. None of the problems discussed above appear to be insurmountable.

6. CONCLUSIONS

The authors believe that a Helmet-Mounted, Head-Up Display as described in this paper offers the pilot a unique and useful information source without many of the more prominent disadvantages usually associated with Helmet-Mounted Displays. Very important weight reductions are possible with this configuration, adverse visual effects are minimized, high voltage separation is unnecessary and retrofit is simple and inexpensive.

Tactically, the device can be used with a Helmet-Mounted Sight to provide off-boresight, head-up interaction with weapon delivery and navigation systems.

7. REFERENCES

Birt, Joseph A. and Task, Harry L., 1973, "Proceedings of: A Symposium on Visually Coupled Systems: Development and Applications," U.S. Air Force Aerospace Medical Division, AMRL-TR-73-1.

Gard, Jerold H., 1978, "A Somewhat Vignetted History of the Head-Up Display," in Proceedings of the Society for Information Display, Volume 19, No. 4, Fourth Quarter 1978. p. 163.

Hershberger, M.L. and Guerin, D.F., 1975, "Binocular Rivalry in Helmet-Mounted Display Applications," USAF: AMRL-TR-75-48, U.S. Aerospace Medical Research Laboratory, Wright- Patterson AFB, Ohio.

Jacobs, R.S., Triggs, T.J. and Aldrich, J.W., 1970, "Helmet-Mounted Display/Sight System Study," USAF: AFFDL-TR-70-83, Vol. I, Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio.

Kocian, D. and Pratt, P., 1973, "Development of a Helmet-Mounted Visor Display," in Proceedings of: A Symposium on Visually Coupled Systems: Development and Application, Birt and Task, (Eds), U.S. Air Force Aerospace Medical Division, AMRL-TR-73-1., p. 225.

Larkins, James T., 1975, "Design of an Optical Link for a Side-Mounted Helmet Display Using Off-the-Shelf Lenses," U.S. Air Force Institute of Technology Master's Thesis, GEO-PH/75/6.

Task, H. Lee, Kocian, Dean F. and Brindle, James H., 1980, "Helmet-Mounted Displays: Design Considerations," in Advancement on Visualization Techniques, Hollister, W.M. (Ed.), AGARDograph No. 255, Harford House, London.

DIFFRACTIVE OPTICS FOR AVIONIC DISPLAYS

Dr. D. W. Swift,
Pilkington P. E. Limited,
St. Asaph, Clwyd, U.K.

SUMMARY

The paper describes what diffractive optical elements are, how they work, and how they are made. It explains in broad terms how the properties of one special class of these elements (conformal holograms) are being used to design Head Up Displays with larger instantaneous fields of view than the current generation and with improved photometric performance, but notes some of the attendant problems.

1. INTRODUCTION

A great deal has been heard in the last few years about Head Up Displays (HUDs) using diffractive optics. Two views in particular are sometimes put forward : on the one hand that diffractive optics can do nothing which cannot be done equally well by conventional means, and on the other that it can solve all the outstanding problems of current avionic displays. Neither of these extremes is valid. This paper is intended to explain what diffractive optics actually has to offer and where its limitations lie. To do this it is necessary to review briefly what is meant by diffractive optics, and to consider some of the optical problems associated with the design of a HUD.

2. DIFFRACTIVE OPTICS

As the name makes clear, diffractive optical elements operate by means of diffraction rather than refraction or reflection. As a class they are not new; well known and long established examples are diffraction gratings and zone plates. The general element can be thought of in several different, but equivalent, ways. One particularly useful description is to regard the element as a hologram of a point. This corresponds to the way in which the elements are made and explains the alternative name of holographic optical element (HOE) which is in common use especially in the USA. Although they are now accepted, neither of these names is wholly satisfactory, and others such as interference optics could be used with equal justification. For brevity the acronym HOE will be used in this paper.

2.1 Imaging Properties

Some of the interesting properties of HOEs follow immediately from the hologram description. Since the interference which creates the hologram takes place between two spatially and temporally coherent beams, the hologram itself consists of continuous fringes rather than the complex discontinuous pattern characteristic of holograms of extended objects. The "object" beam and the "reference" beam when the HOE is made differ only in their geometrical arrangement, and so they are essentially interchangeable. In Figure 1 for example, a HOE is made by interference between beams from points A and B. If the HOE is reconstructed using the beam from A alone it will reconstruct B, and vice versa. Notice, however, that in the former case it acts as a diverging lens plus a prism, but in the latter case as a converging lens plus a prism in the opposite orientation. The reason for this apparent anomaly is that the hologram has multiple orders of diffraction, just as a grating has, and if the A reconstruction is using the +1 order then the B reconstruction is using the -1 order. The consequences of this will be examined a little later.

Clearly, the HOE has lens-like properties in that it can "image" a point A to a point B, but it is not identical to a lens. It seems to offer considerably more geometrical freedom than a conventional lens could, as can be seen in Figure 2. Each of the four HOEs shown has identical paraxial optical power, and each images the point A to the same point B, despite the differences in substrate position and shape. The imagery for points A and B (the construction points) is perfect, so the lens properties of the HOE are similar to those of a stigmatic aspheric conventional element.

2.2 Image Aberrations

For some purposes (e.g. laser optics) stigmatic imagery of this kind is ideal. For most purposes, including displays, it is necessary to consider what happens to other points in the field, such as C (Figure 2). All the HOEs shown in Figures 1 and 2 will form some kind of image of C, but the image will suffer from aberrations analogous to the conventional Seidel aberrations. The nature and in particular the magnitude of the aberrations does depend, critically, on the substrate shape, and so will be very different for each of the HOEs in Figure 2. In practice this severely limits the apparent freedom to locate and shape elements arbitrarily which was mentioned earlier. It is worth bearing in mind that a typical conventional HUD may have, say, five optical elements in it to correct the aberrations adequately for its purpose. Each element has several degrees of freedom which the designer can use : the radii of curvature of the surfaces, the refractive index (and dispersion, but more of that later) of the glass, and the thickness and position of the element. The HOE as described so far has fewer degrees of freedom (no usable equivalents to refractive index, dispersion or thickness) but there are others available. The HOE need not be constructed from points : one or both beams may be deliberately aberrated to build in correction to a reverse aberration. Overall the HOE is thus similar to a conventional element, and one might expect good aberration correction in any given system to require a similar (but not necessarily the same) number of elements. Although the Seidel aberrations are of similar magnitude to conventional elements used in a similar manner, this is not true of chromatic aberration. The deviation of light passing through a HOE is a diffraction/interference effect and therefore strongly wavelength dependent. The diffractive optical power for red light is necessarily nearly twice that for blue. Such elements therefore suffer from extremely severe chromatic aberration : in fact for most purposes it is not so much an aberration as a disaster! The problem can be mitigated by using a narrow spectral bandwidth source, or by using the geometry to provide optical power as we shall see in Section 3.3. In fact both techniques are used in practical HUD designs.

2.3 Construction Geometry

The range of elements available using the holographic construction method is most conveniently demonstrated using the diagram of Figure 3. Interference fringes are formed where the difference in optical paths from the two sources is constant. If A and B represent the two sources, the fringes are a family of hyperboloids of revolution, represented by the curves in the figure. A substrate coated with photosensitive material anywhere in the field will record the fringes within the sensitive layer. Examples corresponding to one of the cases shown in Figure 2(c) and a reflecting element (e) are indicated. The reflecting element results when the construction beams are incident on the photo-sensitive layer from opposite sides instead of the same side. The other family of curves in Figure 3, corresponding to ellipsoids of revolution, are loci of points the sum of whose distances to A and B are constant. They represent the fringes formed when A is a source and B a sink - i.e. light is directed towards B by means of auxiliary optics - or vice versa. (The case where A and B are both sinks is equivalent to that where both are sources, but more difficult to realise and therefore of no practical interest). Fringes of the remaining conics can be obtained by moving A or B to infinity (giving paraboloid fringes), or to a common point (giving spherical fringes). If both A and B go to infinity plane fringes result.

3. PHOTOMETRIC EFFICIENCY

3.1 Thin Holograms

It is convenient at this point to consider an alternative representation of a HOE, namely that of a diffraction grating of variable grating spacing and orientation distributed over the substrate surface. This is a useful model for design purposes, by the traditional method of ray tracing. The geometrical properties already considered can all be adequately predicted on the assumption that the HOE consists of line fringes on a surface, where the only condition to be satisfied is that light is propagated whenever rays from adjacent fringes are in phase with one another - the grating condition. This condition requires that the paths from adjacent fringes differ by an integral number of wavelengths, and the choice of integer gives rise to the existence of different orders of diffraction, mentioned earlier. Notice that for such a surface (two dimensional or "thin") HOE there is no distinction between a transmission and a reflection element, since if light propagated forward at a given angle satisfies the grating condition, so also does light reflected backwards at the same angle (Figure 4).

Clearly, if light can be shared over a large number of orders in this way, the proportion of the incident light which finds its way into the single wanted order (i.e. the photometric efficiency of the HOE) cannot be high. This is doubly serious, since it implies both poor light utilisation and a large amount of unwanted light (i.e. low contrast, or glare).

3.2 Thick Holograms

The solution is to use a thick phase hologram (Figure 5). The fringes are now no longer lines on a surface, but surfaces in a volume. It should be a phase and not an amplitude hologram (that is, the fringes should consist of refractive index variations and not absorption variations) to avoid light loss by absorption. "Thick" in this context means many optical wavelengths. A thick HOE must still satisfy the grating condition, but it must also satisfy a second conidition : that all the light from any one fringe must be in phase. This is sometimes called the Bragg condition by analogy with X-ray diffraction but I prefer to call it the mirror condition, since it implies that propagation occurs along a direction as though the fringes acted as mirrors (within the host material of course - one must allow for refraction). Notice that for a thin HOE a wavelength always exists which is capable of propagation in any given direction, although this wavelength may not actually be present in the incident light. The effect of adding the mirror condition for a thick HOE is that only one particular wavelength will be propagated in one particular direction, but this will occur with very high photometric efficiency. For a practical case the HOE will operate over a certain spectral passband and a certain angular passband, the two being strongly related to one another.

3.3 Conformal Holograms

It also follows from the mirror condition that transmission HOEs will have fringes which tend to run through the photosensitive layer (Figure 5a), whereas reflection HOE fringes will tend to run parallel to the layer (Figure 5b). The special case where they run exactly or at least closely parallel to the substrate, and are therefore essentially the same shape as the substrate is of particular interest because this case does not suffer from chromatic aberration. This makes it especially useful. We have referred to these as "conformal" HOEs. They act as narrow band reflectors (Figure 6) and are very similar to multilayer dielectric coatings on a conventionally-shaped mirror. The colour photographs made by Lippmann nearly a century ago were essentially conformal HOEs of this kind, on flat substrates of course.

4. MANUFACTURE

As noted in the previous section, only thick phase HOEs are of interest for avionic displays of the current type, and at the present time only one material is known which can be used to produce elements with satisfactory properties. This is dichromated gelatin. It is a difficult material to work with, partly because it is a mixture (of about eighteen amino acids and various impurities) rather than a compound, and partly because of its nature. Consequently considerable effort is going into the search for alternatives. In the meantime gelatin will be with us at least for the next few years, and methods have been developed to handle it. The full process is complex and not important in this context, but in summary it involves:

(i) Coating the substrate.
(ii) Sensitizing the gelatin with ammonium dichromate.
(iii) Exposing to the interference fringe pattern.
(iv) Processing by removing water from the exposed gelatin.
(v) Baking.
(vi) Encapsulating.

The mechanism is not yet fully understood, but it involves both chemical and physical aspects. Consequently, there are significant differences from photographic processing and it has for example not proved satisfactory to use photographic industry coating techniques because the physical properties of the resultant gelatin layers are inadequately homogeneous. Some or all of the steps noted are capable of modification, and it is worth noting that no two workers in this field seem to use, or even to be able to use, exactly the same techniques. The gelatin itself is of course hydrophilic, and for this reason it is essential that the final HOE is sealed against atmospheric moisture. Providing that this is done the durability of the HOEs appears to be good. Variation of water content of the gelatin layer during processing causes a considerable variation in the thickness of the layers, and is a critical factor in the tuning of the HOE. (A transmission HOE, where the fringes are or are almost perpendicular to the substrate and therefore parallel to the direction in which the swelling and shrinkage occurs, is much less sensitive in this respect than a reflection HOE. This is one of the reasons why transmission HOEs are generally easier to produce.) Ambient humidity in the production area must therefore be closely controlled, as must ambient temperature for consistency and stability.

Cleanliness is also essential, and once again more critical than in the photographic case because any scattered light reaching the sensitive material during exposure leads to unwanted fringes and consequently scatter from the final HOE. The advantage of conformal HOEs in avoiding chromatic aberration has already been mentioned, but there is a further advantage during manufacture since they can be made using a single beam and a mirror in optical contact with the substrate : a simple adaptation of both the Denisyuk method for reflection holograms and Lippmann's century-old technique. The advantage is that the stability requirement is much more easily met using this method.

5. APPLICATION TO THE HUD

Having presented the background in previous sections, I now want to explain what diffractive optics has to offer in the HUD. There appear to be two areas where it can be useful, namely to improve the photometry, and to provide larger fields of view.

5.1 Photometric Advantage

The potential photometric advantage is illustrated in Figure 7. The figures are approximate only, to illustrate the point. A conventional combiner reflects about 25% of the light from the display, and transmits about 70% of that from the external scene. If a P43 or P53 phosphor CRT is used and the light in the central emission peak only is considered, a HOE combiner can (although it need not) reflect about 90%. It transmits about 80%, i.e. almost everything outside the operational passband, with the mild disadvantage of a slight pinkish colouration. Sunlight which illuminates and is scattered by the CRT phosphor, and is then reflected by the combiner, is reduced in the HOE case, with a consequent improvement in display contrast of a factor of up to six for a given effective phosphor brightness. To be valuable, this assumes the availability of a narrow band phosphor of suitable brightness and robustness of course.

Whilst the use of a HOE combiner rather than a conventional one may seem generally beneficial (assuming of course that all other requirements such as low scatter and environmental stability can be met in the required HOE) there is one serious disadvantage. The narrow spectral bandwidth is essential to achieve the advantages, but it is necessarily accompanied by a narrow angular bandwidth. This implies a limitation on the acceptable vertical excursions of the pilot's eyes, and necessitates either a compromise or a more complex type of HOE in practice.

5.2 Field of View

The increased field requirement is more difficult to consider in general terms because the problem is so strongly space and geometry dependent. However, it will be clear that if a large instantaneous field of view is needed it is essential to have either a larger collimating element or to place it closer to the pilot's eyes. This cannot readily be done using the conventional HUD layout indicated schematically in Figure 7. One alternative which would approximate the ideal situation is to use a spherical mirror centred on the eyes (and producing a real exit pupil at the eyes), but this presents the problem that the input and output beams are physically in the same space, which is impracticable. There are two ways round this : use the mirror off-axis or use a beamsplitter. Both have been proposed or built previously in non-diffractive versions, and both have recently appeared in diffractive versions.

The properties of diffractive optics used to advantage in the off-axis case are the possibility of realising the large off-axis aspheric collimator/combiner whilst maintaining the integrity of the view of the external world through the element, and the ability to produce this element with axial astigmatism of opposite sign to that which occurs in use. Unfortunately, off-axis designs of this kind tend to be a poor fit into the typical fighter aircraft cockpit, and they are difficult to correct optically due to the large off-axis angle and so are expensive. (Most of the correction must be done in a relay lens which, if conventional as is the case in the current state of the art, includes several tilted and/or decentred and/or truncated elements).

The alternative approach of using a beamsplitter poses new problems, but allows the collimating mirror to operate on, or at least near to, the axis. There is a considerable photometric advantage in going slightly off-axis even when a beamsplitter is used since this allows the light to meet the beamsplitter at a different angle on each of its two passes, and hence to be reflected efficiently on one pass and transmitted efficiently on the other. This useful trick allows a compact design to be obtained with little or no sacrifice of display brightness, and it could not be done without the use of a HOE. We call designs of this type, where the system is off-axis for photometric rather than geometrical reasons (and where the off-axis angle is much less extreme), quasi-axial. Several designs have been and are being investigated and although all have problems, several show promise. It is not my purpose here to consider any of these in detail but the next paper will discuss one such design.

The foregoing considerations are of course very far from being comprehensive. Amongst the many topics which I have not covered but which merit discussion I might mention in particular the problems of incorporating standby displays and recording cameras into diffractive HUDs.

6. CONCLUSIONS

Conformal or near-conformal HOEs are potentially of great value in Head Up Displays for two main reasons. They offer new possibilities for the design of wide angle displays, and they offer photometric advantages. Other types of HOE may also prove valuable in the longer term, but some problems remain to be solved, and notably the severe chromatic aberration. HOEs alone, however, cannot provide complete answers for all existing HUD problems. One of the more persistent ones at the present time, exacerbated by the increasing use of bubble canopies, is that of unwanted sunlight reflections. Cockpit geometry as a primary constraint on optical performance has been mentioned already in the foregoing, and it will be obvious that the optical system designer is strongly dependent upon cockpit configuration.

Whilst it is clear that the optical system requirements cannot dictate details of cockpit layout or canopy design, the recent increase in display fields implies that closer and earlier co-operation between cockpit designer and optical system designer is desirable if optimum results are to be obtained. I would like to think that this Symposium is a contribution to such co-operation.

7. ACKNOWLEDGEMENTS

I should like to thank the directors of Pilkington P. E. Limited for permission to publish this paper, and MoD (PE) for project support of much of the work on which it is based. My thanks are also due to my colleagues in PPL and in the Pilkington R. & D. laboratories for their helpful comments.

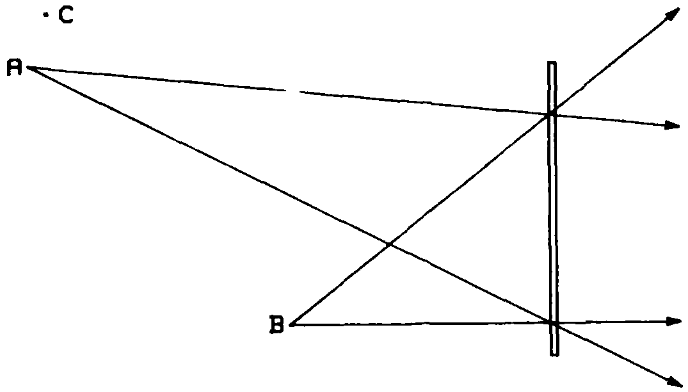


Figure 1 Hologram of a point

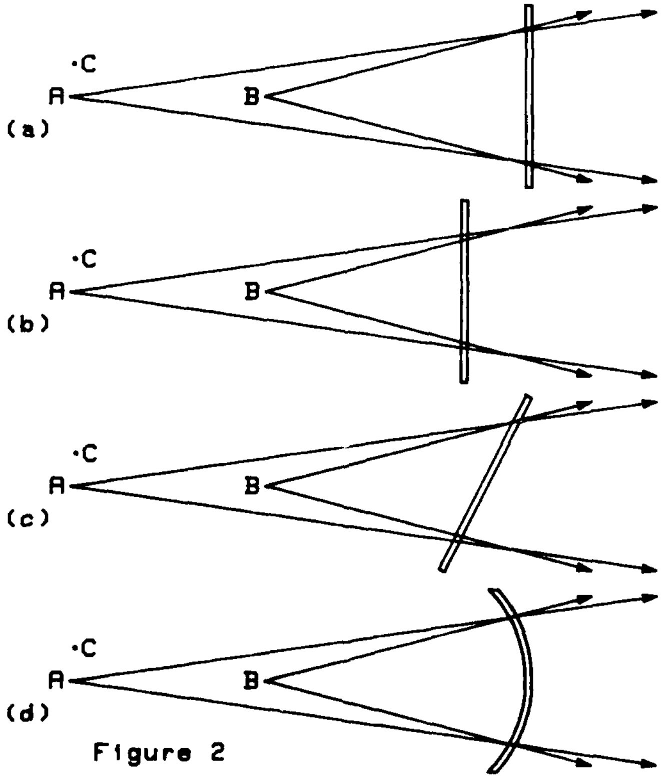


Figure 2
Paraxially equivalent elements

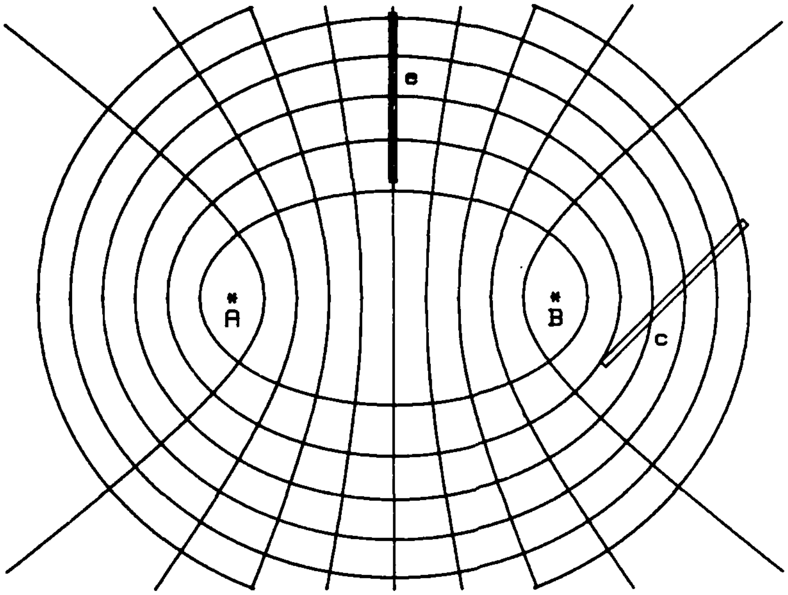


Figure 3 Fringe system

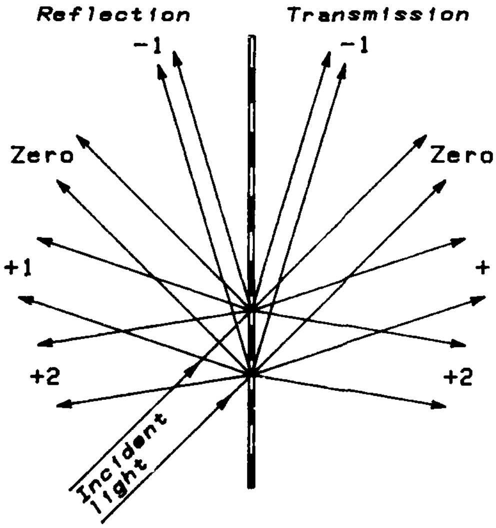


Figure 4 Thin grating

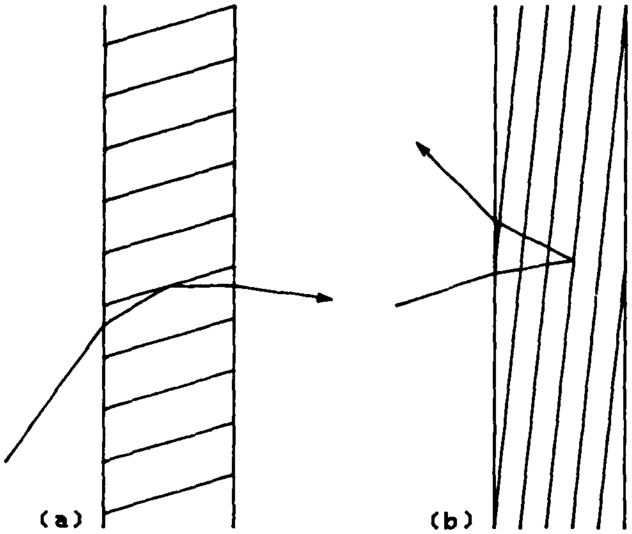


Figure 5 Thick holograms

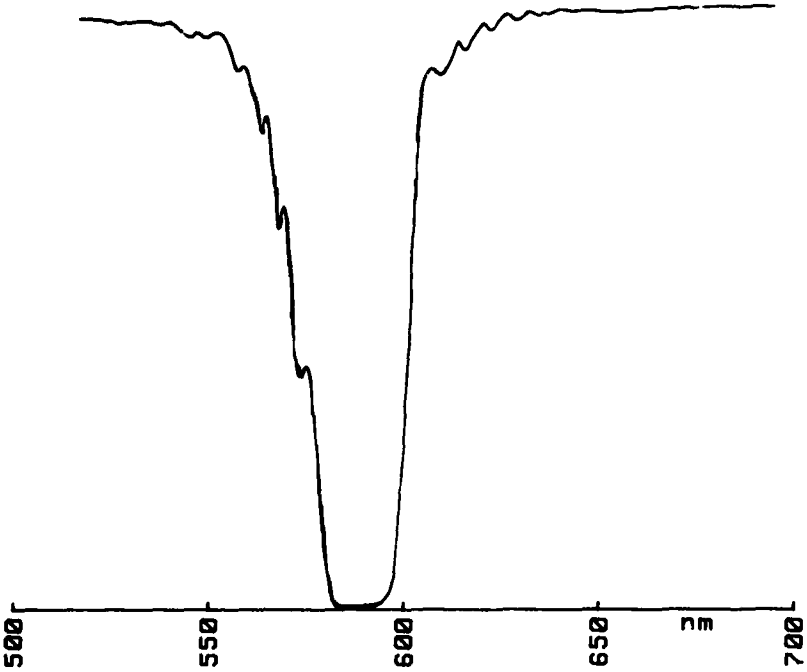
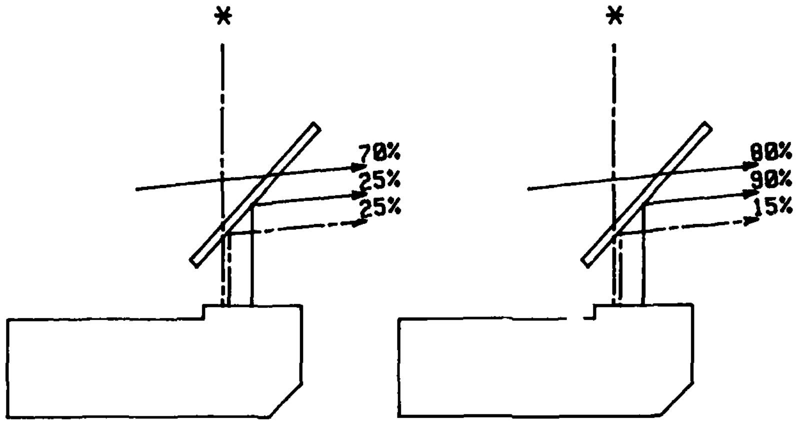


Figure 6 Transmission (typical)



(a) Conventional (b) Holographic

Figure 7 Photometric performance

WIDE FIELD OF VIEW HEAD-UP DISPLAYS

by

J. R. Banbury

Flight Systems Department
Royal Aircraft Establishment
Farnborough, Hants, UK

SUMMARY

The head-up displays currently fitted to production aircraft have a restricted field of view caused by the relatively small diameter of the collimating optics. There is a growing interest in alternative designs which make a greater field of view available to the pilot.

Several possible design options for achieving a wide field are outlined. The new methods usually rely on the properties of diffractive optical elements to achieve a satisfactory performance with respect to accuracy, photometric efficiency and sunlight rejection. Some advantages arising from the particular characteristics of diffractive elements are considered.

Most wide field of view displays are of the 'projected porthole' type, *ie* the exit pupil of the system is not within the equipment but is instead projected to the observer's eye position. Definitions of the instantaneous and total fields of view are discussed and compared with those for the conventional head-up display.

As wide field of view displays become more readily available it is important to establish whether the additional cost and bulk of the equipment is justified by gains in operational efficiency. The paper concludes by outlining some possible uses of the larger field.

1 INTRODUCTION

The importance of the head-up display in a military aircraft cockpit has increased steadily over the past fifteen years. It is an extension of the earlier gun-sight concept, providing greater flexibility and accuracy in weapon aiming whilst at the same time giving essential flight data and thereby reducing the need for constant checks on 'head-down' cockpit instruments. The head-up display has proved its value especially for times of high stress and high work-load, for high-speed low-level flight and for precision weapon-aiming, to such an extent that it has now become an essential part of the modern fighter aircraft. For the ground attack rôle the head-up display gives vital assistance to the pilot both at the delivery point and in maintaining a flight profile which provides the best chance of survival on the outward and return journeys.

Another factor contributing to the relevance of the head-up display in determining overall aircraft capability is the growing need for all-weather, twenty-four hour operation. The display is very convenient for presentation of both cueing information and full pictorial images from electronic sensors such as FLIR, LLTV and radar equipment carried by the aircraft.

Against this background the head-up display fitted to production aircraft has a rather restricted field of view, and there is a growing interest in alternative designs which make a greater field available to the pilot. The purpose of this paper is to discuss in general terms some of the main implications of a significant increase in this field of view, not the least of these being the distinctions which should be drawn to avoid confusion in the interpretation of display specifications.

2 FIELD OF VIEW LIMITATIONS IN CURRENT HEAD-UP DISPLAYS

The starting point for discussion is the conventional head-up display in almost universal use at present, represented diagrammatically in Fig 1a. The field of view instantaneously available, *ie* without head movement by the observer, is limited by a 'porthole' which is the image of the collimating optics in the plane combiner. This gives rise to the well-known shape of instantaneous field shown in Fig 1b. The larger total field is accessible either by head movement or by sliding of the combiner in the fore-aft direction. The display has been considered in some detail by Chorley (1974).

An improvement in the vertical instantaneous field is obtainable by using a dual combiner as shown in Fig 2. Here two portholes are generated one above the other by reflection of the collimating optics in the two separate combiners (Fig 2a). The upper porthole appears smaller because it is further from the observer, and the net extension of instantaneous field is shown in Fig 2b. This simple expedient reduces the need for vertical head movement or changes in the axial position of the combiner assembly in order to gain access to the total available field. However it is achieved at the expense of a complex monocular/binocular changeover within the field and a problem of grading reflectance in the central region of combiner overlap. The overlap can only be correct for one head level in the vertical plane.

Referring to Fig 1, there are two definitions used for field of view specifications. These are:

(i) the total field of view (TFOV) available when transverse head movement or longitudinal combiner movement is allowed, and

(ii) the instantaneous field of view (IFOV) available from a fixed head position.

The values of TFOV and IFOV for a given equipment clearly depend on the distance from the observer to the HUD combiner; this is dictated by the ejection and crash clearance constraints of the particular cockpit into which the equipment is installed. It is usual to specify the fields of view achieved for observation from a particular position described as the 'design eye' for the cockpit.

The TFOV limit comes from the cathode-ray-tube screen diameter (d_s) and the effective focal length of the collimator (f_c);

$$\mathrm{TFOV} = 2\tan^{-1}\left(\frac{d_s}{2f_c}\right) .$$

The collimator is shown for simplicity as a basic single lens. In practice a multi-element assembly is needed to provide the flat field and angular accuracy required. Examples are given by Freeman (1969) and Chorley (1974).

The IFOV limit comes from the diameter of the collimating optics (D_c) and the distance along the optical axis to the plane of the observer's eyes (ℓ).

$$\mathrm{IFOV}_{\mathrm{elevation}} = 2\tan^{-1}\left(\frac{D_c}{2\ell}\right) .$$

The shape of the field comes from the use of two separated eyes and the definition therefore assumes that either eye may be used to provide a contribution to the instantaneous field. This is a satisfactory assumption for most observers, although it is worth noting that some individuals have one strongly dominant eye and will therefore not necessarily see equally well the extra field associated with the other eye. This situation is aggravated when the display is used for TV raster images at night, since the brain is presented with conflicting information from two eyes which normally provide the same data from a slightly different perspective.

Fig 3 shows ray diagrams for the conventional head-up display with a straightened optical axis, to simplify representation of the field of view definitions for the azimuth direction and to facilitate comparison with the projected-porthole displays discussed in section 4.

$$\mathrm{IFOV}_{\mathrm{azimuth}} = 2\tan^{-1}\left(\frac{D_c + d_e}{2\ell}\right) .$$

Apart from the increasing need for a larger field of view, there is some advantage if all or most of the field is available to both eyes simultaneously. A third definition applicable to head-up displays is therefore the overlapping binocular instantaneous field of view (BIFOV) visible to both eyes from the plane containing the 'design eye' position.

$$\mathrm{BIFOV} = 2\tan^{-1}\left(\frac{D_c - d_e}{2\ell}\right) .$$

The eye separation (d_e) produces an increase in $\mathrm{IFOV}_{\mathrm{azimuth}}$ and a decrease in $\mathrm{IFOV}_{\mathrm{binocular}}$ when compared with the value achieved in elevation. It will be evident from the small size of the shaded areas in Figs 1b and 2b that the BIFOV has little useful relevance to the conventional type of HUD.

When considering quoted numerical values it is important to remember the shape of the available field. Typical figures would be a TFOV of 25 degrees and an IFOV of 18 degrees in azimuth by 10 degrees in elevation, but these are peak values and can be misleading for practical use of moving symbology because the limits of the field are made up from overlapping circles.

3 ACHIEVEMENT OF A WIDE FIELD OF VIEW

It seems appropriate to consider meeting the need for a wider field by increasing the size of the collimating optics. This has indeed been done in some cases, up to a diameter of 200 and even 250 mm. Unfortunately the benefit from this approach is limited because a larger (and much heavier) unit must be mounted with the combiner further from the pilot in order to satisfy the cockpit restrictions and carry the weight on rigid mountings to maintain accuracy. As the size of the collimating element increases it becomes advantageous to use a mirror for the collimator, indeed there is something to be said for integrating the function of combiner and collimator within a single element. This is the off-axis mirror approach discussed later.

When a large field of view is specified, straightforward line-of-sight geometry leads immediately to a need for the minimum possible spacing between collimator, combiner and observer. Given the crash clearance and ejection requirements in a fighter aircraft, at least one and possibly two or more large optical elements are required and the problem centres around finding methods to fold up a compact system which is capable of high accuracy, high brightness and efficient sun rejection together with moderate cost and minimum weight. It is important to achieve a good 'look-up' angle with respect to the longitudinal flight datum (LFD) of the aircraft, as well as sufficient 'look-down' over the nose. The problem is complicated by the fact that current aircraft windscreen and canopy positions were determined without allowing for the installation of wide FOV head-up displays.

It is well known that the need to achieve full visibility against bright backgrounds involves running the display cathode-ray-tube at very high levels, close to the limit of currently available phosphors. Energy considerations dictate that, for a given emission of light from the CRT screen in terms of photons per unit solid angle, achievement of a wider field of view must involve either more efficient light collection - resulting in a smaller f-number for the display optics - or a limitation of the exit pupil volume within which the display can be viewed. If it is required in addition that the angular resolution and accuracy shall be maintained despite the increase in total field, then a considerable improvement in the performance of the various components of the head-up display is needed. The better specification must be achieved without an excessive increase in weight or cost, and within the installation constraints of the aircraft. Since a good design will produce an improvement in operational effectiveness, which in turn will increase the percentage of successful missions, it is not easy to place a fixed limit on the permissible weight and cost. However, these considerations will form an important part of any comparison between the various design options available.

4 'PROJECTED-PORTHOLE' HEAD-UP DISPLAYS

This title is useful because it covers a series of new head-up displays which are collectively intended to offer a greater field of view and particularly a major increase in IFOV. The displays have a number of common features; it is convenient to consider these before describing several methods for practical implementation of the basic principles. In Fig 3 the standard head-up display is redrawn with the folding mirror and combiner eliminated so as to reduce the diagram to basic functional elements along a straight optical axis. The TFOV and IFOV limits have already been defined and may be compared with those for the family of 'projected-porthole' displays represented by Figs 4 and 5.

The key characteristic of the new displays is the use of two distinct optical elements. In Fig 4 a relay lens L_r forms a real intermediate image of the cathode-ray-tube screen at the focal plane of the collimating lens L_c , and sample ray paths are shown for light refracted by L_c which is subsequently collimated before reaching the observer's eyes. The insertion of a relay lens increases the flexibility of practical design by allowing a magnification factor (which may be greater or less than unity) between the CRT and intermediate image planes, and by permitting a real aerial image at the focal plane of the collimator instead of a solid object. It will be seen in section 6 that good use is made of these features in the various practical arrangements for head-up displays.

Another property of the basic optical system is the concentration of output light rays through a common exit pupil for all field angles. With a given CRT screen size, this allows a large instantaneous field to be observed from within a relatively small pupil volume (shown shaded in Fig 4), by comparison with the conventional HUD which gives a small instantaneous field observable from a relatively large volume. These characteristics are consistent with the basic energy principle mentioned in section 3.

The apparent brightness of the final image at infinity is not affected by the addition of a relay lens (apart from the small transmission losses), because there is no diffusing screen at the intermediate image. Use of a diffusing screen in the intermediate image plane would increase the size of the region within which the display could be viewed, since the aperture of the relay lens would no longer limit the exit pupil, but the display brightness would be reduced in relation to the amount by which the cross-sectional area of the viewing volume increased. This option is not available since the cathode-ray-tube already has to operate near the brightness limit of available phosphors in order to ensure a display visible under all ambient lighting conditions.

Fig 4a shows how the size of the exit pupil is related to the effective relay lens aperture diameter and its magnification by the collimating lens into the exit pupil plane. A high magnification factor (ℓ/s) provides a large exit pupil for a given size and weight of relay lens. However, there is a conflict of interest because this is achieved either by a long exit pupil to collimator spacing (increased ℓ), which reduces the field of view for a given collimator diameter, or by strengthening the optical power of the relay and the collimator (reduced spacing s), which increases the system aberrations. It will therefore be evident that design of a practical system must be a compromise between the various parameters of the specification, strongly influenced by the detailed geometry of the aircraft into which it will be installed. Two basic conditions are always satisfied:

(i) the intermediate image must be located in the focal plane of the collimator, in order to achieve a collimated display;

(ii) the exit pupil and relay lens aperture planes are conjugate with respect to the collimator.

Definitions for TFOV, IFOV and BIFOV can now be established by reference to Figs 4 and 5. The rays drawn in Fig 4a demonstrate the instantaneous field of view in elevation which can be seen from an observer's eye placed anywhere within the diamond-shaped exit pupil (shown shaded), of maximum height d_p given by

$$d_p = \frac{\ell}{s} D_r \quad ,$$

where D_r = relay lens aperture diameter.
The instantaneous field of view is

$$\mathrm{IFOV}_{\text{full exit pupil}} = 2 \tan^{-1}\left(\frac{D_c - d_p}{2\ell}\right) .$$

By comparison with the above, Fig 4b indicates the larger IFOV available from the centre of the exit pupil:

$$\mathrm{IFOV}_{\text{pupil centre}} = 2 \tan^{-1}\left(\frac{D_c}{2\ell}\right)$$

which is equivalent to the value quoted in section 2 for the conventional HUD. The ray diagram shows that the volume of the exit pupil within which the whole of this increased IFOV can be observed is substantially reduced and slightly displaced in the forward direction. This occurs because the diameter of the collimator (D_c) is insufficient to pass the whole beam of rays leaving the relay lens at the larger field angle, as demonstrated by the dotted rays in the diagram.

It is important to draw a clear distinction between the two quite different values of IFOV when discussing the field of view achievable from a given HUD design and geometrical installation. The maximum useful field for dynamic symbology will in practice lie between these two limits. An observer trying to maintain a central position under conditions of high vibration (*eg* buffeting in low-level, high-speed flight) would be able to use an elevation field appropriate to vertical head movement of the order of ±10 to ±20 mm within the pupil, depending on the amplitude and frequency distribution of the vibration encountered.

Fig 4c shows the ray for the lower field limit visible from the top of the exit pupil, and the ray for the upper field limit visible from the bottom of the pupil. The angle between these two rays is the total field (TFOV) available when head movement is allowed in the exit pupil plane.

$$\mathrm{TFOV} = 2 \tan^{-1}\left(\frac{Md_s}{2f_c}\right)$$

where $M = \dfrac{d_i}{d_s}$.

The fields of view in azimuth are shown by Fig 5. Rays are drawn in Fig 5a for IFOV and BIFOV limits visible from any head position such that both eyes are within the shaded exit pupil volume.

$$\mathrm{IFOV}_{\text{azimuth}} = 2 \tan^{-1}\left(\frac{D_c - d_p + 2d_e}{2\ell}\right)$$

$$\mathrm{BIFOV} = 2 \tan^{-1}\left(\frac{D_c - d_p}{2\ell}\right) \quad .$$

Fig 5b is drawn for the special case in which two eyes are placed symmetrically about the central optical axis and located in the exit pupil plane. Larger values of IFOV and BIFOV are available:

$$\mathrm{IFOV}_{\text{azimuth}} = 2 \tan^{-1}\left(\frac{D_c + d_e}{2\ell}\right)$$

$$\mathrm{BIFOV} = 2 \tan^{-1}\left(\frac{D_c - d_e}{2\ell}\right) \quad .$$

These are equivalent to the values obtained in section 2. Once again there is an important difference between the field visible from a fixed central head position and the smaller field which remains visible at all times with a reasonable amount of head movement. Only data contained within the latter field limits is immediately accessible without the need for a deliberate extra head movement by the observer.

It should be noted that all the field of view expressions given above are related to the spacing ℓ between collimator and exit pupil plane. However, it is clear from Fig 4a that where considerable axial head movement is anticipated it will be advantangeous to place the exit pupil plane forward of the 'design eye' position, to make best use of the diamond-shaped pupil volume. In this case the display field of view specifications referred to the 'design eye' position will of course be less than those referred to the exit pupil plane.

The diagrams discussed above have shown the general principles common to the various types of projected-porthole display in terms of a basic system on a straight optical axis, thereby providing a convenient comparison with the conventional HUD similarly represented in Fig 3. There are a number of options for practical realisation of a projected-porthole HUD. In addition to the possibilities for insertion of plane mirrors to fold the optical axis, either or both of the basic optical elements L_c, L_r can be transmissive or reflective components. However, weight considerations usually dictate that the large collimator required for a wide field of view should be a reflective element. At least one multi-element sub-assembly (usually for L_r) is needed to provide satisfactory correction of optical aberrations to achieve the accuracy and flat field required for the collimated image.

The field of view equations show that whereas the TFOV achieved is dependent on the CRT screen size and the collimator focal length, the IFOV values are directly related to the collimator dimensions. Therefore it is the IFOV, and particularly the BIFOV, which show a major increase by comparison with the conventional HUD. The greater optical and geometrical design flexibility provided by the use of a relay lens and a mirror collimator generally allows for a substantial increase in the ratio $D_c/2\ell$ within the practical constraints of an aircraft cockpit. The extent of the improvement which can be obtained is illustrated by the typical field values given in Fig 6. Continuous lines on the diagram show the limits of the instantaneous field (IFOV) which can be seen using two (separated) eyes, whereas the region within the dotted lines represents the field of view visible simultaneously to both eyes (BIFOV). The larger field is for a projected-porthole display, the smaller central field being typical of a conventional HUD as shown in Fig 1. The precise performance achieved depends of course on the details of the installation and on the specific type of projected-porthole HUD chosen.

5 THE USE OF DIFFRACTIVE OPTICS

Diffractive optics is a relatively recent technology which has generated considerable interest because it offers several advantages when applied to the problems of wide field of view HUD. Since the subject has been covered in a separate paper (Swift 1982) this section is restricted to a short discussion of the properties which are of most interest for the present application.

The active part of a diffractive optical element is a thin film, typically 5-20 μm thick, which is usually sealed between glass plates and contains an array of fringes recorded by holographic techniques. Dichromated gelatin is currently used because it exhibits very low scattering and absorption of light, resulting in a virtually transparent optical element. Diffraction of light occurs as it passes through the fringe pattern of alternating high and low refractive index material.

At the present time only mirror elements are employed for the HUD application and the characteristics of most interest are:

(i) high transmission over most of the visible band;

(ii) high reflectance within a narrow band of wavelengths matched to the display light.

The diffractive element exhibits a very sharply defined transmission curve with wavelength, as shown in Fig 7, and there is a corresponding narrow band reflection characteristic in which the peak can approach 100% if required. The reflection efficiency depends on the film thickness and the ratio of maximum to minimum refractive index for the fringes within the material. (Kogelnik 1969, McCauley *et al* 1973). The steeply-sided changeover from transmission to reflection at the sides of the reflective passband enables the diffractive element to provide a highly efficient mirror characteristic over the chosen bandwidth whilst at the same time allowing high photometric transmission with the minimum of colouration. When applied to a HUD combiner, on either a plane or a curved substrate, this gives an almost ideal overlay of narrow-band display light onto an outside scene. Indeed the performance can be so good that some designs of HUDs are now possible in which more than one element is interposed between the observer and the outside world, resulting in very efficient folding of the display optical axis to produce a compact system. Examples will be seen in the next section.

A further benefit offered by diffractive elements is the increased number of variables available for correction of optical aberrations. All optical systems exhibit greater aberrations as the field of view is increased, and for a precision collimated display methods must be found for controlling them to within an acceptable level. Some designs, especially where there is a significant off-axis angle at the collimator on the central axis of the display, have inherently high basic aberrations and the use of a diffractive collimator can be of major assistance in these cases. The extra variables available concern the two construction beams employed to expose a diffractive collimator; either or both beams may be deliberately aberrated to give partial compensation for the subsequent 'replay' aberrations of the element when it is used to collimate narrow band light for the HUD. (Au *et al* 1976, 1978.)

It might be expected that the new technique would bring problems as well as advantages and this is indeed correct. The objective in devising new display designs is always to make best use of the benefits whilst avoiding serious penalties from the associated disadvantages. With diffractive elements there are two major sources of difficulty:

(i) multiple solutions of the diffraction equation for zero, ±1 and higher orders;

(ii) strong angular dispersion with wavelength whenever the property of ray deviation by diffraction is used.

In the HUD case multiple solutions of the diffraction equation may cause secondary images, usually uncollimated. Practical designs either ensure that the unwanted diffraction orders are not visible under the conditions of display operation or alternatively use special cases in which they are exactly overlaid. Angular dispersion with wavelength is a serious limitation which precludes the use of some otherwise interesting designs; narrow-band operation is obviously helpful and it is worth noting that the problem is absent for the special cases in which the diffraction orders all coincide.

A brief comment on terminology may be helpful to those not closely associated with diffractive optics. This title is used to avoid any easy confusion with conventional holography and holograms. A diffractive optical element is made by holographic techniques, *ie* the fringes by which it operates are produced through interference between coherent light beams from a common laser source. It is sometimes referred to as a holographic optical element. This is a correct description because the diffractive element can be considered as a hologram of a point source, which will subsequently deviate any incident light beam on 'replay' in accordance with the diffraction equation. However, it is a special case in holography; the element contains only information about its own optical properties within the recorded fringe pattern, and it requires an external object source before an image containing data can be produced in the form of a display. It is for this reason that a distinction is made from the conventional hologram, which contains a latent image often with three-dimensional information. The terms diffractive optics, diffractive mirror, diffractive lens, etc, are therefore a better description of optical elements made by this technique.

6 EXAMPLES OF DESIGN OPTIONS

The foregoing discussion has followed a general approach to the basic principles of conventional and projected-porthole displays. It has been stated that the latter type has the important advantages of greater instantaneous field of view and geometrical design flexibility appropriate to the problem of installing wide field of view collimated displays within a restricted aircraft cockpit. This section provides a brief description of four different methods for practical realisation of the projected-porthole display. These are intended only as examples from a longer list of possibilities; the first two are currently offered commercially and the others are included because they have characteristics which can be of particular interest depending on the application. No specific titles are used here and the description therefore refers to types A, B, C, D (Fig 8).

Type A differs from B, C and D in two main respects:

(i) the functions of combiner and collimator are performed by a single large optical element;

(ii) the centre-line of the display has a substantial off-axis incidence angle at the collimator.

The collimator can be a diffractive mirror used in conjunction with a CRT having a narrow-band phosphor emission, to achieve a major improvement in photometric efficiency when compared with the conventional HUD (Fig 1). It is also possible to reduce optical errors by using aberrated construction beams for exposure of the diffractive mirror, as discussed in the previous section. A HUD using this principle has been described elsewhere. (Lewis *et al*, Au *et al* 1978.)

Types B, C and D have a much smaller off-axis incidence angle at the collimator and are therefore often referred to as 'quasi-axial'. The small off-axis angle is used to achieve high photometric efficiency with diffractive optical elements by exploiting the shift of peak reflectance wavelength with incidence angle. The collimator and combiner are separated, tilted with respect to each other and tuned such that narrow band light from the CRT reaches each element at the correct angle for high reflectance. At the same time the outside scene can be viewed without significant colouration because only a narrow bandwidth of the transmitted light is lost at each reflector. Type B has been described by Berry and Byrd (1981), Hussey (1981).

The main features of the four examples are shown in Fig 8. The diagram is not to scale and is intended only to indicate the broad principles of operation. It will be seen that types A and D have one large optical element in the field of view, whereas B and C each have two. The intermediate image positions are quite different in relation to the forward view of the observer and are located progressively higher in the order A, C, B, D. All types have some good features for which the relative importance depends on the application. Type C, for instance, has a major sun reflection off the sloping combiner into the observer's eyes. It is therefore unsuitable for an open cockpit, in the form shown here, but can nevertheless give a particularly good look-up angle and may therefore be of interest where overhead sunlight is not encountered. This is typical of the many trade-off considerations relevant to design of a practical display.

The IFOV, BIFOV and TFOV limits were discussed in section 4 for the whole family of projected-porthole displays and made no allowance for additional vignetting which might be caused by folding mirrors forming an essential part of a particular practical arrangement. It will be seen from Fig 8 that the designs employ various folding techniques which affect the detailed field limitations in different ways. Such considerations are outside the scope of this paper. The main limitation likely to apply to all types is that the full intermediate image size appropriate to the maximum possible TFOV as defined earlier will be inconveniently (and unnecessarily) large. It would therefore normally be deliberately restricted in order to obtain the optimum overall display specification within the geometrical constraints.

7 USES OF THE LARGER FIELD

It has been shown that methods exist to increase the field of view for HUDs. The improvement involves a larger, heavier and more costly display so it is natural to consider whether the better specification is really needed for operational sorties in military aircraft.

The potential value of a larger field can be considered separately under the broad headings (a) overlay of symbology onto the actual outside world and (b) presentation of a collimated display against a dark background. The first case usually involves cursive (stroke-written) symbols, some having calibrated movements which must be matched as accurately as possible to the view of the real world. The second case concerns a TV raster image with electronically superimposed symbology, where precise absolute accuracy may be less important although little deviation from a 1:1 angular representation is possible without disorientation problems for the aircraft pilot. The division of functions is roughly a day/night distinction except that (a) is sometimes useful at night, for example in connection with identifiable illuminated landmarks.

Three examples will be mentioned for the direct-overlay (daytime) case:

(i) off-axis target acquisition and weapon aiming;

(ii) navigation way-point fixing;

(iii) data presentation outside the normal eye-scan pattern.

A greater field of view offers clear advantages for (i) and (ii), but in some circumstances these advantages will only be fully realised if there is no degradation of absolute system accuracy, in relation to values now achieved within the smaller field of conventional HUDs. With regard to (iii), it is likely that some additional data would help to ease pilot work-load if kept clear of the central eye-scan pattern to avoid excessive display clutter. Possible examples are barometric setting, weapon status and various warnings. The extra photometric efficiency realised by a system using diffractive optics is an important factor in maintaining adequate display luminance if a higher writing speed is used to provide more information spread over a larger field.

Operation of the HUD with a TV raster display from FLIR or LLTV sensors is relevant to low-level flight, navigation and target acquisition at night. A large instantaneous field of view reduces the need for pilot head movement and improves performance if the system angular resolution is maintained. However the correct trade-off is less obvious if only the overall picture quality is retained, *ie* if the angular resolution is degraded directly as the field of view increases. Therefore the full potential benefit depends to some extent on possible improvements in sensor resolution. One point which can be emphasised is the importance of a good instantaneous field of view in elevation as the aircraft banks into low-level turns. In this situation the 'look-up' angle achieved above LFD becomes critical to performance. With existing FLIR/LLTV sensors there is sufficient resolution to make good use of all the increased IFOV in elevation which is offered by current projected-porthole displays. The availability of a binocular azimuth field (BIFOV) comparable with the IFOV in elevation means that the pilot can see all or most of the raster display with both eyes without leaning forward. The greater instantaneous field of view is particularly appropriate in high-performance aircraft where the pilot is tightly strapped into his seat to cope with high-g manoeuvres.

8 CONCLUSIONS

Several HUDs are now available which offer a larger total field of view and a much greater instantaneous field (both IFOV and BIFOV). These displays also achieve a significant increase in photometric efficiency when compared with conventional and dual combiner HUDs. Consequent improvements in operational performance are expected both in daytime (cursive) and nighttime (raster) operation. The new HUDs have been made practicable by continuing advances in diffractive optics technology, optical design techniques and cathode-ray-tube performance.

The basic principles of projected-porthole displays have been discussed, with associated field of view definitions and four examples of methods for practical realisation in the compact form needed to suit the geometrical constraints of a military aircraft. The displays all have a limited exit pupil volume which should be carefully positioned and of adequate size to allow reasonable pilot head movement without loss of the display. However, the overall accuracy is reduced as the exit pupil is made larger; good optical design is therefore essential to achieve the best performance. It has been shown that description of the field of view is more complex than for a conventional HUD, and specifically that it may be referred to the exit pupil or the 'design eye' position which may not be coplanar. Care is therefore needed when comparing the specifications of different systems.

The best design for a particular purpose depends very much on the requirements of the user and the constraints of the installation. It is likely that there will be a progressively greater interest in the capabilities of these new wide field of view HUDs, with initial application most appropriate to fighter aircraft fitted with the more sophisticated modern electronic facilities.

REFERENCES

1 A. Au, A. Graube and L.G. Cook, Holographic lens for pilot's head-up display, final report for Naval Air Development Centre, Phase 3, Contract No.N62269-75-C-0299 (1976)

2 A. Au, A. Graube and L.G. Cook, Holographic lens for pilot's head-up display, final report for Naval Air Development Centre, Phase 4, Contract No.N62269-76-C-0188 (1978)

3 R.L. Berry and J.C. Byrd, Proceedings of IEEE National Aerospace and Electronics Conference (NAECON), Dayton, May 19-21, pp 1261-1268 (1981)

4 R.A. Chorley, Head-up display optics, AGARD lecture series number 71, Optoelectronics (1974)

5 M.H. Freeman, Head-up displays - A review, Optics Technology, 63-70 (1969)

6 M.H. Freeman, Head-up displays - Part 2, Optics Technology, 175-182 (1969)

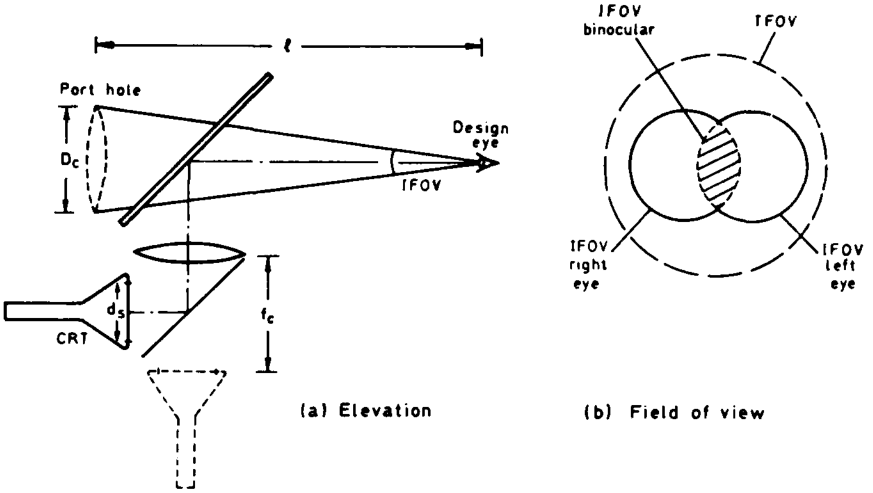
7 D.W. Hussey, Wide angle raster head-up display design and application to future single-seat fighters, AGARD Avionics Panel 42nd Symposium, Aghios-Andreas, Greece (1981)

8 H. Kogelnik, Bell Syst. Tech. Journal, 48, 9, 2909-2947 (1969)

9 W.N. Lewis, *et al*, Trade-off study for a head-up display in new technologies, final report for Naval Air Development Centre, Contract No.N62269-76-C-0231 (1977)

10 D.G. McCauley, C.E. Simpson and W.J. Murbach, Applied Optics, 12, 2, 232-242 (1973)

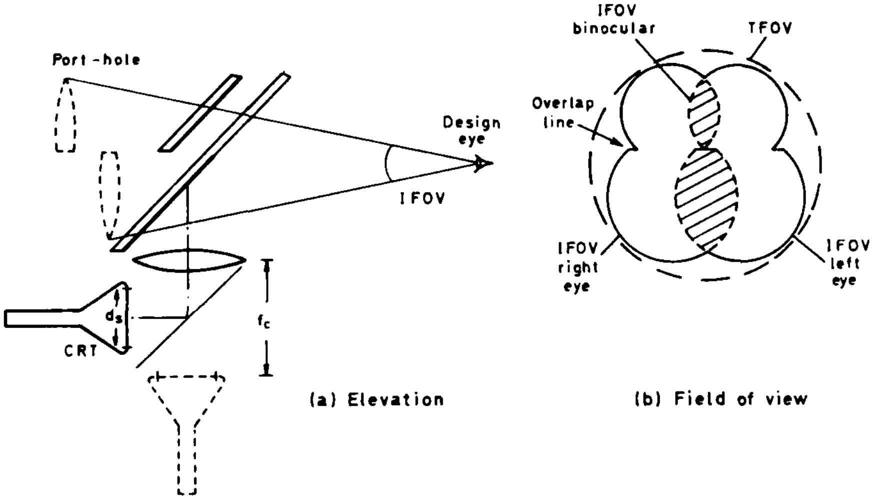
11 D.W. Swift, Diffractive optics for avionic displays, AGARD, ibid. (1982)



(a) Elevation

(b) Field of view

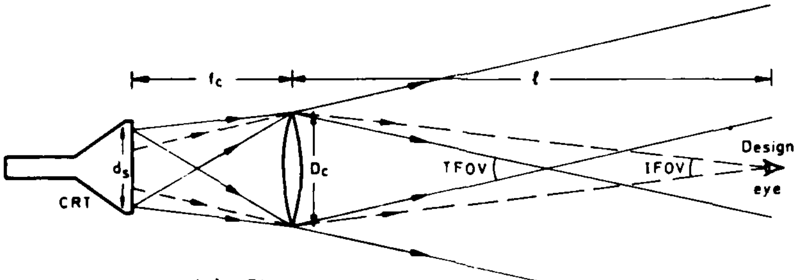
Fig 1 CONVENTIONAL HEAD-UP DISPLAY



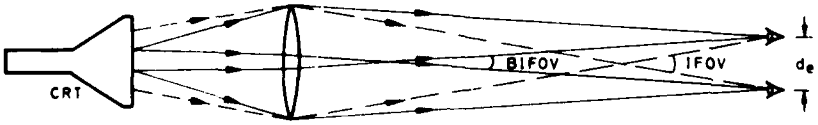
(a) Elevation

(b) Field of view

Fig 2 DUAL COMBINER HEAD-UP DISPLAY

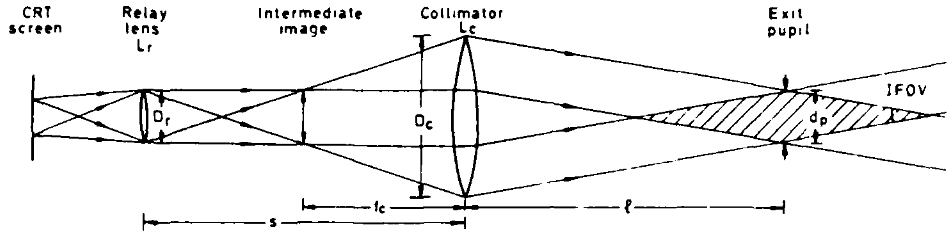


(a) Elevation

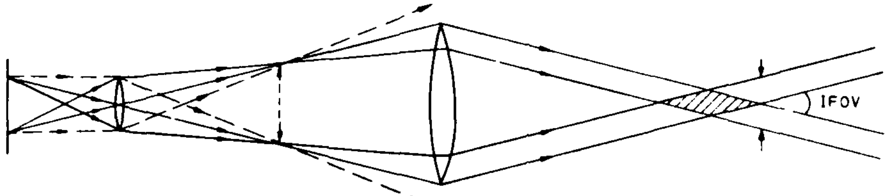


(b) Azimuth

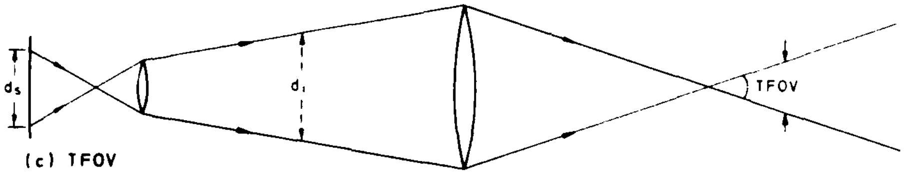
Fig 3 CONVENTIONAL HUD - STRAIGHTENED OPTICAL AXIS



(a) IFOV (full exit pupil)

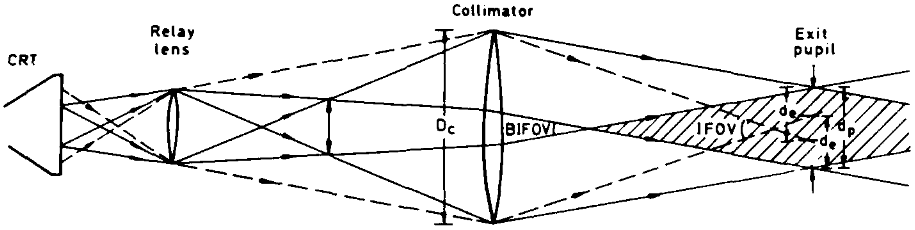


(b) IFOV (pupil centre)

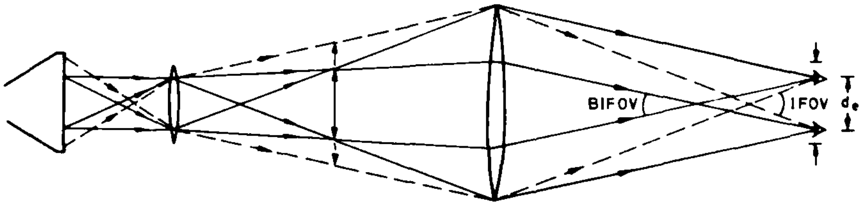


(c) TFOV

Fig 4 PROJECTED PORT-HOLE DISPLAY-FOV IN ELEVATION



(a) IFOV and BIFOV (full exit pupil)



(b) IFOV and BIFOV (eyes centred in exit pupil)

Fig 5 PROJECTED PORT-HOLE DISPLAY - FOV IN AZIMUTH

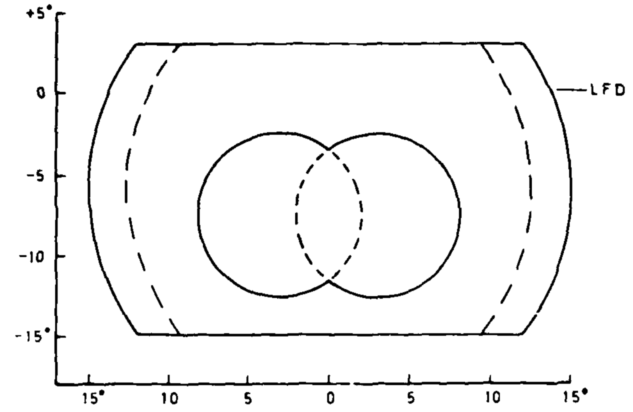


Fig 6 COMPARISON OF HUD INSTANTANEOUS FIELDS OF VIEW

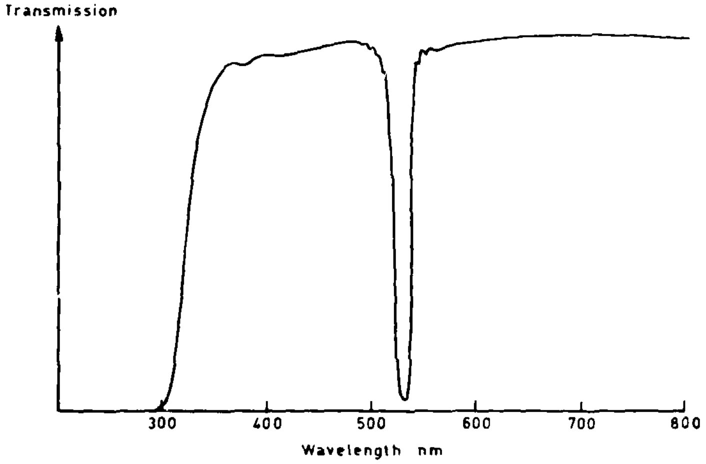


Fig 7 TRANSMISSION CHARACTERISTIC FOR A TYPICAL NARROW-BAND COMBINER

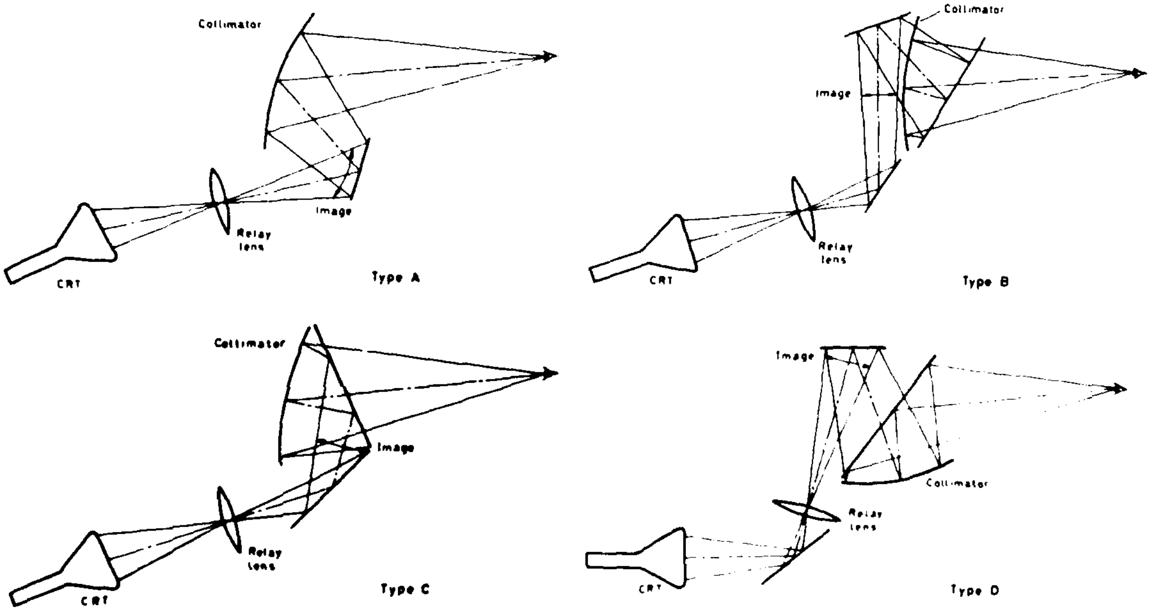


Fig 8 SOME PROJECTED-PORTHOLE HUD DESIGN OPTIONS

THE F18 HORIZONTAL INDICATOR
OPTICAL SYSTEM

Alan Boot
Ferranti plc
EDINBURGH
EH4 4AD
Scotland

SUMMARY

The design of cockpit displays which are both visible in sunlight, and which whilst visible at night do not significantly interfere with the pilot's normal night time operation present the designer with a significant challenge.

Such a display is the Combined Map and Electronic Display (COMED) which functions as the Horizontal Indicator (HI) in the U.S. Navy F18 Aircraft.

This paper outlines the operational environment and the optical performance requirements of the F18 HI, and the technical solutions which have been adopted in order to satisfy these requirements.

In particular, the means of combining the Map and CRT images and achieving intrinsically high brightness, contrast and resolution figures are discussed, as is the mechanism for generating the accurately controlled exit pupil which impacts significantly on both the high and low ambient illumination performance. The use of lightweight fresnel lenses and the associated problems which have been encountered are also highlighted.

In conclusion, a comparison is drawn between the achievable performance with this and alternative display systems.

1. INTRODUCTION

The operational desirability of a map display in many types of aircraft is now an established fact, as is evidenced by its appearance in their operational requirements. However, although general pilot and navigator acceptance has led to this continuing requirement their acceptance is not without criticism. In particular there have been residual problems at both ends of this illumination spectrum. At the high end, not only do operators have readability problems associated with contrast degredation when direct sunlight falls onto the display, they also have problems when the sun shines directly into their eyes.

At the other end of the spectrum when the cockpit is close to complete darkness, a map display which either floods it with light or generates multiple reflections from the canopy will for operational reasons have to be switched off, thus rendering it useless.

In order to solve these problems it is essential to design a display which has high brightness, high contrast and high resolution in the daytime and a very low level of luminance with an accurately controlled exit pupil, which results in neither cockpit flooding nor reflections, at night time.

The following discussion is weighted towards those features of a Field Lens Viewing System which contribute towards meeting these requirements.

2. THE FIELD LENS VIEWING SYSTEM

A diagramatic representation of a field lens viewing system for a map display is shown in fig. 1. It comprises:-

An Intermediate Map Image: this is usually generated by projecting an image from a 35mm film onto an Imaging Screen.

A Relay Lens: it is the function of the Relay Lens to project the Intermediate Map Image into the plane of the Field Lens at the chosen magnification (2-3X).

A Field Lens: the Field Lens creates an image of the Relay Lens in the plane of the observer's eyes.

An Exit Pupil: the Exit Pupil is the image of the Relay Lens in the plane of the observer's eyes which is created by the Field Lens.

2.1. Operation and Advantages

The operation and main advantages of a field lens viewing system are as follows.

In a normal projection system, the percieved luminance of a display will be inversely proportional to the square of the magnification. Thus, for a comparable size of final image, the intermediate map image will be between four and nine times as bright (for viewing system magnifications of 2X and 3X respectively) as a simple rear projection system. This intrinsically high luminance, which is NOT reduced by the further magnification in the field lens viewing system, is essential if a high final luminance is to be achieved whilst at the same time some of the luminance is to be traded off in the interest of other parameters.

Similar advantages exist in the case of a cathode ray tube: suppose for example that the Intermediate Map Imaging Screen is replaced by a CRT and the perceived performance of this tube is compared with that of a full sized tube or, in the case where the final requirement is a combined map and CRT image, with a rear port tube. Apart from the fact that the electron geometry will be somewhat easier with a small tube, for an equivalent drive power more than twice the luminance will be achieved than with a full sized tube and in the case of a full sized rear port tube which will not have aluminising on the rear of the phosphor this value will exceed four times.

On the minus side, it should be noted that the map image resolution, CRT line width and positioning accuracy all degrade linearly with respect to the viewing system magnification.

2.2. The Relay Lens

Examination of Field Lens Viewing System Diagram in fig. 1. reveals that the size of the Exit Pupil is related to the diameter of the Relay Lens. Thus, not only is it necessary to choose a focal length which will generate the map image in the Field Lens at the correct magnification, it is also necessary to choose a diameter (and have relative aperture) which will generate the required size of the exit pupil. Tentative calculations on a system of this type, say a 30" viewing distance, an 8" diameter exit pupil and a 7" diameter Field Lens together with a sensible distance between the Map Image and the Field Lens, produce some horrific figures for the Relay Lens numerical aperture and field angle. However, further examination of fig. 1 will reveal the observer's eyes in the exit pupil: it will be recognised that an image of these eyes will be generated in the relay lens by the field lens. It is in fact only these two small zones within the Relay Lens which are used at any one time by an observer in inspecting the final image in the Field Lens. Thus, although there is a requirement for a very large numerical aperture and field angle for the Relay Lens, it is the resolution over these small zones and not the overall resolution which has to be high. In fact it is relatively easy to design a lens which is diffraction limited for the eye image zones: what is more difficult, and what are the limiting factors in the Relay Lens design, is the control of field curvature, distortion and changes in perceived distortion from one eye to the other and with head movement. The design of this lens therefore departs somewhat from normal classical requirements, its weighting being more akin to that used in satisfying the parallax parameters which are used to define a Head Up Display Objective performance.

2.3. The Field Lens

The use of a Field Lens in the plane of the final image to guide the image forming rays of light into the Exit Pupil rather than using a diffuse scattering screen has a number of significant advantages.

As has already been noted, the intrinsic luminance of the final image is high: this would be degraded by a scattering screen as also would the contrast when ambient light fell on to this screen. As it is, the high luminance is not degraded, and any ambient light falling on the Field Lens and final image passes straight through them without degrading the contrast, and strikes the inside of the optical system. Examination of the viewing system diagram shows that all ambient light (with the exception of that passing through the Exit Pupil) will strike the cone joining the Field Lens and Relay Lens where it will be absorbed by the matt black surface which is designed into the system. Ambient light which passes through the Exit Pupil can reach the Intermediate Map Image; however since the observer's head will normally fill this pupil, the illumination at the imaging screen from this source will be low.

2.4. The Exit Pupil

From the previous paragraph, it is clear that the diameter of the Exit Pupil should be chosen to give maximum head movement (the final image cannot be seen from outside the pupil) whilst at the same time not making it so large that rays of ambient light (e.g. direct sunlight) can enter the Exit Pupil and Field Lens alongside the observer's head and degrade the contrast.

It will be appreciated that the foregoing description of a Field Lens System is somewhat simplified and that it has avoided addressing a number of intrinsic problems. The following section which describes a practical combined map and cathode ray tube display in detail identifies these problems and the solutions which can be adopted to overcome them.

3. COMED - A PRACTICAL COMBINED MAP AND ELECTRONIC DISPLAY

The Optical System of a combined map and electronic display can be considered in two parts, the Projection Optics and the Viewing Optics. The projection optical system and the viewing system are shown in figs. 2 and 3 respectively.

3.1. The Projection Optics

It is the function of the projection optics to produce a high luminance, high contrast, high resolution image of a 35mm colour microtransparency on the map imaging screen at the appropriate magnification. Further, in order to achieve even luminance of the final image, it is essential that the that the light leaving the map imaging screen should be directed into the entrance pupil of the viewing optics.

In order to meet these requirements certain basic optical design features must be incorporated into the projection optics. These features which include a narrow angle throw and a large numerical aperture projection system are highlighted in the following description.

3.1.1. The Condenser and Reflector

It is the function of the reflector and condenser to collect as much light as can be possibly used and to project this through the film to form an image of the filament in the entrance pupil of the projection lens.

It is worth commenting that oversize condensers which illuminate unwanted parts of the film or overfill the projection lens entrance pupil are a waste of time. In order to achieve optimum performance the working numerical aperture and focal length of the Condenser/Reflector system should be carefully matched to the projection lens and techniques which enhance the peripheral illumination of the film image should if possible be incorporated to offset the normal edge "transmission" fall off encountered in the projection lens. The use of selective dielectric coatings and heat absorbant glass is of course mandatory if temperature rises in the film are to be avoided.

3.1.2. The Film Gate

The glass gate in fig. 2 is conspicuous by its absence. It is of course well known that the absence of this gate enables a very high film slew speed to be achieved. In addition however film gate reflections, which could be just one more of the small factors which would reduce the overall contrast, are also avoided.

3.1.3. The Projection Lens

The narrow angle projection lens is designed with as large a numerical aperature as is practicable. This tends to be something of a delicate balancing exercise between available diameter, depth of focus, number of elements (offsets contrast) tolerance on magnification and so on. In addition to these considerations particular attention has to be paid in the final design to the use of anti-reflection coatings and to the internal structure of the lens if contrast is to be maximised.

3.1.4. The Deflection Mirror

It is almost inevitable that folding will have to take place between the projection lens and the map imaging screen. Advantage must be taken of this fact in the optical design to produce a mirror housing which is under the control of the optical designer. In this way a housing which incorporates light baffles which will absorb stray light rather than being surrounded by electronic components which will reflect the stray light can be produced and again degradation in contrast will be avoided.

The use of an overcoated silver deflection mirror will give a better performance than overcoated aluminium.

3.1.5. The Map Imaging Screen

Although a narrow angle projection lens has been used, inspection of the viewing optics shows that there is still quite a large angle between the direction of an incident ray at the edge of the map imaging screen and the direction of the centre of the relay lens group of elements. The requirement for the light to be directed from the imaging screen into the centre of the viewing optics entrance pupil in order to give an even final image luminance can be met by impressing a fresnel lens onto the map's imaging screen. From a fresnel lens design point of view the better side of the screen for this is the one adjacent to the projection lens. This is perhaps somewhat fortunate in that not only are the fresnel rings diffused by the scattering surface on the visible side of the screen but also specular reflections of the CRT from the fresnel facets which may have occurred will not be present.

Although the imaging surface of the screen is chosen for its high gain, high resolution and high contrast characteristics, there is a significant area magnification by the viewing optics, and the screen structure and scintillations become apparent. This is overcome by vibrating the screen in a circular motion in its own plane, which gives a significant improvement not only in the screen structure but also in suppressing the residual fresnel ring structure.

3.2. The Viewing Optics

Having arranged for a bright high contrast, high resolution map image at the map imaging screen from which the light is travelling into the centre of the viewing optics entrance pupil, and having installed a bright flat faced cathode ray tube as is shown in fig. 3, it is the function of the viewing optics to combine these two images to produce a final image with a linear magnification of 2-3X in the plane of the Field Lens.

Comparison of the integrated practical Field Lens Viewing system components which are all mounted on a single housing (see fig. 3) with the diagramatic representation in fig. 1 reveals considerable additional complexity. The reasons for this will become apparent in the following description.

3.2.1. The Field Flattening Elements

Adjacent to both the map imaging screen and the CRT are a pair of field flattening lens elements. In the diagramatic system (from which these components are omitted) the final image, as seen from the exit pupil, would tend to curve away from the observer rather like the surface of a sphere. It is the primary function of the field flattening elements to counteract this effect to produce a relatively flat final image. (Similar lens groups are found adjacent to the CRT in wide angle Head Up Displays where they ensure accurate collimation of the off axis image.)

3.2.2. The Combining Pellicle

Between the two field flattening lens groups is a pellicle beam splitter (combiner). This thin taut membrain has a neutral dielectric (low loss) coating and is positioned such that an observer looking into the system will see at the field lens, the map image superimposed on the cathode ray tube display. The use of a pellicle for this purpose avoids the problems of astigmatism which are experienced with a thin glass plate. It also avoids the complexities of a double glass plate with the beam splitting coating between which, whilst not actually avoiding astigmatism, introduces similar amounts into each channel with the result that differential parallax for horizontal and vertical head motion is eliminated. Perhaps a word of warning should be sounded concerning most commercially available pellicles: these are made from cellulose nitrate which apart from being flammable, will relax their tension in the presence of many solvent vapours. This may not be picked up using the normal lists of contaminants quoted in MIL SPECS.

3.2.3. The Relay Lens

The major lens group (the relay lens) which follows the pellicle is organised in two parts and uses a retrofocus construction. This is to say that there is a negative group spaced off in front of the main lens. The reason for this is to increase the intrinsic air gap between the relay lens and the CRT and map imaging screen such that there is sufficient space for the introduction of both the field flattening elements and the pellicle. As was noted in the discussion of the simple field lens viewing system, it is the diameter of the pupil of the relay lens which defines the size of the exit pupil. Thus, as the diameter of the exit pupil increases, so does the diameter and complexity of the relay lens. In fact, in this case even with a retrofocus construction, the rear air gap is not really large enough. As a result, it is necessary to truncate the rear elements of the relay lens in the vertical direction which, however, only results in a reduction in height of the exit pupil. This maintains the full flexibility of head movement in the horizontal direction, prevents the ingress of light over the observer's head and as the seat height is normally adjustable, does not prove an inconvenience in the vertical direction.

As with all other glass components in the system, each element has a high efficiency anti-reflection coating in the interest of achieving maximum contrast. In addition, all the metalwork on the inside of the viewing optics housing is carefully designed and surface treated to avoid reflections and the consequential contrast reduction.

3.2.4. The Field Lens Assembly

The final component in the Viewing Optics Housing is the Field Lens Assembly. This assembly comprises, a fresnel field lens, a prismatic lifter and a contrast enhancement pack.

In order to achieve accurate control over this formation of the exit pupil, it is necessary to match the fresnel design to the characteristics of the relay lens. The choice of a fresnel for this purpose may seem sensible in view of the weight saving which can be achieved when compared with a solid glass or plastic field lens. However, there are disadvantages - reflections from the fresnel facets and diffusion from the peaks and troughs present problems - but the overwhelming reason for choosing a fresnel lens is that a solid lens is not practicable; the required numerical aperture is just not achievable with normal lenses. Thus, having chosen a fresnel lens, extreme care has to be exercised in the choice of draft angles in cutting the outer facets if reflections and double images are to be avoided. However, it is possible to design a lens, and with some difficulty fabricate the diamond tooling necessary for its manufacture.

It will be noted from fig. 3 that the exit pupil is not in line with the viewing system optical axis: this is a positive choice and not an installation requirement. The plane glass outer surface of the display is coated with a high efficiency anti-reflection coating. However, even with today's advanced coating technology the reflection coefficient will be such that under some circumstances the operator would be able to see reflections of himself, his seat, or the sky behind, if this surface were normal to his line of view. It is much better to lift the optical axis so that he "sees" a reflection of his hopefully darkly clad chest. This deflection is achieved by the same process as is used in the fresnel lens; the ruling of suitably profiled horizontal grooves. Care has to be taken in the choice of draft angles and the relative and absolute spatial frequency of these grooves and those of the fresnel if spurious exit pupils and Moiré interference are to be avoided, and resolution and contrast are not to be seriously impaired.

The obvious choice for the contrast enhancement pack is a circularly polarised laminate with an anti-reflection coated front surface. However, all is not that simple.

It is well known that light from quartz halogen projection lamps is significantly polarised and moreover that a mirror such as the dielectric pellicle mirror will introduce further polarisation.

If the fresnel lens and prismatic lifter were made from an acrylic material (which is quite normal) all would be well. However, acrylic components will not always satisfy the environmental conditions of all operational requirements. Thus, in conditions where very high temperatures are met the stresses set up between the acrylic components and their anti-reflection coatings can cause buckling. In this case a high temperature alternative material is required. Polycarbonate is almost the only choice. Unfortunately polycarbonates exhibit a marked degree of optical activity when stressed The result is that the linear polariser in the contrast enhancement pack functions as an analyser and multi-coloured stress profile images are produced. The processing and precautions which can be introduced to remove the stresses in these components are to no avail as the first minor temperature excursion will re-introduce stresses and the consequential stress patterns.

Since the function of the contrast enhancement pack is to suppress reflections from already anti-reflection coated components, the use of a neutral density filter affords sufficient if not the maximum achievable reflection suppression under these circumstances.

4. PERFORMANCE SUMMARY

In the preceding discussions the values of the performance parameters of the COMED system described have not been quantified, rather the features which affect these parameters have been identified. In addition not only have the intrinsic features of the field lens viewing system, which have the potential of satisfying the design requirements, been highlighted, mention has been made of the problems which have to be solved and the care and attention to design detail which is necessary if optimum performance is to be achieved.

It will have been recognised for example, that much of the intrinsic high brightness of the system will have been lost at the pellicle combiner and at the contrast enhancement pack and that continuous attention has been paid to maximising contrast within the display.

The following summary indicates the typical performance outcome together with some of the component parameters for a design exercise of this type.

4.1. System Parameters

Projection Lamp - 12 volts 50 watts
Overall Map Image - Magnification 15X
Relay Lens - FO.8 75°
Fresnel Field Lens - FO.56 7" diagonal
Prismatic Lifter Angle - 12°
Exit Pupil Size - >9" wide x 7" high
Map Display Luminance - ~ 1000 foot lamberts
Contrast viewed from exit pupil with display surrounded by a hemispherical source with 10,000 ft lamberts luminance 10:1
Spurious Exit Pupils from which light can strike instruments or canopy <1% primary pupil

5. CONCLUSIONS

The COMED Optical System which has been described and the accompanying performance parameters show that it is possible to a large degree to overcome some of the residual problems with combined map and electronic display viewability in both high and low ambient illumination conditions.

Whilst simple map displays with diffusing screens can achieve the same or even higher luminance figures (with 100 watt lamps) the achievable contrast under these circumstances is poor. Thus although they solve to a similar extent to COMED the accommodation problem when the sunlight is in the operator's eyes, they cannot compete when directly illuminated. In addition of course they cannot offer the electronic display facility.

Where rear port combined CRT displays are concerned both the contrast and the luminance are intrinsically low and neither the direct illumination nor the accommodation problem is solved.

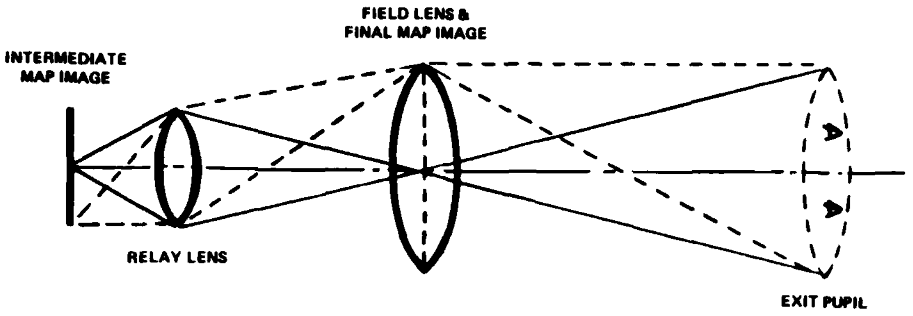
Under very low ambient conditions the COMED configuration ensures that substantially all the light from the display passes through the exit pupil: there is very little 'stray' light which can illuminate instrument panels or cause reflections from the canopy. In addition, by the simple expedient of leaning slightly forward the operator can move his head out of the exit pupil (with knowledge that a very subdued image is immediately available should he require it) and he can scan the night sky with no cockpit generated light to impede his vision. The illumination of cockpit instruments and the luminance of reflections from the canopy from either a simple map display or a rear port CRT display are orders higher than with COMED. Under these conditions, low level accommodation and outside observation are virtually impossible with the display switched on. The result is that such a display is switched off and the instant (at a glance) orientation facility which can be offered under extremely low ambient conditions without substantial loss of low level accommodation by the Field Lens System Exit Pupil is lost.

ACKNOWLEDGEMENT

In achieving the extreme performance parameters of this optical system, credit has to be given to the optical designers and engineers of Pilkington P. E., without whose expertise and tolerance, the successful realisation of the optical design concept would not have been possible.

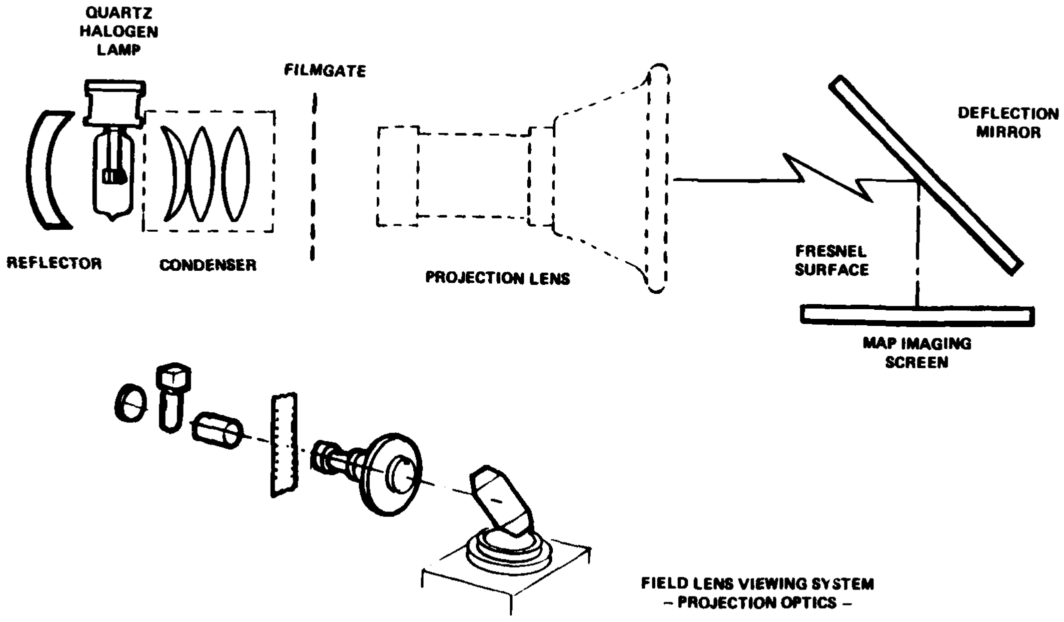
REFERENCE

Norrie, D. G. Optics Systems for use in Map and Cathode Ray Tube Displays. International Lens Design Conference Procedings. S.P.I.E. Vol. 237, pp. 524 - 529. Oakland, California, 1980.



FIELD LENS VIEWING SYSTEM

FIG 1



FIELD LENS VIEWING SYSTEM
– PROJECTION OPTICS –

FIG 2

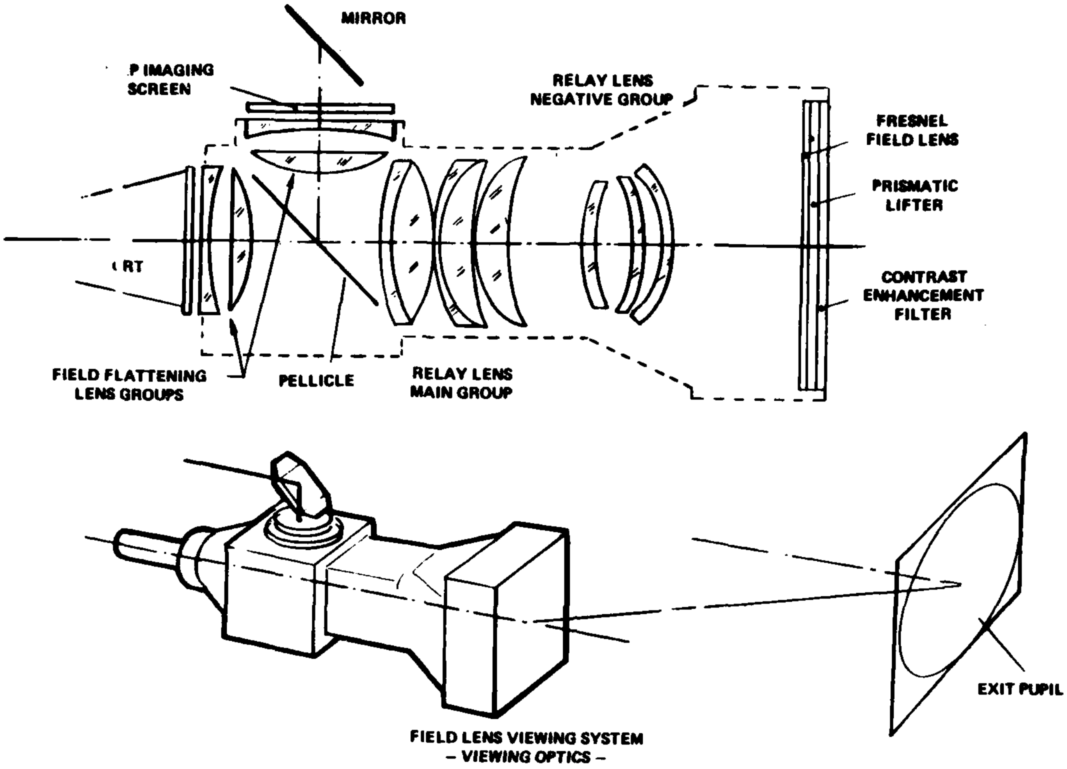

MIRROR
P IMAGING SCREEN
RELAY LENS NEGATIVE GROUP
FRESNEL FIELD LENS
PRISMATIC LIFTER
CRT
CONTRAST ENHANCEMENT FILTER
FIELD FLATTENING LENS GROUPS
PELLICLE
RELAY LENS MAIN GROUP
EXIT PUPIL
FIELD LENS VIEWING SYSTEM
– VIEWING OPTICS –

FIG 3

DISCUSSION AVIONICS PANEL SPRING MEETING
On
ADVANCED AVIONICS AND THE MILITARY AIRCRAFT MAN/MACHINE INTERFACE
26-29 April, 1982

SESSION Nr. 5 DISPLAY TECHNOLOGY Chmn F. Stringer, UK

Paper Nr. 26
Title : LIMITING PERFORMANCE OF THE EYE, DISPLAY SYSTEM
Author : Prof. Ir. D. Bosman
Speaker : J. Walraven
Comment : I guess that one of the main demands you require for a display is that you meet the requirements for visual acuity of the eye. I guess you would strive for resolution of the order of 60 cycles per degree. You can probably do better than that actually with displays now-days. But I just wonder whether it still might be useful to strive for that, because we don't have to think only about visual acuity which is a matter of resolution, but also the ability of the eye to make very fine discrimination between adjacent lines which are a little bit offset. It is the reason why we used to use slide rules with fairly good accuracy. I think this is a general problem with display where you are often doing a sighting problem where you have a Reference of say cross-hairs on a target, and in that case you need a very high resolution to really utilize what the eye can do. Do you agree to that?

Response : Yes, I agree under photopic conditions. The eye can do much more, maybe ten times better, than is suggested by the 60 cycles per degree limit. However, this is very variable under luminance conditions and in the case of night flying you need a size of markings of at least three minutes of arc, which is much worse than the vernier resolution that you just mentioned.

Paper Nr. 29
Title : ELECTROLUMINESCENT LIGHTING & OTHER TECHNIQUES FOR IMPROVING NIGHT VISION GOGGLES COMPATABILITY WITH COCKPIT DISPLAYS
Author : Dr. H. L. Task, L. L. Griffin, presented by tape, responses by Dr. Reising
Speaker : J. Bagge
Comment : I would like to know if there has been any problem in getting this special equipment, especially the louvres to do this experiment from the manufacturers?
Response : Well they were able to obtain the equipment for this experiment of course, and are now in the process of equipping some special operations aircraft with this technique. But I do not know how many aircraft we are talking about, so I don't know how easy it would be to obtain these louvres on a wide production basis.

Paper Nr. 29
Title : ELECTROLUMINESCENT LIGHTING & OTHER TECHNIQUES FOR IMPROVING NIGHT VISION GOGGLES COMPATABILITY WITH COCKPIT DISPLAYS
Author : Dr. H. L. Task, L. L. Griffin, presented by tape, responses by Dr. Reising
Speaker : A. Boot
Comment : Do I detect necessity taking precedence over Mil Specs; the louvre filter material with which I think I am familiar will not meet the high temperature requirements, of the normal Mil Specs; for the type of aircraft which are under discussion.

Response : Well one of the problems was that it seemed to melt a little when it was put on, so maybe the specs were right. I guess when you have airplanes which operate in a very special environment such as that one did, you try whatever techniques you can. That was an experiment and based on that they are considering modifying the louvres or increasing the spec. You are absolutely right, there was a problem with that.

Paper Nr. 30
Title : THE HELMET-MOUNTED HUD: A CHANGE IN DESIGN AND APPLICATIONS APPROACH FOR HELMET-MOUNTED DISPLAYS
Author : J Bridenbaugh, Wm Kama, Dr H. L. Task, taped presentation, Dr. Reising responding to questions.
Speaker : R. Collinson
Comment : I think the phrase is "deja vu". We produced a device called "Pipelight" for the RAE about three years ago. It was identical, the problems we encountered were with the cost and the weight of the bundle. Certainly with a smaller bundle you are there.

Paper Nr. 30
Title : THE HELMET-MOUNTED HUD: A CHANGE IN DESIGN AND APPLICATIONS APPROACH FOR HELMET-MOUNTED DISPLAYS
Author : J Bridenbaugh, Wm Kama, Dr H. L. Task, taped presentation, Dr. Reising responding to questions.
Speaker : Dr. G. Hunt
Comment : It seems to me that the problem of making a satisfactory helmet mounted display can be essentially divided into two parts. The first part is to get a satisfactory image on an image plane mounted somewhere on the helmet. The second problem is to project that image on a second image plane out at infinity, and having whatever field of view you need for your application. The fiber optic bundle is an attempt to tackle the first problem, but in my view it is the second problem which is the more difficult one, that is getting a wide field of view in combination with good eye relief, and keeping the mass of your optical system down to acceptably low levels. This is in fact the reason why the helmet-mounted display manufacturers have found the total problem so difficult, and the reasons why the masses which were shown in the chart were so high. It could be that we need some new optical techniques. One thinks in terms of

DISCUSSION

diffractive optics which is going to be the subject of the next two papers, as one route in this direction. As for solving the problem of getting the image plane up on to the helmet, I would have thought that some of the new miniature flat panel displays as a replacement for the CRT were probably the more profitable route to follow rather than using fiber optic bundles.

Paper Nr. 30
Title : THE HELMET-MOUNTED HUD: A CHANGE IN DESIGN AND APPLICATIONS APPROACH FOR HELMET-MOUNTED DISPLAYS
Author : J Bridenbaugh, Wm Kama, Dr H. L. Task, taped presentation, Dr. Reising responding to questions.
Speaker : J. Laycock
Comment : In both this paper and the paper by Prof. Bosman you placed the emphasis on the spatial resolution of the dot-matrix type presentation of the fiber-optic bundle. In both of these presentations you have neglected to the temporal aspect of vision, where by vibrating the fiber optic bundle you can get increased resolution out of it, by getting the eye to integrate it. Would you like to comment on whether this is feasible in a fiber optic transmission link to a helmet-mounted system and if not, taking Dr. Hunt's suggestion, whether you could incorporate liquid crystal with a spatial shift, by multiplexing the elements, and do all the spatial filtering in the addressing rather than in the optics.

Response : I am not sure about all this, because it is not my area of expertise, however, I would imagine anytime you shake fiber optic bundles it is going to cause fibers to break, that is the big problem. The second thing is on the liquid crystal or any other flat panel device. I have a liquid crystal watch on, and I have been hearing for 10 years now how they are just ready to go into the airplane. I don't see them yet. I don't see any flat panel matrix device. If we had liquid crystals or other flat panel displays, with high resolution, and they would work under all specs, I think we would take them in a minute but, I still don't see them.

Paper Nr. 30
Title : THE HELMET-MOUNTED HUD: A CHANGE IN DESIGN AND APPLICATIONS APPROACH FOR HELMET-MOUNTED DISPLAYS
Author : J Bridenbaugh, Wm Kama, Dr H. L. Task, taped presentation, Dr. Reising responding to questions.
Speaker : F. Stringer
Comment : In partial answer to that, I have flown a helmet display at low level and we had no problem with shaking the thing, although we were shaking severely. One thing I did notice when I flew was that bright background was a problem. It is very good when you look down into dark ground, but if you look into a bright cloud, you start to have difficulties.

Paper Nr. 30
Title : THE HELMET-MOUNTED HUD: A CHANGE IN DESIGN AND APPLICATIONS APPROACH FOR HELMET-MOUNTED DISPLAYS
Author : J Bridenbaugh, Wm Kama, Dr H. L. Task, taped presentation, Dr. Reising responding to questions.
Speaker : R. Collinson
Comment : The point I should have made with "Pipe-light" was it was originally intended for a low light level TV viewing system with a head steered FLIR camera, and in fact the design feature was a 40 degree field of view. All the design objectives of the quality of imaging were maintained, the major problem was just the cost and weight of the fiber bundle.

Response : One thing I wanted to make clear is that when the author was talking about the helmet mounted HUD in this presentation he is backing off from the full video to only symbology, because he thinks with that the lower resolution fiber optics bundles he will be able to cope with symbology. But he is backing off from the big goal of putting sensor video on the helmet.

Paper Nr. 30
Title : THE HELMET-MOUNTED HUD: A CHANGE IN DESIGN AND APPLICATIONS APPROACH FOR HELMET-MOUNTED DISPLAYS
Author : J Bridenbaugh, Wm Kama, Dr H. L. Task, taped presentation, Dr. Reising responding to questions.
Speaker : Prof. D. Bosman
Comment : Have you tried, since you have optics already, to transmit the Fourier transform of the picture and then reconstruct it in the optics.

Response : I don't think so. This was their first series of experiments with these new fiber optics bundles. I am sure they would appreciate having these suggestions because they are planning a full research program, looking at the fiber-optics bundles.

Paper Nr. 30
Title : THE HELMET-MOUNTED HUD: A CHANGE IN DESIGN AND APPLICATIONS APPROACH FOR HELMET-MOUNTED DISPLAYS
Author : J Bridenbaugh, Wm Kama, Dr H. L. Task, taped presentation, Dr. Reising responding to questions.
Speaker : Y. Brault
Comment : I was told by some fighter pilots that in high "g" conditions it is very difficult for the pilot to move the head without having physiological trouble. If this is true, it means that you cannot use the helmet-mounted sight in combat conditions, can you comment on that?

Response : I think the way we would approach that is as follows. I have seen some high "g" seats that have rollers on the back of the seat. You don't have to lift your head up, you would let your head rest on the rollers and roll it.

DISCUSSION

Paper Nr. 30
Title : THE HELMET-MOUNTED HUD: A CHANGE IN DESIGN AND APPLICATIONS APPROACH FOR HELMET-MOUNTED DISPLAYS
Author : J Bridenbaugh, Wm Kama, Dr H. L. Task, taped presentation, Dr. Reising responding to questions.
Speaker : R. G. White
Comment : You talked about the display resolution aspects. I presume you are going to fly this helmet-mounted head-up display in cloud as well as in clear visibility. Have you given any thought to the accuracy of the helmet position sensing device, and the response time of the system for up-dating the attitude presentation? Are you satisfied that you are not going to induce disorientation effects due to lags and lack of accuracy in this side of your system.

Response : I don't think we will. The next step is to put this in a simulator and start flying it, then we will get a better feel for the lags in the system. But the HUD presentation is only given when the pilot looks at boresight and when the pilot looks off boresight the HUD presentation is not given. Disorientation because of conflicting velocity vectors etc. Will not occur, because it will only be presented in the boresight mode.

Comment : What I was worried about is when you do come back to boresight. If you are doing any form of an up and down scan and you have lags present you can have a problem. We've done some similar work on a simulator, and in one of our exercises we did have serious lags in the simulator system. We ended up with pilots trying to fly the aircraft by moving their heads up and down.

Paper Nr. 30
Title : THE HELMET-MOUNTED HUD: A CHANGE IN DESIGN AND APPLICATIONS APPROACH FOR HELMET-MOUNTED DISPLAYS
Author : J Bridenbaugh, Wm Kama, Dr H. L. Task, taped presentation, Dr. Reising responding to questions.
Speaker : N. Fraser
Comment : Would you like to comment on:
(a) The current techniques for fitting the helmet to the pilot's head.
(b) The physiological difficulties of say an hour and-a half flight.
(c) The current harmonization techniques used.

Response : (a) To my knowledge we have a facility at Wright-Patterson, which basically gets a head mould of the pilot and the interlinings are then designed according to that head mould, so they do fit rather snugly.

(b) If you fly 1.5 hours in a fighter you get tired, there is no question about that. But, I don't think the weight of that fiber optics bundle is going to contribute to it.

(c) There is a technique based on a magnetic sensing technique which seems to be doing very well on helmet-mounted sights.

Paper Nr. 31
Title : DIFFRACTIVE OPTICS IN THE COCKPIT
Author : Dr. D. W. Swift
Speaker : Wg Cdr Scouller
Comment : To what extent do the limits of the pilot's head movement vary, between conventional and diffractive HUD's, in all three planes.

Response : Current diffractive optics HUD designs have a real exit pupil. This imposes a limitation on head movement which is different in nature to, and more stringent than, a conventional HUD. In addition the angular bandwidths of the Holographic Optical Elements impose a further limitation. In general the former effect will limit lateral head movement, and the latter effect will limit vertical head movement. Fore and aft movement is more complicated and causes the display brightness to fall off first at the top and bottom of the field.
Actual values depend upon the precise design, and are among the key performance characteristics which are calculated during the design stages of a diffractive optic HUD. However, with current technology, permissible head movement with a diffractive optic HUD will be considerably less than with a conventional HUD.

Paper Nr. 31
Title : DIFFRACTIVE OPTICS IN THE COCKPIT
Author : Dr. D. W. Swift
Speaker : D. Bosman
Comment : How well can (non)-uniformity of the characteristics of the component be controlled?

Response : There are two aspects to this question. The type of non-uniform element which is needed in HUD designs can be made very conveniently as a HOE; this feature is in fact a major advantage of diffractive optics. The element 'e' in Figure 3, for example, varies in the appropriate manner for viewing from A (or B). On the other hand unwanted non-uniformity can occur unless the process is very closely controlled, and this increases the difficulty of producing high quality elements. With close control, as indicated in Section 4, very uniform elements or elements with precise predetermined non-uniformity can be and are being produced.

Paper Nr. 32
Title : WIDE FIELD OF VIEW HEAD-UP DISPLAY
Author : Dr. J. R. Banbury
Speaker : Wg Cdr Scouller
Comment : To what extent are we likely to be able to use color with the diffractive optics. In

DISCUSSION

particular when do you see the possibility of having two colors available in the HUD.

Response : We are well aware of the interest in color for head-up displays. This will almost certainly come in the future, as the necessary technology is developed, but wide field of view monochrome head-up displays are already available as shown by the commercial designs currently offered.
One of several problems associated with color is the need to correct the optical system for the wavelength to be used, since the full accuracy of a monochrome display would presumably still be required.

Paper Nr. 32
Title : WIDE FIELD OF VIEW HEAD-UP DISPLAY
Author : Dr. J. R. Banbury
Speaker : J. Campbell
Comment : The future promise of diffractive optics with regard to HUDS is being fulfilled and a diffractive optics HUD Type B layout in Dr. Banbury's paper, has now been ordered for a number of aircraft and is providing the benefits of wide Field of View.

Response : I agree that diffractive optics is already providing benefits for wide field-of-view head-up displays.

Paper Nr. 32
Title : WIDE FIELD OF VIEW HEAD-UP DISPLAY
Author : Dr. J. R. Banbury
Speaker : F. Stringer
Comment : Could you comment on displays that require two holograms or two gratings, and on the difficulties of ensuring that they are at a particular angle for a particular job?

Response : I think that Marconi has already answered that, in the fact that they are offering such a display with two combiners at an angle to each other, so we must say that this technology is with us as well. The only time I mentioned the future was in connection with color. I would accept that in monochrome the wide-field of view display is here now. The same goes for the tilted combiners, which I think have been demonstrated to be possible

Paper Nr. 32
Title : WIDE FIELD OF VIEW HEAD-UP DISPLAY
Author : Dr. J. R. Banbury
Speaker : R. A. Chorley
Comment : Would you agree that the greatly increased binocular FOV obtained in pupil forming HUD's is advantageous in ordinary cursive modes as well as raster? Pilots who have experienced these displays seem to find them more compatible to use than types with limited binocular field.

Response : Yes, work on helmet-mounted displays has shown that there is a particular problem with binocular rivalry when different displays are presented to the two eyes. A head-up display with large areas of the available field only seen by one eye or the other can also be uncomfortable. A large binocular field is desirable for the TV raster case, but to a lesser extent it has also been found preferable for cursive display images which contain less data.
In recognizing the beneficial effects of binocular field in head-up displays, it is assumed that the accuracy is sufficient to ensure that the benefits are not obscured by the presence of binocular disparity between the images for the two eyes.

Paper Nr. 27
Title : THE ARCHITECTURE OF HIGH INTEGRITY DISPLAY SYSTEMS
Author : J. A. Grice, G. A. Ward
Speaker : F. Stringer
Comment : (a) What arrangements would you make to prevent common mode failure in the data bus?
(B) In view of ergonomic problems in combat, why bother about arrangements to allow multi-positioning of the displays by the pilot?

Response : (a) The Mil-Std-1553 B Data Bus is a Dual Bus. Each processor has two receivers and two line drivers. There are two sets of wires which can be physically separated. There should always be a reversionary Bus controller when the primary bus controller fails, so for the data bus to fail really means a <u>double failure.</u> In the case of the data bus failure the safety critical subsystems (FCS, Armament, and Gen A/C) would still operate with their own data buses. Displays would be restricted to stand-by instruments. Separate independent external interfaces could be provided as a reversion for essential safety critical data (E.G. IN data to FCS) However these are not included in the system architectures shown and the study so far has been mainly into the Avionics bus and the effect of the different architectures on the bus.
(B) It is my considered opinion that one primary and one reversionary display are sufficient for each format. The discussion on full flexibility was to indicate and highlight the areas of increased complexity within the system as reasons for <u>not</u> providing full flexibility.
Full flexibility would allow different pilots to exercise different preferences, if there were any. But could complicate training.

Paper Nr. 27
Title : THE ARCHITECTURE OF HIGH INTEGRITY DISPLAY SYSTEMS
Author : J. A. Grice, G. A. Ward
Speaker : P. B. Rayner
Comment : Can I advise caution in using very high MTBF assumptions in determining system design, for three reasons :-
1. With high levels of integration the tendency is to ask each box to do more complex

DISCUSSION

tasks so that component counts stay roughly consistent.

2. Boxes will still require power supplies and connectors, whose individual MTBF's are unlikely to improve dramatically.

3. MTBF's in excess of about 5000 hours are likely to be virtually impossible to demonstrate by practical tests.

Response : To some extent I agree with these comments. However the VHSIC program does quote a reliability goal of 20 to 100 times better than present values and there are good technological reasons for the VHSIC micro-chips containing large subsystems to be very reliable. Over 1000 hours MTBF is already being achieved with processors on current A/C. So 20,000 hours MTBF for future processors is reasonable on this basis. Of course the VHSIC goal still remains to be achieved and proved.
It was realized when doing the calculations that the boxes as drawn included everything including connectors and 1553 B interface.
The reliability demonstration for these high MTBF's would obviously take a very long time. The point made in my paper regarding only one failure in the life of the A/C underlines this aspect.

Paper Nr. 27
Title : THE ARCHITECTURE OF HIGH INTEGRITY DISPLAY SYSTEMS
Author : J. A. Grice, G. A. Ward
Speaker : R. Seifert
Comment : (a) As I understand it, you assume having one common (dual) data bus for Avionics and FCS only?
(B) If you have additional buses for individual systems, wouldn't that affect the architecture particularly the interface architecture considerably?

Response : (a) No, the FCS can have its own internal subsystem data bus. The FCS interfaces with the rest of the Avionics via the Avionics bus which is a dual data bus.
(B) Not really. How the equipment interfaces within a major subsystem, if it is off the Avionics data bus does not affect the interface with the Avionics data bus very much. The paper attempts to show some of the effects of the different overall systems architecture. The need for additional subsystem buses can be assessed once the overall systems architecture has been decided. I.E. Design is top down, not bottom up.

Paper Nr. 27
Title : THE ARCHITECTURE OF HIGH INTEGRITY DISPLAY SYSTEMS
Author : J. A. Grice, G. A. Ward
Speaker : W. H. McKinlay
Comment : Presumably the first stage in defining a system architecture is the high level functional design taking account among other things of basic data flows, pilot system interactions, sensors, weapons, display needs, etc. It would be interesting to know what high level system design techniques were used or recommended. How would complexity/weight/cost best be reduced.

Response : In this case the system evolved in response to operational requirements of air combat and ground attack in a hostile environment using post systems experience. Since the work was theoretical, we concentrated on the systems architecture of a complex system rather than doing a trade-off or cost-effectiveness study of the different equipments. The assumptions for most of the work were that the equipments included were necessary and would meet the operational performance requirements.
One of the purposes was to look for systems criteria which should be met and system parameters which should be optimized.
Complexity, weight and cost can be reduced by removing some of the less essential equipment and having fewer reversions and hence simpler software.

Paper Nr. 27
Title : THE ARCHITECTURE OF HIGH INTEGRITY DISPLAY SYSTEMS
Author : J. A. Grice, G. A. Ward
Speaker : R. G. White
Comment : One of the advertised advantages of a 1553B data bus is the ability to add new sub-systems easily. How would you add a Direct Voice Input sub-system to your architecture? Would you federate it to the keyboards to minimize bus traffic or could it be interfaced directly with the avionics bus?

Response : The question is an interesting one. When the system was defined it was decided not to include DVI. Having excluded it for the system architecture work the integration of DVI was not really studied in detail. So any ideas presented her are only my initial thoughts.
The general assumption has been that the most promising area to reduce pilot workload is to use DVI instead of an MFK and to initiate moding changes. So broadly speaking the DVI interface should be similar to MFK and Mode Control Panel interfaces. The control panels would also be part of the system for normal back-up which means some centralized co-ordination of mode changes and MFK inputs is needed (probably the bus controller).
The exact interface of DVI might depend on the systems architecture adopted. In the fully federated system DVI would probably interface via the displays processor and not directly with the Avionics bus. Mode changes and destination changes could be transmitted on the bus rather than all the DVI words which would be more efficient (fewer digital words)
In the centralized and semi-federated systems the DVI could go directly onto the 1553B data bus (as shown in paper 13 for the Marconi equipment) and interface with any other terminal on the bus. The digital words (16 data bits) transmitted would have to be interpreted appropriately by the receiver. Care should be taken not to overload the data bus with this method.

DISCUSSION

Paper Nr. 33
Title : THE F-18 HORIZONTAL INDICATOR OPTICAL SYSTEM
Author : A. Boot
Speaker : R. Mac Pherson
Comment : Do you have any vibration problems with your pellicle? In particular do you anticipate any difficulties with the operational vibrational environment?

Response : Whilst acknowledging that the pellicle does have resonant modes, early flight trials to check out actual rather than MIL Spec vibration levels did not visibly excite any of these modes.

Paper Nr. 33
Title : THE F-18 HORIZONTAL INDICATOR OPTICAL SYSTEM
Author : A. Boot
Speaker : M. Gassie
Comment : Est ce qu'il n'aurait pas été plus judicieux, votre système tel que vous l'avez décrit me parait complexe, en effet il y a combiné d'une part d'un système optique relativement complexe et d'un CRT, un CRT que vous n'utilisez que pour produire des symboles.
Est ce qu'il n'aurait pas été plus judicieux d'utiliser uniquement le CRT a la fois pour les symboles et pour présenter une image du film qui est présenté sous forme vidéo.
Est ce qu'il n'aurait pas été possible d'utiliser un film et de le prendre par une camera de vidéo par exemple, la base étant la même au départ, c'est à dire un film de 35 mm et non pas une mémoire numérique.

Response : (a) Data Storage : Electronic data storage systems cannot currently compete with color film as a data storage medium in terms of relative capacity.

(b) Use of color CRT : If the map (filmstrip mechanism) is stored remotely from the cockpit and map data supplied to a color CRT display via a video link we have a nominally viable system. However when the current performance of CRT displays in terms of luminance/contrast/resolution in a high luminance cockpit environment is compared with the performance of a COMED type of display the COMED wins on all counts. It may be that in the future the performance of CRT displays will improve to the point where they are competitive with optically projected map displays. However, there is still a lot of mileage in the COMED system.

Paper Nr. 33
Title : THE F-18 HORIZONTAL INDICATOR OPTICAL SYSTEM
Author : A. Boot
Speaker : R.M. Taylor
Comment : How is dimming achieved, is it continuous to extinction, is there a color temperature change, and how do any changes affect the ability of the operator to discriminate colors in the image at night at low display luminance?

Response : Map dimming is achieved by a combination of a filter >100:1 (with no color shift) and electronic dimming >100:1 (with some color shift) down to a minimum level but not to extinction. With luminous levels of about one foot Lambert, photopic vision is maintained. At extremely low levels, it is not intended that there should be color (or detail) discrimination: the object is pilot re-orientation at a glance.

ROUND TABLE DISCUSSION

AVIONICS PANEL SPRING 1982 MEETING

on

ADVANCED AVIONICS AND THE MILITARY AIRCRAFT MAN/MACHINE INTERFACE

Members

Dr. G. H. Hunt - RAE (Chairman)
Prof. K. H. Doetsch - T. U. Braunschweig
Mr. W. I. McFarlane - BAe, Warton
Mr. T. Sueta - U. S. Army, Fort Monmouth
Col. G. Varin - Centre D'Essais en Vol, Bretigny

Dr. Hunt - We have had four technical sessions, in addition to this Round Table and the Introductory papers. They were devoted to color display, voice interaction, complex systems, and display technologies. The intention of the symposium as I said at the beginning was to discuss each of these topics in some depth, and obviously there are some interactions between them. Nevertheless for the purpose of this round table I plan to initiate discussions on these topics separately. I will ask one of the members to lead off the discussion and then invite inputs from the floor. I think of the four topics voice interaction was perhaps the most controversial. It is certainly the one which is in the earliest phase of development and therefore perhaps there are more questions in peoples minds about its practicability, its virtues, and its cost effectiveness and therefore I propose that this is the one we start off with. I hope we don't get so immersed in it that we crowd out the other sessions. I will ask Mr. McFarlane to start the discussion.

Mr. McFarlane - I was most interested in this session because I am involved in systems and cockpit design. We have been looking forward for some years to being able to take advantage of these systems to simplify our cockpit procedures. However to start some discussion going perhaps I will be somewhat critical of the session as a whole.
First of all I think most of the papers emphasized what DVI (Direct Voice Input) and voice synthesis will do as independent systems. This I believe assumes integrity levels which have not been demonstrated. Therefore our existing warnings, data input systems, and display methods will probably have to be retained as well as DVI and voice synthesis, although there may be some ergonomic relaxation in the design of the other systems. Similarly, warnings by voice could clearly be very powerful indeed, but what happens if the pilot decides to accept an amber warning and continue to fly. How do you keep reminding him that there are limited conditions under which he should fly? Do you not have to continue using the existing display systems? The question I should like to put to you for discussion is this. Is enough being done to integrate and get the best use out of DVI, voice synthesis, and our existing systems and how do we avoid the helmet mounted display system problem which we heard described fairly graphically the other day, saying "We attempted to do to much at the beginning and therefore we have done very little"; are we not in grave danger of doing the same thing with voice?

Col. Varin - I will try to answer this question. First of all, voice is one means of control available to the pilot. Up to now the hands and feet were sufficient to fly the aircraft and use its systems, with the eye remaining the best sensor to monitor the work done either by the pilot or the machine (although we have already used the eye to orientate guns in helicopters). Today the aircraft systems, including the Nav-Attack and ECM especially for single seater fighters, become more and more sophisticated. It tends to increase quite a lot the workload of the crew and makes the design of the cockpit more and more difficult. So it was natural to try to find another means of command to help the pilot when possible and give the possibility of better design of the cockpit.
I would to explain myself on this point as a pilot first, but also as a pilot having been involved in these tests from the very beginning. First, we don't intend to fly the aircraft and control the systems only by use of voice and have our hands remain in our pockets. Second, before deciding that a task should be handled by voice command we have already thought about failure and remote control. In this respect I would even accept having a rather complicated multiplexed box or keyboard situated somewhat poorly in the cockpit which gives me even with some difficulty the possibility of continuing the mission.
From my own experience I can tell you that when flying in bad weather conditions or in a high speed, low level, turbulent situation it is not very easy to look down, to find the right button on a keyboard to press it, and to be sure to have the right function on. Many times I would have been very pleased to remain on the controls looking headup. To come back on the voice command, you must divide the flight into different phases and find out on which ones it is useful, helpful, useless, or impossible to use voice. Secondly in all cases you must have a return of the information requested. We have tried to call up information by voice, such as G-load, altitude, or different flight parameters. This return can be done by the voice itself. We have to retain a remote control exactly as we have maintained secondary flight instruments in spite of head-up and head-down CRT's. It is with this background that tests are done in France. If anyone is interested I can say a few words later on, on how we procede in the simulator at the French Air Test Center, and how we will proceed during in-flight tests in summer of the coming year.

Dr. Hunt - I will now ask for comments from the floor.

Mr. F. S. Stringer - I would like to refer to the question of DVI, and the comment that sometimes we develop systems too rapidly and then find that we have not made much progress at all. I am concerned that with the development of DVI we do look at the total subject. We have to avoid as I have said many times before looking for problems to fit our solutions. I believe one of the important issues in DVI apart from reliability of the system itself is the completion of the loop, and that is an indication to the pilot that the system has interpreted what the pilot intended it should interpret. It is important that the pilot knows that the system has accepted the right message and that he have complete verification quickly without having to revert to the very situation that we are trying to avoid, that is referral to some visual display or head-down position to verify that the loop has been connected completely. If he does that we will have created an even more complex set of avionics and more workload rather than less for the pilot, and inevitably he will say I am going to avoid using one or the other of these systems. Therefore it is absolutely essential that in addition to our attacking the problems of DVI itself, and there are many problems there which I am sure were aired, we must also tackle the problem of verification which is just as important.

Dr. Hunt - I am sure you are right, but it seems you are also posing an additional question effectively. You are hypothesizing a feedback system and saying we have to have good feedback, but what sort of feedback do you think it should be? It should obviously impose minimum workload on the pilot or aircrew, but what should it be, how are you going to get the message back?

Mr. R. G. White - I would like to complicate the questions Mr. Stringer has raised. There is a body of opinion that believes synthetic voice or DVO (Direct Voice Output) is the natural method of feeding back information for DVI systems and it would solve some of the problems that Mr. Stringer has postulated. However I have some worries about this. DVO imposes a short term memory load on the man in a situation where maybe his workload is too high for this to be acceptable. Also in DVO it would be the machine that dictates the timing of the machine-to-man communications. This may take place when it is inconvenient for the pilot. In other words when the machine speaks the man will have to listen and I am not so sure that he will always do that. If you have a visual display as the method of feeding back DVI, then the man can choose the timing of this machine-to-man communication, which in some situations will be better. We come back really to Col. Varin's remark that we have to look at each phase of flight. You will find there are phases of flight where DVO is an acceptable form of feedback and there will be other phases of flight where the helmet-mounted display or the headup display would provide better means of feedback.

Another worry about using DVO as a feedback for DVI is as follows. I think one thing that came out of this conference is that synthetic speech is potentially a very powerful method of warning within the cockpit. I think if we use this medium for feeding back DVI, then we are going to compromise the effectiveness of the medium as a warning.

Col. Varin - I agree. When I was speaking of return, we already have an example. When you change a radio frequency you have to check that you have the proper frequency. Instead of having to turn a switch somewhere and read the frequency it is easier to ask the frequency and read it instead of finding a knob somewhere. When you have headup and you are in an attack-mode, if you request a given armament and you see the display changing to be able to use the armament you have the return automatically. If you ask for a particular bombing mode and see the complete configuration coming on you know that everything is okay. Also for example, if you have a failure, you can have a light coming on for a failure, you have to listen of course, but when something occurs you then have to take your checklist, read it and go through the actions you have to do, but if the voice can say "Okay, you have to do this now" I think it is easier than having to take the book. If you don't want to do the action at that time then that could be a problem and we have to think about it.

Mr. McFarlane - May I ask a question of the flying people in the audience? Although we all accept that voice is a very powerful method of putting warnings into the system, what happens when you get multiple warnings? Will the pilots accept that the designer is going to predetermine the order in which those warnings are going to occur for every phase of flight and every eventuality. We have had desperate trouble in other areas trying to get pilots to accept our predictions of automation, are they going to accept it in direct voice?

Wg. Cdr. D. C. Sculler - The straight answer is "He won't". He will be forced into selectively rejecting bits of information. He will then be faced with the problem of recall of information that he deliberately put into his short term memory, after he has dealt with what he believes to be the more important job. I would like to develop this further, that you should not be talking about direct voice systems in isolation, but it is finding the appropriate mix of tactile, visual, and audio that is required. Our methods up to now (and I am looking back over the whole span of aviation) has been empirical in approach. There probably has not been any better way of doing it. It seems that to find the right way of mixing these things we need to develop something like Broadbent's model, not just as a simple model, but a rather more detailed understanding of the way a pilot flies an airplane. I believe that there are quite significant commonalities in the ways in which people do things, having watched people flying for many years. I suggest that we need in parallel to our empirical work to try to produce a behavior model of the way in which people operate aircraft in the different flight phases. One way of doing it might be to use experienced pilots to break down flight phases into time segments, to describe qualitatively their actions, and then to correlate this with film of their hand and eye movements. With a large enough sample, I suspect the behavioral model could be produced. I am surprised that we have not had more behavioral psychologists here at the conference.

Dr. R. Seifert - Someone has said that with the voice warning system, we might have trouble with the yellow warnings. It is my understanding with the current state-of-the-art we will only use the voice warning with the high priority or red warnings, it would be too much if we used voice for every warning we have in the aircraft. On the other hand, as I understand it in the agreed approach in the literature, we will in any case have redundancy between visual and verbal. In certain phases of flight such as combat the audio may be shut down or loaded by intercommunication, it may even be shut down completely by the pilot. We must differentiate between phases of mission.

Dr. Hunt - Is someone, among the psychologists and human factors experts who Wg Cdr Schuller addressed, bold enough to respond to his plea for a more exact methodological analysis of pilot analysis and pilot behavior?

Dr. Seifert - I think we could do that if someone pays for it. It is a very time consuming and money consuming effort to have a group of pilots flying in an experimental aircraft equipped to record hand and eye movement and doing real air-to-air combat, and then comparing that with the theoretical breakdown into mission function analysis, function elements as we do in weapon systems design already. We can do it theoretically and we prove whether it is right in the simulation and later in flight test, but to do this in real flight testing would be very expensive, about 3 million marks I would say.

Dr. Hunt - I understand what you are saying providing you accept the premise that it is necessary to do it in real flight, but there are presumably degrees of realism in simulation which would at least allow you to make some approach to providing the information that Wg Cdr. Schuller is asking for.

Dr. Seifert - Yes, we could do that, it would be less expensive, but still expensive. At the moment I do not think anyone will pay for that.

Col. Varin - I would like to come back for a while on this alarm problem. I agree that we can't have all the alarm panel backed in voice, the red and amber and so on. We have already checked and tried to find out in all those alarms the ones you can't delay, where you must do something immediately or there will not be time to do it later. For example in CCV aircraft, if you have one or two channel failures in flight control, you have to reduce the flight envelope, you can't maintain in supersonic or at 9 g's for example, you can't delay you must do something. In that case I think it will help you. If it is during combat maneuver when you have no time at all to think what is going on and you are in pursuit, and you have to reduce the flight envelope, in that case you can introduce the voice. Another one is for safety altitude, we have introduced a safety altitude in combat at low level. If you are below this safety altitude which is calculated as a function of your "g" possibility, speed, angle of dive, then a voice says you are approaching your safety altitude. That is why I come back to this stage in flight where you have to cancel a comeback, we have cancelled a lot of things, we are not using the voice at all in close combat, because you have no time to speak, you have something else to do, and you come back to everything having to be done with hands only. But in other phases of flight, I think things are different.

Prof. Doetsch - Its up to a professor of course to call attention to one of the fundamentals in this dispute between Mr. Stringer and his neighbor on voice input and output. Every spoken word has gone and has been spoken, that is true for input as well as for warning as an output. If at the moment it is spoken you are distracted in a situation of high stress, you have lost it forever, whereas in the visual channel you have of course this big documentation which remains there, the switch you have pressed has turned its label on and you have done it. Your return on the indicator digital or otherwise remains for you to check up when you have the time and you are not distracted. I think we should think of that fundamental difference between the oral and the visual channel.

Mr. J. Melocco - I would like to make a comment on your last intervention. I think the problem has already been met in the design of multi-function display. When you change a page on a multifunction display that is it, it is gone, there is no memory there and this is communication between pilot and system. I don't think it would be more difficult with voice input than with the multifunction display.

Dr. Hunt - Can I suggest that you are in fact getting the feedback from your new page of display. I understand perfectly that with a voice input to a display system you will get this feedback, but if your voice input is not to a display then you will not get this feedback.

Mr. Melocco - Yes, all right, but in the alarm warning functions, and I don't think Col. Varin will disagree with what I say, we do not intend to remove the alarm warning Panel. We will retain that indicator, we will use that Panel as a memory for a failure; if the pilot does not have time to absorb an alarm for instance, he will wait, but he will still have the light in front of him, and he will come back to it when he has time to take action. I don't think its a real problem.

Mr. J. R. Costet - Je voudrais un peu commenter cet aspect. En ce qui concerne l'utilisation de ce type de commandes dans le cockpit, nous avons, bien sûr, rencontré ce problème au simulateur, mais cela ne nous a pas empêché de pouvoir simuler et jouer completement des interceptions puisque toutes les commandes utilisées avaient une trace visuelle, si vous voulez, donc il n'a pas été question de basculer des "target switch" par exemple, mais des poussoirs qui étaient allumés, le Col. Varin pourrait préciser cela, si vous le désirez, mais effectivement ce genre de problème doit être regardé avec précaution mais il ne semble pas que technologiquement il y ait de ce point de vue une impossibilité absolue. Pour reprendre la question soulevée par Mr. Stringer, je crois qu'il y a un malentendu qu'il faudrait peut être éviter et nous sommes tous d'accord pour dire qu'il ne faut pas aller trop vite, et ne pas vouloir remplacer, offrir un moyen complet HV permettant de remplacer ce qui existe par une autre chose qui serait supposée meilleure, cela c'est effectivement tres dangereux. La boucle complète d'analyse doit être éffectuée, et nous sommes exactement au moment ou nous entamons cette boucle d'analyse, mais pour cette analyse qui est un travail ergonomique difficile et long et doit etre traité cas par cas, il est nécessaire que les utilisateurs c'est a dire les pilotes et les concepteurs aient une perception commune de la facon dont cela peut marcher dans le detail et dont on a pu discuter de ca autour de simulateurs ou d'essais en vol, mais cela n'est que le debut de la boucle, il faut ensuite, avion par avion et cas par cas, regarder comment on peut abaisser la charge de travail, réduire éventuellement un problème de surface de planche de bord ou d'emplacement de commandes, et rechercher cas par cas le service que peut apporter les commandes à la voix, reboucler et progresser de cette facon; cela peut etre assez long, mais je crois qu'il faut admettre qu'il ne doit pas y avoir, *au moins de la part des concepteurs, d'idées* préconçues définitives au départ, en tout cas chez nous, il n'y en a pas.

Col. Varin - I would like to add something to the one question given a few minutes ago. This was regarding the fact that when you do something with voice you do not know what was on. If you take a new aircraft such as the F-18, which I had a chance to fly, when you change a radio channel by a multiplex keyboard, you look at the channel and in a few seconds it is not indicated anymore. This is the same for VOR or AFF. You always have the possibility to come back and ask what was my frequency, but we already have accepted to not always have a display of all the information. This may be a new way of working with machine but I think it is acceptable.

Dr. Hunt - I would like to turn to Mr. Sueta because he has experience with a somewhat different vehicle, and I think in our minds we are tending to think only of the single-seat combat aircraft, whereas his operation is concerned with multi-crew combat helicopters.

Mr. Sueta - *I couldn't help but think back to when the US Army started to take their helicopters* and bring them down close to the ground in order to avoid air defense. I went along just to find out what that environment was and to find out what instrumentation was critical and needed. So I asked the question of the pilot when we got back on the ground, "What instruments did you look at?" and I had watched him. He never once looked at the instrument panel, his eyes were outside the windscreen. The question we finally ended up with and the only thing that he had time for or that was critical with him was had he lost his engine or had he lost in effect rotor speed so he had no maneuverability. The end result of that was a simple audio warning in the case that he had lost his engine. That was the only instrumentation that we provided him. Now in looking at voice, as Dr. Hunt has said my interest is in helicopters, slow moving close to the ground, moving below the trees sometimes. Frankly I think the role of interactive voice is a very positive one, and what I would propose is very simple, that whatever you can do with a keyboard you can do with voice. Now, I want to make sure we understand I am not talking about safety of flight actions, positive control, but I am talking about all those kinds of actions you perform with a keyboard. In fact what we are trying to do is determine if we can have a one-man crew in a helicopter, and I think it is pretty obvious if he is going to try to fly low, that he cannot have his head down in the cockpit at the same time he is flying low. The role that I would see is to replace the keyboard with those functions that are appropriate. We could perhaps change the way we are thinking of doing business. For example we are now saying we want to communicate. Then in order to communicate we want to first determine what radio do we want to talk on, we have four on some of our helicopters, what channel of the thousands that we have available, are we going to talk on, and I am wondering is that the way we really want to go about our business. Should we not be more natural? If I want to talk to Corn Cob 6, or Devil Dog, or Red Dog or whoever it is, shouldn't the role of interactive voice be that of interpreting the request from the crew to talk to Red Dog 6? His feedback is automatic because now Red Dog 6 will come back to him with a response. (Applause)

Dr. Santucci - Je voudrais ajouter une remarque générale, c'est que la commande vocale est quelque chose de très nouveau dans le monde de l'aéronautique, et on l'étudie avec des pilotes qui ont passé leur carrière à prendre de l'information sous forme visuelle et à répondre sous forme motrice, c'est a dire qu'ils ont au fond d'eux-mêmes, des archétypes qui les incitent à prendre de l'information visuelle et à répondre de façon motrice, aussi, je crois que dans cette commande vocale, il faut peut être se tourner vers d'autres domaines pour voir quelles sont les réactions des gens qui parlent avec une machine, pourquoi vers d'autres domaines? Parceque peut être on peut avoir accès plus rapidement à la formation de ces gens dans ce domaine, puisque chez nous, dans l'aéronautique, il est beaucoup plus long de former un pilote, et il faut bien noter à ce propos là, que nous sommes en train de parler de systèmes qui, lorsqu'ils seront en opération, seront appliqués par des gens qui sont en formation maintenant, dans les écoles, autrement dit, si on peut plus loin dans de concept, introduire la communication verbale avec la machine, il faut peut être très rapidement se retourner vers les écoles de formation pour commencer très tôt à introduire ce système si les problèmes techniques, bien sùr, sont resolus.

Mr. W. M. McKinlay - I believe that practically every new technology that we have had in the cockpit has to some extent misled us and certainly failed to reveal its potential until we have made a major effort to apply it in the full context of a cockpit and an operation and in the right context of time. In other words if voice input is going to be the thing five to ten years from now we should be thinking about what operations, cockpits, and systems, will look like then, not what they look like now. Therefore some of the questions we should be asking are what will the relationship between the man and his systems be then, how much automation will be used in the airplane, will we still be nagging the systems by punching numbers into them the whole time or will we be wishing to get slightly higher level information from them about threats of some kind. Will we be wishing to reprogram them more strategically than tactically, what sort of dialogue are we going to have with our systems? If I can end up, I used to be a navigator, and some of the talk that has been going on here about the relationship between the pilot and the rest of the system reminds me of what life might have been like if we had thought like this about 30 years ago.
We would have equipped the navigator with a keyboard on his back and the pilot would have flown

along alternatively banging numbers in through the keyboard and shouting continuously in both ears of the navigator. In fact, he did not do that, he had an intelligent system and he reprogrammed it in a subtle manner once in a while.

Mr. V. P. Schmit - I think Mr. Sueta has touched on a very useful aspect of DVI which I don't believe has been brought up at the conference. This is a use of a more natural dialogue, not using DVI as a sort of multi-function keyboard alternative, but actually talk to the machine in a more sensible fashion. For instance now perhaps way-points do not have to be identified by numbers. You could actually identify them by geographic locations. This on the other hand presents perhaps even more problems for DVI, given our current technology. Listening to the conference as a total tyro in the DVI-DVO end of the game, it struck me that we have the technology to do the bit that's less important on the shelf right now, ie. the DVI-DVO can be done at present. For the bit that appears to be useful we are subject to considerable constraints. If one goes down the line of natural language with DVI, instead of just treating it as a keyboard alternative the vocabulary that you have to have available for your DVI system will be far in excess of the very restricted vocabularies that people are contemplating at present as an absolute requirement for getting a workable DVI system.

Dr. Hunt - We are in great danger of spending the entire session just on DVI. But there is one area which we have not touched on which we should, just to see if anyone has any comments. This is the question of the accuracy of DVI as an input medium to an Avionics system. People have done experiments with various keyboards and measured a percentage of correct input and they have done the same with DVI. But there are more variables perhaps with DVI, in terms of vocabulary and syntax and so on. Is there anyone working in the equipment side of voice interactive systems who would like to predict the sort of numbers which are likely to be available in terms of this performance accuracy in say the next five or ten years and whether in fact we need to do anything about trying to standardize performance measures, so that when we compare Box A with Box B, the answers are in fact meaningful ones which have general acceptance.

Dr. B. Beek - I will comment on that particular question, but there is something else I am concerned with. Most of the people here seem to be very involved with the ergonomics problems and human behavior factors and they have even coined a new term for what we call voice input systems, they call it DVI. It seems the people who are concerned with avionics approaches have said Okay technologists and speech processor we will take your box and we will coin a new set of words and see how we can use this for our applications." What they have forgotten is that technology which is presently available for voice input systems was not designed for avionics applications; when we designed our systems, we designed them for very high signal-to-noise ratios. When you are talking about cockpit applications you have so many additional complications, for example g-force profiles that we don't know very much about. We know from some tests it does change the voice characteristics, we don't really know how well it works in voice and then you complicate it with oxygen masks that can vibrate as well as breathing, so you have a real problem. So I really caution most of the people here that when you start putting your parameters into the system requirements that you should feed it back to the speech technologists so they can start looking at redesigning their voice input systems to be more applicable to your particular application. Voice input systems have many applications and this is only one of them, this is fairly new and there is a lot of interest now in the United States as well as in Europe.
As far as recognition is concerned I can say generally that whatever recognition you experience in the lab when you take it into the field your recognition rates are going to go down significantly. You have to run experiments into the field. For some reason error rates in the lab are 1 or 2 %, but when you take them into the field they go up to 10 or 20% sometimes. Familiarity with the equipment will help, motivation will help, so at the present time to give you a feeling of where we are I am talking about current systems which are built and already in use (they are all isolated word recognition systems, that is they must have a pause before and after each of the words or special phrases). Such systems work at an error rate of about 2 %. These are for very good systems. The rate is also very dependent on the vocabulary that you pick. If you pick very difficult words where the words are only different by one phonym, error rates are going to increase. It is a function of many different things. We can do a fairly good job at continuous digit recognition now. So I believe that the first system that really should go into this type of application would be one where you might combine isolated word recognition to perform functions and then maybe use it in combination with connected digit recognition. I think in this case we could consider 1 or 2 % error rates, and that in the future they would stay in this range.
Now there are two types of errors to be concerned with. One is an error of rejection, you set threshholds to some degree where the machine cannot make a proper recognition so either the display won't change or an alarm will take place which says try again. The other type of recognition is much more serious. You say one thing and the machine interprets it as something else. That is much more serious and I think the designers of these systems have to understand these types of errors to determine which one they want and possibly when.

Mr. R. Bell - The first problem in predicting performance is one that Dr. Beek just brought up. All testing to date has been on isolated digit recognition and this is one reason we have been very reluctant to release figures, because they don't equate to any other equipment, so you can't draw a parallel. But the first thing I would do is to challenge Dr. Beek slightly on his definition of the two types of errors, because while I agree entirely with the errors versus rejects, I would hesitate to have the machine fire out a warning every time it gets a word which it doesn't recognize, because what is it going to do with all the noises it is getting which is not speech, because it is going to be firing warnings at the pilot all the time. That is what I was hinting at the other day, when I said we must be very careful in feedback not to provide nuisance information to the operator. However going on to the accuracy rates, if you tune up the standard equipment, as far as you can, the best you get is about 98% with reasonable people who are motivated. When you go to a new speaker it is our experience that in the early stages performance is not too impressive and it does drop to about the 80 % level. But a lot of this testing and quoting of figures is based on using recorded references for the sake of commonality so that you can test the machine on the same data and expect to draw some sort of conclusion of one test versus another. But you get a remarkable difference when you put a man in the loop. What you have to remember is that a human being is a very adaptive system, and we don't fully understand how he operates. Pilots are extremely good at this. Perhaps we should not rely on it, but it is certainly to some extent a saving grace in speech recognition. When you put this man in the loop after an initial familiarization period and then retrain him, that is go through the training session again, it is remarkable how the performance levels go up. Now as far as quoting figures for continuous speech recognition, on connected digit recognition again there are problems here, because there are many references where in the digit string the person thinks he said one thing but in fact he said something else. So the he thinks the machine made errors, when in fact it was him who made the error. We have exactly the same problems with keyboards, we have got to be careful here of looking for ways of criticizing the equipment when in fact the equipment is not doing anything wrong at all. That is exactly why we must set down these standard test protocols, so that even if the actual test is a function of the detailed application, the way we are going to go about testing it and how we are going to interpret the results must be laid down.

Dr. Hunt - Since we are going to rapidly run out of time and not get onto any of the other session topics, I will ask if anyone on the round table wants to use a maximum of one minute to say anything more on voice interactive systems.

Mr. Sueta - I foresee the need for a new look at sensors for voice recognition. All the microphones we now have are primarily analogue, trying to work in noise, and I am wondering if there isn't some powerful mechanism in the processing that we have that would allow us to look for different kind of sensors that might help us particularly in the signal-to-noise ratio prior to the recogniton stage.

Prof. Doetsch - I would like to express regret that we did not discuss during the conference in any detail the question of reversionary control. What do we envisage in the way of reversionary control for voice input control? Certainly it lends itself to synchronization. I remember in the early auto-pilot development which I had something to do with, we had to introduce auto trimming and that caused me a lot of headaches because they were apt to run away and be a bigger danger than not having it, and having a jump and the autopilot had to be switched off or shut itself off. That could happen also in reversion from voice command at least on the control side but also in other fields, weapon detection and so on, if we do not slave every knob and every switch that has to be operated in the degraded mode or reversionary mode.

Dr. Hunt - To achieve any sort of balance at all, we must move on. I think it would be nice to maintain a sort of controversial note to our discussions, and perhaps color is the most controversial area of the other subjects we covered in the symposium. Perhaps Prof. Doetsch would like to start?

Prof. Doetsch - I suppose I should, because in my statement in paper number 2 I put down some verbal comments from the last conference which were not carried by the majority of speakers here. It was stated there that color was not helpful when brightness contrast is great, it is beneficial with very small brightness contrast between targets and so on. The practical implication is that in very nice controlled conditions it is good, it is not very good in high performance aircraft maneuvering violently. It is useful on the other hand in transport aircraft with not so violent maneuvering. I found in the conference here that most people were very enthusiastic, my neighbor here as well. The opinion from the last conference it is not necessarily my own. What would be the general feeling here.

Col. Varin - I think I will have to answer first. I will say this just to start the discussion. At the French Aircraft Test Center, in spite of my job of Chief Test Pilot, I am in charge of coordination of the pilots' point of view of Nav and Nav-Attack and cockpit design for military and civil aircraft, in order to use when possible the experience from one to the other. The results of our research and tests on the use of color for both civil and combat aircraft are positive. The best example for the civilian side is the Airbus 310, where the color is largely used on the flight instrument display as well as on the Nav display and system functioning and failure presentation. On combat aircraft the choice of color has already been taken for quite a long time now for the Mirage 2000 air defense and for the nuclear penetration version. On that point of view the color is used in different aspects. I think it is easy with the use of color to tell the pilot that everything is good, green for example, or that a parameter has to be followed because it is approaching a limit, purple or yellow, or when its out, or above the limit, indicated in red for example. I will take a few parameters like incidence, temperature, RPM, pressurization, configuration of aircraft. Especially in combat aircraft where many symbols are presented to the pilot the color helps the pilot to determine without any thinking which ones are related to what you are interested in. For example could you imagine interpreting in flight on a 1:1,000,000 map in black and white where no difference will be made to indicate which line is a road, river, or railway. In contour mapping we have found it very helpful to have the ground indicated in different shades of green when it is below the safety height and red when it is above the safety height, that makes the interpretation quite a bit simpler. On a radar display where you might have flight information of the fighter, radar symbols of targets, known or unknown, information on the bogey when identified, ground or computed flight orders to make interception, I think that using colors is a very big help to the pilot who can easily analyze the situation. One can say that the F-18 not using the multiple color and, of course, the F-18 is a very good aircraft. I have flown the F-15, F-16, F-18, the Viggen and the Jaguar, the French and the English and I know that they are all quite easily usable, but having seen what we are now doing on the 2000, that has helped me quite a lot, in just being relaxed, and saving time in immediately going to the right parameter, because its in purple or to the green because thats a fighter or the white because thats the flying symbol. Having done quite a lot I find it a great help.

Dr. Hunt - That is a very powerful advocacy of color by someone who has a lot of first-hand experience.

Sqdn Ldr M. C. Brooke - The point I want to make is that I am surprised that this appears controversial, that is the use of color. Particularly in American aircraft, and most helicopters, color coding on electro-mechanical instruments, particularly on systems instruments, has been used for many, many years. I can't see why the scientific community is surprised that we want to keep color when we go to CRT's or headup displays, or helmet mounted displays.

Dr. Hunt - Perhaps as a member of the scientific community I could have a go at answering that. It seems to me that the real difficulty is the lack of quantitative performance measurements that would indicate to you that the pilot or aircrew man faced with a particular task given a multicolor or monochrome display, can perform so much better. We don't seem to be able to pin down the benefits in particularly exact form. We do have a psychologist who has really done these experiments, perhaps he could advise us.

Mr. Schmit - I touched very briefly on some experiments that we have conducted on selective attention, on displays, particularly related to color coding. I don't know if anyone will remember that I was saying that the only place where display design can have effect, if you remember Broadbent's Model, was in the very early filtering and encoding stages. This is the stage in fact where I have been able to demonstrate fairly significant benefits from color coding. In fact it is in this stage that the information uptake process of color coding actually exists. I think I quoted in the paper gains of something like 200 milliseconds when color coding was used for fixation. Now that was in a laboratory, obviously practical applications will require measurements in a more applied environment. I think this report is in publishing at the moment and I think it shows that color coding does actively help in selective encoding from displays in the early pre-attentive mechanisms, which are not under conscious control.

Dr. Hunt - Perhaps, it was rather unfortunate that the only paper at this symposium that did address some changes in performance with color, which you will remember was in connection with an anti-submarine display, did not succeed in getting any significant difference.

Dr. Seifert - I don't think that performance necessarily increases with color, but that it becomes easier with color. The instant when you first detect the parameter and interpret the parameter, if color is added in a certain natural sense to the symbol, then it makes interpretation easier. You grasp the information in a better way. You cannot measure that.

Dr. J. Laycock - We have been looking at a practical application to try to prove this point, to justify some expenditure in this area. A sensible start point seemed to be a management type display where there are multiple conditions that need to be coded in some form perhaps using symbols in the present monochrome display, and that benefits could actually be gained by introducing color. Now we have heard throughout the presentations that we consider the man to be a sequential operator and we must also ask the question if the introduction of color is also a sequential operation. The tests we have performed suggest that in fact the introduction of color may allow parallel processing to occur and therefore a decision can be reached much more readily. In the formats that we have been investigating we have been able to prove fairly conclusively that you can get a 20 % increase in performance when looking at a management type display. One would hope that this increase in performance would show itself in other types of formats, such as a map presentation format, where you wish to access a display fairly rapidly for specific types of information.

Dr. Seifert - I think this performance gain has something to do with what Herr Mutschler said. There is reduced interference when you have tasks with different levels or different realms of load. When you have one color only then you have a field which is not easily interpretable. But, if you have two colors, one for each measure, then this interference is lessened and performance can go up. I think this is exactly what Herr Mutschler said.

Dr. R. Woodcock - Is there anyone in the audience or on the Panel who would care to provide some advice on the maximum number of colors that can practically be used simultaneously on a CRT.

Dr. Hunt - Are you asking because of the limitations of the CRT or because of the visual limitations of the human eye?

Dr. Woodcock - The visual characteristics. What is useful, not what is technically possible.

Dr. Laycock - I don't mean to hog the floor but I have been tasked by the UK and USAF to actually specify the new military color standards to be used in these two countries. The answer is not simple; you have to in fact look at the situation in which you envisage applying color. If you are going to add incident illumination on the front of the display then obviously it is going to effect the perception of the color that you are displaying. Therefore if you envisage a situation where you have red cockpit lighting, all the colors that you have selected will move toward the red. If you envisage moonlight or starlight on the front of the display, you will come up with a different answer than if you envisage sunlight on the front of the display.

ROUND TABLE DISCUSSION

Trying to reach some kind of number I think it is sensible to suggest that we are considering something in the region of 5 to 7 maximum for a symbology type display. This doesn't apply to a map display, because of course we would like the use of more colors on a map display where subtle changes in color for representation of layering might be more appropriate. However in this area there may be a tendency to move away from present cartographic standards because going back to this problem of color shifting when light is added on to the front of the display, we ask questions such as "Is it best to use light hues, such as yellow, which are going to be washed out by the ambient illumination?" or "Should we be reconsidering other colors which the display can generate?" So I think the answer is towards small numbers for symbology type displays, and though the penetron may only manage three or four it is still quite close to the five or six that we might be considering from the shadow mask.

Mr. McFarlane - From the aircraft designers point of view I would like to re-echo a number of the statements made. The question is not whether we should use color, but when. I am a little bit concerned that we are spending an awful lot of time trying to prove how good it is, when we would be better off putting in that effort to make it work and making it usable in our environment. Whatever the gains they are going to be in rather subtle ways, such as reducing the tension of the pilot and enhancing his ability to deal with situations which cannot be simulated properly. Those advantages should be accepted and we should get on and do it.

Mr. Sueta - The only comments I would add are along the same line. I wonder how many of the arguments we have heard about why color is not useful, are because we really did not have a color display that we could use in the first place.

Col. Varin - Regarding the number of colors, we have divided the flight into a number of stages. For example when you are just working on radar, where you just want to have a quick view of the situation, where are the targets, how you are flying, how you are requested to climb and to accelerate, we do not need so many colors, say 4 is enough. But, in mapping, for example where you have time to go into more detail, for force situation, position of missiles, and ground conditions, you can increase the number of colors up to 6 or 7. In the early stages of introduction of color we were asked and we talked about 6 or 7 colors. But now we are interested in reducing the number of colors or you use a lot of the advantages that color can bring.
Dr. Hunt - Prof. Doetsch, do you think you now have a consensus from this symposium?

Prof. Doetsch - Well I feel much happier now. The only point I was making from the last symposium was that even with large scale tests we have no proof that in combat conditions you benefit very much, and that evidence has to be brought forth.

Dr. Hunt - I am sure that's right, but it is very difficult evidence to pin down. That is our problem. Well, we only have about ten minutes left. and now I would like to open up the discussion and not try to categorize it. I invite anyone who wants to bring something up a subject from the whole spectrum of what has been discussed in the symposium.

Sqdn. Ldr. J. M. Henson - I have been concerned during the symposium to see cockpits drawn with the keyboards down by the pilot's knees and many multi-function displays in the same place. When I started flying ground attack airplanes the 420 knots at 250 feet was possible with a map, a stop watch, and a compass. Since then life has become a little more complicated but with the advent of digital computers and moving map displays one knew where one was far more often than in the past. Now we have come to the situation where we have keyboards, some of which are up at combing level, we have the map as high up in the cockpit as we can fit it, we have the headup display and we are practicing at 250 feet at 600 knots and occasionally getting permission to go down lower than that. It is essential that the pilot looks out and manages his systems at eye level. He cannot look down into the cockpit. Although some keyboards may become like touch typing, it is probably unlikely in the vibration that occurs at low level. So I would like to suggest that we put everything as high up in the cockpit as possible and that everything that it is possible to put into the system before takeoff is put in before takeoff.
Dr. Hunt - Mr. McFarlane, perhaps as a designer of cockpits, trying to cram everything that you can into them, you would like to comment.

Mr. McFarlane - We have not been able to remove as many switches and multi-function keyboards from the cockpit as we would like to do. I put the question back to you to some extent. Will you not permit us to automate more functions and therefore require fewer switches in the cockpit which would ease the problem in the first place? The ones that we do have to be put in have to be arranged hierarchically. The ones you need to use at low altitudes when penetrating with a desire to keep as low as possible, should and will be arranged up on the front combing very close up to the outside world, the ones with more difficulty of access, will only be used on the ground. I think we are getting very close to that with our next generation of cockpits.

Col. Varin - I think as a pilot I am ready to accept a part of that. In fact that is what we are doing in the low level phases of flight where you have no time, you don't want to look into the cockpit and so on. We have already accepted for many of our aircraft to have scheduled layout and functioning, but remaining to the pilot as he wants the possibility to change everything in the sequence, also to change any parameter, or change any input. We have already sequenced for all the missions, low-level especially, a sequence for everyone, just when you select the place of the armament everything is on, on the head-up the armament and everything. It is presented down on a CRT, and if you don't agree you can change, but at least if you have no time, if the weather is not good enough, you can always use what was planned. Of course you remain with keyboards for what you want but you are not using them a lot any longer.

Mr. L. W. Reed - I would like to refer back to a comment of Dr. Beek's regarding means of measuring accuracy and reliability of recognizers. I believe in his comment he was stating we should take advantage of these features regardless of the feedback means. In my paper I do in fact refer to those three factors, of accuracy, total correctness of the recognizer, and reliability, which takes into account those responses wherein the recognizer simply does not understand what was said, and I threw in latency, which is simply the number of times a person would have to repeat a comment. I think in our performance standards for recognizers I propose at least the two factors be included. In an actual flight environment I don't think we are ever going to have an absolutely perfectly accurate recognizer system. However we should be able to take advantage of that figure where the recognizer does not understand and go into a reliable system. Just to throw out some figures which I am not advocating that we work toward at this point, but assume we have a 95% reliable accurate system, I believe we might be able to approach 100% in a reliable system. It seems that these figures would be quite useful in any future work, comparing recognizer systems. I would just throw that open to anyone having comments. One other thing regarding Mr. Sueta's statement, I am in total agreement with what he said regarding the use of a recognizer in the aircraft. That is that we should try to use its characteristics to the best advantage, not just use it to replace a keyboard. We have to be careful in some areas, as this could increase the size of the vocabulary, because in certain cases in the field, we have certain situations which are very transient. For example if we are referring to a certain person we want to call, say Charlie Dog, these designations may change from hour to hour, and this would require training. Unfortunately we are going to be stuck with training for some time, until speaker independent systems come along, so again we have to be very careful on how we can exploit these characteristics of a recognizer, but I agree we must work toward them.

Dr. Hunt - Well we have almost come to the end. It is interesting that we started off with voice interactive systems and ended up with them. I suppose that is an indication of the level of interest in these systems.

It is customary for the Chairman to summarize where he thinks a Symposium has got to. I find it an extremely difficult thing to do. It seems that our discussions over this last session have indicated that there are many questions which remain to be answered. There are no nice neat solutions which are coming out, and indeed I did not expect to find such solutions. We have discussed displays of different types, we have discussed keyboards, complex systems, voice interaction and so on. These technologies are all in very different states of development. Displays obviously have been around a long time, whereas practical flying voice interactive systems have not, so you would not expect to find too much common ground. I suppose if there is a common theme at all, it is the fundamental adaptability of the human being the pilot or other aircrew member. There is no such thing as a standard man on which you can carry out standard experiments. You have to take into account the stress which he is subjected to, and there are all sorts of environmental variations which may result in performance changes. Because of this, doing exact performance measurements is very difficult, and if you cannot do exact performance measurements it follows that trying to optimize your interface between the man and machine is necessarily equally difficult. Therefore I don't think any of us really believe that we can seek an absolute optimum. We have to find solutions which are demonstrated to be practical, workable, and safe, which are of course the essential characteristics of the good interfaces which we are looking for. Of course, whether or not any particular technique is adopted does not depend ultimately only on proper scientific evaluation. I think many of us realize that there are things almost like fashion trends in making these choices, and although we may think it is only in articles like clothes, automobiles, household equipment and so on that fashion plays a major part in deciding what it is that gets on to the market and is actually sold, nevertheless I do believe that even in aerospace fashion does play a significant part. For example, because Boeing decided to adopt color displays on the 757 and 767, that which we previously thought the unthinkable, suddenly became the in-thing and everybody had to have it. That is perhaps a somewhat gross distortion of what happened but there is nevertheless an element of truth in it. I am merely using it as a demonstration of the fact that we must not seek the ultimate in scientific truth, in trying to make our determination of what sort of equipment should be used in aircraft.

One other thing I would like to say in overall discussion is that because of these difficulties in making scientific measurements we often rely on an evolutionary approach, gradually building up experience on one aircraft, and applying that experience in decision making on the next aircraft. This is a very viable thing to do. The difficulty is of course that the time period between one generation of an aircraft and the next seems to be ever-lengthening as aircraft development processes become more expensive and the defense budgets with which we are all involved become tighter. So you have maybe ten or twenty years between one aircraft and its successor. We all know very well that during that period of time the whole state-of-the-art in avionics and system development has totally changed and therefore it becomes extremely difficult to read the experience of the last generation of aircraft into your next generation. That does throw an enormous burden onto us all in trying to envisage how we should use these new technologies in our new aircraft.

So I think we come to the end of this Symposium with a lot of questions left unanswered. I have a firm belief that the subject matter of the conference was a good one for an AGARD Meeting. It is an area in which a lot is being done but a lot remains to be done. It is an area where just getting together and thrashing out our worries and talking over our problems is very worthwhile. I hope you have enjoyed it. Thank you.

APPENDIX

LIST OF ATTENDEES

ALDRIDGE, B.J. Mr	Combat Aircraft Controls Div., Marconi Avionics Ltd., Airport Works, Rochester, Kent ME1 2XX, UK
ALLEN, K. Major	Directorate of Maritime Aviation, Air Doctrine and Operations, 101 Colonel By Dr. Ottawa K1A OK2, Ca
ARGOUSE, M. Mr	SAGEM, 6 Avenue d'Iena, 75783 Paris Cedex 16, Fr
BAGGE, J. Eng.	RDAF, Air Material Command, Royal Danish Air Force, Postbox 130, DK 3500 Vaerloese, De
BALL, W.F. Mr	Head, Tactical Software Eng. Div., Code 319, Naval Weapons Center, China Lake, CA 93555, US
BANBURY, J.R. Dr	Flight Systems Dept., Royal Aircraft Est., Farnborough, Hants., UK
BANNISTER. F.J. Mr	P110 Avionics Team, British Aerospace, Warton, Aerodrome, Preston, Lancs., PR4 1AX, UK
BARDEN, C.H.B. Mr	Smiths Industries, Aerospace & Defence Systems Co., Bishops Cleeve, Cheltenham GL52 4SF, UK
BARNES, A.G. Mr	British Aerospace, Warton, Aerodrome, Preston, Lancs., PR4 1AX, UK
BEDNALL, M.P. Mr	Normalair-Garrett Ltd., Yeovil, Somerset, UK
BEEK, B. Dr	Communications and Control Division, Rome Air Development Center, Griffiss AFB, NY 13441, US
BEEVIS, D. Mr	DCIEM, P.O. Box 2000, 1133 Sheppard Ave. West, Downsview, Ontario M3M 3B9, Ca
BELL, R. Mr	Marconi Avionics Limited, FARL, Airport Works, Rochester, Kent ME1 2XX, UK
BERMAN, J.V.F. Mr	RAF Institute of Aviation Medicine, Farnborough, Hants, UK
BERRY, F.R. Mr	Cossor Electronics Ltd., The Pinnacles, Harlow, Essex, CM19 5BB, UK
BLACKIE, I. Mr	Pointing & Displays Gp., E.O.D. Robertson Ave., Edinburgh, UK
BOLLARD, D. Mr	MEL, Manor Royal, Crawley, Sussex RH10 2PZ, UK
BOLLER, H.E. Mr	FGAN/FAT, Koenigstr.2, D-5307 Wachtberg, Ge
BOOT, A. Mr	Ferranti Ltd., Silverknowles, Ferry Rd., Edinburgh EH4 4AL, UK
BOSMAN, D. Prof.	Bldg. EF, Twente University, P.O. Box 217, 7500 Enschede, Ne
BRACCINI, G. Mrs	Construzioni Aeronautiche, Giovanni Agusta, Spa, Cascina Costa (Gallarate), It
BRAULT, Y. Mr	Thomson CSF, 178 Bld. Gabriel Peri, Malakoff 92240, Fr
BRAY, R.W. Wg. Cdr.	Flight Systems Dept., RAE, Farnborough, Hants., GU14 6TD, UK
BRIDLE, J.S. Mr	Joint Speech Research Unit, Princess Elizabeth Way, Cheltenham, Glos., GL52 5AJ, UK
BRIERLEY, W.E.	Marconi Avionics Ltd., Airadio Products Div., Christopher Martin Rd., Basildon, Essex, UK
BROOKE, M.C. Sqdn. Ldr.	ETPS., ADAEE Boscombe Down, Salisbury, Wilts., UK
BROWNING, M.R.S. Mr	Westland Helicopters Ltd., Somerset, UK
BUBB, P. Dr	MBB Gmbh, Abt. FE301, Unternehmensbereich Flugzeuge, Postfach 801160, D-8000 Munchen 80, Ge
BURDESS, Sqdn Ldr.	RAF Staff College, Bracknell, Berks., RG12 3DD, UK
CALHOUN, G.L. Ms.	2814 Bahns Drive, Xenia, Ohio 45385, US
CAMBELL, J. Mr	Airborne Display Division, Marconi Avionics. Rochester, Kent, UK
CARTER, G.C. Mr	Box 68, Sperry Gyroscope, Downshire Way, Bracknell, Berks., UK
CHADBOURN, R.A. Miss	Advanced Systems Dept., Westland Helicopters Ltd., Yeovil, Somerset, UK
CHAZELLE, X.F. Mr	ESD, 55 Quai Carnot, 92214 St. Cloud, Fr

CHORLEY, R.A. Mr	Smiths Industries, Aerospace & Defence Systems Co., Bishops Cleeve, Cheltenham, GL52 4SF, UK
CHRISTOPHEL, D. Mr	Avions Marcel Dassault-Breguet Av., 40 Blvd Henri Sellier, 92150 Suresnes, Fr
CLARK, W.J.R. Mr	Marconi Avionics, Christopher Martin Rd., Basildon, Essex, UK
COLLINSON, R.P.G. Mr	Marconi Avionics Ltd., Farl. Airport Works, Rochester, Kent, UK
COOKE, N. Mr	Royal Aircraft Est., Clapham, Bedford, MK41 6AE, UK
COOMBES, K.E. Ms.	British Aerospace PLC, Aircraft Cp. Headquarters, Richmond Rd., Kingston-Upon-Thames, Surrey, KT2 5QS, UK
COSTET, J.R. Mr	Crouzet S.A., 25 Rue Jules Vedrines, 26027-Valence-Cedex, Fr
COUSSEDIERE, M. Mr	Thomson CSF, Departement AVG SCFS, 52 rue Guynemer, 92132 Issy-les-Moulineaux, Fr
COX, E.F. Mr	British Aerospace, Warton, Aerodrome, Preston, Lancs., PR4 1AX, UK
CROVELLA, L. Dr	Aeritalia, Gruppo Equipaggiamenti, 10072 Caselle (Torino), It
CUPPLES, E.J. Mr	RADC/IRAA, Griffiss AFB, NY 13441, US
DAVIES, E.B. Dr	MOD/(PE)/RAE, Farnborough, Hants., UK
DAVIES, D. Mr	British Aerospace, Warton, Aerodrome, Preston, Lancs., PR4 1AX, UK
DEGGAN, I. Mr	Marconi Avionics, Eaton Rd., Hemel Hempstead, UK
DIAMOND, F. Dr	RADC/CA., Rome Air Development Ctr. (AFSC), Griffiss AFB, NY 13440, US
DICKINSON, S.M. Mrs	Westland Helicopters, Yeovil, Somerset, BA20 2YB, UK
DOETSCH, K.H. Prof. Dr Ing.	TU Braunschweig, c/o Institut fur Flugfuhrung, D-3300 Braunschweig, Ge
DOVE, B. Mr	Flight Control Systems Division, Mail Stop 477, NASA Langley Research Center, Hampton, VA 23665, US
DOVE, B.L. Mr	Flight Control Systems Div., MS 477, NASA Langley Research Center, Hampton, VA 23665, US
DUELL, M.R. Mr	Electrical Systems Dept., Westland Helicopters Ltd., Yeovil, Somerset, UK
DURECU, Ing.	Avions Marcel Dassault-Breguet Av., 40 Blvd Henri Sellier, 92150 Suresnes, Fr
EAGLES, J.D. Mr	British Aerospace, Warton, Aerodrome, Preston, Lancs., PR4 1AX, UK
EMERSON, T.J. Mr	AFWAL/FIGR, Wright Patterson AFB, OH 45433, US
ENZINGER, F.J. Mr	MBB Gmbh, Manching, Unternehmensbereich Flugzeuge, Postfach 1149, 8072 Manching W.G., Ge
FORSTMANN, R. Mr	AEG-Telefunken, A453V2, IndustriestraBe 29, D-2000 Wedel/Holstein, Ge
FRASER, N.J. Mr	c/o ASED (JAGUAR), British Aerospace, Warton, Aerodrome, Preston, Lancs., PR4 1AX, UK
FREBAULT, J.C. Dr	Thomson-CSF Le Haillan, B.P. No.3, St Medard en Jalles, Gironde, Fr
GARCIA, M. Mr	S.N.I.A.S., Div. Helicopteres – Dpt. Systeme, B.P.13, 13722 Marignane, Fr
GASSIE, M. Eng.	8, Av. de la Tranquilite, 78000 Versailles, Fr
GAUTHIER, F.H. Mr	Thomson-CSF, Division AVS, Departement AVG, 52 rue Guynemer, 92130 Issy-les-Moulineaux, Fr
GEMMELL, D.B. Mr	Smiths Industries, Aerospace & Defence Systems Co., Bishops Cleeve, Cheltenham, GL52 4SF, UK
GERMAIN, J.P. Mr	S.A. Crouzet, 25 rue Jules Vedrines, 26027 Valence Cedex, Fr
GIANOLI, T. Ing.	Aeritalia saipa, Via Privata, Domigliano D'Arco (NA), It
GIBSON, C.P. Mr	Flight Systems F6, F131 Bldg., Royal Aircraft Establishment, Farnborough, Hants., GU14 6TD, UK
GODWIN, A.M. Mr	General Dynamics, P.O. Box 748, Mail Zone 2441, Fort Worth, Texas 76101, US
GOUGH, B.W. Mr	Cossor Electronics Ltd., The Pinnacles, Harlow, Essex, CM19 5BB, UK
GRADY, P. Mr	Avionic System Engineering, British Aerospace, Warton, Aerodrome, Preston, Lancs., PR4 1AX, UK
GRICE, J.A. Mr	EASAMS Ltd., 35 41 Park St., Camberley, Surrey, GU15 3PQ, UK
GUILLARD, J. Mr	26 rue Malakoff, Asnieres, 92600, Fr

HAGEMANN, B. Mr	Dornier Gmbh, Dept. SA 30 P.O. Box D-7990, Friedrichshafen 1, Ge
HATHAWAY, R. Mr	British Aerospace PLC, Aircraft Gp. Headquarters, Richmond Rd., Kingston-Upon-Thames, Surrey, KT2 5QS, UK
HENSON, J.M. Sqn. Ldr.	FS(F) 1 Y20 Bldg., Flight Systems Dept., RAE, Farnborough, Hants., GU14 6TD, UK
HICKS, T.P. Mr	Thorn EMI Electronics Ltd., Electro-Optic Dept., Victoria Rd., Feltham, Middlesex, TW13 7DZ, UK
HILTON, P. Mr	Plessey Co., Martin Rd., Havant, Hants., PO9 5DH, UK
HOIVIK, L. Dr	N.D.R.E., P.O. Box 25, 2007 Kjeller, No
HOLMES, J.N. Mr	Joint Speech Research Unit, Princess Elizabeth Way, Cheltenham, Glos., GL52 5AJ, UK
HOOPER, R.D. Mr	Normalair Garrett Ltd., Electronics Div., Clarence St., Yeovil, Somerset, UK
HORNE, E.M. Cdr. RN	Aircrew Systems (Dir. of Heloprojects), Rm 808 DHP (HG), St. Giles Ct., St Giles High St., London WC2, UK
HORNER, S. Miss	Thorn EMI Electronics Ltd., Electro-Optic Dept., Victoria Rd., Feltham, Middlesex, TW13 7DZ, UK
HUDDLESTON, J. Dr	Ferranti, Western Rd., Bracknell, Berks., RG12 1RA, UK
HUGHES, D. Mr	British Aerospace, Warton, Aerodrome, Preston, Lancs., PR4 1AX, UK
HUNT, G.H. Dr	Q153 Bldg., Royal Aircraft Establishment, Farnborough, Hants., GU14 6TD, UK
HUNTER, P.W. Mr	Smiths Industries, Aerospace & Defence Systems Co., Bishops Cleeve, Cheltenham, GL52 4SF, UK
IBALL, E.K. Mr	Marconi Avionics Ltd., Eaton Rd., Hemel Hempstead, Herts., UK
JACOBSEN, M. Mr	AEG-TELEFUNKEN, Department Manager Avionics, Abt. A 14 V3, Sedanstr. 10 7900, ULM, Ge
JEVONS, P.J. Mr	OR52C (RAF), Rm. 3213, Main Bldg., Ministry of Defence, Horseguards Ave., Whitehall, London WC1, UK
JOHNSON, S.L. Ms.	British Aerospace PLC, Aircraft Gp. Headquarters, Richmond Rd., Kingston-Upon-Thames, Surrey, KT2 5QS, UK
JOHNSON, R. Mr	Rank Electronic Tubes, Sidcup By-Pass, Sidcup, Kent, UK
KALAWSKY, R.S. Mr	British Aerospace PLC, Aircraft Gp., Kingston-Brough Division, Brough, North Humberside, HU15 1EQ, UK
KISTER, H. Ing.	VDO Lufhtfahrtgerate Werk, An der Sandelmuhle 13, 6000 Frankfurt/Main 50, Ge
KLEMM, R. Dr	FGAN-FFM, D 5307 Wachtberg-Werthhoven, Ge
KUNY, W. Mr	MBB Gmbh, Abt. FE 4, Postfach 801160, D-8000 Munchen 80, Ge
LARROQUE, P. Mr	Avions Marcel Dassault-Breguet Av., 78 Quai Carnot, 92214 St. Cloud, Fr
LAYCOCK, J. Dr	Flight Systems F6, F131 Bldg., Royal Aircraft Establishment, Farnborough, Hants., GU14 6TD
LEE, J.J. Mr	British Aerospace, Warton, Aerodrome, Preston, Lancs., PR4 1AX, UK
LINES, D.S. Miss	Westland Helicopters Ltd., Simulation Services, Yeovil, Somerset, UK
LISTER, M.D. Mr	British Aerospace A/C Group, Woodford Aerodrome, Chester Rd., Woodford, Cheshire, UK
LOUGHRAN, D.J. Capt.	Commanding Officer, Attn. SIE/FTCR, Aerospace Engineering Establishment, CFB Cold Lake, Medley, Alta, TOA 2MO, Ca
LOVERING, P.B. Mr	2425 Apricot Dr., Dayton, OH 45431, US
MACKINTOSH, I.W. Mr	Royal Signals and Radar Est., St. Andrews Rd., Malvern, Worcs., UK
MACPHERSON, R. Dr	CRAD/DSP-3, National Defence Headquarters, 101 Colonel By Dr, Ottawa, Ontario K1A OK2, Ca
MAFFIOLETTI, L. Eng.	Logic S.P.A., Via Brescia 29, Cernusco S.N. 20063 (MI), It
MAGGI, M. Mr	Costruzioni Aeronautiche, Giovanni Agusta, Spa, It
MARTENS, R.J. Major	Air Command Hq., Westwin, Manitoba, R2R OTO, Ca
MARTIN, K.W. Mr	British Aerospace, Warton, Aerodrome, Preston, Lancs., PR4 1AX, UK
MASCARENHAS, J. Major	DSET/FAP, Rua Escola do Exercito-13, 1100 Lisboa, Po
MAUREAU, C. Mr	Thomson CSF, 52, rue Guynemer, 92132 Issy-les-Moulineaux, Fr

MAYES, D.J. Mr	Smiths Industries, Aerospace & Defence Systems Co., Bishops Cleeve, Cheltenham, GL52 4SF, UK
MAZZETTI, B. Ing.	Aeritalia, Corso Marche 41, 10146 Torino, It
McFARLANE, W.I. Mr	British Aerospace, Warton, Aerodrome, Preston, Lancs., PR4 1AX, UK
McKINLAY, W.M. Mr	Ferranti PLC, Ferry Rd., Silverknowles, Edinburgh, Scotland, UK
MEEK, R.D. Mr	Smiths Industries, Aerospace & Defence Systems Co., Bishops Cleeve, Cheltenham, GL52 4SF, UK
MELOCCO, J. Mr	Crouzet S.A., Departement Aeronautique, 26027 Valence, Cedex, Fr
MENU, J.P. Dr	Centre d'Etudes et de Recherches de Medecine, 26, Boulevard Victor, 75996 Paris-Armees, Fr
METCALFE, J. Dr	Plessey Electronic Systems Research, Roke Manor, Romsey, SO5 0ZN, UK
MILNER, P. Mr	British Aerospace, Warton, Aerodrome, Preston, Lancs., PR4 1AX, UK
MITCHELL, N. Mr	British Aerospace, Warton, Aerodrome, Preston, Lancs., PR4 1AX, UK
MITCHELL, K. Mr	Marconi Avionics Ltd., Farl, Airport Works, Rochester, Kent, UK
MOORE, R.K. Dr	B110(N), RSRE, Leigh Sinton Rd., Malvern, Worcs., UK
MOREAU, C. I.C.A.	STTE/PNI, 129 rue de la Convention, 75731 Paris, Cedex 15, Fr
MORPHET, F.N. Mr	Thorn EMI Electronics Ltd., Radar Product Group, Radar House, Dawley Rd., Hayes, Middlesex, UK
MULLEY, W. Mr	Code 60201, Naval Air Development Center, Warminster, PA 18974, US
MUTSCHLER, H. Dipl. Ing.	Fraunhofer Institut – IITB, Sebastian-Knepp-Str. 12–14, 7500 Karlsruhe 1, Ge
NICHOLL, S.M Sqn. Ldr.	Rm. 3196, Main Bldg., Ministry of Defence, Horseguards Ave., Whitehall, London WC1, UK
NOBILIO, F. Mr	O.M.I., Ottico Meccanica Italiana, Via Jella Vasca Navale 79, Roma, It
ORME, K.P. Mr	Flight Operations, British Aerospace, Warton, Aerodrome, Preston, Lancs., PR4 1AX, UK
PAETZOLD, H. Mr	Bundesminister der Verteifigung, Ru Fo 3, 5300 Bonn, Postfach 1328, Ge
PARQUIER, Le G. Mr	Thomson-CSF, 173 Blvd. Haussmann, 75008 Paris, Fr
PIGNEROL, P. Ing.	SFENA, B.P. 59, 78141 Velizy Villacoublay, Cedex, Fr
PIGRAM, D.R. Mr	Marconi Avionics Ltd., Christopher Martin Rd., Basildon, Essex, SS14 3EL, UK
PILKINGTON, R.B. Mr	Pilkington P.E. Ltd., Glasco Ed. Road, St. Asaph, UK
PORTE, C. La Capt. (Prof.)	College Militare Royal, St. Jean Quebeck, JOJ IRO, Ca
PRATT, R.L. Dr	AL/8 North Site, RSRE Malvern, Worcs., UK
PREY, P. Lefebvre du	Thomson CSF, 178 Bld. Gabriel Peri, Malakoff 92240, Fr
RAWLINGS, R.C. Mr	MOD(PE) PSO FS(B)2, Royal Aircraft Est., Clapham, Bedford, UK
RAYNER, P.B. Mr	Marconi Avionics Ltd., Airport Works, Rochester, Kent, ME1 2XX, UK
RAYNER, R.W. Mr	Marconi Avionics Ltd., Eaton Rd., Hemel Hempstead, Herts., UK
REED, L.W. Mr	US Army Avionics R&D Activity, Attn: DAVAA-E (Lockwood Reed), Fort Monmouth, NJ 07703, US
REINECKE, M. Mr	Flugmedizinischeo Inst. de Luftwaffe, Abt. Ergonomie-Flugpdatz, 8072 Manching, Ge
REISING, J.M. Dr	AFWAL/FIGR, Wright-Patterson AFB, Ohio, 45433, US
RETH, R-D. von Dr	MBB GmbH DE 23, Postfach 801140, D-8000 Munchen 80, Ge
RICHARDSON, G. Mr	RN 4 Division, Royal Aircraft Establishment, Farnborough, Hants., GU14 6TD, UK
RICHTER, K. Mr	MBB GmbH, Abt. FE135, Postfach 801160, D-8000 Munchen 80, Ge
ROE, G. Mr	British Aerospace, P.L.C., Future Projects Office, Kingston-Brough Division, Brough, North-Humberside, HU15 1EQ, UK
ROGERS, E. Dr	Flight Systems Dept., Royal Aircraft Establishment, Farnborough, Hants, GU14 6TD, UK
ROVETTI, P. Dr	Aermacchi S.p.A., Via Sanvito 80, 21100 Varese, It
ROWE, K.W. Major	DCIEM, P.O. Box 2000, 1133 Sheppard Ave. West, Downsview, Ontario M3M 3B9, Ca
RUST, J.D. Mr	Ferranti PLC, Ferry Rd., Silverknowles, Edinburgh, Scotland, UK
RYLES, J.C. Dr	Chief Scientist, AFWAL/AS, Wright-Patterson AFB, OH 45433, US
SALISBURY, M.P. Mr	British Aerospace, Warton, Aerodrome, Preston, Lancs., PR4 1AX, UK

SANTUCCI, G. Le Medecin en Chef	Centre d'Etudes et de Recherches de Medicine Aerospatiale, 26 Blvd Victor, 75996 Paris Armees, Fr
SCHMIT, V.P. Mr	FS(F)6, F131 Bldg., Royal Aircraft Establishment, Farnborough, Hants., UK
SCHOFIELD, I.E. Mr	British Aerospace, Warton, Aerodrome, Preston, Lancs., PR4 1AX, UK
SCOULLER, D.C. Wg. Cdr.	Royal Air Force, High Wycombe, Bucks., UK
SCUTT, J.A. Mr	British Aerospace, Warton, Aerodrome, Preston, Lancs., PR4 1AX, UK
SEIFERT, R. Dr	MBB Gmbh, Abt. FE301, Unternehmensbereich Flugzeuge, Postfach 801160, D-8000 Munchen 80, Ge
SLADE, A.J. Mr	Westland Helicopters Ltd., Simulation Services, Yeovil, Somerset, UK
SMITH, R.M. Mr	Plessey Electronic Systems Ltd., Plessey UK Ltd., Martin Rd., Havant, Hants PO9 5DH, UK
SMITH, J.H. Mr	Smiths Industries, Aerospace & Defence Systems Co., Bishops Cleeve, Cheltenham, GL52 4SF, UK
SMITH, K.W. Mr	DRPC/MOD(PE), Room 1200, Main Bldg., Ministry of Defence, Horseguards Ave., Whitehall, London WC1, UK
SMITH, R.Y. Ms.	M.E.C., Ferranti PLC, Ferry Rd., Edinburgh EH5 2XS, Scotland, UK
SMITH, T.D. Mr	British Aerospace, Warton, Aerodrome, Preston, Lancs., PR4 1AX, UK
STEIN, H. Mr	DFVLR e. V. Institut fur Flugfhrung, Postfach 3267, 3300 Braunschweig-Flughafen, Ge
STEINER, R. Mr	Dornier GmbH, Dept. SA 30 P.O. Box D-7990, Friedrichshafen 1, Ge
STOERK, P.H.S. Mr	Lufthansa German Airlines, Dept. HAM IF 3, P.O. Box 300, 2000 Hamburg 63, Ge
STRINGER, F.S. Mr	Rm 126, R177 Bldg, Flight Systems, Royal Aircraft Establishment, Farnborough, Hants., GU14 6TD, UK
STURGE, M.J. Mr	Cossor Electronics Ltd., The Pinnacles, Harlow, Essex, CM19 5BB, UK
SUETA, V.J. Mr	US Army Avionics, R & D Activity, Attn: DAVAA-D, Fort Monmouth, NJ 07703, US
SWIFT, D.W. Dr	Pilkington P.E. Ltd., St. Asaph, Clwyd LL17 0LL, UK
TAILLET, J. Dr	O.N.E.R.A., 92320 Chatillon, Fr
TAYLOR, R.M. Mr	RAF Institute of Aviation Medicine, Farnborough, Hants., UK
TAYLOR, W.J. Mr	317 Division, Marconi Avionics Ltd., Elstree Way, Borehamwood, Herts. UK
THEMMEN, H.N. Mr	Fokker B.V., Postbox 7600, Flight Dept., 1117 ZJ Schiphol, Ne
THIEME, K. Mr	AEG-Telefunken, A453V2, IndustriestraBe 29, D-2000 Wedel/Holstein, Ge
THOMAS, D.L.J. Mr	British Aerospace, Warton, Aerodrome, Preston, Lancs., PR4 1AX, UK
THORN, J. Ms.	M.E.C., Ferranti PLC, Ferry Rd., Edinburgh EH5 2XS, Scotland, UK
TIMMERS, H.A. Ir	National Aerospace Lab NLR, Anthony Fokkerweg 2, 1059 CM Amsterdam, Ne
TORELLI, P. Dott. Eng.	C/o FIAR Via G.B. Grassi 93, Milan 20157, It
TURNER, R.D. Mr	319 Division, Marconi Avionics Ltd., Eaton Rd., Hemel Hempstead, Herts., UK
UNDERWOOD, G.W. Mr	British Aerospace PLC, Aircraft Gp., Headquarters, Richmond Rd., Kingston-Upon-Thames, Surrey, KT2 5QS, UK
VALES, C.A. Major	National Defence Headquarters, 101 Colonel By Drive, Ottawa, Ontario K1A 0K2, Attn. DAEM 2-5, Ca
VANDENBERGHE, P. Mr	BARCO Industries N.V., TH Sevenslaam 106, B-8500-Kortrijk, Be
VARIN, G. Colonel	Centre d'Essais en Vol, 91220 Bretiny/Orge, Fr
VOGEL, M. Dr	DFVLR, NE-HF, D-8031 Oberpfaffenhofen, Ge
VOIGT, J.H. Mr	Lufthansa German Airlines, Dept. HAM IZ 3, P.O. Box 300, 2000 Hamburg 63, Ge
VOLES, R. Mr	EMI Electronics Ltd., Thorn EMI Electronics Ltd., 135 Blyth Rd., Hayes, Middx., UB3 2AX, UK
VUILLEMIN, C. Mr	Crouzet S.A., Rue Jules Vedrines, 26027 Valence, Cedex, Fr
WADLOW, A.E. Mr	British Aerospace, Warton, Aerodrome, Preston, Lancs., PR4 1AX, UK
WALRAVEN, J. Dr	Institute for Perception TNO, Postbus 23, 3769 29 Soesterberg, Ne
WANNER, J-C. Gen.	DRET 4 Av. de la Porte D'Issy, Paris 75996, Fr
WARD, G.A. Mr	EASAMS Ltd., 35 41 Park St., Camberley, Surrey, UK

WHEALE, J.L. Dr	Flight Skills Section, RAF Institute of Aviation Medicine, Farnborough, Hampshire, GU14 6SZ, UK
WHITE, R.G. Mr	Flight Systems Dept., Royal Aircraft Est., Farnborough, Hants., GU14 6TD, UK
WHITESIDE, P.J. Mr	British Aerospace, Warton. Aerodrome, Preston, Lancs., PR4 1AX, UK
WILCKENS, V. Dr	DFVLR, 8031 Oberpfaffenhofen, Ge
WILD, J. Mr	Manager, Radar Processing, Marconi Radar Systems, Marconi Labs., West Manningfield Rd., Gt. Baddow, Chelmsford, Essex, UK
WILSON, R.E. Mr	317 Division, Marconi Avionics Ltd., Elstree Way, Borehamwood, Herts., UK
WOODCOCK, R. Dr	Marconi Radar Systems Ltd., Writtle Rd., Chelmsford CM1 3BN, UK
WOODCOCK, B.H. Dr	Pilkington P.E. Ltd., Glascoed Road, St. Asaph, UK
WYKES. K.M. Ms.	British Aerospace, Warton, Aerodrome, Preston, Lancs., PR4 1AX, UK

REPORT DOCUMENTATION PAGE

1. Recipient's Reference	2. Originator's Reference	3. Further Reference	4. Security Classification of Document
	AGARD-CP-329	ISBN 92-835-0315-4	UNCLASSIFIED

5. Originator
Advisory Group for Aerospace Research and Development
North Atlantic Treaty Organization
7 rue Ancelle, 92200 Neuilly sur Seine, France

6. Title
ADVANCED AVIONICS AND THE MILITARY AIRCRAFT MAN/MACHINE INTERFACE

7. Presented at
the Meeting of the Avionics Panel held in Blackpool, UK, 26–29 April, 1982.

8. Author(s)/Editor(s)	9. Date
Various	July 1982

10. Author's/Editor's Address	11. Pages
Various	358

12. Distribution Statement
This document is distributed in accordance with AGARD policies and regulations, which are outlined on the Outside Back Covers of all AGARD publications.

13. Keywords/Descriptors

Military aircraft
Avionics
Man machine systems
Display devices
Color
Speech recognition
Speech synthesis
Input output devices (computers)
Flight crews

14. Abstract

These Proceedings consist of the papers and discussions presented at the Avionics Panel Meeting on "Advanced Avionics and the Military Aircraft Man/Machine Interface" held in Blackpool, England, 26–29 April, 1982. The 30 papers presented were divided as follows; three were introductory, 5 were on Colour Display Systems, 9 were on Voice Input and Output Systems, 6 were on Aircrew Interaction with Complex Systems, and 7 were on Display Technology. The Proceedings also include a Technical Evaluation Report of the Meeting.

AGARD Conference Proceedings No.329
Advisory Group for Aerospace Research and Development, NATO
ADVANCED AVIONICS AND THE MILITARY AIRCRAFT MAN/MACHINE INTERFACE
Published July 1982
358 pages

These Proceedings consist of the papers and discussions presented at the Avionics Panel Meeting on "Advanced Avionics and the Military Aircraft Man/Machine Interface" held in Blackpool, England, 26–29 April, 1982. The 30 papers presented were divided as follows, three were introductory, 5 were on Colour Display Systems, 9 were on Voice Input and Output Systems, 6 were on

P.T.O.

AGARD-CP-329

Military aircraft
Avionics
Man machine systems
Display devices
Color
Speech recognition
Speech synthesis
Input output devices
(computers)
Flight crews

AGARD Conference Proceedings No.329
Advisory Group for Aerospace Research and Development, NATO
ADVANCED AVIONICS AND THE MILITARY AIRCRAFT MAN/MACHINE INTERFACE
Published July 1982
358 pages

These Proceedings consist of the papers and discussions presented at the Avionics Panel Meeting on "Advanced Avionics and the Military Aircraft Man/Machine Interface" held in Blackpool, England, 26–29 April, 1982. The 30 papers presented were divided as follows, three were introductory, 5 were on Colour Display Systems, 9 were on Voice Input and Output Systems, 6 were on

P.T.O.

AGARD-CP-329

Military aircraft
Avionics
Man machine systems
Display devices
Color
Speech recognition
Speech synthesis
Input output devices
(computers)
Flight crews

AGARD Conference Proceedings No.329
Advisory Group for Aerospace Research and Development, NATO
ADVANCED AVIONICS AND THE MILITARY AIRCRAFT MAN/MACHINE INTERFACE
Published July 1982
358 pages

These Proceedings consist of the papers and discussions presented at the Avionics Panel Meeting on "Advanced Avionics and the Military Aircraft Man/Machine Interface" held in Blackpool, England, 26–29 April, 1982. The 30 papers presented were divided as follows, three were introductory, 5 were on Colour Display Systems, 9 were on Voice Input and Output Systems, 6 were on

P.T.O.

AGARD-CP-329

Military aircraft
Avionics
Man machine systems
Display devices
Color
Speech recognition
Speech synthesis
Input output devices
(computers)
Flight crews

AGARD Conference Proceedings No.329
Advisory Group for Aerospace Research and Development, NATO
ADVANCED AVIONICS AND THE MILITARY AIRCRAFT MAN/MACHINE INTERFACE
Published July 1982
358 pages

These Proceedings consist of the papers and discussions presented at the Avionics Panel Meeting on "Advanced Avionics and the Military Aircraft Man/Machine Interface" held in Blackpool, England, 26–29 April, 1982. The 30 papers presented were divided as follows, three were introductory, 5 were on Colour Display Systems, 9 were on Voice Input and Output Systems, 6 were on

P.T.O.

AGARD-CP-329

Military aircraft
Avionics
Man machine systems
Display devices
Color
Speech recognition
Speech synthesis
Input output devices
(computers)
Flight crews

Aircrew Interaction with Complex Systems, and 7 were on Display Technology. The Proceedings also include a Technical Evaluation Report of the Meeting.

ISBN 92-835-0315-4

Aircrew Interaction with Complex Systems, and 7 were on Display Technology. The Proceedings also include a Technical Evaluation Report of the Meeting.

ISBN 92-835-0315-4

Aircrew Interaction with Complex Systems, and 7 were on Display Technology. The Proceedings also include a Technical Evaluation Report of the Meeting.

ISBN 92-835-0315-4

Aircrew Interaction with Complex Systems, and 7 were on Display Technology. The Proceedings also include a Technical Evaluation Report of the Meeting.

ISBN 92-835-0315-4

DATE
FILMED

1-82