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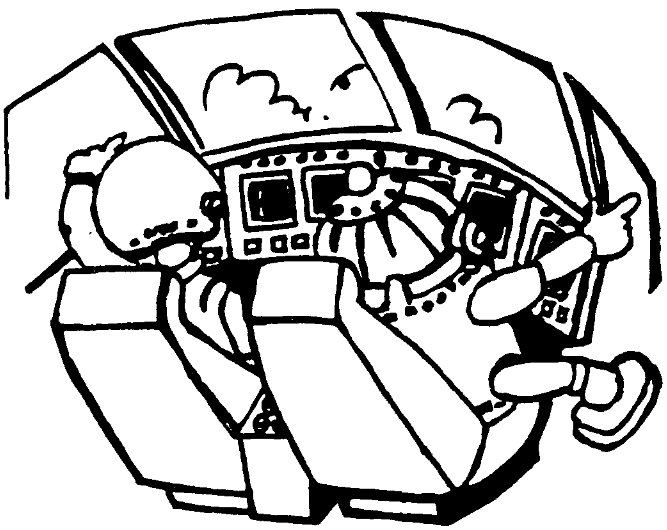
THE HUMAN - ELECTRONIC CREW: IS THE TEAM MATURING?

The 2nd Joint GAF/RAF/USAF Workshop on Human - Electronic Crew Teamwork

Stadttheater Conference Room, Ingolstadt, FRG
25-28 September 1990



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COCKPIT INTEGRATION DIVISION
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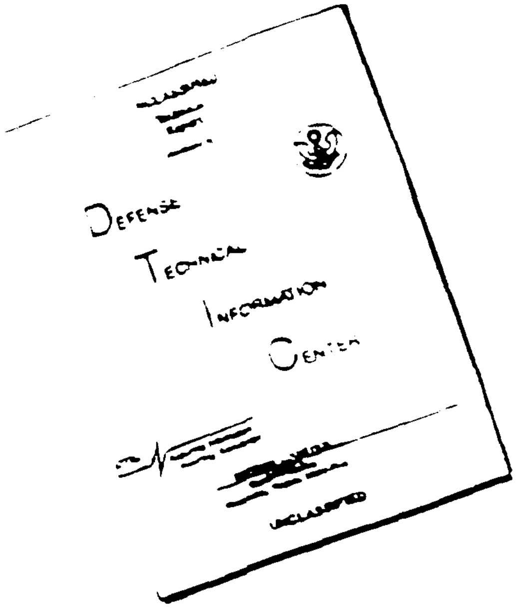

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Advances in artificial intelligence (AI) will enable future fighter/attack aircraft to have a rather unique crew -- one human and one electronic. The objective of the workshop was to bring together AI specialists, aircrew, and cockpit designers in order to exchange ideas relative to 1) the state of the art in aircraft applications of AI technology and 2) the impact on the cockpit of the human/electronic crew. This meeting provided a valuable forum for the experts of several countries to exchange ideas, concepts, and data relative to hardware and software capabilities that can be included in an aircraft system design to aid the human operator in performing the mission.

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CONTENT

WORKSHOP BACKGROUND

Ever since the movie Star Wars showed Luke Skywalker and R2D2 teaming up to destroy the Death Star, there has been considerable speculation as to how an efficient pilot-robot team could be created. Since weight is a critical design factor in airborne systems, the literal building of a pilot-robot team has not been undertaken; rather, the emphasis shifted to incorporating the intelligence of the robot. As work in this area progressed, such terms as "electronic crewmember" and "black box back seater" began to enter the vocabulary of both the crewstation design and computer software communities. While the use of these titles served to stimulate thinking in the area of human-computer teamwork, a major program was needed to start the design and implementation of concepts needed to build an electronic crewmember (EC); in the US this took the form of the Pilot,s Associate Program. The establishment of the Pilot,s Associate Program in 1985 gave credence to the idea that the building of the brain of R2D2, in some very simplified form, might be possible.

In the next two years, numerous discussions were held to explore some of cockpit ramifications created by the use of a pilot-EC team within the aircraft. These discussions occurred in various technical meetings within the US and the UK. In one of the meetings held in the US, attended by representatives of the Air Force of the Federal Republic of Germany as well as US and UK representatives, the idea of the present workshop was born. Although progress on the idea of a workshop concerning human-EC teamwork continued, in 1987 an event occurred which demonstrated the definite need for the workshop.

In April of 1987, USAF representatives gave a paper at a meeting of the Royal Aeronautical Society in London and again at a meeting of the Ergonomics Society in Swansea, Wales. The subject of the paper was "Workload and Situation Awareness in Future Aircraft", and a section of the paper discussed workload sharing between the pilot and the EC. During both meetings the same kinds of questions were asked: Is the pilot always in charge? Can the pilot and EC really be called a team? why do you need the pilot at all?

These thought provoking questions resulted in continued discussions with technical personnel in the US, UK and FRG, and the result was the 1988 workshop entitled, "The Human-Electronic Crew: Can They Work Together" (WRDC-TR-89-7008). Following the 1988 workshop, interest was expressed in holding as additional meeting on the topic of human-electronic teamwork. Sponsorship was obtained from organizations within the three Air Forces, and as a result the present workshop, which the German Air Force generously agreed to host, became a reality.

EXECUTIVE SUMMARY

The meeting was divided into two sections: formal presentations (papers) and a workshop. The papers covered a wide range of topics ranging from artificial intelligence (AI) implementation issues, through pilot-electronic crewmember (EC) dialogue, to the EC's autonomy and building trust between the two crew members. A summary of the ideas from the papers is given below:

Papers

Relative to the papers presented at the Workshop in 1988, the papers at the current Workshop reflect significant progress in the examination of what it actually takes to build an EC. The papers gave examples of a number of expert systems (called "intelligent knowledge base systems" by the Europeans) applied to well defined, narrow applications, e.g., air-to-air tactics aid, displays manager, and a mission planner for air-to-ground roles.

A second difference in the papers relative to the 1988 Workshop was progress in understanding how teams work together, and understanding the issues of the pilot's building trust and confidence in the EC; a mathematical model of how to relate human, machine, and system accuracies, as a function of trust and confidence in the EC was presented. In the 1988 Workshop only the words were mentioned; no methods of attacking this problem were presented. Related to the teamwork issue was the discussion of pilot inferencing or knowing the intent of the pilot.

Workshop

After the presentation of the papers, the second half of the meeting consisted of a workshop; its purpose was to form six teams to deal with AI technology and cockpit implications of the technology. The teams were composed of the three technical disciplines represented at the conference -- pilots, crewstation designers, and artificial intelligence experts. The AI technology was further subdivided into state of knowledge, unresolved issues, and potential directions. At the end of the workshop each of the six team leaders presented the results of their deliberations. Below are the overall views of the different technical disciplines represented at the workshop.

Viewpoints from the Workshop Teams.

In the area of **AI software technology**, it was felt that converting from Lisp to Ada may be more difficult than was first anticipated, and the resulting code may be computationally inefficient. On the positive side, a clear distinction was drawn between real time as it refers to an avionics system, e.g. 30 Hz, and real time as it refers to the human time frame, e.g. 1 or 2 seconds; this has a major impact on the system throughput requirements. The **aircrew issues** dealt with building trust and confidence in the EC, and adaptability of the system. It appears that for the near future the pilot is going to do the adapting; and not the EC, since there are currently no AI systems that truly learn. The **crewstation issues** dealt with how to convey information efficiently between the two members, and concentrated on display formats and new control techniques.

CONCLUSION

The overall worth of the Workshop can be summed up in the comments of a British Tornado pilot who came with a healthy skepticism. At the end of the Workshop, he remarked that he could see a real value in the EC. The example he used was guiding him safely home after a target strike when he was low on fuel. He felt that the EC could be a true lifesaver in this situation.

Besides the technical information gathered, one of the major accomplishments was the positive interchange among the participants. There was a genuine interest in sharing information and ideas in order to attack the common problem of information overload in the cockpit. The participating countries are striving to reach a common goal, and the ideas exchanged in the workshop should prove very beneficial to all of them.

List of Delegates

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THE HUMAN-ELECTRONIC CREW: IS THE TEAM MATURING?

Conference Room at Stadttheater Ingolstadt

Ingolstadt, FRG, 25 - 28 September 1990

LIST OF PAPERS

Reports not included:

KNOWLEDGE BASED SYSTEM APPLICATIONS FOR CONTROL: A SUMMARY OF THE 51ST AGARD GUIDANCE AND CONTROL PANEL, SEPTEMBER, 1990 (no written report)
R. Onken

PILOT VEHICLE INTERFACE DEVELOPMENT ACTIVITIES AT NLR (F-16 MIDLIFE UPDATE, LAH) (paper withdrawn)
M. Piers

FUNCTIONAL INTEGRATION OF ENGINEERING AND HUMAN PERFORMANCE MODELS (paper withdrawn)
K. Corker, E. Hudlicka, S. Baron

THE EFFECT OF AN ARTIFICIALLY INTELLIGENT COMPUTER ON THE COCKPIT DESIGN PARADIGM.

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SUMMARY

Artificially intelligent (AI) computers exist. Computers utilizing knowledge based systems are involved in such diverse activities as diagnosing blood disease and performing geological exploration. There are several programs underway that are investigating the use of AI computers to create an Electronic Crewmember (EC). The EC may eventually replace a human crewmember in the cockpit. The current focus in this area is on the two-person fighter/attack aircraft; however, the concepts appear to be expandable to systems having larger crews such as multi-crew transports. The purpose of this paper is to discuss how the emergence of knowledge based systems will affect the crew station design paradigm. Traditional aspects such as mission and function analysis, task allocation, workload prediction, etc., will undoubtedly be affected by the availability of adaptive decision aiding, intelligent mission management and other EC functions. Levels of autonomy and authority for the crewmembers, and the need for new paradigms will also be discussed.

INTRODUCTION

Artificially intelligent (AI) computers are rapidly being developed for both airborne and ground-based applications. As compared with systems utilizing conventional computers, systems built with AI computers will be fundamentally different in their human-computer interaction because "intelligent functions are performed by both man <u>and</u> computer, and initiative for action is accordingly assigned to both man and computer" (Zachary, Glenn, & Hopson, 1981, p. 100). Intelligent systems impact the crew station (CS) design process in two important ways. First, they can provide the CS designer with an intelligent electronic assistant to aid in a number of steps of the overall design process . Secondly, AI can be brought into the aircraft in the form of a pilot's associate or electronic crewmember (EC) (Small, Lizza, & Zenyuh, 1988). How they specifically affect the CS design process is the subject of the rest of the paper.

CURRENT CREWSTATION DESIGN PARADIGMS

The overall design process involved in human-machine systems is well documented (Gagne, 1962). A paradigm specifically related to the crewstation design process for aircraft is shown in Figure 1. It consists of five steps (Kearns, 1982).

The first step, Mission Analysis, or problem definition, begins with a careful, detailed examination of the intended operational use of the system. This is followed by the derivation and documentation of total system and individual component requirements. The Statement of Need or requirements data published by the future user of the system provides important baseline material for this phase. Typically, the documentation produced in this phase includes a mission description and sequential listing of all of the operations the system must be designed to perform in its expected operational environment. It includes tasks performed by the aircraft, its systems, and each of the crew members (ORLOC, 1981). To augment this data, the designer (or design team) may also perform an analysis of the decisions that have to be made by crew members as the mission progresses. To be successful each step in the process needs strong user involvement. An essential output of this step is the identification of the information that is necessary for the crew to perform the mission.

The second step in the cockpit design process is depicted in Figure 1 as Preliminary Design but is probably more often referred to as "defining a solution". During this phase most of the activity is devoted to generating a design. The requirements are reviewed and decisions made regarding the way functions will be carried out and information will be provided. The dividing line between problem definition and solution development is often vague. Specific designs affect the timelines, timelines can reveal workload problems, which in turn may have an impact on the scenario -- all of which suggests that the process may iterate several times.

A key element in the evolving design is operator or user involvement. The sustained participation of operators with relevant experience results in fewer false starts, better insight into how (and why) the mission is performed today, and a great savings of time in the latter phases of the project.

The last three steps are <u>each</u> very critical to the successful completion of an effective and proven cockpit design; they are also interdependent in that the Mockup Evaluation provides recommended configurations for simulation, and the Simulation Evaluation yields configurations for the In-flight Validation. For the purpose of this discussion, these final steps are combined to provide "Solution Evaluation". Once again, there may not be a clear break between this phase and the solution definition phase. It has been observed that most designers, design, evaluate, redesign, etc., as they go. The transition occurs when formal, total-mission, total-system, pilot-in-the-loop evaluations begin. But even then, decisions made during the problem and solution definition steps are often revisited, changes made, and simulation sessions or even flight tests rescheduled -- all resulting in, as previously suggested, a very iterative or cyclic process.

Early in the process, the evaluations are both part task and part mission. As the design matures the mock-ups and simulators reach higher fidelity and the evaluations eventually become full-task, full mission. Obviously, user participation in the last three steps, mock-up, simulation, and flight test is crucial to achieving the goal of producing a validated cockpit design.

INTELLIGENT DESIGNER'S ASSISTANT

Several years ago USAF engineers conceptualized a system called the Rapidly Reconfigurable Crewstation (RRC) [Fileccia, Reising & Williams, 1988]. The system in its final form would have had a strong impact on the efficacy of the design paradigm just described. Design changes during the process would be easier and faster; the necessary iterations often referred to could be accomplished rapidly, and user participation would be much more efficient, i.e., cockpit redesigns would be done in less than a day rather than in months as is the case today.

The RRC as conceived consisted of an automated layout center, automatic software generation, communications, graphics, real-time simulation, operator's consoles etc. A knowledge based system or artificially intelligent computer, one of the RRC subsystems, was to have served as the cockpit designer's electronic assistant. The assistant would integrate human engineering principles with the more traditional system design disciplines at an early stage in the design paradigm to provide the designer with assistance in the problem and solution definition. The knowledge based system would provide models for simulation, human behavior, performance, graphics and other tools. (Pacific Microelectronics, 1989)

The RRC would not have changed the framework of the fundamental cockpit design paradigm but, with its artificially intelligent computer, would have had a very significant time reducing impact on all of the elements.

The basic concept of RRC remains valid and it is continuing to evolve through industrial interest and activity. The sizeable USAF effort to make it happen within a few years was not able to survive recent budgets cuts. The USAF Cockpit Automation Technology (CAT) program, began in 1986, has survived to automate many of the tools and models which support the cockpit design paradigm. The CAT process employs a variety of analytical and empirical approaches (Kulwicki, McDaniel & Guadagna, 1987).

The paradigm just described has worked very well with systems that had a the computer which was always provided direction by the human to perform primarily data processing tasks, but will it be adequate for the design of systems in which the computers can initiate their own actions and perform a far greater variety of tasks?

THE PARADIGM FOR CREWSTATION NEEDS TO BE MODIFIED.

The overall design paradigm is sound. However, modifications to components of the paradigm are needed. Specifically, the information requirements, level of automation, and evaluation/validation sections need to be modified if an artificially intelligent computer is included in an aircraft system to create or provide an EC.

Information Requirements. A key feature of the design paradigm to be affected by the inclusion of the EC is the function allocation aspect of the information requirements section. Once it is known, in broad terms, what information or data will be provided to the human and to the machine, and what their capabilities are, the designer may begin the allocation of functions between the two. In the classic paradigm, function allocation is static; it is performed early in the design process and is essentially unmodified thereafter. This will not be true when an EC is included; a realtime, dynamic task allocation will have to be a part of the design paradigm.

Dynamic task allocation means that workload can be shifted between the pilot and the EC in realtime during the course of the mission (Emerson, Reising & Britten-Austin, 1987). This exchange can occur both consciously and unconsciously as far as the pilot is concerned; the former involves active consent by the pilot, while the latter involves implied consent. In the conscious case, the task allocation would be communicated at a very high level with a few key actions or words. For example, in the case of a system failure, after being informed, the pilot could merely say, "Fix it." The EC then would carry out all subsequent details. The same high level interaction between the team members could also occur in the case of a mission change. The pilot could say, "New target -- railroad bridge B." The EC would execute all the navigation, threat avoidance, fuel management, and stores selection tasks needed to carry out the mission. Through verbal commands, the pilot consciously reduces his own workload by dynamically allocating tasks to the EC. It may be possible, however, to have a much more subtle dynamic task allocation which involves implied consent by the pilot either before or during the mission.

In describing the mission, knowing the functions and capabilities of the EC, the designer could incorporate the EC's allowable workload for each phase into the knowledge base. The level would be determined by data processing capacity, speed, etc. Once the overall mission has been established and committed to, the pilot-EC team would then be responsible for completing the mission, and the level of workload for each member would be adjusted, if necessary, in realtime to successfully complete the mission. The pilot would not have to command the EC to perform every task. For example, if multiple missiles were fired at the aircraft and the pilot sighted one of them, he might choose to defeat it by a jinking maneuver. This kind of maneuver can be quite difficult and in most cases will occupy most, if not all, of the pilot's resources. The EC, without waiting for permission, would employ its own resources (chaff, flares, and electronic countermeasures) against the remaining missiles. The key aspect of this scenario is the implied permission and automatic task shedding based on the team's acceptance of the mission objectives and the overall governing rules of operation.

Levels of Automation. The inclusion of an EC could also have a dramatic effect on the Level of Automation portion of the Preliminary Design phase of the paradigm. The main difference that AI contributes is providing for differing levels of autonomy (LOA) for the EC. "LOA defines a small set ('levels') of system configurations, each configuration specifying the degree of automation or autonomy (an 'operational relationship') at which each particular subfunction performs. The pilot sets or resets the LOA to a particular level as a consequence of mission planning, anticipated contingencies, or inflight needs" (Krobusek, Boys, & Palko, 1988, p. 124.) Unlike the level of automation subfunction shown in Figure 1, which is determined at the preliminary design stage and essentially frozen, the autonomy levels of the EC open up the ability to assign different authority levels for various mission phases.

Evaluation/Validation. During this phase of the design process, the human and computer are built into a team. In the classic paradigm, the capabilities of the computer were relatively well known early in the evaluation phases, and after the usual difficulties experienced during the "burn in" period, the human could trust the computer to perform in a consistent manner. However, in a system where the computer can have differing levels of autonomy and initiate action on its own, the buildup of trust becomes crucial.

This trust can be envisioned to develop in three stages. At first trust is based on the predictability of individual behaviors. In the second stage trust is based on dependability. "... Dependability may be thought of as a summary statistic of an accumulation of behavioural evidence, which expressed the extent to which a person can be relied upon." (Muir, 1987, p.532). In the third stage of trust, faith is the major component because one team member is willing to bet that the other member will be dependable in the future.

Once the trust is built between the crew member and the EC, the continued overall efficiency of the system depends on such factors as machine accuracy, compliance with the suggestions of the EC (also known as a decision aid), and degree of faith in the continued accuracy of the decision aid (Riley, 1989). Riley's message is that the relationships between the pilot and the EC can be very dynamic, and we are just beginning to understand these relationships.

CONCLUSION

The impact of artificially intelligent computers on the crew station design process will leave the overall paradigm intact but will substantially affect subsections such as information requirements, levels of automation, and evaluation/validation. It may take longer to build an effective team, but the performance capability of the team has the potential of being orders of magnitudes beyond current systems.

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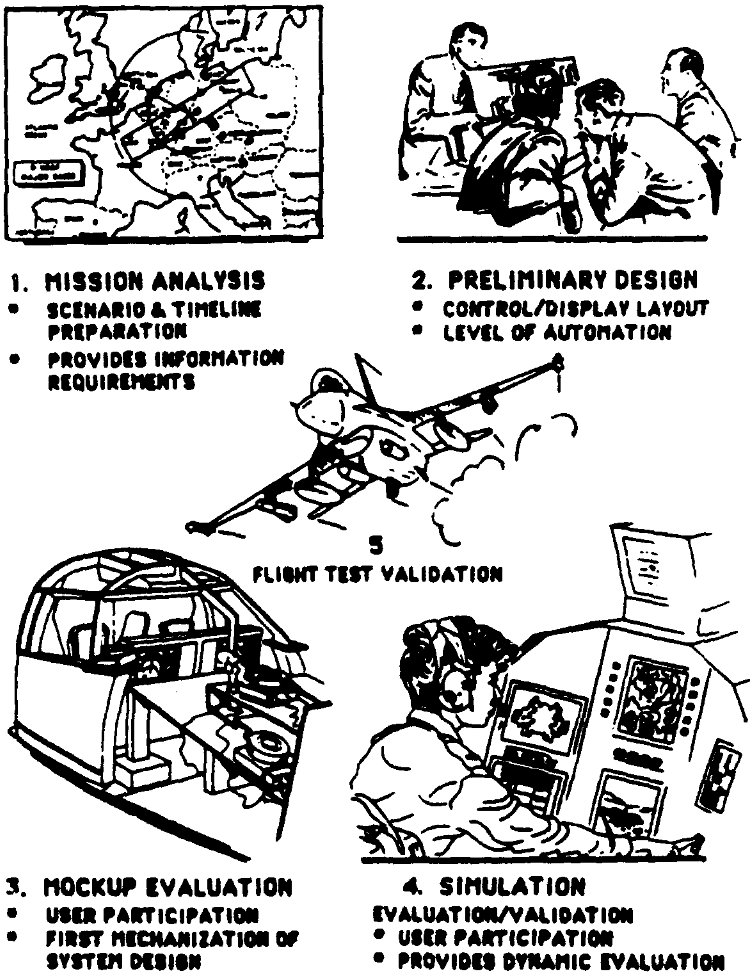

Figure 1. Crew System Design Process.

THE HUMAN-ELECTRONIC CREW: AN OPERATOR'S PERSPECTIVE

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It is my belief that in common with the air combat fighter, the interdiction aircraft and the battle-field helicopter, modern anti-submarine warfare (or ASW) helicopters need some automatic aiding if sensor data is to be correlated and then assimilated by the human crew so that the best tactical solution is selected to optimise operational performance.

The objectives of this paper are to provide:

* an understanding of the complexity of modern ASW helicopter mission systems,

* an insight into the character and pace of an ASW engagement, and,

* an outline of the challenges to be met if expert system technologies are to be implemented.

The structure of a modern ASW helicopter mission system as shown in the accompanying diagram consists of:

* a mission management system: sensors (sonics, active dipping sonar, radar, ESM, MAD), weapons (torpedoes and depth charges),

* an aircraft management system: navigation, communications, data link and (although not shown) flight and engine control system,

* all linked together by data bases and controlled by mission and aircraft management computers.

So, if we can accurately define the interfaces and functions of our mission system, why is there a need for automatic tactical aiding for the crew? I contend that, even if the mission system is successfully integrated, crew workload will remain very high in an ASW helicopter.

Although modern ASW sensors are able to detect target radiated noise, the source level is very weak and passes through a largely unpredictable medium - the sea. The resultant target signatures vary considerably depending on the submarine's speed and depth as well as its aspect relative to the sensors. Consequently, contact is at best intermittent and often of short duration. Acoustic sensors only provide a low data rate. It is therefore difficult to identify manoeuvres by the submarine, without significant operator interpretation of all the acoustic data.

If the target is alerted to the presence of the helicopter then it may evade vigorously by making best use of speed and the local acoustic conditions, including wrecks, and other bottom features. If the submarine believes he is under imminent threat of an attack he may deploy acoustic countermeasures of the target's position, course and speed.

To overcome these problems great emphasis has been placed on improving the performance of our sensors, not only to detect the submarine and maintain contact but also to produce an accurate track from which further sensor deployments or attack points can be predicted. However, improved technology does not necessarily reduce the operator's workload, because:

* the crew must make selections from a variety of sensors and to decide on the most advantageous positions to deploy them relative to the target.

* they must choose the right operating modes,

* they must carry out low-level data fusion and correlation, while monitoring the sensors, and,

* they must have detailed knowledge of both target intelligence and own system capability to fully exploit the submarine's signature.

It can be imagined that during sorties of this nature, the crew have to deal with a high workload caused by a multitude of concurrent, or near concurrent, activities happening over a short time-span. So, it seems that the likely applications for real time expert systems in an ASW helicopter are:

* a tactical advisor,

* a sensor manager, and,

* a classification aid.

Of these the UK MOD Operational Requirements Directorate is actively involved with research projects into a tactical and sensor advisor and is keenly interested in other research into classification aids.

So if such technologies are to be implemented what are the challenges?

* In today's political and economic scene we must positively justify each step of our procurement process, whether for research, a demonstrator, feasibility studies, development or production. The operational benefits need to be established and the price must be affordable. This applies to the potential use of expert systems.

* There is a considerable investment in aircrew training. It will be a challenge to persuade the military staffs that expert and other novel technologies will not replace aircrew expertise but allow the aircrew to be more effective.

* We need to establish which problems can be solved by the application of expert system technology. I have already suggested that automation itself cannot provide all the solutions. Often automation simply generates more data, and so makes the operator's task more difficult. What we need is to ensure that these technologies address the central issue of managing the data and presenting it to the operator in a clear and readily assimilable form together with the tactical advice he needs to fight the battle at that moment, especially in highly dynamic and multi-threat environments.

* If expert systems are to provide this sort of tactical advice then the tactical advisor:

    * must be able to interface with the sensors and aircraft systems,

    * the advisor must be able to communicate its information to the human crew. So, the whole issue of the human-machine interface needs to be explored.

* The expert system must also be able to take account of the balance between risk to survival and mission achievement.

* There may be a need to dynamically share the management of the aircraft and mission systems between the human and electronic crew, depending on the prevailing conditions.

* All this advice needs to be provided to the crew in real-time.

* But, however clever the electronic crew becomes we must always allow for the intuition and initiative of the human crew by allowing interaction between the human and electronic crew.

* We need rapid, flexible and cheap methods of updating the advice. The expert system elements must therefore be "modular" so that amendments can be made without disrupting the remainder of the mission system.

* In dealing with novel technologies we need to:

  * convince the operators of the benefits of expert systems, and,

  * establish the operator's confidence that expert systems will provide reliable advice.

* Lastly, we need to develop formal methodologies to validate expert systems because:

  * it is no use providing such systems if they cannot achieve CA release. For a CA release we need to be able:

    * to confirm the technology is safe, and

    * to measure the performance of the system.

Whilst I have explained in some detail the relevance of expert system technology to my particular domain of interest, the issues, problems and potential benefits are common to all military users of experts systems. Hopefully during the Workshop we will address the challenges I have outlined. We will then be able to return to our laboratories and staff desks with more confidence in our ability to convince the decision makers and fund managers of the value of expert system technology for optimising mission effectiveness.

ISSUES IN REACTIVE RESOURCE ALLOCATION FOR NAVAL SYSTEMS.

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Summary

An analogy is drawn between the tasks and functions envisaged for an electronic co-pilot and the role of a Pricipal Warfare Officer (PWO) in a surface warship. Analytical decision making models are deemed insufficient in the reactive resource allocation task domain and Klein's model of Recognition Primed Decisions seems to offer a more appropriate model on which to base further investigations. Research on Naval reactive resource allocation is outlined together with a way ahead for future work to explore the cognitive nature of the whole command and control task and a decision support environment.

Introduction.

Two years ago, at the previous Workshop, some of the issues pertaining to the development of an electronic co-pilot were debated. These included:

- the need for the KBS component to appreciate the intentionality of the Pilot, and
- the prospect of multiple cooperating expert systems and teaming concepts.

My thesis is that an analogue of a system containing these kinds of features already exists in the operations room of a warship and that work in this Naval domain may therefore be generalisable to a wider range of applications including the fighter cockpit.

The role of Principal Warfare Officer in the Operations Room.

The PWO's primary task is, in essence, the defence and fighting of the ship. In this sense he is acting as the Captain's co-pilot because he is responsible to the Ship's Commanding Officer who is in overall command of the Ship and concerned, above all, with Ship safety. The PWO therefore needs to understand the intentionality of the Captain; that is how he wants to operate and what information he will wish to know.

The PWO is also in command of the Operations Room and the people within it. There may be up to thirty of them in groups dedicated to particular warfare areas or sensor and weapon systems. The PWO is the executive who directs, monitors and coordinates the activities of various teams, expert systems in their own right, who are responsible for the detailed control of sensors and weapons. The increasing trend towards automation means that many of the individual sensor and weapon systems are autonomous yet the PWO will still have veto authority over them. In this sense he is the pilot with the entire Ops Room acting as his pilot's associate.

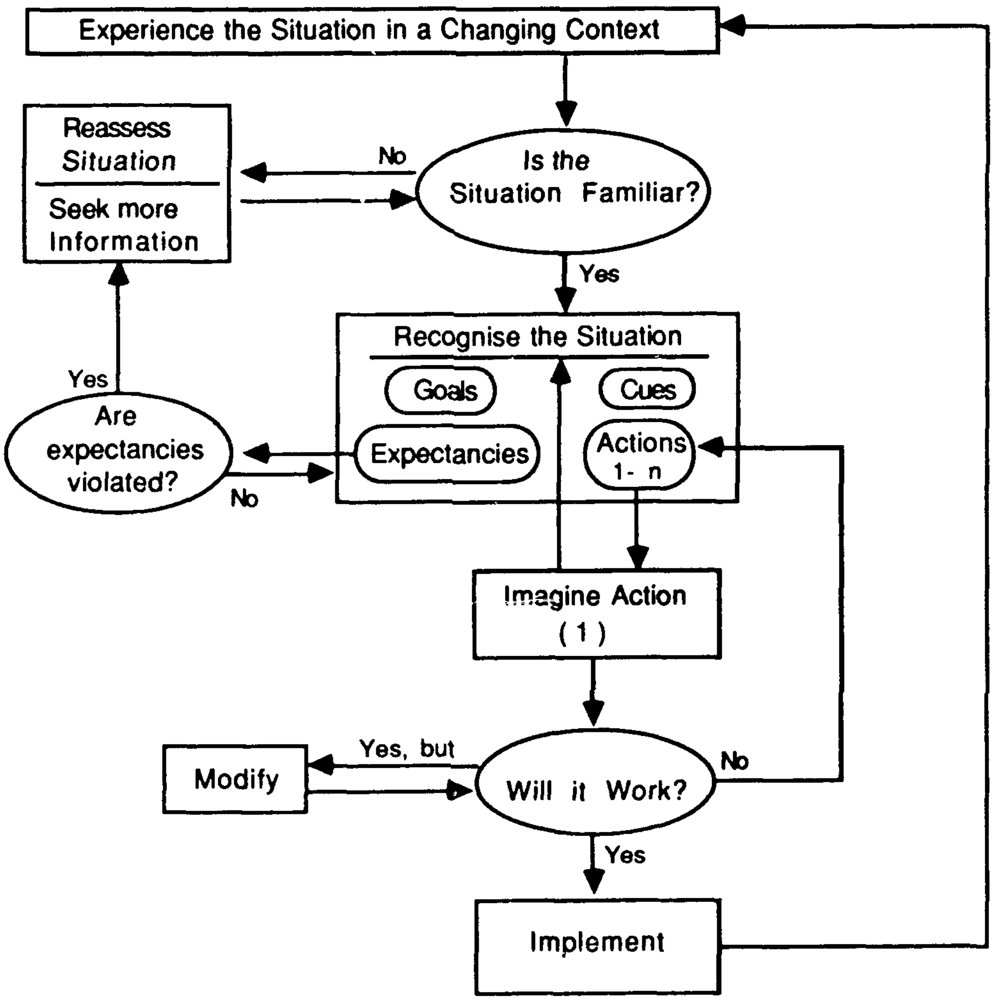
The PWO thus needs to have a good knowlege or understanding of his Commanding Officer and a detailed working knowledge of the equipment and resources available to him. In order to make the best use of these resources the PWO additionally needs to be a good man manager: in the Ops Room he is the head of a team, many of whose members are experts in their own field, and he must ensure that they are motivated to support each other, to provide information as needed and to cooperate in support of the team's objectives.

If the thesis that the PWO is a role model for an electronic co-pilot system is correct then my argument is that research underway at the Admiralty Research Establishment which attempts to support the decision making tasks of a PWO will provide greater insight into the nature of these types of tasks and the human expertise and cognitive processes that are actually used.

Models of decision making.

In order to provide effective decision support it is necessary to have a good model of how human experts make decisions and what information they actually use. There is a plethora of models of a decision process, ranging from Miller Galanter and Pribram's "TOTE" to Wohl's "SHOR" model, but as Brian Sherwood-Jones notes (REF 1) these models only describe a hypothesised process, not necessarily what people actually do. This is further amplified in that it is often impossible to observe decision points - things just seem to happen and only in retrospect can decision makers justify what they did or didn't do. This obviously makes the area rather hard to study and the effective design of support systems rather difficult: decades of research into optimal decision theory have provided little in the way of acceptable real-time operational decision aids. However a way ahead may be indicated by Klein's theory of Recognition Primed Decisions. (REF 2) (See Figure 1)

Figure 1 "Recognition Primed Decision Model" - Klein 1989



In essence Klein argues that expert human decision making under time-stress is non-analytic and certainly does not fit into any optimal decision theory framework. He suggests that experts strive for **adequate** decisions by matching responses to problems identified or recognised as typical. The nature of expertise is such that these suitable, satisficing responses are generated very rapidly; there appears to be no concurrent evaluation of options. Klein continues that what might occur instead is that the expert visualises the chosen response to verify that it will achieve the aim and where it won't he will try to adapt it so that it will. Only if the response seems unworkable will he move on to a new one. Thus experts seem to know intuitively the best decision and can rapidly test it to find ways of disproving it whereas novices seem to be more inclined to compare options, searching for evidence to confirm early hypotheses.

Decision making in Naval context.

Klein's model is intuitively attractive in a Naval context because, based on our experiences, PWO's seem to operate in a remarkably similar fashion, although this has yet to be tested. PWO's are trained and subsequently observed to activate procedural responses to highly time-stressed events such as the detection of a missile head flying towards them. We are now in the area termed resource allocation: more specifically, reactive resource allocation. The response procedures may be very complex (turn off radar, start jamming, fire chaff, manoeuvre ship, activate targeting radar, etc) and usually involve several teams within the Ops Room. Additionally the procedures may be affected by constraints imposed by a higher authority (Rules of Engagement, Force Level plans) or by physical geometry (collision situations). The procedures are well rehearsed by the Ops Room teams but are too time critical for much adaptation or on-line tuning, they just have to happen. The problem is, however, that while one procedure can be carried out effectively, if a battle scenario requires two or more concurrent procedures to be activated using the same set of resources, the teams may be unable to cope. The PWO is likely to become overloaded or the procedures may interact to such an extent that only one is possible - that is the generation of a composite or new satisficing procedure is impossible within the timescales of the threat. Under these circumstances, say the simultaneous attack by a missile and a torpedo, anecdotal evidence suggests that the coping response is likely to entail activating one procedure alone ("let us evade the torpedo rather than the missiles because a big hole below the water-line is worse than a hole in the deck"). To some extent this is another example of a satisficing decision: after all it is generally believed that it is better to do something than to just sit there, undecided, with a sinking feeling. I believe it is in this area that automated real-time decision support does have something to offer.

Reactive Resource Allocation.

A contract underway with Ferranti International (Naval Command and Control Division) aims to produce a reactive resource allocation demonstrator early next year. Entitled RRASSL (Reactive Resource Allocation at Single Ship Level) the demonstrator will use KBS techniques to generate responses to a range of attacks upon a surface ship. By firing rules appropriate to each threat detection it is anticipated that RRASSL will be able to interleave procedures and produce appropriate, optimised responses to meet **combinations** of threats. These new procedures will be presented to the PWO as a list of recommended actions which he will have the opportunity to accept or reject. In addition the system will present a predictive display indicating the various time frames within which actions have to occur and will be able to explain the rules which have triggered the individual resonses.

There are many problems in the design of displays to represent the extra complexity of the time dimension which we intend to explore. In addition how well a PWO will accept advice and recommendations at the time he is highly stressed we intend to examine by means of gaming the system and its user against increasingly complex scenarios. T[illegible]n will be to test that the system can cope with single threat scenarios and generate the same procedures as the PWO's themselves. It is assumed that the procedures for single threats have, to some extent, been optimised by the tactical specialists. Eventually we hope to take the users into high stress, multiple conflicting threat scenarios where we can examine their decision strategies and where they begin to breakdown. This is the area where RRASSL is hoped to demonstrate the advantages of real-time KBS and where the use of an interactive scenario generator should allow assessment of survivability and effectiveness.

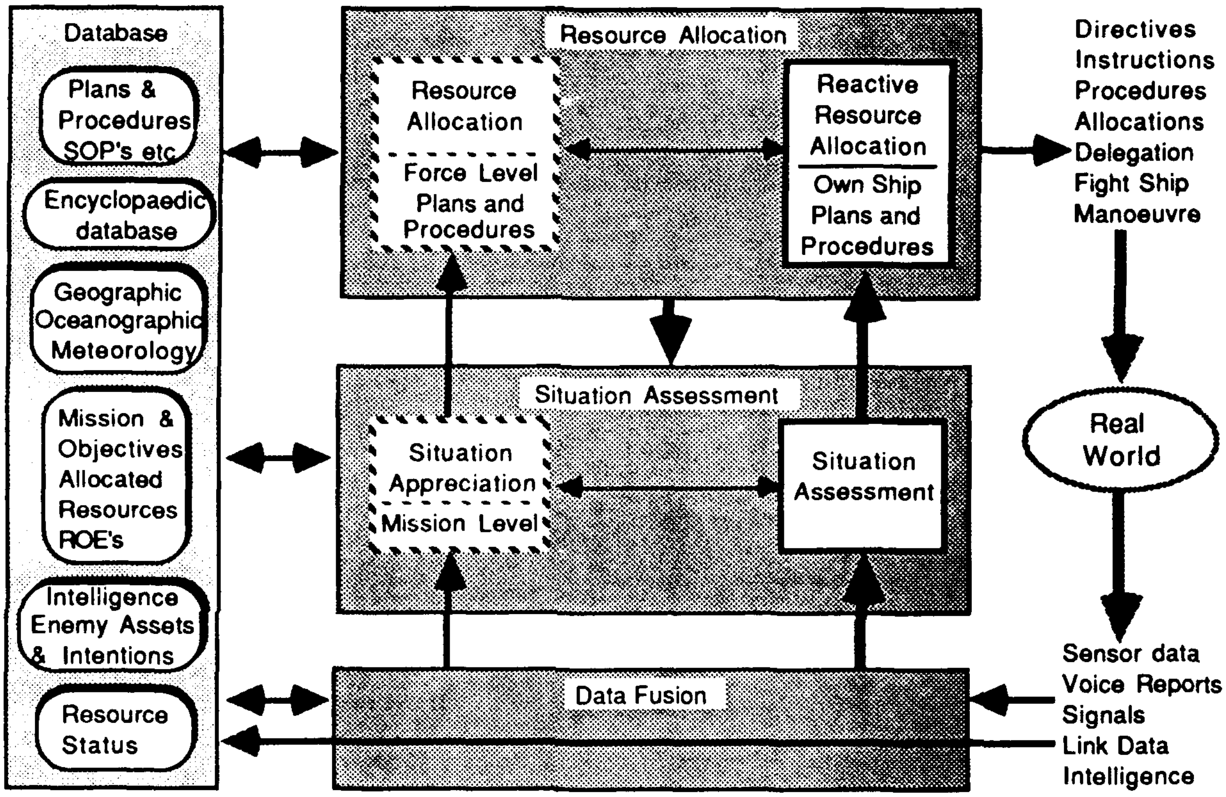
There is some concern that the optimised responses produced by RRASSL may not be readily accepted by the users, if at odds with their intuitive decision making or their individual cognitive styles. Additionally, users may have no basis upon which to accept or reject the recommended actions of RRASSL in real time because it will be performing calculations they cannot do or, perhaps, even proposing responses they cannot recognise. As a consequence, survivability and effectiveness must be treated as the criteria of success and retrospectively evaluated. It seems that users would often prefer to fire missiles at a threat rather than use soft-kill weapons because this "something that goes bang" seems to give them more confidence, even if they have been shown that the probability of success is less. This is perhaps one good reason why KBS might be more successful than humans in this type of responsive system under extreme time pressure.

Another incidental advantage of RRASSL may be its value as a training aid in that it could enable novice PWO's to sample many situations and develop their experience and abilities to react to various threat scenarios. After all novices are often taught by rather analytical means and do not become experts until they have rehearsed and applied their rules in many settings and developed their operational expertise. Not only would this "system as a training aid" concept be a mechanism for developing human expertise it would enable the user to develop his confidence and trust in the operational system and to enrich his understanding of complex multiple threat scenarios.

The human contribution.

But this seems to be arguing the case for automation with little regard for the human contribution to the system and seems to ignore the nature of expertise as described by Klein. The problem is that if human experts do operate according to Klein's model in the time-stressed area of reactive resource allocation, they may do so for the good reason that they are unable to perform concurrent evaluation. One may speculate that this may be the case or it may be that experts have no way of articulating concurrent processing and researchers no operational definition of what to look for. Alternatively, experts may not have the time or processing capability to interleave several procedures (thereby generating a new one) but yet have to find a solution which is adequate. Returning to the whole task of the Ops Room and, by implication, the PWO himself we envisage that the task involves data fusion, situation assessment and resource allocation. Note this is a high level system description (for implementation purposes) rather than a process model (see Figure 2). The functions are rather artificial distinctions: they do not appear to happen in serial and I do not believe that it is possible to observe operators and classify their behaviour according to these categories.

Figure 2



I agree, with Klein, that human expertise really resides in the ability to recognise the problem and identify typical features, that is situation assessment. The PWO, as is any military commander, is aiming to outmanoeuvre the enemy, to gain the tactical high ground, where he can see and dictate the course of the battle to his own advantage and to plan his campaign so that he is not forced into time-stressed defensive actions.

Research at the Admiralty Research Establishment.

The work at ARE, in progress and planned, addresses the whole area of surface ship command and control and aims to tackle the issues I have been discussing.

Data fusion is the starting point in that it reduces the complexity of the data gathering and sensor fusion task by presenting the PWO with a reliable tactical picture in real-time. The work on a KBS data fusion demonstrator, presented at the previous Workshop (REF 3) is midway through implementation and sea trials of the system are due to begin in 1992 on board a Type 23 Frigate.

The next stage is to implement a reactive resource allocation system. As I have mentioned, we hope to begin exploring a prototype RRASSL in March 1991, retaining the option of building an operational RRASSL prototype at a later stage to coincide with the sea trials of the data fusion technology demonstrator.

This means that we will have automation at the input end and the output of the command and control process. Our intention is to utilise these two demonstrators to enable us to identify the functions and processes necessary to complete the system by transforming the output of one into the input for the other. This area, currently termed situation assessment, is the most nebulous and difficult to address: it is hoped that by varying the input and output stages we can treat situation assessment as a black box and begin to infer what it is and how it must operate.

Initial thoughts were that situation assessment involved interpretation of the tactical picture and the generation of a prioritised threat list. Klein suggests that situation assessment involves making inferences about the nature of the problem thereby making response selection easier when it has to happen. This is the area where the PWO operates with uncertain information, trying to identify the enemy's intentions and to predispose his system, including his resources and response procedures to meet whatever might happen. Here intuition and innovative responses have their rightful place. In addition there is more time for the process of imagining "what if" situations. The ability to try out typical threat scenarios and walk through the responses generated by a RRASSL system would assist the PWO in visualising his response procedures. It is postulated that this facility would be very useful at the stage before a battle when details about the enemy's capabilities are becoming more specific and the PWO is trying to tune his resources and response procedures accordingly. A contract to explore and develop a prototype situation assessment module is planned for next year. Future work at ARE involves us in a collaborative programme with the US Government which aims to investigate, by means of prototype development and observational studies, decision making in the areas of situation assessment and resource allocation.

Concluding Remarks.

What then are the issues in reactive resource allocation? Basically I believe that reactive resource allocation can be automated and is a more straightforward problem than initially conceived. It is, after all, more amenable to validation in that it produces a defined output. This output can be evaluated and compared with human performance both for its effectiveness in countering the threat and for its speed of response. A spin-off from the implementation of a resource allocation prototype may be its value as a training aid, enabling experiential learning and student paced development of expertise at the same time as the development of trust and confidence in the system.

The real problem lies in the area of situation assessment where human expertise comes to the fore. We do not have a good understanding of this area. If Klein's model is valid, then assessment of the situation would seem to involve human recognitional processes which are not conscious or open to introspection. Developments in connectionist architectures or neural nets seem to offer a way forward in other recognitional domains like pattern or voice recognition: perhaps this is the technology required for situation assessment. In the meantime, however, I believe that experimental investigations of the situation assessment and resource allocation tasks using human experts teamed with partial decision support is the best way forward.

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THE ELECTRONIC CREW IN ROTARY WING APPLICATIONS

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1. BACKGROUND

The use of the electronic crew in rotary wing applications is being explored in several U.S. Army laboratories. Examples of these development activities include digital map display systems, day/night all-weather sensor system, integrated communication systems, and automatic target acquisition and recognition systems. Those of us in the human engineering crew station design community are focusing our research energy on how to integrate the electronic crew capabilities with the human crew.

The U.S. Army Human Engineering Laboratory has had a program in place for examining the implication of automation in the cockpit. A specific Army aviation mission was considered for developing this program. The mission was helicopter air-to-air combat. The program is entitled the Human Engineering Laboratory Counter-air Program (HELCAP). It addresses the command and control soldier interface issues from the cockpit to the aviation tactical operations center (TOC). This paper presents a review of the program, the automation issues being addressed, and the progress to date.

2. DISCUSSION

In HELCAP, the focus is to establish the human-machine interface criteria whereby Army air defense forces can collaborate with Army aviation units. The general concept is to examine the soldier interfaces at four critical nodes of counter-air operations: the aviation tactical operations center, the helicopter air-to-air cockpit, the air defense tactical operations center, and the air defense fire unit. Embedded in this concept is the fact that the Army aviation community will be using the air defense ground-based sensors that form the backbone of the forward area air defense (FAAD) system. It is essential to pass along time-critical information in an expeditious manner. In the HELCAP program, we anticipate examining the potential for employing cockpit and TOC automation toward successful mission accomplishment. The products will be design guidelines for designing control/display interfaces that exploit artificial intelligence technology in enhancing situation awareness and command and control interfaces.

3. COUNTER-AIR COCKPIT

3.1 Counter-air Display

A required attribute of a counter-air display is the need to provide critical command and control information to the pilot in a manner that makes the information readily usable. Laboratory research was used to develop a counter-air display concept to meet this requirement. Standardized symbology provides a ready source of information about fixed and rotary wing aircraft which are identified as hostile, friendly, or unknown. In addition, target location is represented in a planned position format. Location, velocity, direction and bearing of the identified aircraft from the location of the counter-air helicopter is also provided. Through hooking a specific target, the counter-air helicopter can amplify the information about any single or group of multiple targets. Logic can be built into the display which will provide terrain profile data along with line-of-sight information so that the counter-air helicopter pilot can either choose his point of engagement or evade any nearby threats. Though not yet in the concept display, it should contain other forms of information to facilitate the helicopter counter-air effectiveness. For example, battlefield intelligence indicating the location of hostile anti-aircraft fire units would enhance battlefield survivability and locations of rearm and refuel points with preplanned minimum threat routes to their location would increase time on target.

The sizing of the display has been the subject of considerable study, analysis and experimentation. The parameters of consideration relative to size were:

Geographic areas of coverage
Symbol size
Symbol obscuration
Symbol movement resolution
Symbol update times

The tradeoff between area of coverage/display size/symbol resolution resulted in concepts for using displays as small as three inches for the counter-air application. This display size was considered to accommodate an electronic display already in the Army inventory. Interactive software permitted a display of this size to furnish the pilot with quality counter-air information and enough situation awareness needed to conduct counter-air operations.

3.2 Electronic Map Display

The vital function of a map display system is to assist the air crew in maintaining situational awareness. In addition to geographical information, it should also provide tactical information and logistic information all of which should be presented in an integrated form. The air crew needs to have the system indicate the best route of flight to avoid obstacles, maintain nap-of-the-earth profiles and engage or avoid enemy targets as circumstances dictate. Planning aids delineating routes of flight to accommodate mission needs will be essential to minimize crew size and maximize mission success. Research is in progress at the Human Engineering Laboratory to address the mission planning station and map display characteristics which provide the best user interactions.

3.3 Expert Communicator

The flight regime of Army helicopters is very hazardous. Flight very close to the ground, close to both enemy ground and air elements requires a ready means of communicating with the appropriate command channels. All radio equipment should be integrated into a single system. The channel and security selections should be pre-programmed to accommodate the planned mission profile. This will ensure that the crew can efficiently communicate with the critical command components when required. However, situational changes on the battlefield make it imperative that these automated communication links be flexible enough to be rapidly changed. Concepts of communication systems with these attributes will be explored in future research by the Human Engineering Laboratory

3.4 Subsystem Monitor

This subsystem will act as an electronic copilot. It will present to the pilot a summary status of all critical on-board systems (i.e., hydraulic, electrical, environmental, power plant, etc.). The electronic copilot must integrate the various bits of system information and provide corrective options to the pilot in case of system emergencies. Minimizing work load in times of system failures is essential to mission success.

HELCAP analysis and research in this area has developed a display concept that alerts the pilot on a 'by exception' basis. In this concept, key parameters such as percent torque and fuel time to go will be displayed continuously on the helmet mounted display (HMD). A dedicated area of the HMD will be available to provide systems alert information to the crew. A logic scheme has been developed to provide the crew with immediate information on out-of-tolerance systems conditions. Redundant synthesized voice commands will be available along with information on the multi-function visual display.

3.5 Sensor Suites

The air-to-air combat mission for helicopters necessitates the capability of conducting both day and night operations. Therefore, sensor systems including both imaging and non-imaging will be required. The fusion of the sensor data and the presentation of that data on minimum display surface area is essential. Unique display concepts for implementing fused images must be employed. One concept display under development allows the portrayal of both radar and forward-looking infrared imagery on a single display surface. This concept will enhance crew interaction and at the same time save valuable panel space.

The use of computer capabilities for the processing of target images through automatic target recognition systems will be essentials of the automated cockpit. The long stand-off ranges and the limited target cross-section will make it virtually impossible to attain a visual identification of potential targets. The target acquisition system will have to provide this capability. Present research addresses the methods through which targeting information can be readily assimilated by the crew. These research areas include the effects of clutter and how to restore target images so they can be readily detected and recognized, the effects of chromoticity on target detection and the methodology for determining the functions that can best be performed by the crew and those that can best be performed by the ATR.

3.6 Counter-air Cockpit Development Summary

The automated cockpit components described above have been integrated into the Human Engineering Laboratory HELCAP simulator. This cockpit simulation integrates the data developed through experimentation that identified the number of displays, the information on each and the potential methods of interacting with these displays. The simulator incorporates four panel mounted electronic displays, a helmet-mounted display, voice interactive systems and touch sensitive displays. These concepts will be demonstrated in an integrated demonstration in the third quarter of 1991.

4. TACTICAL OPERATIONS CENTER (TOC)

The HELCAP program has also investigated the essential characteristics of the aviation TOC. The objective of these investigations was to ascertain the types of information that must go through the TOC and formats which make it most easy for the commander to use. Because of the flow of the air battle, the commander must be capable of issuing unambiguous orders to counterair helicopters with very little preparation time. Minimizing the staffing of the TOC is also important in these times of minimum personnel staffing. Here, too, data must be integrated into a ready-to-use form so the field commander can be given a ready grasp of his air picture and assets. The research in this area began with surveys of TOCs in operation during training maneuvers. These surveys resulted in determining the types of information that flow into and out of TOCs and how to code this information. From this start, the research is continuing into the development of user-friendly softwa' procedures for utilizing the automated TOC.

5. SUMMARY

The HELCAP program has been in progress for almost 3 years. Simulated tactical operations centers are being integrated with a simulated futuristic air-to-air helicopter cockpit. Similarly, a state-of-the-art air defense fire unit display is being formulated. These components will use a simulated air battle scenario to provide realistic stimuli for assessing the merits of the initial designs. Present part task data bases have been collected about various modalities to interact with the electronic copilot. These have included eye gaze pointing, using electroencephalogram information, touch screens, bezel switches, and voice recognition systems. Our schedule calls for an integrated demonstration of these soldier-machine concepts in the third quarter of 1991. This demonstration will be the initial phases of an interactive process for enhancing the effectiveness of automation in counter-air operations.

EXTRA-ORDINARY COMPUTER HUMAN OPERATION
(ECHO)

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1 INTRODUCTION

The objective of this paper is to highlight the research being undertaken at Dundee University in collaboration with GEC AVIONICS in addressing human-machine interaction problems. The research will compare and contrast the needs and solutions for the pilot of an aircraft in all conditions (including emergencies) and the physically and/or cognitively impaired person interacting with a personal workstation of the future. The ECHO project is a co-ordinated programme of research between Dundee University and GEC Avionics and results from a concept proposed by Newell in a paper [1] which argues for the advantages of a co-ordinated programme of research into the problems of both 'ordinary' human beings in 'extra-ordinary' situations and 'extra-ordinary' human beings (such as the disabled) in 'ordinary' situations.

The remainder of this paper is split up into five main sections. The first of these gives an overview of the research being carried out by the ECHO project. This is then followed by a section which proposes the view that all human beings can be considered disabled to some extent in relation to the environment they find themselves in. Section four discusses and compares the interface requirements needed to be considered when designing for disabled and able-bodied applications, while user modelling and expert system techniques are addressed in section five. Section six sets out the paper's conclusions.

2 ECHO PROJECT

The ECHO project is concerned with addressing the problems of human-machine interaction where the characteristics of the user and the environment in which the interface is situated can change dramatically and rapidly over time. The ECHO project will focus upon the following three issues :-

1. Increasing and making more efficient use of the bandwidth between the user and the machine.

2. Making a system more adaptive and personalized to the user.

3. Provisions for the system to be able to handle crisis situations without calling upon extra-ordinary human effort and hence error.

In the first instance the research will investigate two very dissimilar application areas, but ones which have very similar design requirements. Ultimately, the systems developed during this project will be appropriate for incorporation into applications other than the two specific areas which the project is looking at initially.

Demonstrators will be developed based on the provision of multimode presentation of information and control of the system, plus intelligent knowledge based prediction of the requirements of both the operator and the task, i.e. the aeroplane and the workstation for the disabled respectively. This work will be developed using the concept of a synthesised cockpit view and the use of intelligent knowledge base system technology for display management being developed by GEC Avionics; and a similar but parallel concept of adaptive and predictive interface design and the use of discourse analysis and dialogue structures for prediction, which is being developed at Dundee University[2].

3 TEMPORARY AND PERMANENT DISABILITY

One view held within the field of rehabilitation engineering is that human beings are all disabled by their environments to varying degrees. This is true of able-bodied people as of those who are classified as disabled. The parallels between disabled people and the able-bodied operating in a stressful environment, such as the pilot, is much closer than it may appear. Table 1 illustrates some examples given by Newell and Cairns[3].

TABLE 1 - Disabling Environments

ENVIRONMENT	EFFECT OF ENVIRONMENT
	TEMPORARY
communication over distance which is too large; noise;	hearing impairment
inadequate illumination; fog; undersea;	visual impairment
protective clothing; cold; fatigue;	motor impairment
stress; fatigue;	cognitive impairment
distance too great; rough terrain;	impairment of mobility

Some, if not all, of these environments and their effects have been documented in avionics literature [4,5,6,7,8,9,10]. In particular, the effects of automation in the cockpit and lack of situational awareness have received much attention with respect to their individual effects on pilots' workload and performance. The cognitive demands placed on a pilot due to the increase in workload/information overload are probably the most common form of impairment faced by today's pilot [10,11,12,13,14].

All human beings are limited in the amount of information that they can cope with at any one time. If they are presented with an amount of information which exceeds this limit (whether it be in visual, auditory or tactile format) then the probable outcome of the situation will be that the person will be unable to perform in a satisfactory manner in order to control the situation they find themselves in.

Wiener[6] has stated that automation in the cockpit has not eliminated human error, but has shifted the nature of errors. That is, as systems have become more automatic, the role of the human being has become less physically active and more cognitive. In relieving the pilot of physical (manual) movements, automation has subsequently marked an increase in the pilot's cognitive workload. Hence the original aims of automation, trying to reduce crew workload and eliminate human error, (which could be considered as trying to decrease the impairments of the crew) have not in fact been met. Reducing physical (manual) procedures has resulted in increased cognitive workload with the consequence that errors have now presented themselves in different ways.

Also, in modern military aircraft, information is sensed in highly sophisticated ways and combined by the aircraft's computers to be presented on electronic displays. These displays are generally well engineered and reliable but in practice seem to encourage the pilot into creating his own mental model of his situation, based on the electronic display symbology alone, and ignoring other important readings being presented to him from his instruments. This can subsequently lead to pilot disorientation and exemplifies the impairment of cognitive processing[4,12].

4 INTERFACE REQUIREMENTS

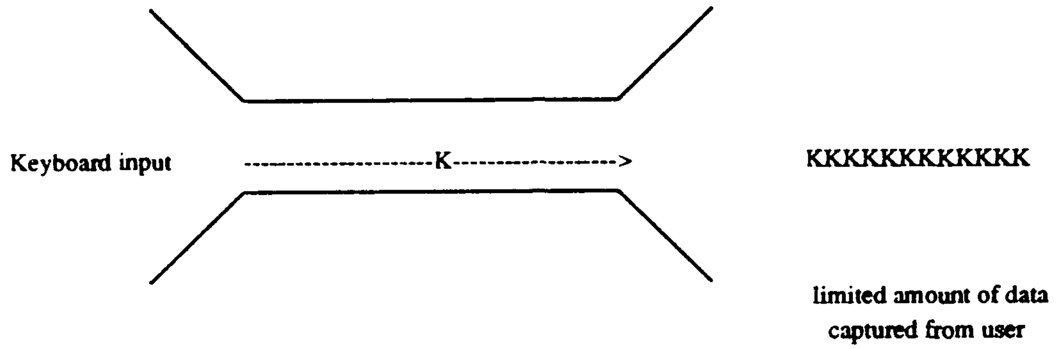
The previous section illustrated how pilots suffer from similar handicaps to those that disabled people do. It is thus illuminating to consider how interface requirements faced by designers of equipment for the disabled compare to those for the ordinary population. The ways in which rehabilitation engineers have increased the bandwidth between a human and computer can then be considered with a view to examining new potential and more mainstream situations. In designing for the disabled, one is forced to consider wider aspects of the interface problem in respect to the real needs and wants of the human. The human interface problems faced are similar to, but more severe than those faced by the designers of equipment for the 'ordinary' population and their solutions can often be more 'user friendly' than those produced by groups without this particular perspective[1].

Speech recognition systems, which are used as an alternative input device, offer benefits to the disabled and for those whose visual attention is otherwise engaged (e.g. pilots). In both of the above cases the interface needs to be able to cope with the variability in the users voice. In military applications, speech recognition systems are used to control the flight management system and its associated displays. Advance models of speech systems require to cope with the human speaker's variability that results from changing environmental conditions typically experienced in military fast jets. These systems require to pass severe acceptance levels - similar to the more severe design constraints which need to be considered when *designing for the disabled. In the case of the pilot, speaker variability* is caused by effects such as noise, acceleration, stress and head position[15]. Likewise, the speech variability of the disabled can be due to particular speech impairments or due to the effects of the distortion of the persons vocal tract due to uncontrollable upper body movement.

4.1 Bandwidth

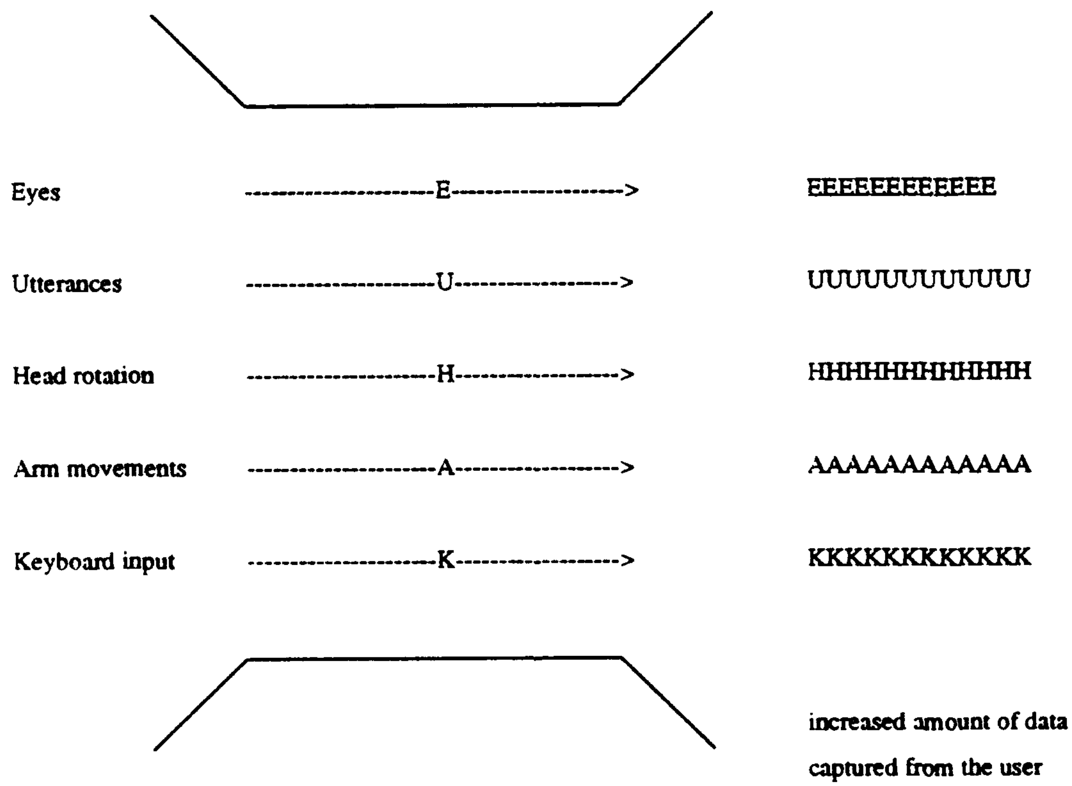
The able-bodied person in a high workload environment and the disabled share a common problem - the bandwidth of the channel which is available in both directions (input and output) is not sufficient for them to effectively and efficiently complete their task. One of the aims of the ECHO project is to investigate how the bandwidth between the computer and the user can be increased. This bandwidth is subject to constraints. In a specific environment, human beings have a limited ability to cope with a particular amount of immediate information which is either presented to them or which they have to operate on, whether that information is presented to them in a visual, auditory or tactile format. A tactile display used by a blind person to read text and the head up display used by pilots are examples of devices which are used to present a limited amount of information to the user, in relation to their limited ability to process it.

Current user-computer dialogues tend to be one-sided with the bandwidth from the computer to the user (e.g. VDU output) far greater than that from the user to the computer (e.g. keyboard input). This imbalance can restrict the effectiveness of the overall system. Figure 1(a) illustrates the narrow input bandwidth between the user and computer. Research into human-computer interaction technology has done a lot to improve information transfer with respect to producing alternative input devices and incorporating techniques to filter out errors. However, not much has been done to increase the quantity of information transferred from the user to the computer system. In order to increase this bandwidth more information requires to be captured from the user. In principle this could be done by directly sensing the user's thoughts or by increasing the number of input channels. Out of the above techniques, the second of these seems more immediately attainable today. This could be done by capturing gestural, vocal and other physiological features. Shein at al [16] illustrate this concept in figure 1(b). Similarly, increasing the output bandwidth needs to be investigated. Most current interfaces only provide output in a visual



Narrow Input Bandwidth Between User And Computer

Figure 1(a)



Widening The Bandwidth To Increase The Quantity Of

Information Transfer Across An Interface

Figure 1(b)

format. More work should be done on investigating alternative (non-visual) sensory modalities. It is believed that systems incorporating higher levels of man-monitoring such as this will result in systems which will produce better user models on which to infer the operators intentions [17].

5 USER MODELLING

In conjunction with investigating the increased bandwidth in human-machine interaction, the ECHO project will also address the subject of user modelling. That is, how can an intelligent knowledge based system be utilized to create a computer system which is more adaptive and personalised to a particular user. For such a system to be efficient, it must be capable of remodelling dynamically in a non-obtrusive way to accomodate the user with whom it is interacting [18]. The result of this adaptive user modelling will lead to improved man-machine communication, assist the user in the correct, effective and efficient use of the system, thereby enhancing the user's knowledge on how to use the system.

As a consequence of our collaboration with GEC Avionics, we will exploit their use of intelligent knowledge based systems for display management in assisting the pilot of a single-seat, high performance aircraft at times of exceptionally high unplanned workload. In parallel to the pilot in the above situation, it is believed that a computer based system developed for the disabled, specifically to cater for groups of people with varying degrees of disabilities, should be capable of being able to handle imprecise information, choose the most promising approach from a number of strategies, perform a measure of logical reasoning, explain its conclusions and offer appropriate advice. The implementation of such an intelligent knowledge based system will use a plan recognition mechanism which is seen by us as involving three stages : monitoring, inferencing and prediction.

- Monitoring is defined as the process of collecting data from a user. Data which is collected from input devices (e.g. keyboard, joystick) in order to directly control a specific task is defined as direct monitoring. Data gathered from the user by sensor/tracker devices which provides information on the type of behaviour the user is exhibiting is defined as attention monitoring.

- Inferencing is defined as the act of drawing conclusions on data which has been gathered from the monitoring stage. (These conclusions may not necessarily be valid). Information is also extracted from relevant knowledge bases into this process. Inferencing can be divided into direct inferencing and attention inferencing. Direct inferencing utilises data collected from the previous direct monitoring stage. Likewise attention inferencing uses data gathered from the previous attention monitoring stage on which to base conclusions.

- Prediction is defined as attempting to guess what to do next based on the previous inferencing and monitoring stages. It is thought of as being the output from the inferencing process and is subsequently used as feedback into the monitoring step, thereby enhancing the plan recognition cycle.

The ECHO project will incorporate the concepts of existing projects[2] at Dundee University into the monitoring, inferencing and prediction stages of the plan recognition mechanism. Examples of these include :-

- predictive and adaptive systems which give significant keysaving when entering text into computer systems

- conversational systems for the speech impaired based on a computer model of the dialogue structures of human conversation

- automatic analysis of gestures made by those with motoric dysfunction

- applications of relational database technology and semantic net hypertext structures for navigating through spoken language

- the use of computer systems to assist those with language dysfunctions.

Also incorporated in this intelligent knowledge based system (IKBS) will be some form of error tolerant interface, as described by Hollnagel [19], which will enable the system to function so that it takes in most of the inevitable variations in human capacity. Such an error monitor can provide important support for overcoming users limitations[20]. Error identification detects irregularities between expected and observed behaviour and has useful implications in the design of an intelligent system, such that distinctions can be made between an inappropriate intention and an incorrect execution of actions[21]. When errors occur due to a user's misunderstanding, it is likely that the user will require some form of explanation before accepting the conclusion that their choice was wrong.

6 CONCLUSION

The main aim of the ECHO research is the development of a workstation which incorporates an increased bandwidth and some form of plan recognition mechanism. In comparing the human computer interface needs of a pilot to those of a disabled user we are presenting the hypothesis that all human beings can be considered disabled to some extent depending on the environment they find themselves in. Although the ECHO research is only looking at comparing two applications (the pilot and the disabled) this line of research could equally be applied to other applications whether they be military or commercial. The aim of forming a more co-ordinated programme of research between existing research groups to raise the issue of parallels between these two fields of research will lead to fruitful discussions and cross-fertilisation of ideas. Investigating in more detail the real needs of people will lead to better design and can result in reduced cost to a project in the long run.

At present the ECHO project is in its early stages. Data is being collected on input and output devices which are currently available and can be used by the disabled. A basic architecture for the computer workstation demonstrator is being specified. This outlines how the ECHO project sees the workstation being developed in its early stages. Investigations into the application of intelligent knowledge based systems are also still in their infancy. It is hoped that we can obtain relevant guidelines and exploit techniques from a workshop such as this.

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Operator acceptance of Sensor Advisor demonstrator[1]

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Summary

The move towards more technologically complex mission systems, for handling increased mission sophistication, coupled with limits on available manpower resources, is leading to increased crew workload and more lengthy training of operators for many existing and future aircraft. RAE has a research programme to investigate how expert systems technology can be exploited to relieve this problem by enabling the development of decision support aids to reduce crew workload and improve operator performance. It examines the technology and its capabilities, and builds specific application projects to demonstrate the benefits of the technology. One aspect of this programme is the development of a means for building validated expert systems that can be reliably deployed.

Expert systems have special properties which complicate the validation process, such as their capability to express complex decision-making processes. They require all participants in system development to have a shared basis on which to set and assess acceptable standards. The VORTEX project, commissioned by RAE, aims to develop this basis from actual experience rather than abstract thinking. It is divided into two parallel strands: an application strand which builds a robust expert system demonstrator called the Sensor Advisor, and a methodology strand which captures the experiences gained from building the demonstrator and consolidates them in a validation-oriented expert systems methodology.

An important validation issue is operator acceptance. It was addressed in VORTEX through careful expert system design, and by involving designated domain experts throughout the demonstrator's life-cycle.

1 Introduction

In 1986 Logica undertook a study on behalf of RAE to investigate the validation of real-time knowledge-based systems [1]. The Study considered the extent to which existing specification and validation methods can be applied to expert systems and outlined an approach to expert-system validation. It also recommended that the next step should be to monitor the development of a laboratory-based demonstrator which applied the methodology. As a result RAE initiated the first phase of the VORTEX project in 1988. The project was divided into two parallel and complementary strands of work: a methodology strand and a demonstrator strand. The demonstrator strand developed a real-time expert system as a means of refining and testing the proposed methodology. Through this strand, actual experience of the early stages of a full expert system life-cycle and insight into the validation issues relevant to later stages of the life-cycle were gained. These results were analysed in the methodology strand and consolidated in a Final Report [2].

The demonstrator strand of the VORTEX project consisted of four well defined phases: application selection, demonstrator definition, demonstrator development, demonstrator delivery and evaluation. Application selection identified several candidates, and specified selection criteria to choose one as the subject of the definition phase. Demonstrator definition built a small feasibility prototype that helped determine whether this application would make a suitable candidate for a demonstrator, and also enabled RAE, domain experts and the development team to gain a clearer idea of the demonstrator's intended functionality and implementation environment. Demonstrator development involved the design, implementation and testing of the demonstrator software. Demonstrator delivery and evaluation installed the demonstrator software on RAE's Symbolics workstation at Farnborough and conducted several validation experiments that aimed to assess the usefulness of the demonstrator's output, the validity of its knowledge base and its future requirements.

The methodology strand analysed the work undertaken in each phase of the application strand and identified the strengths and weaknesses of our approach to building the expert system demonstrator. Two important aspects of this work were the development of verification and validation support tools, and the validation experiments undertaken as part of the delivery and concluding validation phase of the application strand. The support tools facilitate inspection and testing of the knowledge base. The validation experiments provided an insight into the sorts of procedure that could be employed to validate an expert system, and determined what validation was achievable with the current demonstrator. They also prompted further knowledge acquisition, demonstrating the synergy that exists between development and validation in expert systems.

2 VORTEX demonstrator

2.1 Application

The VORTEX demonstrator needed to be both a plausible application for improving mission performance and sufficiently constrained for the purposes of investigating and developing the expert system methodology proposed by the Validation Study. It consists of the Sensor Advisor and its Support Environment. The Sensor Advisor is the software that demonstrates the application of expert systems technology, and the Support Environment is the software that is used to develop, verify and validate the Sensor Advisor.

In consultation with domain experts, RAE chose an ASW tactical decision-aid for a rotary-wing aircraft as the application area. Crew workload can vary considerably during a sortie. For example, workload is often low when flying to a barrier and excessive when prosecuting a target. The demonstrator helps even out these wide variations by advising the Observer on the selection and deployment of sensors for the detection, tracking and prosecution of submarines. Sensor selection recommends the best sensors from the aircraft's sensor suite to deploy for a particular mission scenario, and sensor deployment recommends the best way to use these sensors. In this way, Observers are relieved of some straightforward ASW tasks, thereby providing extra time to consider more important tactical decisions. A further benefit of the expert system is that it can consistently consider all relevant information. It avoids overlooked options at times when it is not clear what actions to take, such as loosing contact with a target, and so can increase the performance of novice or average Observers.

2.2 Sensor Advisor

The Sensor Advisor's knowledge base is expressed in ASW specific terms, using vocabulary and structure familiar to ASW specialists. This is important for validation. Making the knowledge base more accessible to ASW specialists means that they can directly validate its contents. The knowledge base is divided into: domain knowledge such as threat, sensor and weapon data; and problem-solving knowledge such as ASW tactics and their application. Problem-solving knowledge is represented as decisions which need to be made and the tasks which make them. Tasks are typically implemented as production rules, although they can be algorithmic. Together, these components provide a depository within which to record evolving ASW tactics. Because ASW specialists can easily understand the language used to express these tactics, the knowledge base also serves as the basis for discussing and improving them.

The tactical expertise represented in the knowledge base considers the mission brief, sortie data and other information to advise the Observer on which sensors to use and how to use them. For sonobuoys, it specifies the buoy type, position, separation and depth. For MAD, radar and ESM, it advices when and how to use them: for instance, should the radar be used continuously or intermittently, and along what vector, relative to threat bearing, should MAD be used. A concise explanation of the rationale for this advice is also given, based on the key decisions made. This helps build the confidence that Observers have in the Sensor Advisor's recommendations.

Input to the expert system is provided through a simulation of a typical avionic input device. There is also a separate interface used to control a demonstration and inspect the detailed reasoning responsible for the recommended advice. It is divided into a control and trace window. The trace window would not be present on-board the aircraft, but might exist in an operational support station. Its purpose is to build the confidence that ASW specialists and developers have in the Sensor Advisor, by providing a detailed description of the reasoning behind the Sensor Advisor's advice. The control window provides access to the mission system. It lets you simulate mission system events such as sonobuoy detections, and maintain a clear separation between Observer and mission system interaction. This enables a better appreciation of the expected level of interaction between the Observer and the Sensor Advisor.

The Sensor Advisor copes with real-time constraints in the same way as an expert Observer would. Operators can interrupt current reasoning and input unsolicited information such as intelligence on threat type. The Sensor Advisor will then modify its reasoning in-line with this new information. Similarly, asynchronous mission system events can alter the Sensor Advisor's reasoning. Advice is also generated within time limits acceptable to the operator. Domain experts identified situations where response times were critical and described their problem-solving approach accordingly. Thus timing constraints are expressed implicitly within the problem-solving knowledge. Moreover, in some cases the Sensor Advisor will suppress user interaction to increase its speed of response. However, enabling the user to take part in the Sensor Advisor's reasoning process is a significant factor in gaining operator acceptance.

2.3 Support Environment

An important part of the demonstrator is the Support Environment. This environment facilitates the modification and validation of the Sensor Advisor's knowledge base. A syntax-directed editor enables the addition and modification of problem-solving knowledge without the need to remember the exact way tasks are represented. Verification tools are used to check a task's correctness and consistency with respect to the rest of the knowledge base. Validation tools are provided to assist with knowledge base inspection and testing. They are used to view the various elements and inter-relationships within the knowledge base, both statically and at run-time, in a way that is useful to ASW specialists.

This support environment was used by ASW specialists in evaluating the Sensor Advisor. They agreed that it was an important and useful part of the demonstrator, which was essential for the validation, acceptance and maintenance of the Sensor Advisor's knowledge base. This view is consistent with the Rome Air Development Centre's work on a Software Life-Cycle Support Environment [3] which combine development tools with tools to assist in verification and validation.

3 Managing expert system development for acceptance

Mackie and Wylie [4] provide a good model of the acceptance process which suggests the following as being key to a new system gaining acceptance:

- Involve operators in the development such as credible experts and operator representatives. Use their input in the development process and demonstrate the relative advantages, operational validity, reliability and limitations to the operators.
- Communicate with potential operators to identify critical issues such as desired features, beliefs, operational need and disseminate information to show that operator needs have been considered and the benefits can be described.
- Design for acceptance with general design criteria such as operational constraints, clear concise output, quick easy input and application specific features.

The VORTEX methodology recognises that operators, experts, procurers and developers must share responsibility for validating an expert system, if final acceptance is to be achieved. It advocates a life-cycle in which the validation process is integrated with system development. The life-cycle is divided into phases and stages which produce validated products, and the rest of the methodology indicates which aspects to validate at each point and how validation may be accomplished.

Validation can be carried out only against a statement of specification. However, a trade-off exists between the level of abstraction at which the specification is made and the objectivity with which the validation process can be carried out. For expert systems it is very hard to produce a sufficiently detailed specification prior to implementation. This is particularly so for the quality of output generated by the expert system and the range of circumstances under which this effectiveness of operation is expected. The consequence of this for expert system development and acceptance is:

- It is necessary to operate at a high level of impact on operational effectiveness. The whole system cannot be specified at a low level of abstraction and be subjected to strong objective validation. This implies a layered view for the specification of expert systems, that evolves as development proceeds.
- The specification is more evenly distributed across the development life-cycle than is the case for other software technologies. This implies an interactive approach to expert system validation rather than the traditional "specify, implement and test".

The VORTEX methodology seeks to progressively build confidence that operator requirements can be met, while minimizing the risk that the system will operate outside limits of acceptable performance. This approach compliments the NASA Ames-Dryden methodology which advocates incremental confidence building for flight and mission-critical software [5]. It is, therefore, essential that operators and their representatives be involved in expert system life-cycle from the start. In the application strand of VORTEX, ASW specialists were shown how expert systems technology could be applied to the range of situations faced by the operator, operators were involved in the choice of an application that provides valuable support that is not available in existing mission systems, and designated domain experts regularly reviewed and updated the Sensor Advisor.

4 Expert system design and operator acceptance

4.1 Knowledge representation

Greatest benefit from early operator involvement is achieved when the knowledge representation used is both accessible and machine-executable. For the Sensor Advisor, the expertise used to generate advice on ASW tactics is programmed in terms of: what decisions are being made (such as whether to go active or passive); what information is needed to make these decisions (such as mission brief, threat behaviour and water conditions); how the decisions are derived from this information based on expert ASW tactical practice. This problem-solving knowledge is expressed as a hierarchy of tasks and sub-tasks, which is structured in a way that reflects how expert Observers decide on which tactics are best for a given scenario. Making this structure explicit is important for validating the expert system, maintaining it, and explaining its reasoning to operators [6]. It is also an important step in taking experts systems from a nascent technology towards an engineering discipline.

Operators need to see the effect of applying tasks in the knowledge base, as well as understanding their meaning. Seeing how a task affects the Sensor Advisor's reasoning for different scenarios is a necessary part of validating the knowledge base. Enabling operators to inspect the knowledge base and then test it is the most direct way of gaining acceptance. Using intermediate knowledge representations would complicate this process, requiring operators to understand and have confidence in the translation from one representation to another.

4.2 Operability

A factor that determines the acceptability of the Sensor Advisor is the build up of trust by the operators in the system. A good model of trust is described by Muir [7], in which she describes how trust changes over time and is initially dependant on the predictability of the machine. The person's ability to assess this property will depend on his own limitations as a decision maker. Later on the trust in the system will be based on its dependability, where in a risky situation where the system could have been undependable the system provides a useful result. The final stage in the growth of trust is the development of faith. This is where the operator believes the system will be dependable in the future. The Sensor Advisor supports its recommendations with concise rationale based on the key decisions made. This contributes to the trust operators place in advice generated by the system.

Operator interaction is another important factor which determines acceptability. Roth et al [8] compares two ways in which an operator can interact with an "intelligent" decision aid. The capability for sharing in the generation of a solution as a means to achieving operator acceptance being a key feature. This view is supported further by Reason [9] who distinguishes between "prostheses" and "tools".

A typical scenario for the usage of most expert systems is: the operator decides to use the system; the system controls data gathering; the system offers a solution with some explanation; the operator accepts (acts on) or overrides the system solution. In this form of interaction the locus of control resides with the system. The operator is expected to be its servant and put in all the required information, then rapidly switch to be its master and monitor and overrule it. The system is acting as a "cognitive prosthesis" to remedy deficiencies in the user. Roth shows this approach has serious weaknesses and prevents operators taking an active role in the problem-solving process. He goes on to suggest the alternative approach of a "cognitive tool". This involves the operator as an active problem solver in order to cope with unanticipated problems and times when the system heads off on a wrong or unacceptable track. The Sensor Advisor makes explicit its reasoning, supports voluntary operator input, and indicates the boundaries of its knowledge. In this way the operator is able participate in the reasoning process.

The benefits of having operators remaining as active problem solvers is that they can then maintain supervisory control, but with reduced workload. They need to be solving the problem in parallel anyway, so that they know whether to accept or reject the system's suggestions. If they are actively involved in this process, they will have greater confidence in the result and will be able to rapidly judge the system's recommendations. These ideas approach Schuman's "shared frame of reference" [10] in which the system's assumptions about the world, the history of observations entered, the options rejected and the current line of reasoning are all made explicit. The operator needs to be able to assess the state of the system and recognise when the system is beyond its boundary of competence, whether the current line of reasoning is due to faulty input or faulty knowledge.

5 Conclusions

The main conclusions resulting from this paper can be divided into those which relate to expert systems development and those which relate to the design of knowledge-based tactical decision aids. For expert systems development:

- Validation should be an integrated part of the complete expert system development life-cycle, and aim to progressively build confidence that operator requirements can be met
- Operators and their representatives should be involved from the start of development
- Tools to assist with verification and validation of the knowledge base should form a significant part of any expert systems methodology.

For knowledge-based tactical decision-aids:

- The knowledge representation used should closely reflect the way operators reason about which tactics to apply for a given scenario
- Tasks are a good way of expressing and structuring problem-solving knowledge
- Operators need to see the effect of applying statements in a knowledge base, as well as understanding their meaning
- Using a knowledge representation which is both familiar to operators and machine-executable is the most direct way of gaining operator acceptance
- Providing rationale based on key decisions made, and enabling operators to share in the generation of solutions is an important means to achieving operator acceptance.

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COMPUTER AIDED TACTICS IN THE COCKPIT

by

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SUMMARY

One of the most important considerations in the design of future weapon systems will be the introduction of tactical and systems automation. Such facilities will provide computer support to the human operator across the full spectrum of mission management tasks. The growing importance of these aids stems from the continued drive to achieve greater operational effectiveness with an acceptable crew workload. A primary area of application is in the cockpit of a combat aircraft, where the increasing complexity of the systems and severity of the air battle environment place intense demands on the crewman. This paper describes a recent phase of work in the continuing development programme at British Aerospace to provide computer aided tactics in the cockpit. The particular tactical aid COMTAC is discussed, outlining its main features and describing how it has been installed into an 'active cockpit' facility to examine the man machine interface.

INTRODUCTION

A number of years ago, following conceptual discussions with GEC, Ferranti and Smiths in the Industrial Avionics Working Group (Reference 1), British Aerospace initiated an in-house programme of research and development work to produce prototype mission management aids (MMA) for use in combat aircraft. This work has included not only conventional programming techniques, but also the use of intelligent knowledge based systems (Reference 2). Because of the wide sphere of application of mission management aids, a co-ordinated work programme is now underway at all of the main sites of the BAe Military Aircraft Division.

This paper describes a particular computer tactical aid called COMTAC. It is based on earlier experience with a microcomputer tactical aid called MITAC (Reference 3), although COMTAC is much more powerful and has a far more extensive range of tactical algorithms.

The whole programme of work on mission management aids, of which COMTAC is an example, grew out of the realisation that the conventional technological development path was not viable. The provision of increasingly complex systems and weapons to be operated in an increasingly severe air battle environment results in excessive pilot workload and reduced performance. As the new systems and weapons are essential, in order to deal with the growing enemy threat, it is necessary to support the crew with computer aids. These take the form of tactical aids, to assist the crew with attack planning and execution, and systems automation to assist the crew in the operation of onboard systems and weapons.

As already mentioned, COMTAC is a tactical MMA. Its function is to assist the crew in understanding the outside scene, deciding which are the most important targets and threats, working out a range of alternative attack and defence options, and then deciding on the best course of action.

A typical air defence scenario, within which such a tactical aid could be required to operate is shown in Figure 1. The scenario includes three main types of enemy raid: attack on airborne early warning, enemy fighter sweep, and an escorted deep strike raid. Such scenarios have been used in the development programme of COMTAC to demonstrate and assess its effectiveness. In addition to the primary airborne targets and threats, the tactical aid must also deal with numerous other enemy and friendly aircraft in the scene, as well as threats from enemy ground forces, e.g. SAMs.

In addition to the development of the tactical algorithms, it is also of fundamental importance to design an appropriate man machine interface (MMI), with particular emphasis on display formats and crew interaction, so that the tactical aid can be of maximum benefit. This was achieved through a parallel MMI programme, closely related to the algorithmic developments.

Finally it is necessary to demonstrate and assess the tactical aid in a realistic environment. This was done by programming the algorithms and displays into an 'active cockpit' facility, which could be flown and assessed by aircrew.

COMTAC ALGORITHMS

The guts of COMTAC are, of course, its tactical algorithms, which process the outside world data in order to decide on the best course of action. The functional architecture of COMTAC, which shows the relationship between the different algorithmic blocks, is shown in Figure 2.

After their detailed specification, the algorithms were developed and tested on a computer workstation, before being transferred to the 'active cockpit' facility. In order to complete this development and testing, the workstation was programmed with a number of facilities including an outside world model, containing dynamic enemy aircraft and missiles, through which the combat could be run in real time. The tactical behaviour of enemy aircraft can be varied and it is possible for the operator to 'board' any aircraft in the scene to get a pilot's eye view of the combat situation and to vary aircraft manoeuvre of weapon launch decisions. The workstation has a high resolution colour display, which is particularly useful for presenting the results of the tactical computations. Although closely related, the actual cockpit displays were developed separately as part of the parallel MMI programme.

With reference to Figure 2, the first COMTAC function is Situation Assessment. Some of the factors which feature in the situation assessment algorithms are shown in Figure 3. The main purpose of Situation Assessment is to reduce the whole of the outside scene, referred to as the alpha scene, to a smaller selected number of the most important targets and threats, known as the beta scene. This process includes obvious features, like deletion of friendly tracks from the treat list, as well as more complex range and urgency functions, to determine which enemy aircraft will come within engagement range first. Other computations address target behaviour. A final, but important, algorithm decides the target/threat mix that is to constitute the beta scene, to avoid overemphasising either one.

The next COMTAC function is Attack Planning in which a range of different attack options are computed against each aircraft in the beta scene. These include various tactics in terms of aircraft approach paths and missile launch points, as indicated in Figure 4. The aircraft approach paths can be multi leg, including set-up manoeuvres, attack manoeuvres and escape legs. Collision, lead and lag courses are computed, with the appropriate use of energy management in the vertical plane, the options being constrained to ensure that the targets remain in radar view.

On each attack option, full missile firing brackets, from maximum to minimum range, are computed against primary and secondary targets. These include representative performance of the missile in each of its critical phases; an example to illustrate those for a mid-course guided active homing missile are shown in Figure 5. Kill probability functions, varying with launch range, are used to determine the effectiveness of each missile launch opportunity.

The third major COMTAC function is Enemy Counter-Attack Assessment, where the risks associated with each of the attack options is assessed. This is done by examining the attack paths and missile launch opportunities of the enemy threat aircraft (Figure 6), using many of the algorithms from Attack Planning. The effect of enemy missile counterfire is to produce kill probabilities which are then converted into reductions in own survival probability. Enemy surface-to-air missile attacks are included in this process.

Following this comprehensive assessment of enemy counter-attack options, sufficient data has been derived to allow the next process to Defence Planning. As indicated in Figure 7, this process includes evasive manoeuvres, jamming and the use of decoys. The use of these defensive measures increases own survival probability.

The above processes provide a full set of tactical options, known as gamma options, each of which includes a full set of information on attack, counter-attack and defence. This forms the options database.

The final COMTAC function is Options Analysis and Ranking, which decides the best option to go for (the gamma star option) and ranks the alternatives in a preferred order. This is done by analysing the cumulative target kills and own survival probability on each option to determine which one maximises a special tactical value function. This function places different values on the kills achieved against different types of enemy aircraft, e.g. bombers, fighters, AWACS, as well as placing a value on self. It also weights the probability of different forms of enemy tactical response, e.g. bombers more likely to carry straight on, fighters more likely to turn and attack. The numbers in this tactical value function can be varied by the user, depending on the stage of the war and the tactical objectives of the mission. Although the objective is always to achieve the maximum number of target kills, this has to be balanced against own survival probability. With different weightings the recommended option could vary from one giving few kills with no risk to one giving many kills with greater risks.

By pressing an appropriate key the workstation will display any of the gamma options. The operator can adopt the recommended attack or choose an alternative. Information will be available for the selected option to provide attack steering and missile launch control as well as defence cueing. The operator can fly the attack in real time to see how it develops and how well the tactical algorithms cope with the changing situation.

All of the above COMTAC functions are executed on the alpha/beta scene every cycle, to produce updated options. For real-time applications in the cockpit, the aim is to keep the cycle time for these computations below one second. This requires the very latest technology in compact and powerful computers and considerable expertise in designing fast algorithms.

MAN MACHINE INTERFACE

Having designed and developed the COMTAC algorithms, the next important issue to be addressed is the question of how the pilot interacts with the MMA. This will depend on his confidence in its ability as a tactical advisor, bearing in mind that automation has never been applied so extensively in tactical areas which have traditionally been considered the pilot's domain.

The underlying assumption of the MMA development is that it can perform as many or as few tasks as the pilot will sanction it to carry out. Whilst the MMA operates in this assigned role, it is crucial that the pilot's awareness is maintained of the overall situation with which he is faced. How much information does the pilot need in order to monitor the MMA, so that when required he can take over the tasks best suited to him? What are the best means by which to present this information in the most natural way for the pilot to assimilate?

In order to examine such questions, a rapid display prototyping facility was established on which display formats could be generated, assessed and modified in an iterative process, all in a short space of time. Tentative ideas for presenting information to the pilot can now be drawn on a display surface in hours rather than days or weeks. Iterative evaluation and development of formats that show promise can proceed in the same sort of timescale.

The facility comprises a high resolution graphics workstation to which is attached keyboard, bitpad and interactive mouse, the means by which drawing instructions are specified. Formats are drawn using a variety of primitive graphic elements, in a range of colours from a palette of sixteen million, using highly adaptable symbology sizes and character fonts. The software that allows this facility to be used to such good effect has been specified and generated in-house.

The advent of this quick-look facility allows mind's-eye concepts to be quickly sketched out in a representative fashion and stored. A range of options was developed from conventional two-dimensional formats through perspective views to pseudo 3D presentations. In parallel with this range of format options, numerous symbology conventions were raised for discussion and trial. One of the most complex formats (Situation Assessment) was taken and symbology used in various ways to differentiate between the classes of data requiring presentation. The merits of the conventions were assessed and most usable read across onto all the chosen working options.

Assessments are being undertaken by cockpit specialists and project aircrew, the results being used to refine the formats to a good working standard, gradually homing in on a suite of optimised formats.

The main working format is the plan situation display, which presents a long range view of the overall scene surrounding the aircraft. This can be presented with the full detail of the Alpha Scene, or as the more manageable subset, the Beta Scene. The high priority tracks are categorised for height band, sensor source providing the data, co-operating, unknown or hostile. Hostiles are annotated as being designated for attack, allocated to another co-operating aircraft or just of interest.

Tactical analysis of the scene allows the generation of recommended attack options for own aircraft on the Gamma display. The pilot is given the capability to cycle from the gamma star option through the ranked alternatives prior to sanctioning the one he deems best.

Once this option is chosen, then an attack steering format can be selected which presents a tunnel down which to fly. This takes the form of a series of rectangles which define azimuth and elevation steering limits for an approach and attack course, the rate of advance of the rectangles giving a speed cue and discrete event markers being generated to indicate firing brackets.

ACTIVE COCKPIT

Having generated a full set of tactical algorithms and a suite of display formats with symbology conventions, the next important step is to make them dynamic in as realistic a context as possible. BAe Military Aircraft Division operate a number of mission simulator facilities to support aircraft projects and advanced research. Active cockpit facilities at Brough and Warton are being used in this programme, to allow pilot interaction with the MMA whilst performing representative tasks. They provide the displays and controls necessary for pilots to fly out air defence sorties through complex scenarios.

One of the Warton 'active' cockpit facilities is shown diagrammatically in Figure 8. It comprises three main elements:

* The assessment booth, containing cockpit mock-up and outside world projection system.

* The assessment control station.

* The computer hardware and software.

The basic facility includes an aerodynamic response model, which when interfaced to the outside world system and the incepters in the cockpit allows the pilot to fly the simulation and receive realistic visual cues. Basic flight data is provided by a simulated head-up display superimposed on the outside world. Provision of aircraft system models and head down display formats for fuel, hydraulics and engines ensures that the pilot can be loaded with a realistic system management task.

Display format control is by means of either multifunction buttons on the bezels or the throttle mounted XY controller for cursor control on the three display heads.

The set of displays for mission management comprises:

* A radar format, which can be shown in either plan or range/azimuth form.

* A self defence format, which locates primary threats and uncorrelated RF sources within a compass rose.

* A long range plan situation format, which locates and identifies targets indicated by onboard and remote sensors. This display can have track or north orientation, different range scales, selective decluttering and alternative forms of attitude information.

* An attack steering format in the form of a tunnel of rectangles.

The plan format is used to display the Alpha and Beta scenes and the Gamma options. When the most promising attack option has been selected, steering information is provided on the attack steering format.

The facility allows different scenarios to be introduced to test the ruggedness of the MMA. A broad opinion of its effectiveness will be sought by working closely with a large sample of pilots in formal assessments on a number of missions. In this way the scope of the MMA and the necessary man machine interface will be optimised.

FUTURE DEVELOPMENTS

This paper has described some recent work on a tactical mission management aid, addressing one key area in the wider MMA scene, which covers all aspects of tactical and systems automation.

Many lessons have been learned and insights gained from the work done so far, which will be used in a continuing programme of research and development to extend and improve the tactical MMA. This will include new and more efficient algorithms to represent aircraft and missile performance, development of better tactics with enhanced multi-target sequencing, operation in the jamming environment, and group operations.

Work is also under way on new approaches to the presentation of tactical information to the crewman in innovative pictorial form.

Another very useful outcome of the work done so far has been a clear realisation of the computing power required to run a comprehensive tactical MMA in real time.

In addition to the tactical core of MMA work, the programme will be expanded to include other important areas in the total MMA system architecture.

The application of intelligent tactical and systems automation in combat aircraft is seen as a very powerful method of providing the necessary increases in operational effectiveness.

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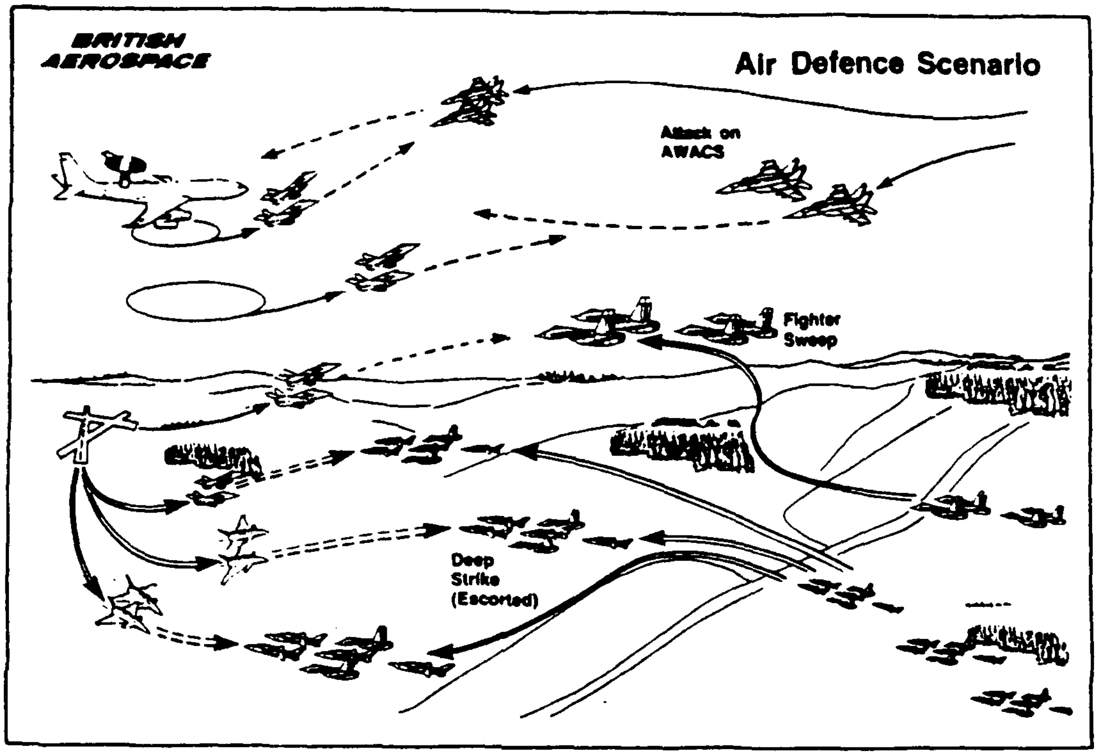

Figure 1

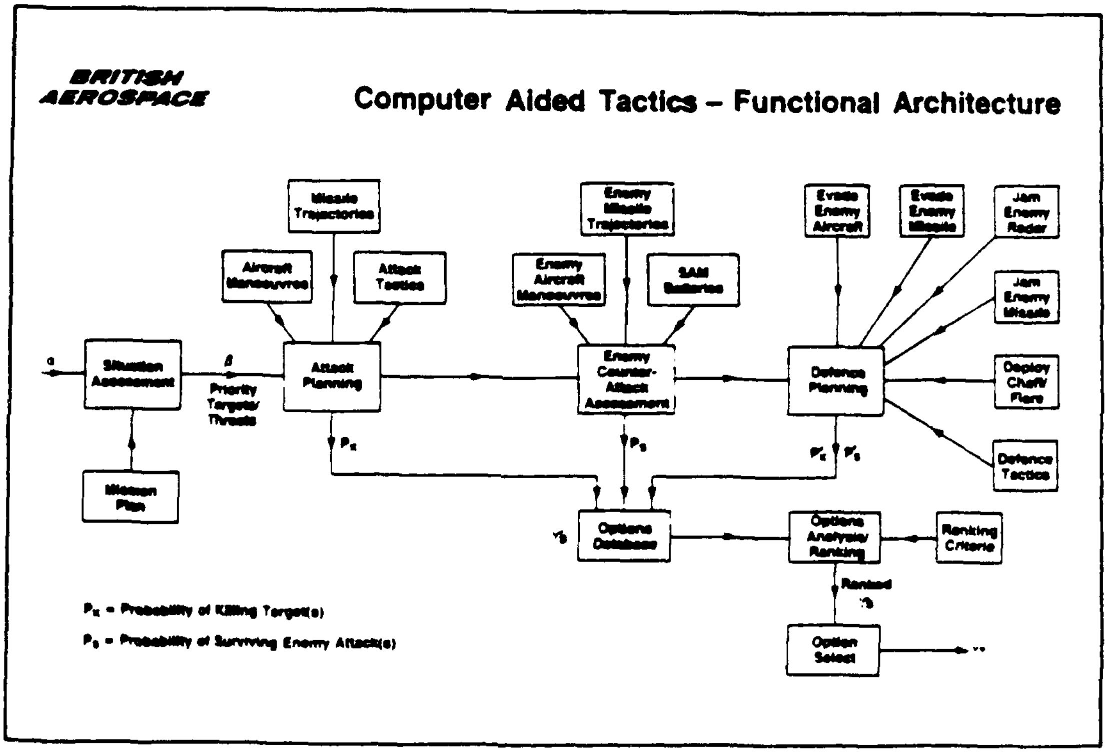

Figure 2

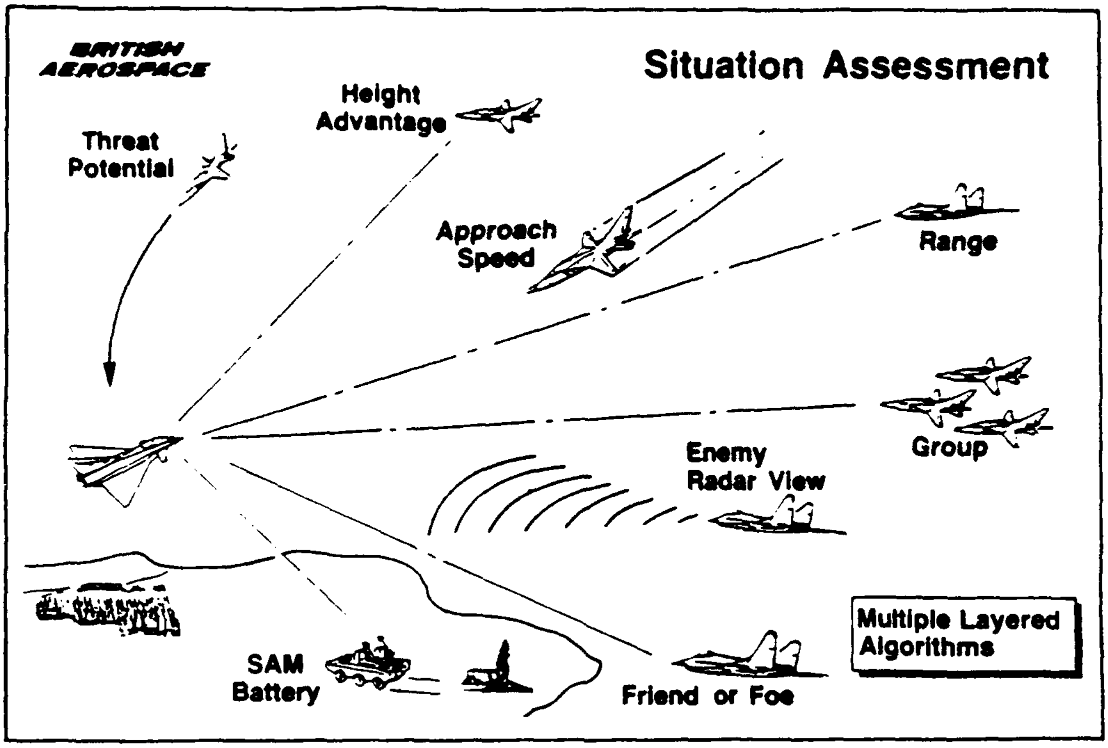

Figure 3

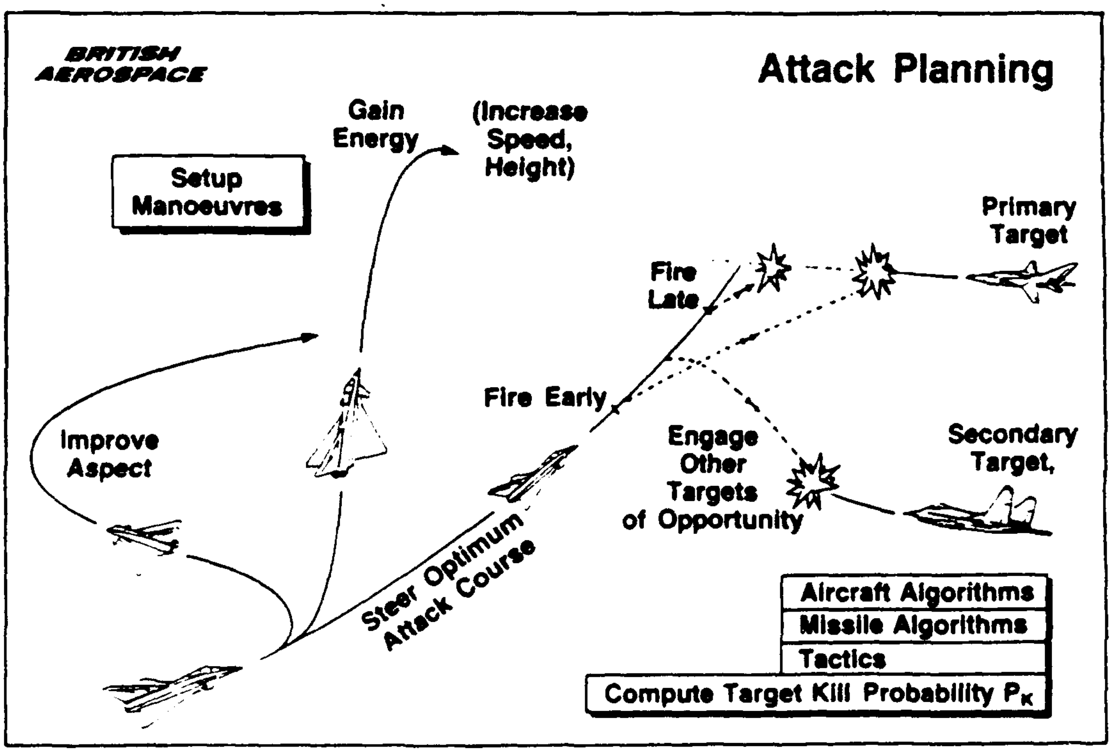

Figure 4

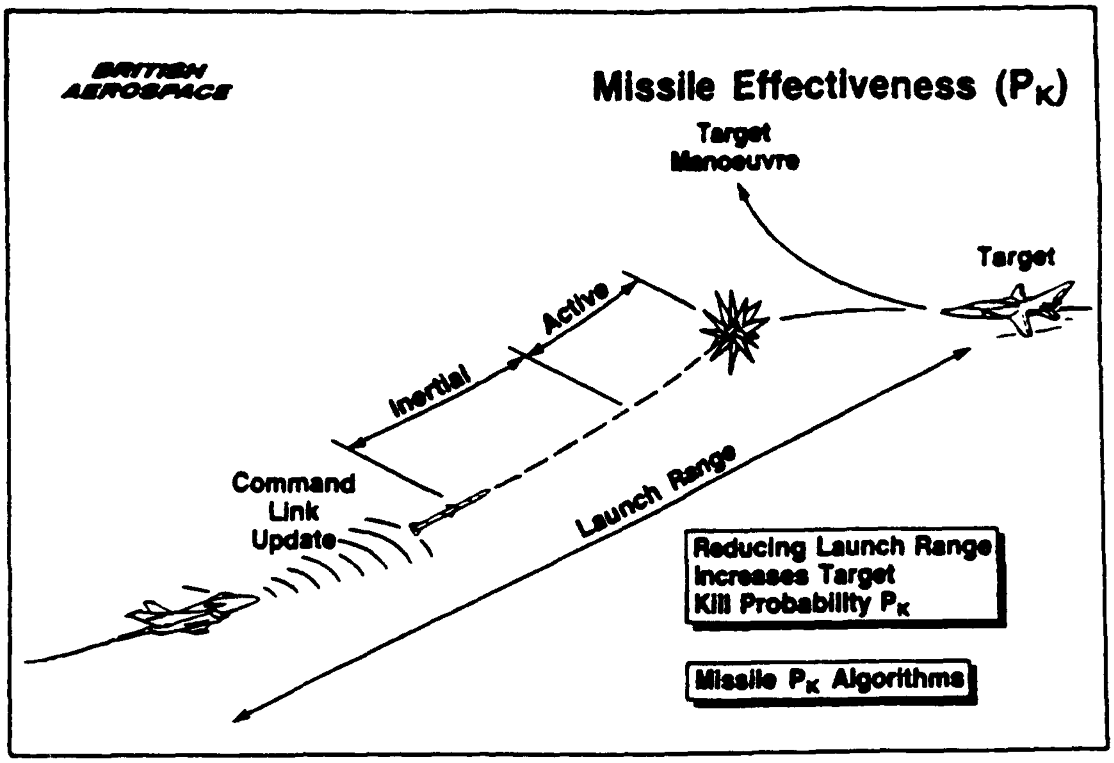

Figure 5

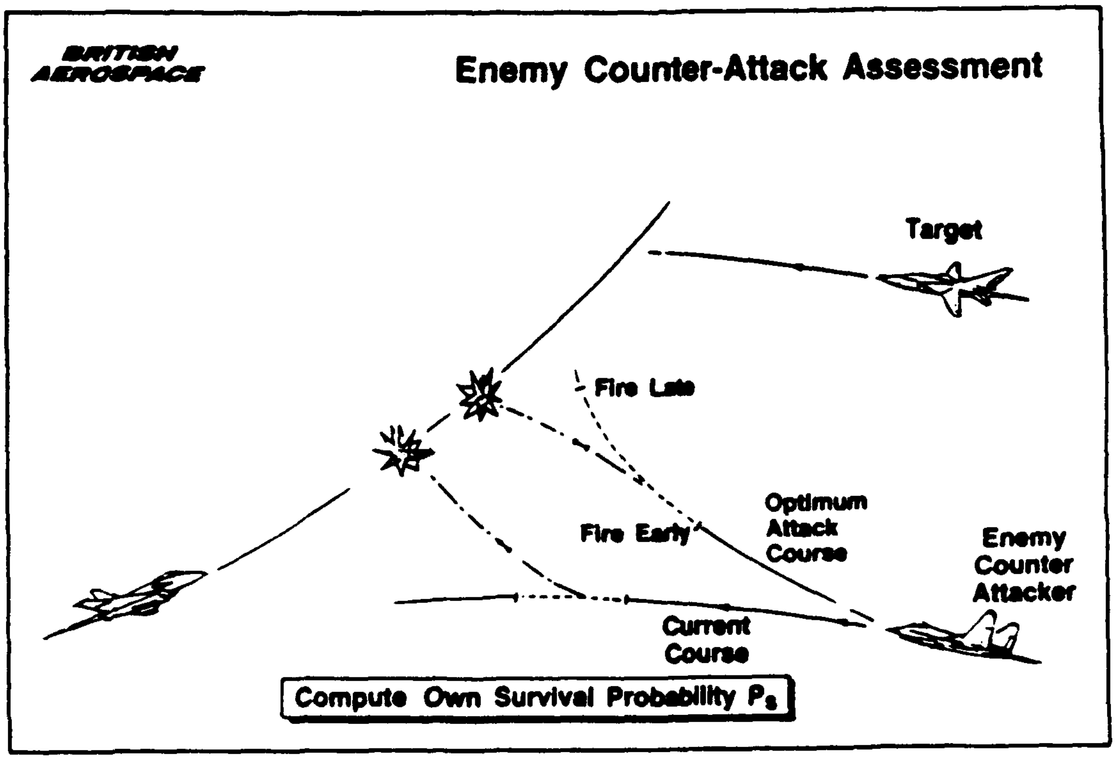

Figure 6

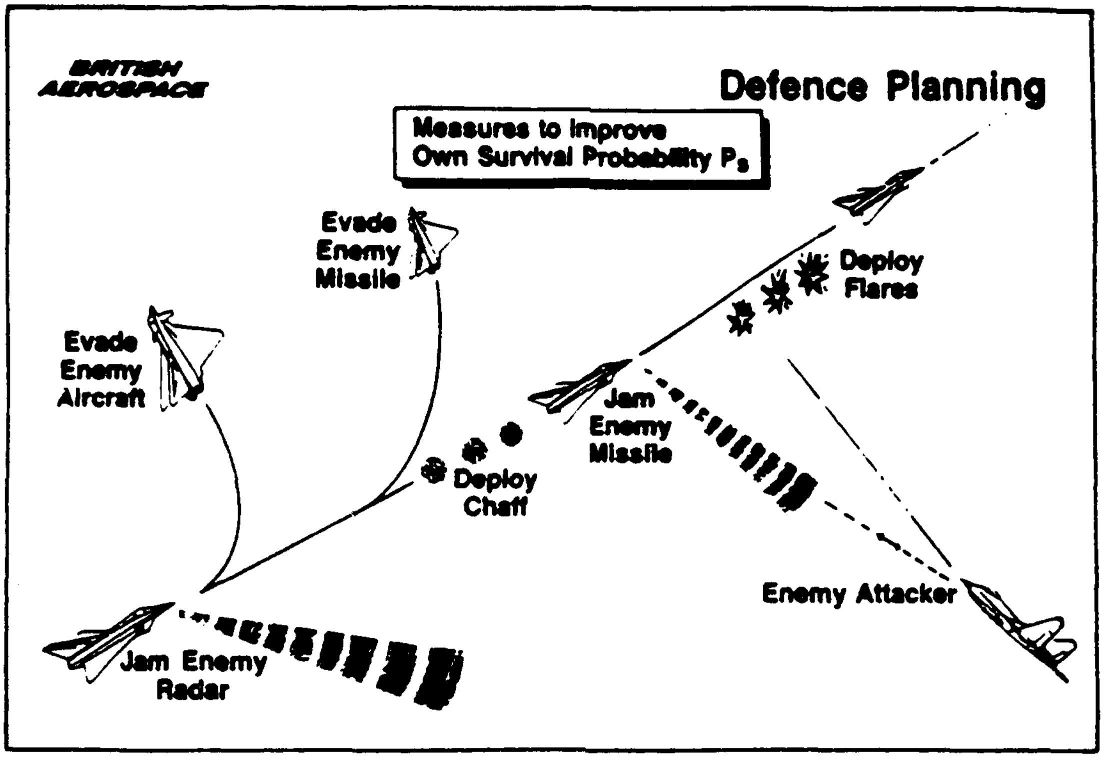

Figure 7

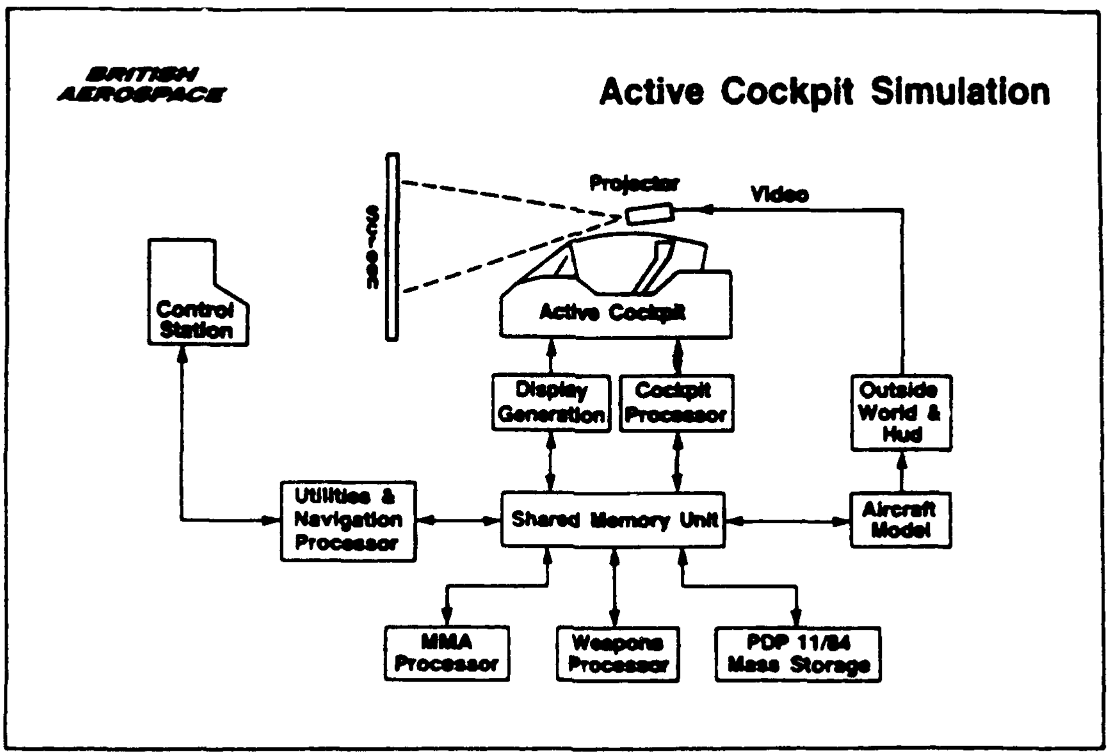

Figure 8

The Intelligent Displays Manager: A Prototype Electronic Crew Member

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Summary - The potential benefits of KBS in reducing crew workload and enhancing performance, especially during times of exceptional stress, are being explored in an Intelligent Displays Manager Demonstrator. The prototype was sponsored by MM4a, the Royal Aerospace Establishment, Farnborough, being one element in a broader spectrum of KBS work funded by RAE. Subsequently private venture funding has been used to enhance the performance of the demonstrator and to broaden the scope of the work. The aim has been to explore the underlying KBS mechanisms necessary to anticipate a pilot's information needs as a mission progresses and in response to the unexpected. Future work is directed towards the use of KBS "planned dialogues" with symbols rather than text, as a means of rapidly conveying large quantities of complex information of varying priorities and consequences, to a pilot, as an "unfolding story" of connected and consistent information.

Introduction - This paper addresses just one aspect of the Human-Electronic Crew as a team, the management of the information displayed to a pilot. Electronic displays technology, whether using a single large display surface or a number of smaller discrete surfaces allows ever more complex information to be presented, in a growing number of combinations, using a bewildering array of symbols and formats, and with the potential for an equally bewildering array of switches or menus for selecting what is to be displayed. The management of cockpit displays thus represents yet one more element in the workload of an already very busy combat pilot.

The Intelligent Displays Manager Demonstrator emulates some of the functions of a navigator in a two man machine. Given a knowledge of pilot inputs, aircraft parameters, aircraft sensors, the mission plan, typical occurrences in a mission and typical pilot behaviour and training it attempts to:-

* Estimate the pilot's mental model of the situation.
* Estimate current pilot workload.
* Anticipate the activities the pilot is able to carry out.
* Set up the corresponding displays, symbology and formats.

The Concept - Fundamental to the thinking has been the concept of two cooperating experts (figure 1). The Aircraft State Expert (ASE) estimates the pilot's mental model of the total situation, it determines what states the pilot believes the aircraft is in. From this mental model the Displays Expert estimates current workload and thus the tasks the pilot is able to undertake, it then determines what information should be displayed , how and where.

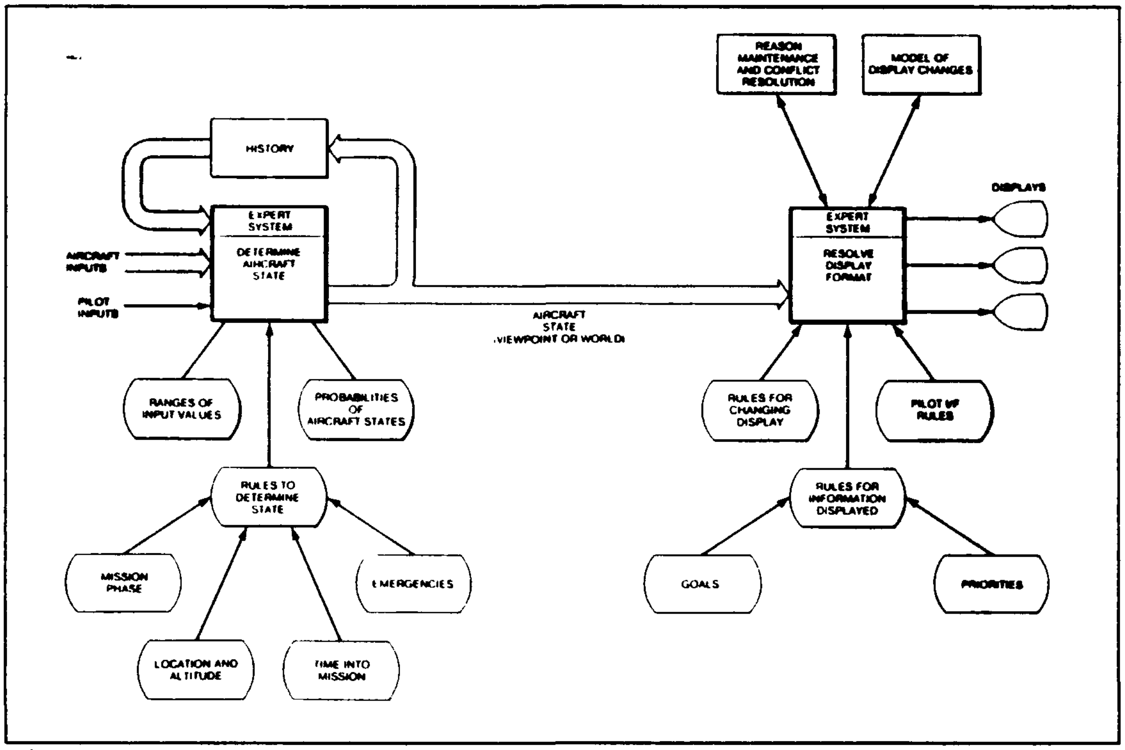

Figure 1 - The Intelligent Displays Manager Concept

Knowledge Representation - Schank's notion of scripts or typical/expected sequences of events has proved a very useful way of representing pilot training, typical actions and behaviour, and one that is equally meaningful to both aircrew and developers. Figure 2 was developed during one of a number of knowledge gathering meetings with aircrew of the Experimental Flying Dept., RAE. It describes conditions, pilot actions and options in response to an air-to-air counter-attack or "bounce". This knowledge of typical actions and events is built into the rule sets or knowledge sources within the Aircraft State Expert.

Workload Assessment - This is based on the notion that there are a range of tasks a two man crew perform and thus that must be performed by a pilot supported by an electronic crew member. 13 task areas have been identified, each with an associated priority and workload

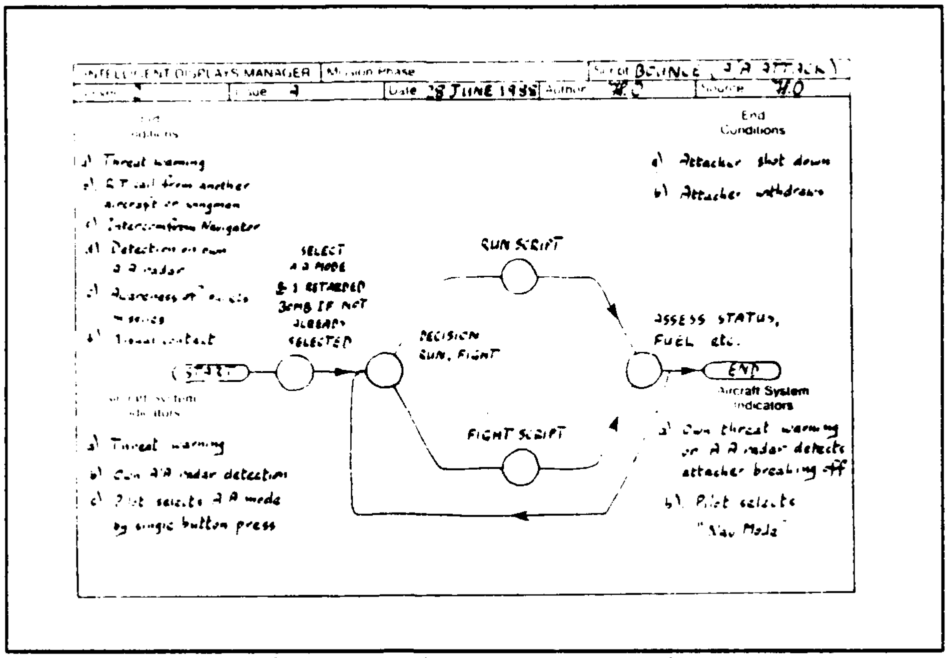

Figure 2 - Typical Script Representing a "Bounce"

according to the mission phase and current script. The units of workload are arbitrary and relate to a "perfect" 2 man crew able to handle everything. 65 units represents a typical maximum for a pilot. In figure 3 the pilot can be expected to carry out the first 4 tasks (63 units). Lower priority tasks will be ignored. It follows that an intelligent aircraft should recognise this limit and take responsibility for those lower priority tasks.

The Displays Expert uses the list of tasks that the pilot is judged to be able to carry out to create a "display list" of all information to be presented, with the preferred display surface, symbology and alternatives in the event of clutter.

The Demonstrator - (Figure 4). The current demonstrator is built on knowledge of a long range air interdiction mission, this being a tractable yet sufficiently challenging focus for the work. It has

Bounce: Fight		
1	Fly: Control Aircraft	20
2	Weapons Delivery	20
3	A/A Threat Avoidance: Position Aircraft	15
4	Terrain Avoidance: Control Aircraft	8
5	Weapons & ECM: Monitor Status	15
6	A/A Threat: Advise & Monitor	10
7	Fly: Monitor Aircraft Systems	10
8	Ground Threat Avoidance: Position Aircraft	1
9	Ground Threat Avoidance: Countermeasures	1
10	Terrain Avoidance: Advise	8
11	Navigate: Control Aircraft	5
12	Navigate: Plan & Monitor	8
13	Weapons & ECM: Selection	0
	Workload Total	121

Figure 3 - Pilot Tasks & Workload: Air-to-Air Counter-Attack, the "Bounce"

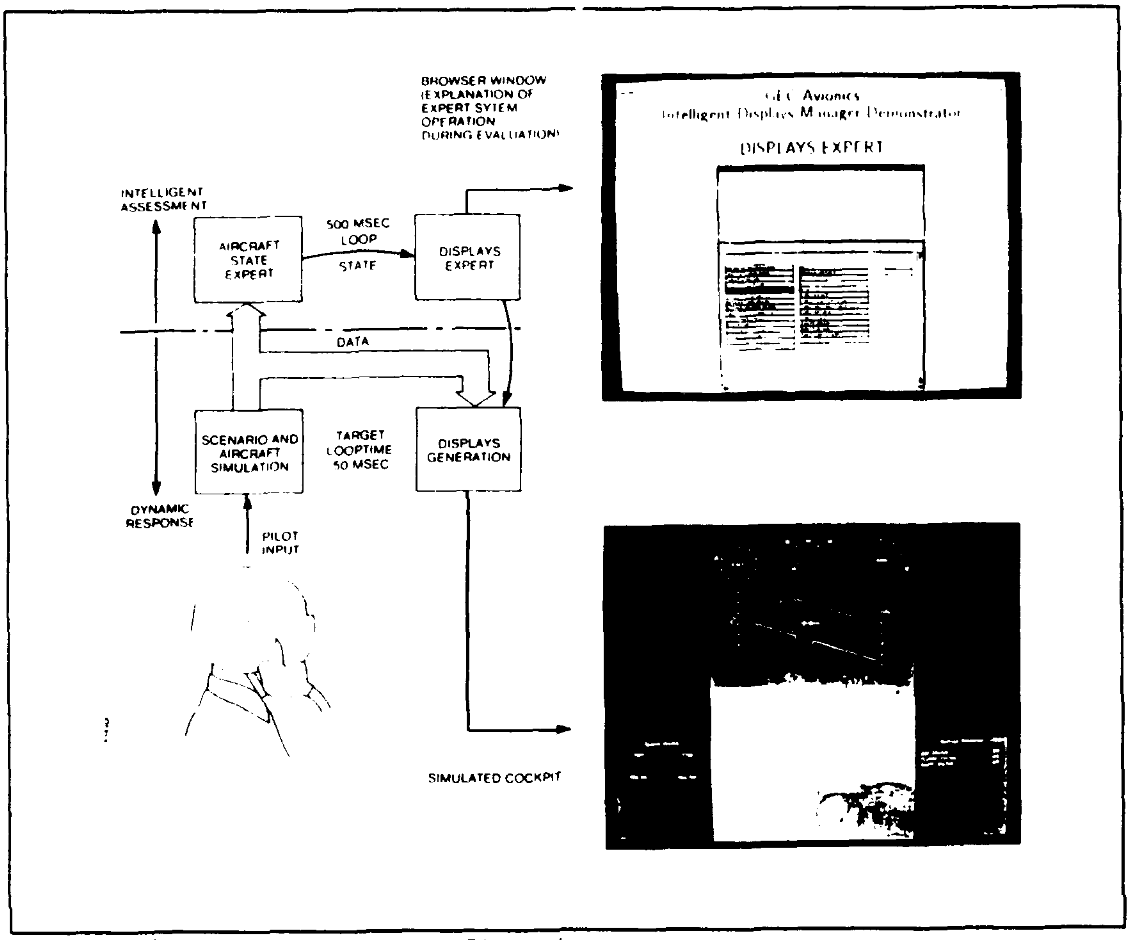

Figure 4 - Demonstrator Structure

been implemented on 2 networked Sun Microsystems workstations using a proprietary real time AI toolkit whose initial development was sponsored by RAE. In addition to the 2 expert systems there are two areas of conventional software written in the "C" language, the scenario/aircraft model and the graphics software.

The team assumed initially that the development of the expert systems would be the most difficult and risky task, in the event achieving a demonstrator having near real time performance using conventional graphics software proved much more difficult, with much effort being spent in measuring and optim[illegible]ing performance. See table I.

Table I - Demonstrator Performance

Expert	Iteration	Rules	Facts	Demons
Aircraft State	250 msec	100	None	20
Displays	3 sec max	34	375	1

Although the data on a dynamic display must be updated at faster than 25 frames/second the management or control of what is displayed can be carried out more slowly, say every 500 milli-second.

Where Next

The Generalised State Estimator - Current work has shown the feasibility of estimating a combat pilot's mental model of a complex evolving situation. We believe that a Generalised State Estimator will support the management of a variety of aircraft systems:- stores; communications; threat assessment; routing and planning; emergency and reversionary action; as well as highly trained operators of other military and civil systems. Recognising that a great deal of knowledge will be required in any real application, a Generalised State Estimator Construction System (GSECS) has been developed. This takes knowledge in the form of script diagrams, generated using a proprietary diagramming tool and automatically constructs a dedicated state estimator.

Planned Dialogues - A pilot and navigator convey significant amounts of information to each other through very terse statements. We should expect that a pilot will wish to communicate with an electronic crew member in an equally terse dialogue. Current dialogue research is largely based on the facilities of a computer workstation and is very dependent on the use of text. Such

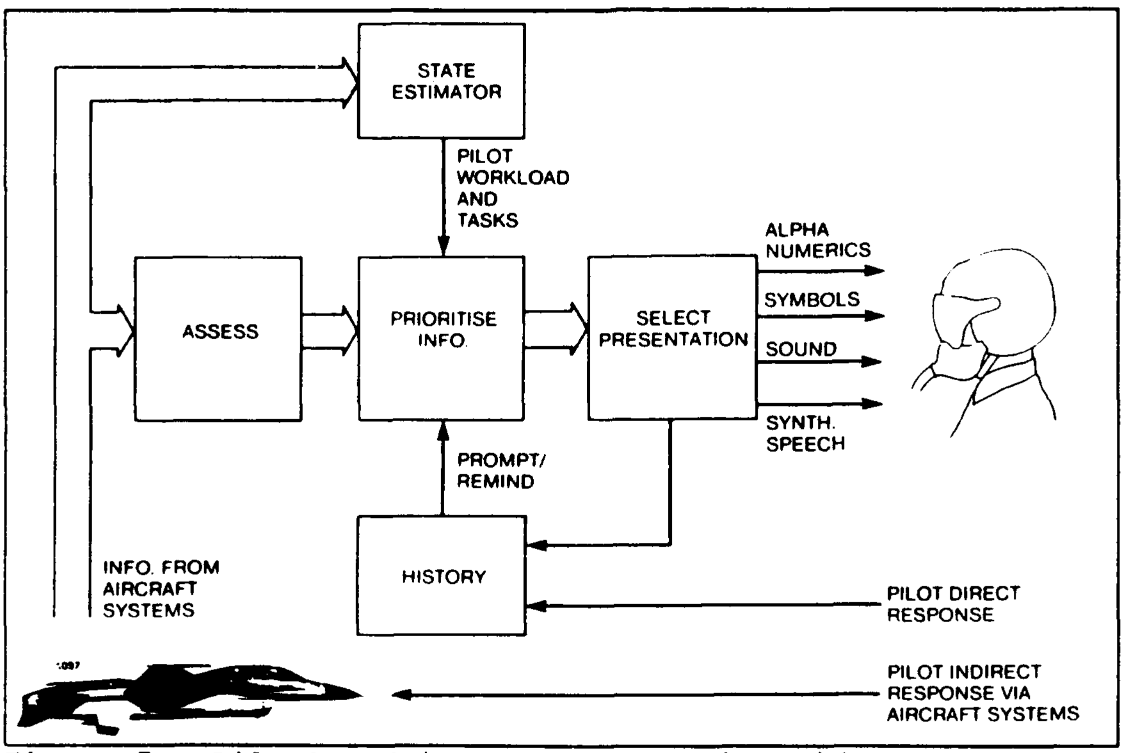

Figure 5 - Pilot's Advisory and Prompting Aid

dialogues are relaxed and conversational. This style is not appropriate to a busy cockpit, where the communication is via switches, indicators, symbolic and alphanumeric displays, direct voice input and synthesised speech.

The goal of our "planned dialogues" work (figure 5) is to rapidly convey to the pilot a whole picture. Large quantities of complex and competing information with varying priorities and consequences to a pilot, is presented as a connected and consistent "unfolding story". The pilot's goals for the dialogue are largely inferred as is his current workload so that a minimum of interaction is required. The machine's goal is to plan the most effective way of conveying appropriate information.

Outstanding Issues

Robust Communication - The HOTAS (Hands On Throttle And Stick) concept recognises that under some conditions a pilot can become temporarily disabled from inputting commands to his machine. Equally he can be restricted from receiving information. A further development of the planned dialogue concept is that of more robust communication between man and machine using redundant, complementary and adaptive information paths.

Broader Scenario - The prototype Displays Manager uses a single, well defined scenario. A flyable displays manager will require knowledge of a full range of scenarios, air-to-air, air-to-ground, from take-off to landing. GSECS will assist with system building, but very considerable knowledge gathering will be required.

Intelligent Displays Manager in an Intelligent Aircraft - Although aircrew have seen the demonstrator a rigorous evaluation has not been carried out. Most significant among the comments was the request for more and deeper information, with advice and prompting at key mission phases (eg to arm before target engagement). This suggests the demonstrator raised crew expectations by making the cockpit displays more "transparent", an "intelligent window" into the aircraft systems and the overall situation. Future development of the Intelligent Displays Manager should not then be of a system on its own, but rather as a key and integrated element in an intelligent aircraft, whose systems are able to give information as well as data, the Displays Manager selecting the best means of presentation.

Flying on the Limits of the Envelope - The Displays Manager estimates workload. However the present demonstrator has no means of sensing and thus modifying its estimates in response to pilot fatigue or injury. The real aim is to allow a pilot to fly closer to the limits of his and his machine's envelope. To achieve, this a more important measure than workload is the degree to which a pilot is in control of the situation, that is, the degree to which his mental model is both accurate and complete. We need to investigate how to continuously measure this level of control.

Conclusion - The Intelligent Displays Manager should be seen as part of a larger whole, an intelligent aircraft. GSECS provides the means for building a flyable displays manager covering a full range of scenarios. Planned dialogues with more robust communication will allow man and machine to communicate more effectively. But these are only the means to an end. That end is to give a pilot the edge over the opposition, allowing him to remain fully in control while operating on the limits of the envelope. The Intelligent Displays Manager then, as a member of the human-electronic crew has shown that the team can work together by demonstrating the feasibility of estimating a pilot's mental model of his situation, of estimating his workload and of selecting an appropriate set of supporting displays.

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FFCS - the German Pilots Associate

W.B. Herbst MBB

Abstract: As result of the conceptual design work which has lead to the European Fighter Aircraft (EFA) it was concluded that in modern air combat, beyond usual air combat in particular, the pilot needs to be assisted by intelligent on-board equipment in order to fully exploit airframe, avionics and weapon capabilities. Such tactical flight director system was developed by MBB's military aircraft division and successfully evaluated by the German Airforce in a large scale manned simmulation. It was demonstrated that combat effectiveness can be improved by a factor of 2 to 6 dependant on the typ of air combat scenario.

(1) Introduction

The impact of new air-to-air weapons on air combat characteristics and thus on fighter design requirements was subject of extensive investigations early in the EFA development cycle. In particular, it was found that the introduction of the new generation of radars and of AMRAAM would alter the traditional concept of using radar guided medium range missels as stand-off weapon. The multi-mode/multi-target capability of new radars and the more flexible fire control scheme of AMRAAM on both the red and blue side would force opponents to maneuver offensively and defensively even at supersonic speeds (ref. 1). It was concluded that beyond visual range (BVR) air combat is a complex maneuvering and weapon system control problem with employment of very peculiar tactics. Fig. 1 shows the result of a typical engagement. Firing distances are in the order of 30 km, altitude varies between low level and 11 km and average speed would be as high as M = 1.8. The duration of such engagements would be as short as 2-3 minutes and there is a strong requirement for critical and rapid tactical decision making about maneuvering the aircraft, operating sensors and deploying weapons in a head-down environment.

Tactical displays - as used in contemporary aircraft - are restricted to a display of the tactical situation. The pilot would have to make his own tectical decisions. It was concluded from combat simulation that due to the complexity of the situation and the speed of rolling events the pilot would be faced with great difficulties to fight successfully even if a perfect situation picture is provided to him.

Consequently the need for computerized tactical decision assistance was recognized.

(2) System Concept

Fig.3 is a block diagram of the Fire Flight Control System (FFCS) as developed in MBB in the 1980-1988 time period. Its main elements are

- Sensor Fusion:
  This subsystem is fed with signals coming from the aircraft sensors, primarily its radar in combination with other sensors as radar warning, IR-sensor, IFF and cross communication. It develops a most reliable set of information about target positions and target maneuvers.

- Sensor Management:
  Based on sensor fusion analysis and on an assessment of situation including target priorization, provided by the tactical processor, this subroutine controls the aircraft sensors, primarily the radar in terms of its field of view, scanning pattern, moding etc. It unloads the pilot from any manual radar operation.

- Tactical Processor:
  This is the heart of the system. It constitutes a real time simulation of the on-going combat based on stored information about opponents airframe and weapon system performance, the real time situation as provided by sensor fusion and on the assumption of best tactical behavior of all participating players in the game. This real time simulation allows a continous prediction of probable events. As a result this system developes tactical advices about how to maneuver the aircraft and to deploy the weapons towards best tactical results, i.e. winning the game and/or survive.

- Display and Control:
  The tactical advice, developed in the tactical processor has to be communicated to the pilot. Eventually, the pilot has to make up his own mind about how to fight and he may - or may not - tend to rely on the computer system. The link to the pilot is mechanized by a head-down display (HDD) and a head-up display (HUD).

  The HDD is used to display primarily the current situation as processed by sensor fusion **(Fig.5)**. The HUD is used to provide to the pilot the tactical advice, developed by the tactical processor, about how to maneuver the aircraft **(Fig. 4)**. It consists of a moving symbol which would have to be consistant with the advised maneuver state. This symbol is commanding to the pilot continuously the "optimum" maneuver according to the decision making process in the tactical processor.

- Resource Management
  This subroutine runs a continuous record of remaining weapons, fuel and defensive devices and advises the pilot about it.

The FFCS has been developed within a eight years time period. Extensive research was required to develop proper algorithms particularly for the tactical processor. Unfortunately, mathematical gaming theory is not sufficiently developed yet to provide a closed loop solution to the combat problem. Therefore, certain gaming elements had to be supplemented by heuristic methods as developed in computer combat modeling.

A very unique problem was the man-machine interface, the interface between the computer and the pilot. First of all, this required to run the computer programs in real time very early in the systems development and to use real time cockpit simulation. Also, the entire combat scenario including the opponents had to be simulated. Essentially, the FFCS was developed and matured using a real time man against computer system.

As a prerequisit for FFCS development the entire weapon system hardware (aircraft, avionics, sensors, weapons in the read and blue side) had to be substituted by computer models (Fig. 7)

(3) System Evaluation

The FFCS was developed in a man vs. computer environment and there was the question about its applicability in a man vs. man environment. Would the system eventually represent nothing but a very expensive computer game? Would a human opponent be able to outmaneuver the opponents and win the game against the computer guided opponent, just like a good chess-player may win against a chess-computer?

The system, therefore, was evaluated extensively within a large scale manned simulator experiment (ref.3). The blue side was implemented in MBB's dome simulator which was connected via a high speed optical cable with the dual dome facility of the IABG over a distance of about 2000 m (Fig.6). Identical fighter aircraft of EFA type and the same radars and weapons were used for blue and red opponents. The trial was conducted both in a fighter vs. fighter and also in a fighter vs. fighter escorted intruder environment (Fig.2). Red fighters were equipped with a standard (F-18 type) fire control and situation display system. Blue fighters, in addition, were equipped with FFCS.

The experiment was carried out by operational german airforce pilots. The campaign lastet about 3 weeks including extensive training, system familarization and the establishment of a baseline without a FFCS. Most important, the pilots were periodically rotated between red and blue, i.e. "red pilots" have been familiar with with "blue FFCS tactics". About 300 engagements have been conducted, good enough for the generation of a reliable statistical result.

That result was very promising in two respects:

- a factor of two was demonstrated in the fighter vs. fighter environment in terms of an improvement of overall exchange ratio.

  a factor of six was demonstrated in the fighter vs. fighter escorted intruder environment.

- pilots evenually expressed great appreciation and acceptance of the system. The conclusion was that they would need such system in modern BVR air combat. "Red pilots" always finished the engagements all over wet and exhausted. "Blue pilots" came out relaxed and smiling.

  In fact, the analysis of time histories recorded durning the engagements reveiled a significantly higher stress-level for "red pilots". Average "g" level was higher and, in particular, peak "g" values and "g"-onsets showed much higher values of red compared with blue.

In general "red pilots" were unable to compete against the FFCS assisted "blue" opponents and most attempts to "cheat" the FFCS have been unsuccessful. Red was always lagging behind blue in making tactical decisions and therefore blue was able to dictate the course of the game.

Pilots also were satisfied with the display system. Very soon they recognised that the command signal on the HUD was giving good suggestions in most situations and they learned to interpret its dynamics and the characteristics of its motion. In combination with the HDD they managed to maintain "situation awareness" throughout the engagement.

<u>Fig.8</u> summerizes the results. It represents a parametric analysis of increasing supersonic maneuver performance (4g-Machnumber) and its impact on BVR combat effectiveness (lower curve). This curve would shift upwards significantly for FFCS assisted fighter aircraft. Within certain constraints expensive aircraft performance could be substituted by incorperation of an FFCS.

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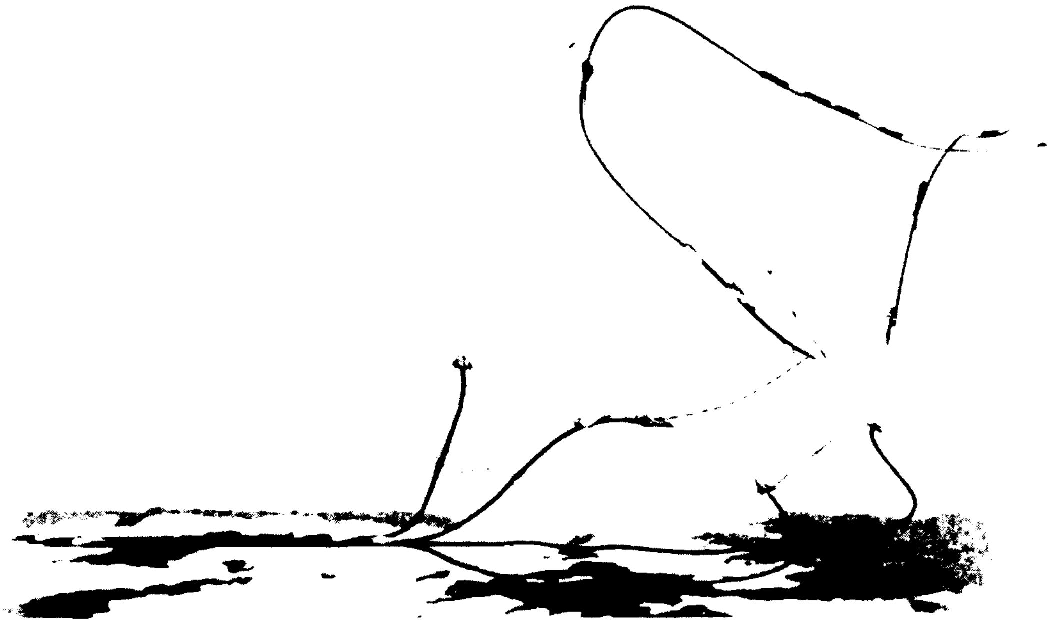

Fig 1 TYPICAL MEDIUM RANGE AIR COMBAT.
RESULT OF COMPUTER SIMULATION (ref.2)

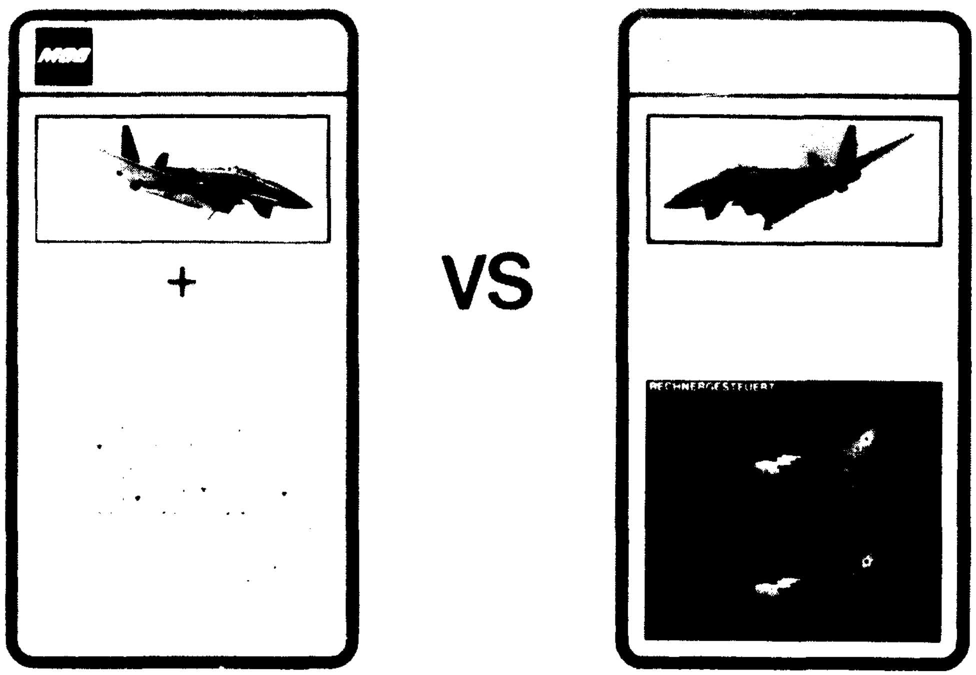

Fig.2 THE SET-UP OF FCCS EXPERIMENT

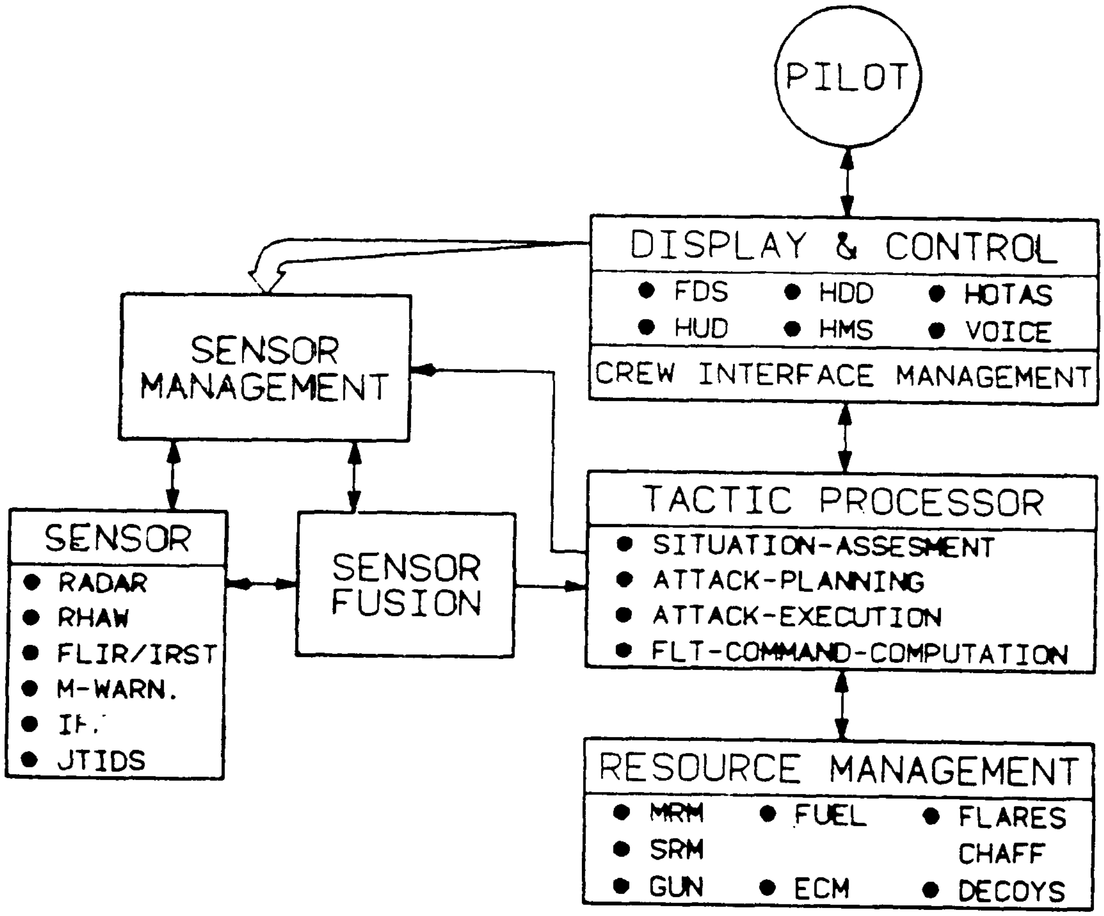

Fig.3 BLOCKDIAGRAMM OF SYSTEM

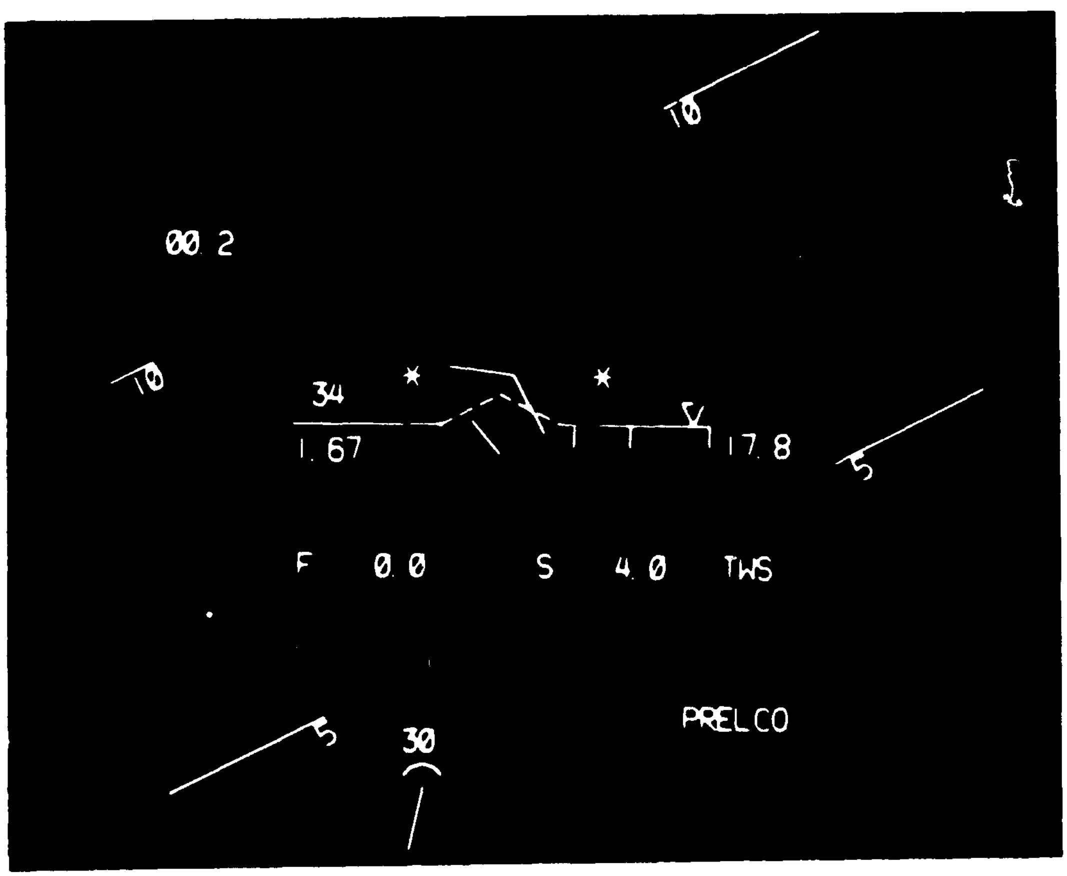

Fig.4 HUD SYMBOLOGY

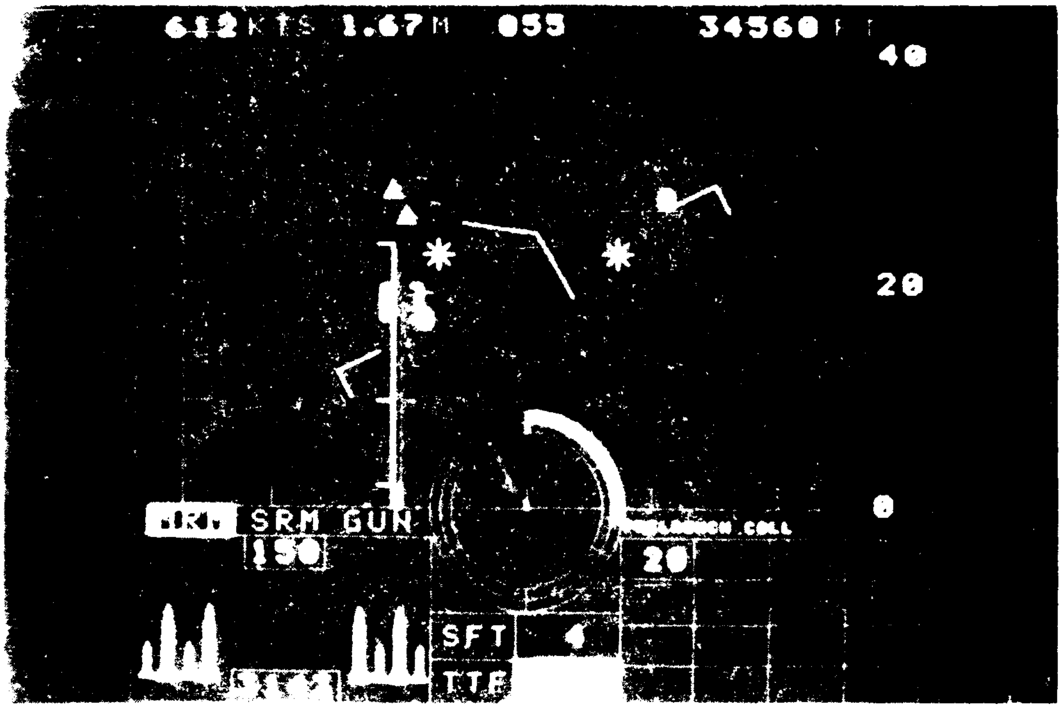

Fig.5 HDD SYMBOLOGY

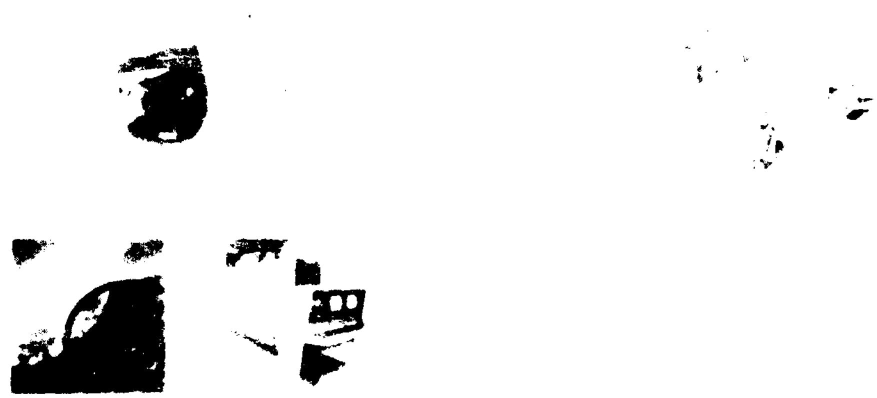

Fig.6 LARGE SCALE MANNED SIMULATION EXERCISE USING THE COMPLETE [illegible] & LARGE DOME FACILITIES FOR FCCS EVALUATION

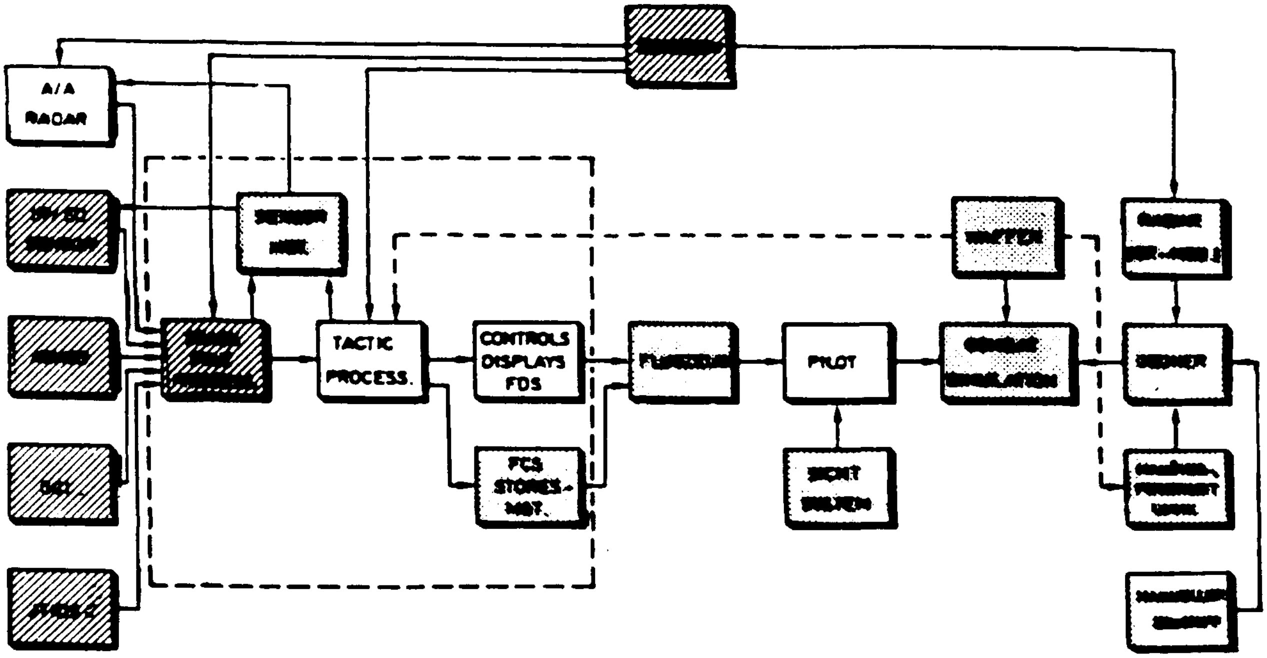

Fig.7 FCCS SIMULATION

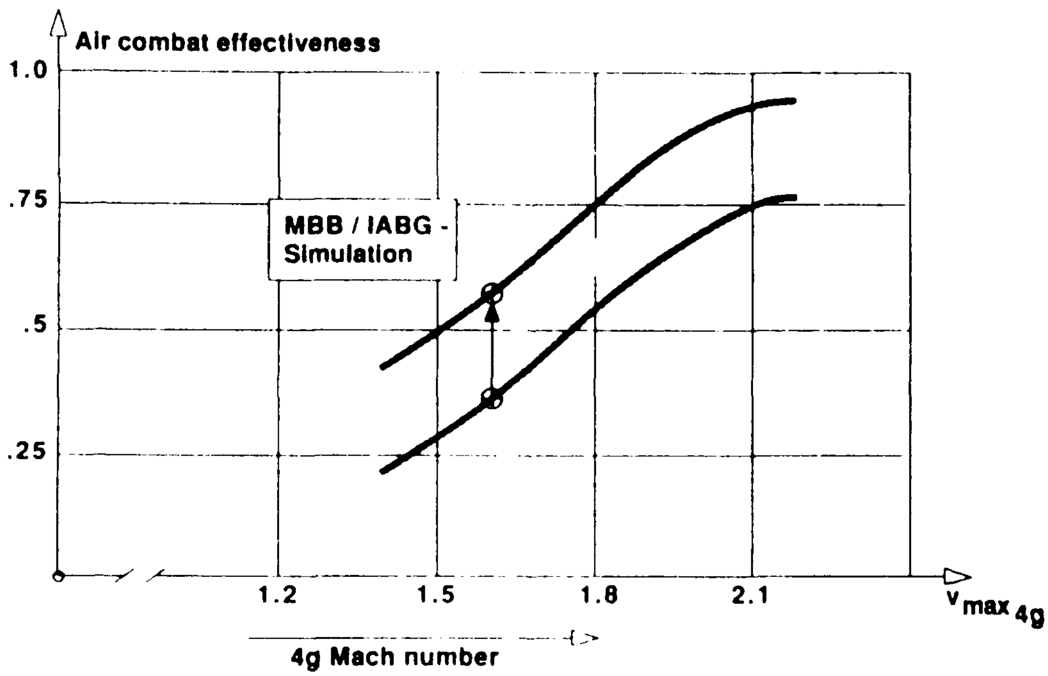

Fig.8 COMBAT EFFECTIVENESS IMPROVEMENT

KNOWLEDGE-BASED COCKPIT ASSISTANT

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Abstract

An electronic cockpit assistant for IFR operations is presented, as implemented in a flight simulation facility at the University of the German Armed Forces in Munich.
The aiding functions are primarily focussed on situation assessment and planning tasks during the approach and landing flight phases. These functions are aimed at achieving a similar workload level for the pilot as in the dual pilot case as well as enhanced effectiveness of flight guidance. Extensive use of speech system capabilities is made with regard to communication between the pilot and the automatic aiding functions.
Results of the flight simulation tests will be presented.

1. Introduction

Today's civil air transportation is characterized by flights under Instrument Flight Rules (IFR). This kind of flight operation guarantees flight execution with almost full independence of the weather conditions. Lacking visual references, the complexity of the flight systems and IFR procedures, however, cause accidents as a result of pilot errors [1].
To address the problem of IFR flights, the single-pilot IFR flight (SPIFR) as an application example has been selected with regard to the fact that the relative total of accidents for SPIFR flights due to pilot error is significantly higher than for the dual-pilot case. An electronic Assistant for SPIFR Operation (ASPIO) has been developed to assist the pilot in situation assessment, planning and plan execution. In particular, assistance is provided for

- understanding the current flight situation with regard to external and internal events
- replanning the flight route (if necessary)
- executing the actual flight plan
- monitoring the consistency between flight plan and control actions

The system has been implemented and tested in a flight simulator with good acceptance by the pilots.

2. Structure of the ASPIO system

To achieve the aforementioned assisting functions, ASPIO has been structured in several modules [2], as depicted in figure 1.

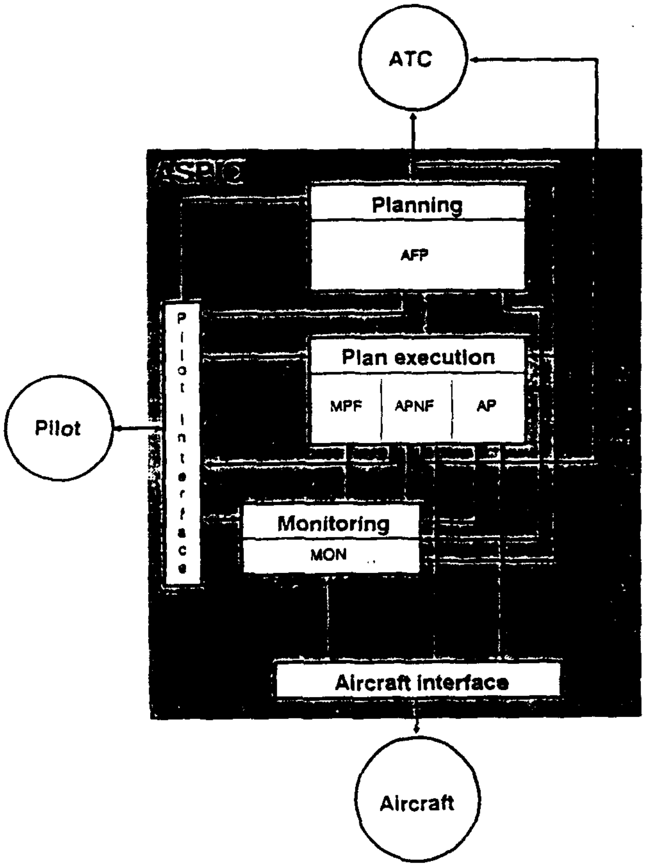

Fig 1: Structure of ASPIO modules

For ATC communication it is posited that a two way data link will be available at the time, when this kind of systems might come into service. This results in ATC instructions being directly fed into the ASPIO system.

The aircraft interface on the ASPIO side is established by a data pool, which contains all aircraft relevant data about flight status (including autopilot settings, radio navigation and communication settings or status of aircraft subsystems).

The pilot interface comprises all components for the communication between ASPIO and the pilot. Extensive use is made of speech communication in either way. The pilot inputs into ASPIO can optionally be carried out by speech messages in analogy to the phraseology of the communication between pilot and co-pilot in a two-man cockpit.

According to the specified functions, there are three main functional blocks for planning and situation assessment, plan execution and monitoring.

The planning functions of ASPIO are performed in the Automatic Flight Planner (AFP). This module is activated when significant deviations from the actual flight plan occur or can be anticipated. This is the case if new ATC instructions are not in accordance with the flight plan or if adverse weather conditions occur. The AFP checks whether the flight plan is affected and performs replanning if necessary. The planning results are presented to the pilot as recommendations. If not corrected by the pilot, these results then replace former flight plan instructions and serve as an input into the following ASPIO modules.

Automatic management of flight plan execution is performed by the Model Pilot Flying (MPF). The flight plan set up by the AFP is used to determine the actions the pilot is supposed to carry out during the various flight segments. To achieve this, the MPF is construed as a reference model of the pilot. It controls all the necessary actions by firing rules that are pertinent to actual flight goals or subgoals. There are also rules for transition from one goal to another or to the processing of ATC instructions.

The pilot actions expected by the MPF serve as an input to the Monitor (MON). This module compares these expectations with the actual activities of the pilot during the execution of the flight. If there are any inconsistencies, the MON sends messages to the pilot by using the speech output. In this case, a feed back to the AFP and MPF modules also exists.

To assist the pilot in executing the flight plan, the Automatic Pilot Not Flying (APNF) offers a variety of functions usually performed by the co-pilot in the two-man cockpit crew.
Among these functions are instrument setting, flap and gear setting, ATC communication, checklist execution and callout procedures, performed via speech messages. The APNF can also be directly tasked by the pilot with respect to navigational calculations or requests about flight-relevant information.

The last module of the ASPIO system is an autopilot (AP) which can be used by the pilot and by the APNF as well. Therefore, the pilot has the possibility to hand over control of the aircraft to ASPIO in the same way as he can pass it on to the co-pilot in a two-man cockpit. In that case, the MPF module will accept the role of tasking the APNF, which sets the AP modes and the command values.

3. Simulation facility

The ASPIO system is implemented in the flight simulation facility shown in figure 2.
The central computer is a UNIX IRIS 4D/140GTX Graphics workstation with four central processor units. Aircraft dynamics, autopilot, radio navigation signals and wind characteristics are simulated and a high performance head down instrumentation display is generated. Furthermore, the workstation is used to run the ASPIO modules APNF, MON, MPF and AFP and to perform the interfacing with speech input and output, the stick force simulation unit and a control and display panel. The image outside vision is generated by additional IRIS workstations. Also a radar display for use as a combined ATC controller/instructor workstation is installed.

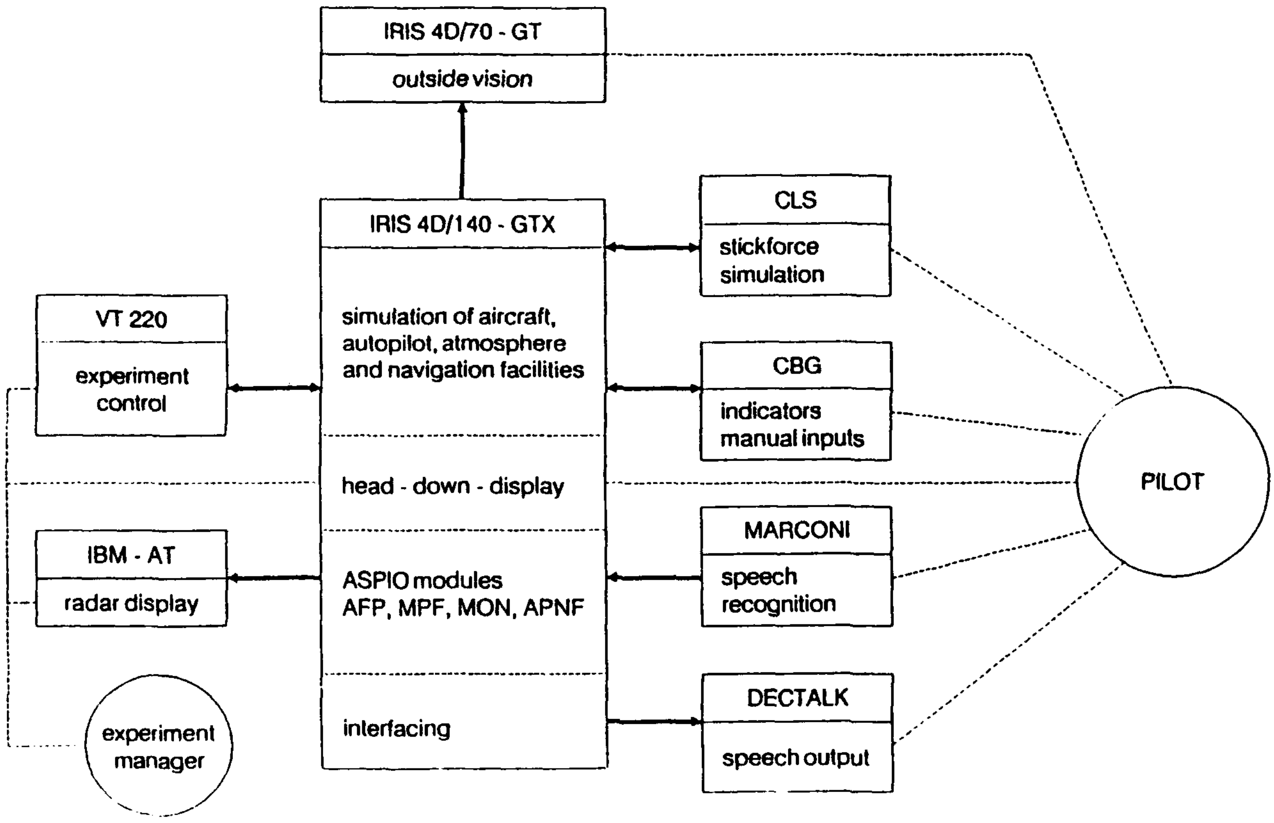

Fig 2: *Experimental setup*

4. Evaluation of the ASPIO system

The ASPIO system has been tested on quite realistic conditions. The possible benefit with regard to flight safety has been evaluated. The following criteria have been considered:

- flight accuracy
- pilot errors
- duration and quality of planning and decision making
- pilot workload
- pilot acceptance

Three different IFR scenarios have been developed comprising typical standard situations together with unanticipated events and emergency cases [3]. Nine professional pilots have been available as subjects.

For the evaluation of flight accuracy the standard deviation of the airspeed from the required one has been used. This parameter had to be manually controlled by the pilot. In all cases, the evaluation of the airspeed time histories shows that there are significantly greater deviations from the required speed before they are discovered and corrected by the pilot. It can be stated that the improvement in flight accuracy with ASPIO is highly significant.

Data for the evaluation of the pilot errors and of the duration and quality of planning and decision making could be elicited. Using ASPIO, no pilot errors have been observed. Without ASPIO, different errors occured. Some of them could lead to compromising safety. Considering the planning and decision making functions, excellent performance of the system became evident. These processes have been significantly accelerated. Problem solving with respect to the necessity of selecting a destination alternate took up to 1.5 minutes as pilot planning time. The corresponding planning process in the AFP module followed by the speech output to the pilot needed only about 2 seconds. All automatically derived planning results have been accepted by the pilots.

The pilot workload during the test runs has been determined by means of the SWAT method (subjective workload assessment technique) in combination with secondary task measurements (tapping). The results show a reduction of the pilot workload during all scenarios although the correlation between the results of both methods is not very high (r=0.35).

The pilot acceptance of the ASPIO system has been proved through the evaluation of a questionnaire using the technique of the semantic differential.

5. Concluding remarks

To assist pilots in IFR-operations, the ASPIO system has been developed and implemented on a flight simulator for the purpose of thorough system testing.
Test runs have been carried out showing a very high pilot acceptance rate. The evaluation results highlight improvement in system performance and avoidance of major pilot error consequences. The positive impact of the ASPIO system on flight safety has been proved.

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Methods for Determining the Role of the Human in Cockpits of the Future

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The classical method for determining the role of the human in a complex system involves allocation of functions or tasks to human or machine performance. Function/task allocations can be either static or dynamic. Static allocations identify which functions or tasks should be allocated to human performance vs machine performance based on an assessment of the requirements associated with the function/task and the unique capabilities and limitations of the human and machine. Static allocations are usually made on the basis of lists (Fitts' Lists) which compare the relative capabilities and limitations of human and machine performance in specific dimensions.

Dynamic allocations make the assumption that the optimum allocation strategy can change with operational conditions, workloads, and mission priorities. According to Rouse (1977) a dynamic approach allocates a particular task to the decision maker (man or machine) which has the resources available at the moment for performing the task. Rouse (1981) identified the advantages of a dynamic approach as compared with a static approach as: improved utilization of system resources; less variability of the human's workload; and providing the human with improved knowledge of the overall system. Revesman and Greenstein (1983) recommended an approach wherein the human and computer work on tasks in parallel with the computer selecting actions so as to minimize interference with the human. Here the human is not forced to change planned actions he or she retains the primary role in the system. This implementation requires that the computer must make predictions about the human's actions and must, therefore, have a model of the human in terms of the actions he/she will take at a point in time and under certain circumstances. The computer would use this model of human decision making to predict the human's actions and to select other actions which do not replicate or interfere with the human's actions. The notion of adaptive human-computer interfaces was expounded by Norcio and Stanley (1988). An interface can be adapted to the user in two ways: enabling the user to modify the interface; and dynamic adaptation wherein the system itself modifies the interface. This latter approach is designated the adaptive interface. It changes with respect to the particular user and current context. The information that the adaptive interface needs includes four domains:

- knowledge of the user (expertise with the system);
- knowledge of the interaction (modalities of interaction and dialogue management);
- knowledge of the task/domain (goals); and
- knowledge of the system (characteristics).

According to Woods (1985) the role of the human has shifted with increased control automation and developments in computational technologies. The shift is away from perceptual-motor skills needed for direct manual control to cognitive skills such as those required to support such roles as monitor, planner, and fault manager. The key to effective application of computational technology is to conceive, model, design, and evaluate the joint human-machine cognitive system. The configuration or organization of the human and machine components is a critical determinant of the performance of the system as a whole. This means using computational technology to aid the user in the process of reaching a decision, not to make or recommend solutions. If joint cognitive system design is to be effective, we need models and data that describe the critical factors for overall system performance (Woods, 1985).

One specific approach for addressing the role of the human in a complex man-machine system has been developed by Carlow Associates for the US Army Human Engineering Laboratory. This approach, designated the HFE/MANPRINT IDEA (Integrated Decision/Engineering Aid), and described by Malone et al (1989) addresses the issue of establishing the optimum role of the human in a three step process: 1) identifying candidate roles of the human; 2) identifying specific requirements attendant to these roles; and 3) modelling human performance as expected in the selected set of assigned roles. In dealing with human-computer systems it is important to realize that the issue is not so much defining the allocation of system functions or tasks to human or machine performance as establishing the role of man in the system. In a human-machine system where both components are equally competent to perform individual functions and tasks, the design issue is to determine the role of the human vs automation in the performance of each function or task. The emphasis on the role of human in the system acknowledges the fact that the human has some role in every system function or task. In some cases that role may encompass actual performance of the function or task. It is also important to realize that an assigned role for human performance may change with changes in operational conditions. Thus a task optimally performed by a human under certain conditions of workload, time constraints, or task priority, may be more optimally automated under other conditions. It is also important to keep in mind that automating a function or task does not logically mean that the human does not have a role, that he or she has effectively been designed out of the system for that specific function of task. Rather, in an automated function or task, the role of the human is that of a manager, monitor, decision maker, system integrator, or backup performer.

In the IDEA methodology the candidate roles of the human are developed through application of an automated tool designated the "Role of Man Tool". This tool provides the analyst with the capability to import a set of functions or tasks and to assign roles to human performance and automation in the performance of each function and task. As each function/task is presented to the analyst, a decision is required as to which component (human or machine) should be the performer of the function or task. Where an assignment cannot be readily made, the analyst selects a consultation capability from the tool, and the tool presents a series of questions where the analyst is asked to scale some dimension of the task, operational conditions and environment, user capabilities, and mission priorities, and, based on analyst responses, the tool recommends that the task be assigned to human or machine performance. In each case where an assignment of task performance has been made, the analyst is asked to identify the role of the human, and the role of the machine in the performance of the task.

The assigned roles for each task are then exported to the IDEA automated task analysis tool where specific requirements for task performance are identified for each task, under the specific allocation strategy and role assignments. The task analysis tool comprises a data bank of issues and concerns for human performance of system tasks as affected by the selected roles of the human and the machine in the completion of the tasks. For tasks which are cognitive in nature, by reason of the task itself or the assigned role of the human in the performance of the task, the task data are exported to an IDEA Cognitive Task Analysis Tool for a refined analysis addressing the cognitive aspects of required human performance, and the resultant task data are then imported back into the Task Analysis Tool.

The results of the task analysis are then exported to the NETWORK IDEA tool which describes task sequences in a graphic flowchart format, with task descriptions available in text format. The task descriptions maintained in the NETWORK tool comprise a subset of the requirements derived for each task in the Task Analysis Tool. These task descriptions include specification of the performer of the task, the tasks which must precede the specific task, and the tasks which are dependent on the specific task, the designation of the role of the human in task performance if other than performer, the estimated time required for task completion, and the process variables associated with performance of the task. Process variables include factors that have a bearing on task performance and which can vary for any simulation exercise. Process variables typically include capabilities or readiness of aircraft systems, operational/environmental conditions, mission data, and threat characteristics.

The NETWORK data are then exported to the IDEA simulation tool, SIMWAM (Simulation for Workload Assessment and Modeling) for exercising the task sequence as specified in the NETWORK tool. SIMWAM is an interactive, microprocessor-based simulation of human performance and workload. It was originally developed by Carlow Associates for the US Navy in addressing the question of the impact of the introduction of automated status boards on manning levels of the aircraft carrier aircraft management system. The system currently requires 36 operators to control the launch and recovery of carrier-based aircraft. A simulation was conducted of the task sequences required for each of the 36 operators to launch 11 aircraft and simultaneously recover 12 aircraft using the SIMWAM model. A second simulation was completed for the situation wherein task sequences had been altered as a function of the introduction of automated status boards. Comparison of the performance effects and workloads under each simulation condition indicated that system manning could be reduced by 11% (elimination of 4 billets) with the introduction of automated status boards.The Role of Man Tool, Task Analysis Tool, and SIMWAM have been applied in an integrated manner to the analysis of human performance requirements for the Forward Area Air Defense System (FAADS) built on the Bradley vehicle, for FMC. The simulation provided concepts for assigning roles of human performance as a function of FAADS weapon suite. While the application of the IDEA tools for defining roles and requirements for human performance in systems has been limited to multi-operator systems, the tools are directly applicable to the question of the role of the single human pilot in cockpits of the future. In this regard the Role of Man tool will support the determination of the feasible allocations of functions to human or automation and will assist in the determination of the roles of the human pilot in functions assigned to automation. The Task Analysis and Cognitive Task Analysis tools will support the derivation of requirements associated with each allocation strategy and role of human model. The NETWORK tool will allow the graphic depiction of the sequence of pilot functions or tasks and will ensure that these sequences are internally consistent. The SIMWAM tool will identify potential performance problems and will quantify the workload of the pilot for a simulated mission under the candidate function allocation strategies. The net result of the application of these tools is a first approximation of which roles of the human are feasible, what problems are to be expected in specific role of human models, and what human performance characteristics should be further investigated in more comprehensive, but more expensive man-in-the-loop simulations.

Figure 1 depicts the relationships among IDEA tools. As indicated in this figure, the Role-of-Man Tool produces candidate function/task allocation strategies which are analyzed to greater detail by the Task Analysis and Cognitive Task Analysis Tools. Task requirements data are exported to the NETWORK task sequencing tool, where graphic depictions of function or task sequences are developed. The NETWORK tool also formats the function/task data for the SIMWAM human performance and workload simulation tool. The SIMWAM tool identifies workload imbalances and performance problems with specific function or task allocation strategies. Results of the SIMWAM simulations are then fed back to the Role-of-Man Tool for final determination of the optimum role of the human in cockpits of the future.

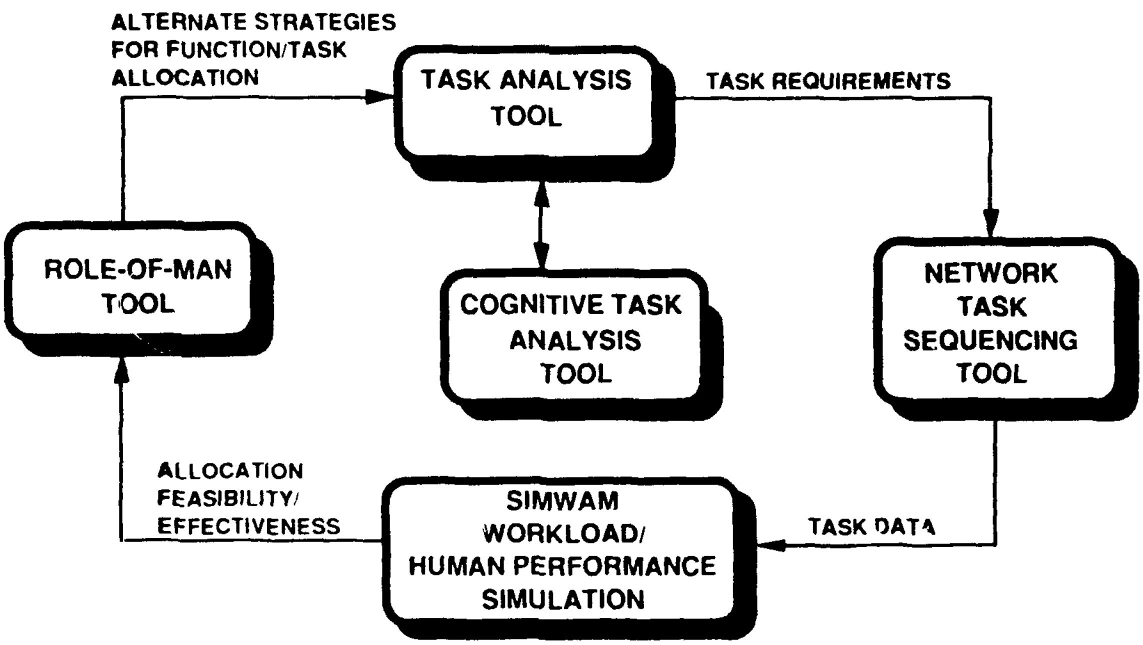

Figure 1. IDEA Tool Relationships

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A Standardized Electronic Crewmember Interface

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Background:

A need exists to develop a standardized functional interface (an Interface Control Description) between the crew members and the displays and controls required to accomplish missions. This need is born out of practices which have dealt with crew station design as a collection of subsystem terminal interfaces of individual displays and controls.

During the 1960 and 70's crew station design evolved into a series of military standards that described each electromechanical display, coupled with an overall configuration military standard geographical placement of these displays and controls. The crew member was also placed in a position where he or she could have visual and manual access to these displays and controls while maintaining an out-the-window-view for primary flying tasks. Superimposed on this somewhat orderly configuration, the electronic display was unleashed. No longer were the restrictions of previous electromechanical controls and displays meaningful. Now different references, symbols, images and displays interactions could be had through software editing and development. The familiar crew station configuration had been changed and no one knew the consequences. Each manufacturer was free to propose "the solution" as long as the customer was satisfied, "it" became the standard (until the next display was produced).

At this same time new and improved sensor, weapons, and mission management capability made it possible to quadruple the information to the crew. All possible options were provided regardless of the potential for use since no one wanted to restrict the "users" capability to employ the new wizardry (who knew what the battle would demand for a system that would not be fielded for the next 7 to 10 years). The result was an over abundance of capability and an overwhelming number of paths to accomplish the mission functions.

For example, a current production aircraft has 52 different employment modes of the weapons and sensors it carries. It is not surprising that the crews learn to use only a very few of these and can easily become confused if a switch is misplaced and slips into another mode of operation. In addition, each of these 52 modes of operation have from 7 to 14 procedural steps that have to be executed by memory to accomplish a given function. Not only are the steps different but the logic is different. (I feel free to be critical of this design since I was deeply involved in its conception and development since 1977). The impact of this design is viewed as misused weapon system capability since many modes are never employed; but the real cost is in training. Due to the design that we are flying coupled with reduced training dollars the crews are required to use most of their flying hours allocation for meeting proficiency training requirement. With little educational hours available for dedicated mission tactical training the crews must accomplish the mission training at the same time that they are achieving their proficiency training requirements.

At great expense, crews are currently trained to fly a particular aircraft. Because there is no standard for the functional interface between the crewmember and the electronic systems of the air vehicle, previously learned knowledge has little utility when the same crewmember must fly in different aircraft. The differences in aircraft system designs causes wide disparities in various aircraft avionics functional interfaces. Therefore, there is little benefit or leverage from previous training on other aircraft systems. Even for experienced crewmembers, task training costs remain high and consume the majority of flight hours available for pure mission training. With fewer mission training hours available, crewmember performance in high workload situations may be adversely affected.

Discussion:

With advancing technology, particularly in the area of knowledge based systems, a wide variety of functions currently performed by human crewmembers will be able to be performed by aircraft electronic systems. Without direction and planning, functional allocation in systems design could be haphazard and current differences in the operator functional interfaces between aircraft platforms could become even more diverse. Major DoD initiatives in the same areas of avionics integrated systems and hardware/software standardization will provide new opportunities for automating functions. Given this, a program to standardize the interface between human crewmembers and virtual electronic crewmembers could have very large payoffs. The payoffs could be realized not only for new weapon system developments, but also for retrofit applications (within service, multiservice, and international).

The MANPRINT (Manpower and Personnel Integration) program brought with its inception the promise that we can no longer afford to look at each of the domains of MANPRINT (manpower, personnel, safety, biomedical and health hazards, human factors engineering, and training) as separate entities to be applied individually or not at all. Each development must fully research and develop the impact and product of each domain for the synergistic improvement of the man-machine interface. The definition of the work split between the human crew members and the interaction with the electronic crew member in a consistent mission functional manner is essential for the MANPRINT impacts of future weapon systems crew stations.

This paper proposes the development of a plan to define the MANPRINT requirements for specification, design, and documentation of man-machine functional interfaces. Initial application would be to Army rotary wing aircraft. The resultant plan would include interfaces with other ongoing DoD standardization thrusts. It would also include a strategic implementation roadmap.

Both the US Air Force and the US Army are working on research projects that will directly contribute to this effort. The first effort which I wish to discuss is the US Army Research Institute Aviation R&D Activity work to identify the mission functional requirements across all Army aircraft. To date they have completed the AH64, UH60, CH47D, OH58D and the LHX mission functional allocation timeline analyses.

This has produced a firm foundation of mission functional definition that is not contaminated with the individual crew station configuration until the analysis drops below the function level to the individual task level. The mission is first broken down into mission segments and then to the functional mission requirements. It is at this level of the functional mission requirement that I feel the strongest and still most meaningful identification of the definition of the crew interface control description occurs.

The second work is conducted by Robert G. Eggleston of the U.S. Air Force Armstrong Aeromedical Research Laboratory. His work on exploring the development of acquisition and development of the interface design process appears to be directly applicable. The general problem that he sees is that of developing knowledge acquisition for creating an expert system (such as the Air Force Pilot Associate Program) which captures applied domain expertise for use in the creation of a computation emulation of an expert.Initially their goal is to produce or build a cognitive rather than a computational model. They believe "that the generation of a cognitive model prior to the creation of a computational model would, by creating a specification enhance the construction of the computational model tools."

My understanding of the relationship between these two activities is that they both are focusing on the interface as an entity within itself. Through the successful identification of this entity referred to as the interface) we can build a common standard for the crew to "touch." This precludes all descriptive specifications that would attempt to define a "standard set of displays" or limit the uniqueness of a configuration that could have mission and crew tailored interactions. These would also permit full tailored design, development and implementation without loosing the "familiar feeling" and common logical interface.

The challenge before us is to define and design a function interface standards for cockpits that represents the crew "model"of the expected functional capabilities and limitation. This then permits the tailoring of the cockpit for accomplishing specific mission requirements in a manner which fully exploits the alternative available without deviation from the "familiar model" of the crew interface from one aircraft configuration to the next.

Application of new sophisticated technologies to weapon system development has led to increased system capability. It also has increased mission complexity and produced higher workload levels, particularly in the cognitive areas. Therefore, the emerging knowledge based systems are needed to help the pilot cope with the information overload with which he must contend. The introduction of these future technologies including Machine Intelligence, and Artificial Intelligence as part of an Expert System will allow automation of a wider variety of functions. It is important to note, however, that the problem of functional differences could be worsened depending upon the degree to which systems designers embrace the opportunities for automation inherent in the new techniques.

In the near future it will likely be feasible and even practical to automate a wider variety of functions. However, unless care is taken in the design, the information available to the pilot could be reduced such that he would be taken out of his Situational Awareness. Both flight safety and mission effectiveness could be adversely affected.

This proposed effort would result in a coherent plan to apply automation prudently to weapons systems. A primary goal would be to reduce the pilot's workload in high workload situations to acceptable levels without sacrificing his Situational Awareness and even hopefully enhance it. The product of the proposed effort would be a Standard Operator Functional Interface (SOFI). The steps to accomplish a system hardware/software interface are:

a. Develop a list and organize all currently documented rotary wing aircraft aircrew functions. Include those functions which could conceivably be allocated to the aircrew.

b. Segregate the functions into groupings independent of the aircraft type and mission.

c. Document current allocations (man and machine) and, where possible, the rationale for such allocations.

d. Modify the allocations based on an analysis of human interactions with predicted future technological innovations. The proposed allocations will embed machine tasks in the operational context and will use real time decision aiding concepts to provide support of the pilots Situational Awareness. This will result i na draft SOFI.

e. Model missions using current attentional demand probabilistic modeling techniques will be employed to provide a reasonable degree of workload, while maximizing the pilot's Situational Awareness. This will result in high operational mission effectiveness. This step will be iterative in that the suggested Standard Operator Functional Interface will be repeatedly modified to achieve a balance between acceptable workload, and optimal Situational Awareness and Mission Effectiveness.

f. The functional allocation rationale and model results would be validated in simulator activities.

g. A roadmap would be developed which would relate the SOFI to the Joint Integrated Avionics Working Group (JIAWG) and the Joint Services Review Committee (JSRC) hardware/software developments. The roadmap would also include means for evolving the SOFI as new applicable technologies become available.

The product will be a Standard Operator Functional Interface which would incorporate emerging knowledge based technology but at the same time actively involve the pilot in mission accomplishment and optimize his Situational Awareness. The resulting standard interface would contribute to reduced training costs, the promotion of an efficient system design process and enhanced operational performance. The roadmap would be used to relate the SOFI to other DoD activities and to plan for technology insertions as they become available.

Summary:

With the fast technological development pace and the progress being made on new integrated avionics systems, it is important to address the above issues now. A feasible approach has been described which not only considers application of new knowledge based systems into weapons systems (new and old), but it also is complimentary with other ongoing DoD standardization initiatives. The roadmap would be particularly useful in formulating a long term investment strategy.

I propose to begin with an approximate 4 month Phase I effort. This would result in a Program Plan to develop the following:

a. Standard Operator Functional Interface as described.

b. A description of the application of the SOFI to new and inservice weapons systems.

c. A plan to compliment other relevant DoD standardization activities.

d. A roadmap for incorporating new technologies as they become available.

Your views and description of related effort are most welcome in helping to further define the requirements and products of the effort.

A framework for the consideration of issues in the development of expert systems applications.

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September 17, 1990

Abstract

It is argued that the successful development of applications using expert systems requires the consideration of a wide range of issues, both technical and extra-technical. This document presents a framework intended to facilitate the consideration and addressing of what are argued as important issues in the development of applications based on "expert systems" technology.

Introduction

The Knowledge Engineering Group (KEG) was set up to promote the use of Artificial Intelligence (AI) and Expert Systems (ES) within HP. KEG provides consultancy and application development support to HP entities working in the areas of AI and expert systems, and pursues research goals aimed at producing methods to support the principled development of both AI and Expert Systems. The rationale behind the promotion of this technology is that both AI and ES offer substantial potential for developing applications which promote productivity gains and cost savings for the user.

Issues (or contributory factors) may be roughly partitioned into three areas, reflecting the chronological order in which the issues generally present themselves:

- project initiation issues
- software engineering process issues
- domain analysis issues

Recent commentaries on the reasons for failure of expert systems applications suggest that the keystone reason for failure is an insufficient amount of attention devoted to project initiation issues, resulting in misconceptions of the utility/contribution of the systems subsequently developed. Whilst expert systems technology has generated some stable techniques, the mere application of those techniques to arbitrary domains is no guarantee of success. The following discussion will attempt to demonstrate the reasons why a preliminary analysis phase is so important to the success of an application. It should be noted that the categorisation implies nothing about the relative importance of the issues; as will be argued, the issues are often interdependent and comparable in importance. Although devoting attention to the resolution of non-technical issues is important, the balanced consideration of technical issues is also a highly important factor in the success of an ES application.

In this document, the term "application" is taken to mean any application of expert systems technology to an arbitrary domain. The rationale behind the genesis of an ES applications project may vary considerably with circumstances. It may be an exploratory venture, to assess the potential contribution of the technology, or to assess the tractability of the domain. Neither of these issues are easy to decide in vacuo; an existing system and the experience gained in developing it provide much of the information required for making such decisions.

It should also be noted that the term "expert system" need not necessarily involve "Artificial Intelligence" techniques, sometimes a conventional software approach is appropriate. If a domain can be mapped into a decision tree, then there is no reason why a system based on such a formulation of knowledge should not be termed "expert". It does, after all, capture and animate (albeit in a limited fashion) expert knowledge.

The software engineering process issues are not discussed in this document. There is some contention as to whether software engineering methodology can make a significant contribution to expert systems applications development. Certainly, for "exploratory" ventures, it is difficult to see how a methodology could be of assistance, either in specifying the functionality of the system or in implementing the code.

It appears that the different methodologies available provide differing levels of contribution but it has proved difficult to identify which methodologies provide the optimum contribution in a particular set of developmental circumstances. What is clear is that further analysis is required in this area and it is one of the KEG's objectives to attempt such an analysis.

Project initiation issues

Issues involved in this area may again be divided into three categories:

- market opportunity issues
- operational definition issues
- project instantiation issues

These issues are crucial in that they help determine the scope and range of appropriate effort and resource expenditure. There is an analogy with stocks and shares. One can gamble for high payback on the futures markets (e.g. currency speculation), this sort of venture is accompanied by high risks of failure and loss. On the other hand, one can take a cautious approach and invest in less volatile stock but the payback is commensurately smaller. It is frequently (but not always) the case that the greater the potential rewards, the higher the likelihood of failure, the more secure the return, the smaller the rewards. Different circumstances provide different contexts for approaching ES applications development.

Market opportunity issues

The market opportunity issues may be subdivided further into issues of application identification and contribution, both of which are somewhat interdependent. It is difficult to conceive of an application which makes a contribution but is not used — and it would be a surprising case in which an application was used extensively in internal business operations but did not make some contribution towards efficiency or cost savings benefits.

Application identification issues

The success or failure of an expert systems application can depend crucially on the identification of an opportunity for the system's use. This is highly important for "planned" applications, less so for exploratory ventures — but only if the latter are to be regarded primarily as educational exercises.

If exploratory ventures are intended to identify potential contributions from advanced software techniques and to assess the tractability of domains, then the investment of resources should have some chance of paying off eventually with a useable — and used system.

Unused applications, unless undertaken to promote the growth of internal expertise and familiarity with the technology, show little return on the investment of resources that went into their development. Identifying a market opportunity for the application is not an easy task and a substantial amount of effort should be devoted to this — as much (and possibly more) as would be devoted to a conventional software project of similar adventurousness. It is essentially an investment decision and should be treated as such.

Application contribution issues

The identification of the market or opportunity for an expert system should be accompanied by a realistic assessment of the potential contribution of the application.

Potential contribution, however, is rarely a clear-cut issue: as with many situations it is often the case that the 80-20 rule holds (80% of the work can be done with 20% of the resources). The optimal strategy — if the rule holds — is to identify the 80% of the application domain which can be tackled with an application embodying 20% of the resources. This implies (and is often the case) that the applications system need not be an "elephant" (and perhaps not even a "buffalo") in order to make a substantial contribution.

It is important to analyse carefully the application domain in order to identify what would be a "reasonable" contribution from an expert systems application. By doing so, developers can concentrate on providing solutions to a focussed set of problems and thus have a much better chance of developing a system which is capable of making a significant contribution.

Operational definition issues

Developers should be clear about the objectives for the application development, whether it be a full application or a cautious exploratory venture. Due to the novelty of the techniques to many engineers, the power (and complexity) of the techniques can seduce developers into straying off the developmental path. It is vital to have a clear idea of the eventual functionality of the applications system; without a detailed specification (often not possible for exploratory ventures) it is all too possible to be sidetracked into devoting scarce resources towards addressing non-central (but nevertheless, "interesting") issues.

As with any project, there should be an operational definition of success. This is particularly important for exploratory ventures where the eventual size and scope of the system is not properly estimable until more about the domain is known. In many cases, a prototype system is an appropriate result but there should be some objective, decideable criteria of success.

Depending on the tractability (or otherwise) of the domain, a prototype system which could handle successfully a limited range of problems of an intermediate level of difficulty would be a reasonable criterion of success. Some domains are more difficult to formalise than others and the system developers will usually have a good idea of what constitutes a "limited range of problems of an intermediate level of difficulty".

It is important not to over-enthuse about the eventual functionality of applications systems. In the U.S., it is the considered opinion of many commentators that one of the main reasons for the U.S. retrenchment in investment in AI is a general disillusionment brought about by vendors' and developers' non-fulfilment of earlier over-optimistic claims. However, it is important to bear in mind that focussed applications of advanced software technology are capable of providing a substantial payoff.

Project instantiation issues

These issues are generally more technical in nature than the strategic issues discussed above, however, these too are central to the technical success of the application development.

- resource constraints
- prototype issues
- access to domain expertise
- access to user population

Careful attention to the resolution of these issues acts to promote the establishment of a favourable grounding from which a development may begin.

Resource constraints

The objectives of an application development should be set with reference to the constraints on available resources. This may seem a self-evident assertion but unfamiliarity with the capabilities of the technology can lead to expectations of functionality which are unrealistic with respect to the amount of resources allocated. In addition, the realisation of differing degrees and areas of functionality results in markedly different demands on resources.

It is difficult to provide a precise analysis of this particular aspect of development for two reasons; firstly, much depends on the type and scope of the development being attempted, secondly, there are subtle interactions between various components and techniques available for inclusion in an application development.

From a preliminary (qualitative) analysis of these interactions, this particular issue appears to present developers with considerable problems. The interactions are many and complex; some care is necessary to ensure that the core problems of the development issues are being tackled. It is our experience that application developments can be made overly difficult (and costly) through the inclusion of peripheral features, e.g. "explanation" and "user-friendly interface", which are not central to the functionality of the system. This can lead to situations in which not only are the wrong problems solved, but also the core problems (which act as the rationale for the development) remain unaddressed through consequent lack of resources (the latter having been consumed by the solution of the wrong problems).

Prototype issues

Many applications developments require the development of a prototype system for preliminary evaluation purposes. It is not often possible to specify adequately the functionality of the final system, sometimes it is undesirable to do so, particularly in the case of incremental development techniques, where each stage has a major effect on determining the direction and scope of the next phase.

Given the subtlety and complexity of the interaction between the elements and features of an expert system (such as that that exists between providing a multiple solution facility and an explanation facility), it is often not possible to predict satisfactorily the effects of such interactions upon the tractability of the system and several different implementation paths may need to be explored in order to achieve the design goals of the system. In consequence, it is frequently desirable to discard a prototype and start again, from a position of superior knowledge and experience.

The inappropriate retention of a prototype can constrain seriously the eventual functionality of an application development — sufficiently for the application to fail to meet the agreed criteria. A more frequent result is increased difficulty of integration of required features and elements, as the aforementioned interactions generally demand careful architectural planning.

Access to domain expertise

It is almost tautological to observe that in order to develop successfully an expert system application, the developers should have access to domain expertise. However, there are normally several possible sources of domain expertise, some more readily available than others. Domain expertise may be either "decontextualised" (theories, rules of working practice etc) or "contextual" (case-based heuristics, "on-the-job" learning. etc). Decontextualised domain expertise is often made available in manuals or texts and is largely easy to access. Contextualised knowledge is rarely set down and more often available only through direct access to the experts who have this expertise.

Experts are nearly always in demand — their knowledge is frequently a scarce resource and it can be difficult for systems developers to gain sufficient access.

Access to user population

The development of an expert system without user input to the design process can be disastrous. Whilst it may be the case that users' ability to visualise the eventual system may be limited, the careful consideration of users' needs can dramatically improve the useability of an application.

A subsequent section of this document discusses the technical issues involved in considering this particular aspect of applications development. It is important that the set of eventual users are identified, there is often a substantial difference in requirements between sets of potential users, which should affect fundamentally the design of the system.

Domain analysis issues

In order to separate more conveniently the technical issues of domain analysis, they have been categorised according to three dimensions and a framework produced accordingly. This framework provides the major technical thrust of this document.

Firstly the dimensions of the framework will be discussed and then each section of the framework will be separately addressed. For the preliminary version of this document, sections will be little more than a rough outline of the scope of the area, accompanied by a description of existing and relevant work in the field. It is intended that eventually, each of the sections will be completed in some detail.

Framework dimensions

The vertical dimension attempts to capture an intuitive difference between what one may call the "informational" and "procedural" aspects of the domain. There are aspects to experts' activities (specifically "consulting") which are rarely addressed when considering domain knowledge and expertise. These aspects are discussed in more detail in a subsequent section where it is argued that these additional non-domain-specific activities demand careful consideration. Admittedly, the dichotomy presented here is an over-simplification of a more complex dimension, however a simplifying differentiation does allow of a certain utility for the purposes of expressing interrelated technical issues within the framework proposed.

The horizontal dimension expresses the familiar "expert(s)" vs. "user(s)" distinction. Once again this dichotomisation of a complex dimension is an oversimplification in the interests of clarity of presentation.

The third ("before" vs. "after") dimension represents a temporal differentiation which promotes consideration of the "current" human-mediated system, as well as the issues of the proposed computer-mediated system. Some recent commentary argues that there are many non-technical factors in play in human-mediated systems which have an important role in the way the system works. Encouraging the developers to look for and examine these non-technical factors helps them to create an application which fits more neatly into the target organisational system.. The word "system" here includes the experts, the users, information provision/usage, etc. Essentially, this dimension allows of the contrasting of the current (human-mediated) system with the proposed (computer-mediated) system.

The "front" four topics (1a, 1b, 1c and 1d) can be viewed as representing the issues ivolved in characterising the "current" human-mediated system, the "back" four boxes can be viewed as representing issues involved in creating the actual application. Movement from "front" to "back" represents the process of implementation. As the KEG is interested in producing methods to support the principled development of both AI and Expert Systems, this process of implementation is one of the main spheres of interest. The specification of how one might move (from the characterisation contained in the "front" box to the implementation techniques embodied in the corresponding "back" box) would be equivalent to a methodology for the building of an expert system application. However, before such a specification can be attempted, the issues embodied in the topics need to be instantiated in some detail.

1a: Domain knowledge characterisation

The effective representation of domain knowledge is generally considered to be a major element of success for a KBS, different types of domain knowledge hold different implications for the selection of knowledge representation schemes. In addition, the type of domain knowledge has fundamental effects on problem-solving.

The prescriptions presented by Stefik (Stefik, et al., 1982) remain valid ten years on and still provide a valuable way of characterising domain knowledge. Stefik distinguishes different types of

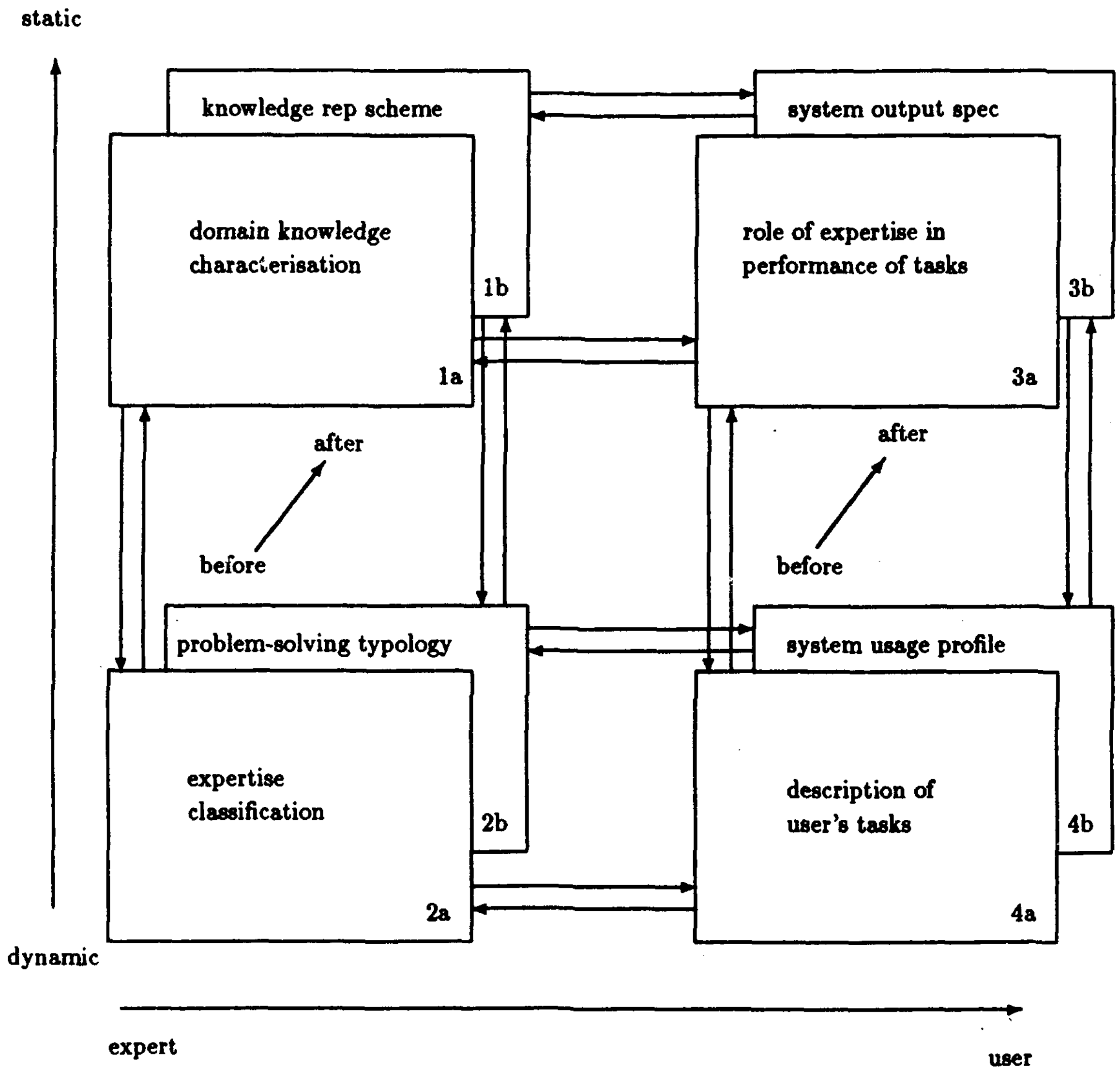

Figure 1: Framework of technical issues

domain knowledge via constraints that the former levy upon the type of problem-solving which can be performed:

- *size of solution space*
- stability of data
- reliability of data

These dimensions provide only a partial characterisation of domain knowledge. From cognitive psychology, Guilford's (Guilford, 1954) model of the intellect proposes other, more general attributes:

- figural
- semantic
- symbolic
- behavioural

Although this is a more general descriptive scheme, it does offer some useful characterisation — reasoning with figural or behavioural knowledge is somewhat beyond the limits of robust KBS technology and is currently a research issue. Whilst this may be quite well known to experienced practitioners, it is a useful datum to those who are less familiar with the limits of the technology.

The issue of the structure of knowledge has been addressed in other cognitively-motivated work. Durding, et. al (Durding, et. al. 1977) have investigated preferred knowledge structures for a number of tasks. The structures used in the empirical test included:

- *hierarchy*
- network
- list
- categorized list
- table
- categorized table
- incomplete table
- categorized incomplete table

The results of the work demonstrated the desirability of a second order isomorphism between the user's internal representation, the retrieval system's internal representation and the external data objects represented. In essence, to facilitate processing, it is important to preserve structure.

1b: Knowledge representation scheme

The choice of a computer-mediated knowledge representation scheme in which to model the human-mediated domain knowledge is often a critical technical issue. Cognitively-motivated research indicates that problem-solving may be severely impaired by inappropriate representation schemes.

Apart from the above fairly crucial consideration, there are other important implications in co-operative problem solving paradigms and where reasoning support is required. It is necessary in both these cases for the user to be able to develop an understanding of the way the system conducts the problem solving. The development of this understanding is heavily dependent on the degree of match between the knowledge structures held respectively by the system and the user.

The interaction of several contributory factors makes the choice rather complex. The notion of using an intermediate, abstract representation has been recommended by several commentators as a means by which a better understanding of the interaction may be achieved by the developers, thus enhancing the liklihood of selecting the most appropriate computer-mediated knowledge representation.

The recently-formulated KADS KBS development methodology (Hayward, et.al, 1987) proposes a candidate intermediate representation in the form of a declarative description of the representation of descriptive definitions of domain terms, domain objects and their relationships to each other and suggests that this representation can be considered as independent of the domain tasks. The structural features of the descriptions are preserved in the intermediate representation and implementation decisions can be postponed until a satisfactory model of the domain is developed.

This essentially static model is then used as input and output parameters to a task-dependent model of domain problem-solving expertise. Several experiments have been conducted using this methodology and favourable reports of the technique have been received.

2a: Expertise classification

In this framework, the distinction between "domain knowledge" and "expertise" reflects more a distinction between "knowing what" and "knowing how"; issues which are at least separable, if not independent. Whether "expertise" exists independently of "domain knowledge" is not yet clear and evading the issue entirely, the rest of this section will equate "expertise" with "reasoning".

Having a descriptive definition of domain terms, objects and relationships is a necessary but not sufficient condition for the demonstration of expertise. It is also necessary to be able to manipulate and reason with this knowledge in some fashion, usually by making inferences, performing problem-solving, etc.

The type of reasoning displayed by the expert in the human-mediated system has profound implications for the problem-solving architecture of the computer-mediated system. Some general, abstract types of reasoning have been identified:

- goal-directed reasoning
- data-directed reasoning
- causal reasoning/reasoning from first principles

Goal-directed reasoning involves the matching of hypotheses to the data, a kind of iterative "best-guess" process. Data-directed reasoning involves working forwards logically from the data given (usually via the application of rules). Causal reasoning involves developing causal explanations of the data, working from first principles. Generally, causal reasoning expertise is beyond the scope of robust KBS technology and largely remains in the province of AI research.

Because of the impact that these different types of expertise have on the KBS architecture, the most useful detailed classification schemes are the problem typologies which have arisen out of work in KBS. It is mainly by these problem typologies that it is pc ssible to provide useful characterisations of different types of reasoning tasks.

2b: Problem-solving typology

The KADS KBS development methodology provides a problem typology which is used as a library from which the developer draws a problem-solving template appropriate for the domain reasoning task. The KADS problem typology includes analysis, modification and synthesis tasks, examples of which are shown below:

- modelling
- planning
- identification
- fault diagnosis
- heuristic classification
- causal tracing
- prediction of behaviour
- repair
- configuration

It is of some concern that this formulation lacks both a robust theoretical underpinning and empirical support. KADS are currently seeking a formal specification of these tasks and it is uncertain whether formal techniques are sufficiently expressive to produce useful specifications. The formal description of behaviour is a recognised bete noir.

3a: Role of expertise in performance of user's task

It is important to consider the importance of the expertise to the user. There are profound implications for the necessity/desirability of reasoning support or explanation, both of which have subsequent implications for the choice of problem-solving paradigm and knowledge representation scheme.

If the expertise is a central component in the user's performance of tasks, then it is likely that reasoning support will be required. More obviously, if there are critical decisions (financial, medical treatment) to be made on the basis of the problem solutions provided by the system, then support for the reasoned solution will be (understandably) demanded by the user.

On the other hand, providing unnecessary reasoning support consumes resources unnecessarily. If the expertise plays only peripheral role in the execution of the user's task, say as a minor input parameter, then merely providing the solution (in the appropriate structural form) will suffice.

There appear to be two main components of this issue — whether the interaction is an "oracular" vs. "consultative" type and whether the user is expected to take an active role in the problem-solving or not. From a pragmatic viewpoint, an oracular interaction, whereby an expert merely delivers a judgement, places fewer demands upon the system designer than does a consultative interaction.

Results from empirical studies tend to resist generalisation as subjects are usually students and must be considered as atypical users. However, as with many issues in HCI, the notions of "models of users" and "users' models" play a large part in developing an understanding of interactions between user and expert.

A robust cognitive theory of models of users and users' models has yet to be developed, although both ES applications development and conventional software applications development both suffer from this same problem. With regard to the style and content of the user/expert interaction, some limited contribution from the discipline of social psychology should be acknowledged.

Dramaturgical theory provide the notion of "altercasting", which is the notion of "taking the role of the other" and its operation can be identified in user-expert interactions.

When a computer user consults a systems advisor and asks (for example) for advice on how to print a text file, the advisor has two choices:

1. to provide the user with advice for solving the particular problem encountered
2. to provide advice for solving a class of problems (including the particular problem encountered).

In order to decide which of the two options to take, the advisor has to consider the user's objectives in seeking advice. By taking the role of the other, the adviser could reason (for example) that a frequent user of the system should be provided with a more complex general solution, being quite likely to be encounter associated printing problems as well as possibly being interested in gaining mastery of the equipment. On the other hand, with an infrequent user, a suitable incantation could be provided on the basis that they are less likely to require the more complex general solution and may not be so interested in gaining mastery of the equipment.

The notion of altercasting provides a useful way of characterising the extent to which the expert is required to develop models of the users' requirements — and of characterising users potential requirements. Users who are pressed for time or who have more prosaic attitudes towards computers are more likely to require specific rather than general solutions.

It is worth noting that successful altercasting requires the altercaster to have reasonably accurate insights into the user's objectives — i.e. to have some understanding of the user's tasks and priorities.

3b: System information output specification

The development of an understanding of the role of the expertise in the performance of the user's tasks will assist the developers in understanding the implications for the output from the application.

The oracular style of interaction is more likely to be appropriate for smaller systems, frequently based on decision-tree animation. The availability of comparatively cheap ES shells which constrain the developer to simple decision trees promotes an oracle-style interaction, where system works through the decision tree as the user inputs the data, providing a canonical answer at the end of the interaction.

Such shells — and the systems developed in them — typically do not provide dynamic explanations of reasoning; reasoning support is usually provided at data entry time and is normally confined to explanations of why the system requires some piece of data and is based on the current position in the decision tree.

4a: Description of user's tasks

Functionality is an important factor in the success of any software application. In conventional software engineering, system functionality is addressed during the systems analysis phase of the development lifecycle. In the case of ES applications, particularly small applications developed within a shell, it is possible to avoid completely the direct addressing of this issue. In consequence, it is all too easy to develop systems with inappropriate or inadequate functionality. With larger systems is also all too easy to concentrate on the solution of technical problems at the expense of addressing the issue of functionality.

Although the subject of "tasks" has been of interest to workers in the KBS field, the orientation taken is primarily toward mapping generic tasks into a problem-solving typology or, alternatively to attempt to provide a formal notation for describing tasks.

There is a need for a descriptive notation for tasks, but there is also a requirement that a task description needs to be understandable by the user in order for feedback to take place. The use of a problem-solving typology or a formal notation is quite likely to present a barrier to the user's provision of feedback.

4b: System usage profile

In the domain of KBS applications it is particularly important to develop a good understanding of what tasks the user actually performs. This will assist the development of a correlational understanding of what would constitute an adequate and appropriate scope and range of functionality of the intended application.

It has been observed that human-mediated systems have a high bandwidth of communications between processes and that some of this bandwidth is carried in the socio-political parts of the system. When developing a computer-mediated system for introduction into the milieu of human affairs it is important to recognise that artefactual systems need to be tailored carefully if they are to augment and not disrupt the flow of communications and processes, this principle is doubly important in information-technology applications.

Attempting to understand the systems in the world with which we interact is an inherent facet of the human condition. It is impossible to prevent people from attempting to develop their own models of the systems with which they interact. It is entirely possible and in fact, usually the case, that this factor leads to changes in the processes embodied in the remaining human-mediated parts of the system. For example, the majority of KBS applications can be (ab)used for educational purposes, whether the developers intended it or not. This can have effects on the perceived functionality of the application and also affect the success of its deployment.

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REQUIREMENTS ANALYSIS FOR PILOT DISPLAYS

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1 Introduction

The design of interfaces between pilot and systems continues to be a difficult and complex activity. One of the major problems in designing the interface is the definition of the information needs of the pilot. This problem is at its worst in a novel application of which there is no significant operational experience. The development of systems based on IKBS technology includes many such applications. These systems will change the way in which the pilot interacts with his systems, and it is a basic assumption that a degree of decision making will be shared between the pilot and the system. It is then critical that the pilot is able to understand what the system is attempting to convey to him.

Little research has been done on developing methods and techniques which will allow the effective design of real time user interfaces for novel applications. The critical issues in designing the interface are to ensure that:

a. Sufficient information is available for each step in the decision sequence.

b. The information is accessible within the time available for the decision step.

c. The information is presented within the context of the overall task structure.

Most designers of interfaces would claim that this is what they set out to do. However merely displaying information does not ensure that the pilot is able to access the information. The information displayed must be such that it can be absorbed by the pilot within the time available. This means that he cannot afford to spend time searching large arrays of data to locate the information he needs.

The area which causes most problems is in the analysis of the requirement. The normal approach is to consider the system as excluding the human component. Thus the analysis is conducted with respect to the needs of the pilot, this assumes that the tasks carried out by the pilot will be the same for the new system as they are in the current system. Quite separately there may be an activity to define the pilot task breakdown, while assuming a specific instance of the current system.

These two activities miss the fundamental point. In an aircraft we have a complete system which includes airframe, weapons, sensors, computers and a pilot, i.e. the pilot is part of the complete system. An approach that deals with this problem is the use of a requirements specification for a total system which includes the pilot as a processing element as well a the computer.

2 The Aircraft as a Total System

If we are to regard the aircraft as a total system, then we must take an integrated systems view. We can regard the system as a set of interconnected processes which execute a defined function. Such a view would represent a classic engineering view. However, once we start to include the man in the system we have to consider it as a socio-technical system. An important characteristic of such systems is that they have a *purpose*. That purpose is supplied by the human component of the system. In fact, all systems have a purpose, however, in many cases that purpose only exists as a set of concepts developed by the designer and a set of uses discovered by the user.

In order to understand a socio-technical system it then becomes necessary to understand the various goals that the system will attempt to satisfy. These goals can then be mapped to the functions performed by the system, which can in turn be mapped to the process which will execute them. A critical part of the analysis of socio-technical systems is that the selection of processes to carry out functions is carried out at a later stage of the analysis. In some systems, such as we may consider for future aircraft, the allocation of processes may be carried out in operation. The critical point here is to recognise that these processes include the pilot as a processor.

If we consider the system as attempting to satisfy a set of goals then we need to make careful analysis of those goals (Harris and Barnard 1984). The first aspect to recognise is that the various goals will not all be compatible so if we consider a ground attack aircraft in the role of battlefield support, then its goals will include success in engagement of targets, success in avoiding threats and success in maintaining a safe flight envelope. Such goals are clearly in conflict since greatest success in engagement is achieved by flying high and slow which maximises the exposure to threats. In Figure 1 this goal hierarchy is decomposed to show some of the sub goals.

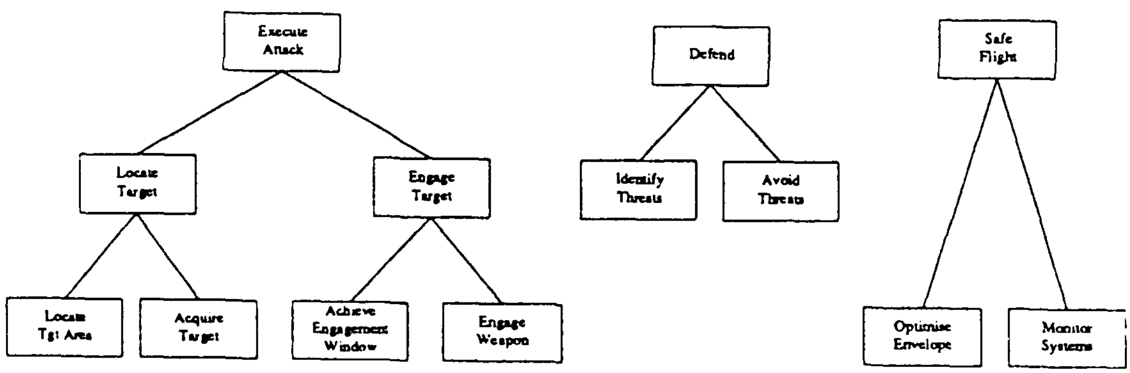

Figure 1 Decomposed Goal Hierarchy

As we examine the goal decomposition we can see that some subgoals are executed sequentially while others are executed concurrently. Thus, in developing a set of functions that allow these goals to be achieved, it is necessary to define some functions that balance the resources devoted to the achievement of conflicting goals. In the Pilot's Associate Model this set of functions are included in the Exec Manager. It is an interesting component of the Pilot's Associate programme that it is recognised that some of these balancing functions, if not all, need to be transferred from the pilot to the AI system.

The decomposed goals then need to be mapped to a set of functions, with defined data flows that are needed to support them. To do this there is a need to develop suitable models of the system functionality. In Figure 2 (page 10), the basic model used for the Pilot's Associate programme is shown, this assumes a very high interconnection between the core functions. This view assumes significant complexity of data flows between functions and the control that must be applied via the Exec Manager Function. This particular view of the system separates the pilot from the computer based system, and has thus carried out an allocation of function between the human and machine processors.

An alternative model of the functional decomposition of the systems can be developed using a basic C3I control model approach (Morgan 1982). This model assumes that there is a hierarchy of functions, in particular with respect to planning, as shown in Figure 3.

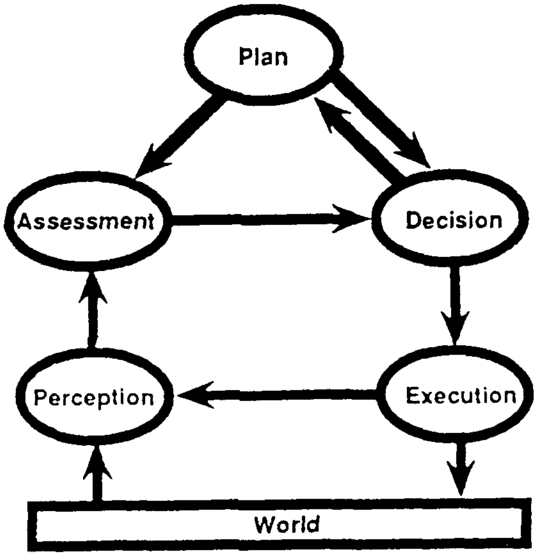

Figure 3 Generalised Control Model

In this model the processes are as follows:

Perception - interpretation of incoming signals to produce a view of various systems. This process includes data fusion.

Assessment - the interpretation of the fused data to develop an assessed view of the world by adding to it intelligence and other data. This includes situation assessment and systems monitoring.

Decision - the evaluation of the assessed view in the context of plans to select appropriate action.

Planning - the development of a local plan in the context of high level plans and the recent situation. This process is cycled at a slower rate than the other processes. Classical control theory would suggest that the ratio should be about 10 between the planning cycle and the execution cycle.

Action - the execution and monitoring of the chosen responses. This includes both the selection of operating models and the direct control of some systems.

This general view can be mapped to the aircraft as shown in Figure 4. In this view, data flow is shown as continuous line and control flow as a broken line.

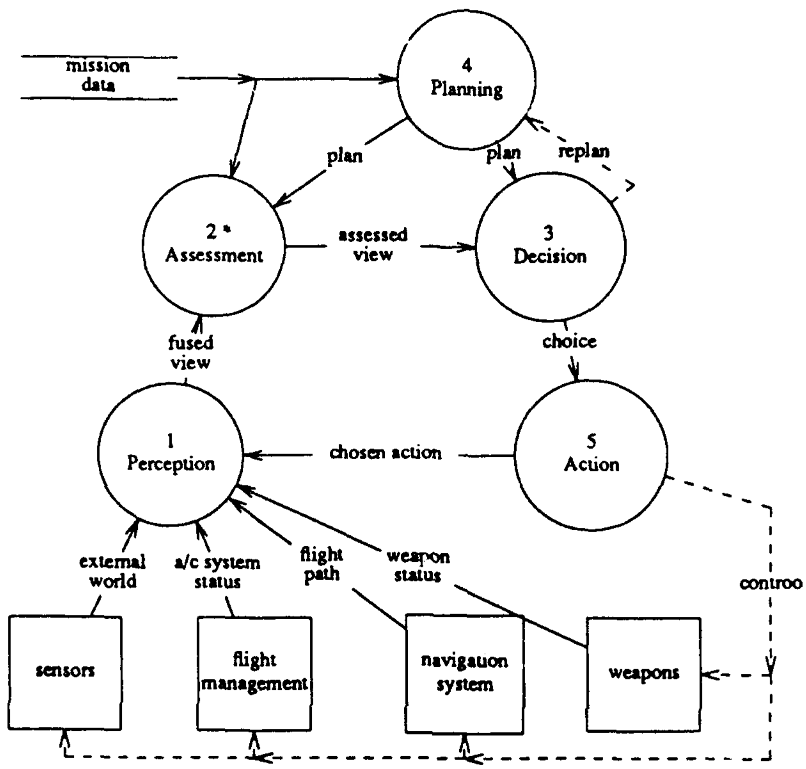

Figure 4 Control Model for Ground Attack

Whichever model of processing that we use to describe the aircraft system we are then presented with the key problem of defining the methods of interaction between the pilot and the other aircraft system. This then leads to the problem defining, the requirement for the pilot displays and controls. (Displays include auditory and tactile communications as well as visual). The next section discusses an approach for pilot display requirements analysis.

3 DISPLAY REQUIREMENTS ANALYSIS

The principal issue for the pilot's display system is to ensure that he is able to access the appropriate data for his current task. As we have seen from the discussion above, definition of the current task is a complex problem since he will be attempting to satisfy more than one goal at any moment in time. In the ground attack example discussed above we identify three processes in which he must have an involvement, Figure 5. In fact, there has to be a fourth process which is the management of the amount of effort given to each process and the setting of their priorities. The display systems must provide him with sufficient information for him to meet these goals. This need would seem relatively straightforward if the data transfer rate between the displays and the man were high. However, individuals are only able to take data at a relatively slow rate.

Assumptions are frequently made about the human ability to process visual information based on the achievable visual resolution, the visual area available to the edge and the rate at which data items are absorbed. This results in quotations for information transfer at very high rates. The reality is that the human visual system is a highly selective processor. For information about which there has to be a recognition decision then it would appear that the data absorption rate is around 12 items per second, Clare 1979.

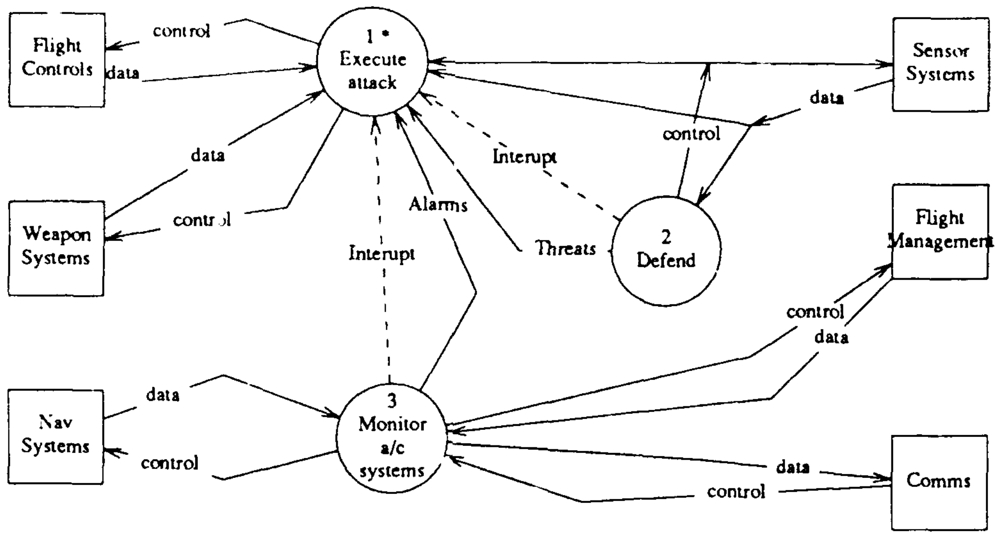

Figure 5 Mapping of Functions to Goals for Ground Attack

The low rate of data take up is often hidden by the fact that each individual has a detailed representation of what to look for in any display. Thus in carrying out a task he is able to attend to specific locations and details of the items needed for that task. This is the reason for the need to maintain consistency in the location and coding of displayed information.

The major problem in presenting information in complex displays then becomes the time needed to learn where to find the information necessary for each task step. The way we can overcome this problem is to simplify the displays, preferably to the point where only that information necessary for a decision step is presented. This, however, creates the dilemma of how do we define that information.

4 Tools for Requirements Analysis

There are a number of tools which have been developed to model and specify data flow as aids to software design. Since we are concerned with the data flow between the human and machine components it is logical that such tools could be of use. There are a number of studies investigating such an approach of which the application of Job Process Charts (JPC) (Tainsh 1985) and their integration with CORE (Mobbs 1985) has provided a good example. However, these approaches have been limited because they have dealt primarily with information flow. Because a critical aspect of the human processor is the rate at which information can be assimilated and the way in which the information is structured, it is necessary that any requirements expression must take into account the time period within which processes must take place and the data structures that need to be imposed.

The Yourdon methodology, like CORE, addresses data flow, but it also addresses the structure of data. This allows the designer to focus on the critical component of the information flows from the system to the pilot - that is the key information that he must absorb in the limited time available. Recent extensions to the Yourdon methodology by Hatley and Pirbhai (1987) address real time interactions and control flow; and this allows temporal constraints and interactions to be identified and modelled, thereby refining the basic data structure established above.

If we consider the functional model, as put forward for the Pilot's Associate then using the Hatley-Pirbhai notation we get a decomposition as shown in Figure 6. This decomposition has omitted the Exec Manager for clarity as it interacts with all the core functions by providing supervision and control. What can be seen is that the resulting data flows are complex and the pilot seems a distant entity from the core functions. In contrast the functional decomposition based on the control model shown in Figure 4 appears simpler.

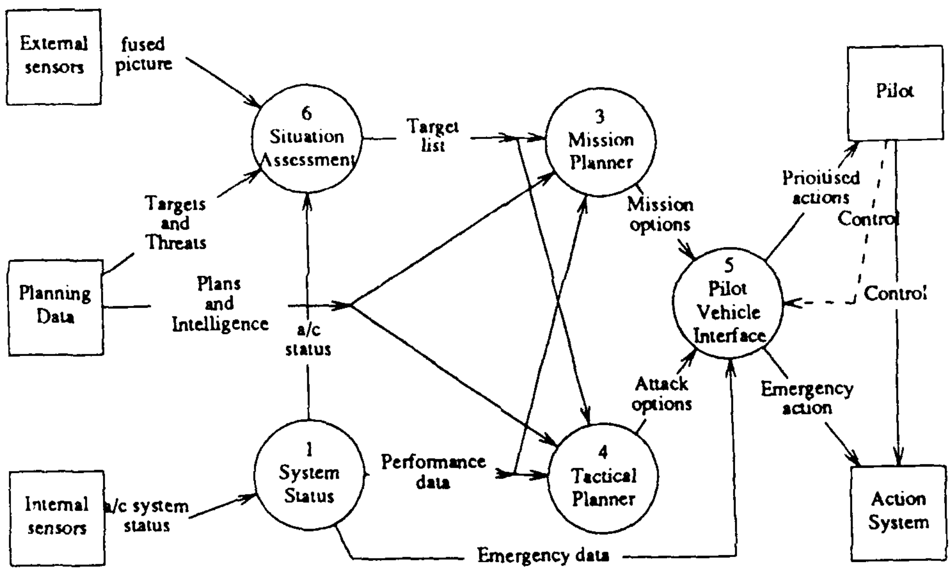

Figure 6 Data Flow Decomposition of Pilot's Associate Functions

However, neither of the representations at this level deals with displayed information. The problem is that they show the overall structure and not the functional structure necessary for a coping with a current set of incompatible goals. If we return to the earlier goal decomposition for the ground attack example, then we define a set of functions each concerned with the three top level goals. The pilot needs to interact with each of these functions as is shown in Figure 7. This example is taken from a decomposition of the assessment function where a control model has been used to devise the functionality. In this view we can see that the pilot is concerned with three separate sources of information. In most cases this would be achieved by using a visual display for the Attack Picture and auditory displays to gain attention for priority interrupts for the other two displays. In current designs since there is little scope for prioritising interrupts the only option is to switch a particular alarm off, as is often done with the radar warning system.

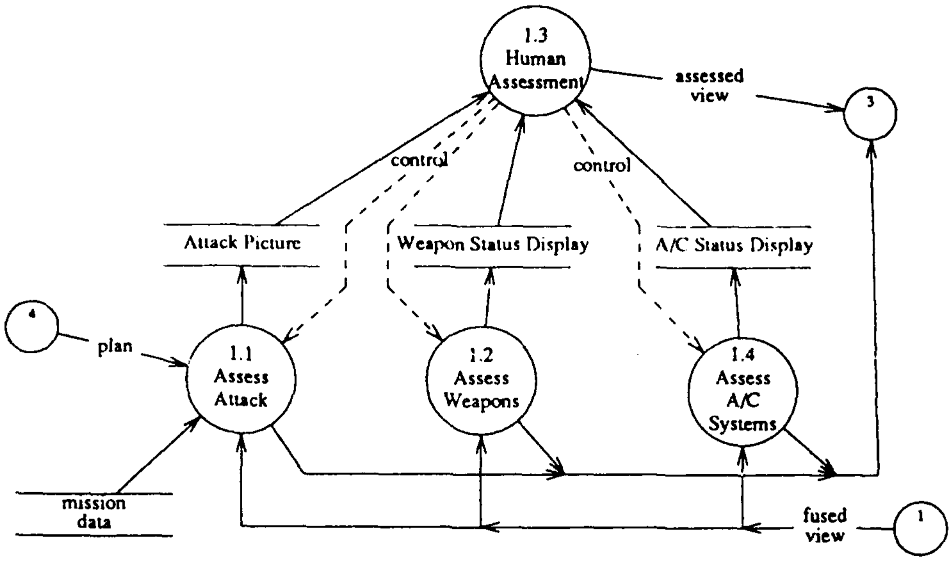

Figure 7 Data and Control Flow for Displays

If we consider how we could manage this interaction more effectively then we can introduce the Exec Manager to control the displayed information, this is shown in Figure 8. What also becomes apparent is that if the pilot is to be ultimately responsible then there must be direct interaction between him and the Exec Manager. This has been shown as a control dialogue rather than a data exchange. It is this dialogue which will need to be of the most intimate nature.

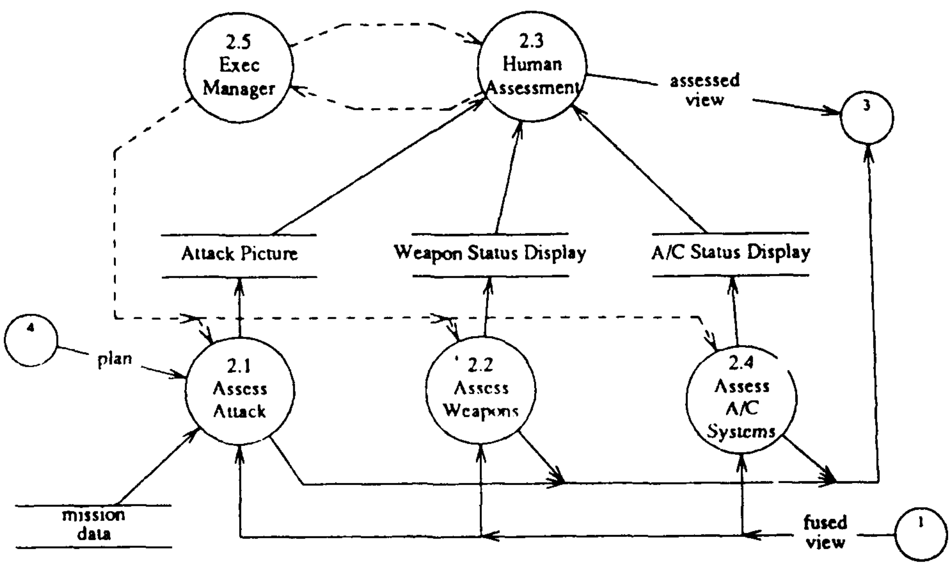

Figure 8 Data and Control Flows for Displays with Exec Manager

The goal decomposition will need to be done to a level which matches functions which have to be performed within the time period a pilot would dwell on a task element. At that level, the time and data needs can be defined and a specification given to the interface designer of information X to be assimilated in time T. Clearly the whole of the mission profile is not analysed in this depth. It will only be necessary to carry out such an exercise when there are multiple tasks to be completed under time pressure.

A major benefit of this approach is that it is possible to define time and information requirements for single screens or screen sequences from the analysis that has been carried out. These requirements can then be used to define performance criteria which can be used to test design solutions before the full integration of the whole system. Thus it will be possible to test critical displays early in the design process against objective measures of performance.

5 Conclusion

The successful integration of intelligent cooperative systems into the cockpit depends on our being able to provide for effective interaction between the pilot and the other aircraft systems. To achieve this it will be necessary to have a good definition of the data which must be exchanged between the pilot and the other systems. In this paper a methodology is proposed where by a detailed requirement of the data with its associated control is developed by the following steps.

a) Detailed decomposition of the system goals carried out to task units which the pilot would complete as a single entity.

b) Development of a set of functions of the total system required to achieve those task units.

c) Mapping of processes to those functions, where the pilot is a processing resource, and developing the associated control and data flow model.

d) Using that control and data model as a specification for the interface designer to design and test display options.

Therefore the major benefit of this approach is the possibility to test design solutions before the full integration of the whole system. Thus it will be possible to test critical displays early in the design process against objective measures of performance.

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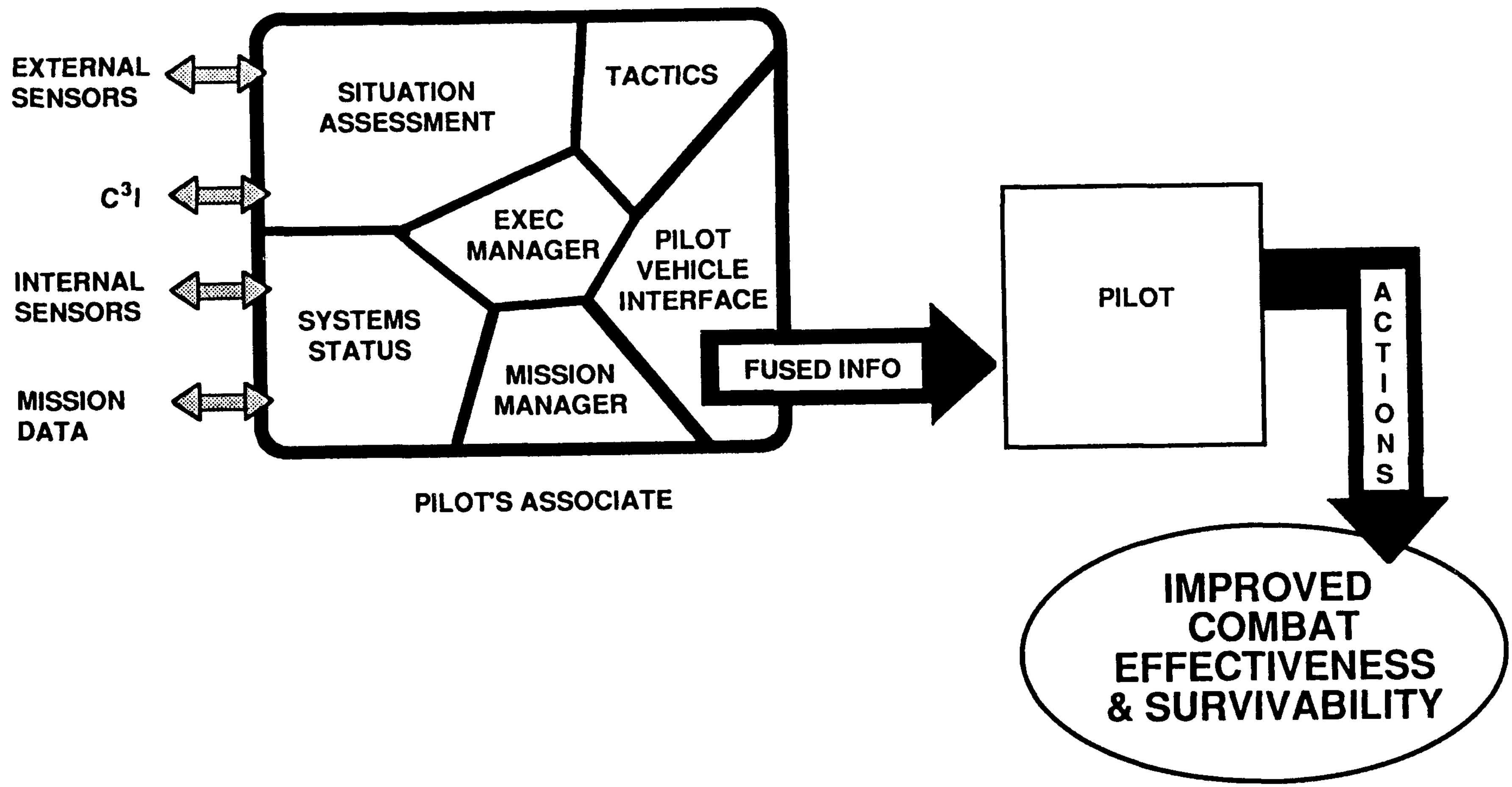

Figure 2 : Pilots Associate Concept

THE IMPORTANCE OF IMPLICIT AND EXPLICIT KNOWLEDGE REPRESENTATIONS FOR FIELDING AN OPERATIONAL PILOT'S ASSOCIATE[1]

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SUMMARY

Fielding an operational Pilot's Associate (PA) will require both implicit and explicit representations of knowledge. Speed and memory performance requirements for PA will be aided by the use of implicit representations of knowledge. Acquiring and maintaining the large knowledge bases for PA will, by contrast, be aided by having explicit knowledge representations. The PA teams have until now been mainly concerned with implicit representations because they have been focused on real-time performance in a limited set of scenarios. Explicit representations will become more important as they scale the system up to include more scenarios. We describe how machine learning techniques can automatically transform the explicit representations into the implicit representations. We discuss the advantages of this approach for system maintenance as well as implications for pilot training.

1. EXPERT PERFORMANCE REQUIRES IMPLICIT KNOWLEDGE REPRESENTATIONS

The US Air Force's PA program is developing artificial intelligence software for an electronic co-pilot. Future aircraft will have tremendous sensor, control, and information resources. These resources will be potentially of great assistance, but they will also be capable of easily overloading the pilot if they are not made available to him in an intelligent way. The goal of PA is to monitor the status of the pilot's mission and understand the situation and the pilot's goals and intentions. This understanding will be required to properly assist the pilot.

1.1 Pilot's Associate Requirements

Monitoring a mission and understanding a pilot's intentions in real-time is an extremely challenging task. It requires *several kinds of expertise*. In particular, the PA system includes five cooperating expert systems. The System Status module monitors the internal state of the aircraft. The Situation Assessment module monitors the state of the world external to the aircraft. The Mission Planner module performs route planning for the entire mission. The Tactics Planner module creates tactical plans for short term actions and maneuvers. The Pilot Vehicle Interface module interprets pilot actions and information requests and transmits information from the other modules to the pilot.

Each of these modules require *large knowledge bases* to attain expert performance in their task. Much of this knowledge is shared between different modules, but it may be represented differently and reasoned about differently in each module. Finally, all of the required interpretation, message passing, and decision making must take place in *real-time* and with a high degree of reliability and accuracy.

1.2 Need for Implicit Knowledge Representations

The principal reason that PA must have implicit representations of knowledge is the real-time requirement.

[1]This work was supported in part by the Learning Systems Pilot Aiding contract from the Wright Research and Development Center (Contract Number F33615-88-C-1739). We are pleased to acknowledge the support of our contract's technical moniter, Gurdial Saini. We are also indebted to the folowing members of Lockheed's Pilot's Associate team: Mark Hoffman and Gary Edwards of ISX, David Smith of Lockheed, Norm Geddes of Applied Systems Intelligence, and Belinda Hoshstrasser of Search Technology. Jerry DeJong of the University of Illinois has also been an important contributor to this effort.

One of the key ways for PA to achieve fast performance is to compile out intermediate reasoning steps and retain only the final decisions or actions associated with a given initial state. For example, having a SAM radar tracking you is generally a bad situation. One strategy to defeat the radar is to become invisible by reducing the aircraft's signal-to-noise ratio. One way to do this if the SAM is using doppler is to deny doppler range data. This can be done by flying a constant distance from the SAM site. One way to do this is to fly a circular path around the SAM. This requires that the pilot turns to a certain heading.

PA does not need to retain all of this background knowledge about defeating a SAM site. It simply needs to know what actions should be taken in the situation that a SAM site is tracking it. Thus, PA's Tactics Planner (TP) might have a plan that ascertains the conditions under which it was being tracked and then simply recommends that the pilot turn to a certain heading. All of the intermediate reasoning about why this action is appropriate can be omitted.

In addition to omitting intermediate reasoning steps, there is a second important way of implicitly representing knowledge that contributes to efficient performance in PA. This is to have specialized control structures for the different PA modules. For example, most tactical maneuvers have explicit timing constraints that must be satisfied if they are to be successful. The TP, however, does not explicitly represent many of these temporal constraints. This is because they are implicitly represented in the TP's control structure which continually montors a situation over time until a particular condition is observed. This condition's occurance will correspond to the temporal constraint being realized.

For example, there might be a constraint that the pilot maintains a certain heading *until* the SAM site switches from track to search mode. The TP does not have to explicitly represent this constraint. Rather, its control structure is such that it will repeatedly sample the mode of the SAM site's radar and will report success of the maneuver only when the radar is observed in search mode. The *until* relation is nowhere explicitly represented in the TP. It is implicit in the control structure.

To summarize, implicit representations of knowledge play an important role in achieving real-time performance for PA. Two principal sources of implicit knowledge in PA are compiling out intermediate reasoning steps and having special purpose control structures.

2. KNOWLEDGE ACQUISITION IS FACILITATED BY EXPLICIT KNOWLEDGE REPRESENTATIONS

Figure 1 contains two rules that are part of the TP's specialized representation for a simple doppler notch plan. One rule, in effect, states that this plan should be selected if there is a SAM-site in track mode. The other says that if the plane is not flying close to a perpendicular heading from the SAM then suggest a new heading to the pilot that will satisfy the perpendicular requirement. We conjecture that it is much more difficult to produce the tactical plan in this complex representation than it is to acquire general rules in a simple representation such as the rule in Figure 2. The TP, however, could never operate in real-time if it represented and reasoned about rules such as the one in Figure 2. Thus, even though it may be easier to obtain simple rules, they are not in themselves sufficient for the Tactics Planner.

We have been using Explanation Based Learning (1,4) to (semi)-automatically transform the simple rules into the specialized representation required for PA (2,3,5,6). The major steps in this translation process are depicted in Figure 3. We use EBL to learn a tactical plan by observing a single example of a tactic flown on a flight simulator. EBL accomplishes this by using an explicit domain theory to explain how the example achieves a stated goal. For example, the goal might be to have a SAM-site switch from track mode to search mode. The domain theory contains general knowledge about the world. We have used a set of rules such as the one shown in Figure 2 to learn a doppler notch plan for the PA TP by observing a single example of a pilot flying such a maneuver on a flight simulator. The result of the EBL process is the macro shown in Figure 4.

The macro shown in Figure 4 is essentially the explanation of how the pilot achieved the goal of defeating the SAM with the intermediate reasoning steps of the explanation removed. All that remains are the initial conditions and any actions that were performed and the conclusion. This macro rule, however, is still far from the representation required by the TP. Most of the required information is present, but it is far from the correct format. For example, the TP uses different types of information in different ways. For example, Figure 1 contains a *selection rule* and an *execution rule*. Selection rules check for conditions that must be true in order for a plan to be viable. That is, only select a plan if these conditions are satisfied. Execution rules monitor conditions that can change during the life of the plan and recommends that the pilot take actions to achieve a desired state of the condition, if necessary.

We have defined two ways of categorizing the clauses in the EBL macro that allow us to properly partition the clauses as required by the Tactics Planner. First, we categorize a clause according to whether it represents something that a pilot can easily control. For example, turning a sensor on or off is easily controllable, but getting a sensor locked-on to a track object or making the sensor operational if it is malfunctioning are not necessarily easily controlled by the pilot. Second, we categorize clauses acording to whether their arguments are constants or variables. If the arguments are variables we further distinguish whether they are bound in the goal of the plan.

Using these categorizations we can automatically sort the macro's clauses into TP rule types. For example, execution rules come from clauses that are easily-pilot-controllable and have variables that are not bound in the post-conditions of the macro. Since they are not bound in the post-condition they are updateable during the execution of the plan. Selection rules come from clauses that are not easily controllable and have constants as arguments. The constant arguments act like test conditions. Since they are not easily controllable the plan should only be selected if these clauses are satisfied.

After the macro clauses are partitioned according to different types of rules there is still a further translation step required to put them in the specialized syntax of the TP's rules. We are presently working on this step, and it appears that most of this process can also be automated. In summary, our research has shown that most of the specialized knowledge required for the PA TP can be automatically acquired using explanation based learning and an explicit and relatively simple domain theory.

3. SYSTEM MAINTENANCE IS FACILITATED BY EXPLICIT KNOWLEDGE REPRESENTATIONS

An important issue for our approach to acquiring knowledge is the size of the required explicit domain theory. If the required domain theory for EBL is sufficiently large then it might be more work to build this domain theory than it would be to simply build all of the tactical plans directly, even if the explicit domain theory rules are each individually easier to build. We believe, however, that this will not be case. Our argument to support this belief is that the EBL domain theory is essentially a model of the primitive functionality of the aircraft and its environment. Tactical plans, in contrast, model all possible behaviours arising from the functionality of the aircraft and its environment. This is analogous to a set of axioms and the set of all possible theorems that can be derived from the axioms. The former is typically a finite set and the latter is typically infinite.

Thus, this argument implies that it will not only be easier to create an initial PA system using our approach, but once the system has been developed it will be much easier to modify and adapt the system. This is because the same underlying explicit domain theory should be able to be re-compiled in different ways to create the new plans.

At least as important for system maintenance is the fact that (semi)-automatically generated plans should have several advantages over hand-generated plans. Automatically generated plans should be more *consistent*. For example, it is well accepted among TP knowledge engineers that there is significant variability in how different knowledge engineers will develop the same plan, and even how the same knowledge engineer will develop the same plan if he/she were to do it on different days. We further expect that automatically generated plans will be more *complete*. For example, our automatically generated doppler notch plan included the TRACK-ID as a parameter to send to the PVI. This parameter had been inadverdently omitted by a TP knowledge engineer who had previously developed this plan by hand. This omission was the cause of a pernicious and long-undetected bug in our simulator system. In a similar sense we expect the automatically generated plans shoud be more *accurate* and also better *justified* and better *documented* than hand-generated plans.

4. IMPLICATIONS FOR PILOT TRAINING

An important issue that has not yet received much attention is that pilots will both want and need to have a thorough familiarity and understanding of the system's behaviors, capabilities, and limitations. It is precisely this sort of information that is typically only implicit in the knowledge representations needed by the performance requirements of PA. In order to present this information to a pilot, it will have to somewhere be represented explicitly. Thus, the representations needed for acquiring PA knowledge bases should also be valuable for training pilots in the use of PA.

Training pilots to use PA is one aspect of pilot training. This aspect will be valuable to even experienced pilots if they have not yet used a PA system. The explicit representations needed for acquiring knowledge should also be useful for another apsect of pilot training, training inexperienced pilots. For example, the PA performance system might be limited to advising a novice pilot to turn to a particular heading in a situation where a SAM-site is tracking him. In contrast, by using the intermediate knowledge explicitly represented for our learning system, a training system could also explain why the PA is giving this advice and why PA expects it to be successful.

6. CONCLUSION

We are quite optimistic that over the next year we will successfully demonstrate that our EBL approach can be successfully employed to learn simple plans for the PA Tactical Planner. There remains, however, the question about how successfully this approach will scale up. At present we only have conjectures that the combinatorics of developing the domain theory needed for EBL will be more favorable than the combinatorics of directly develoing tactical plans. In addition to the scaling-up question there are several other important research areas that require attention with respect to our EBL approach, e.g., temporal reasoning, geometric reasoning, reasoning with uncertainty, reasoning about psychological models of wingmen and enemies, reasoning with imperfect domain theories.

Although this list may appear daunting, we are encouraged by our progress to date. One reason for optimism is that we have made significant progress on at least one of these issues even though we had not originally planned to address it for this effort. This was the problem of temporal reasoning. We had originally hoped that we could choose scenarios that would not require explicit temporal reasoning, but we found that this was not feasible. This was a significant technical challenge for us, but we were able to develop a limited solution to the problem that appears to work well for this domain (5). Finally, we expect that our approach will be useful to PA even before all of these issues are resolved. For example, some of our results are already being incorporated by the PA team into their plans for the next phase of PA, e.g., the principles we presented above for automatically identifying types of TP rules. We expect this trend to grow stronger as our work progresses.

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```
(DEFRULE SIMPLE-DOPPLER-NOTCH-MANEUVER-SELECTION
  TEMPS SAM-SITE RADAR NOA
  IF     (SETQ SAM-SITE (CADAAR (ASSERTIONS '(DEGRADE +) :WHO PARENTS)))
         (SETQ RADAR (PROP 'RADAR-MODE SAM-SITE))
         (EQ 'TRACK RADAR)
  THEN   (ASSERT '(INVOCATION-REQUEST))
         (ASSERT '(SAM-SITE-DATA ,SAM-SITE))
  GOAL   ((SELECT-DOPPLER-NOTCH-MANEUVER)))
```

Figure 1

```
(DEFRULE SIMPLE-DOPPLER-NOTCH-MANEUVER-UPDATE-HEADING
  TEMPS NOA HEADING
  LOCAL SAM-SITE (CADAAR (ASSERTIONS '(SAM-SITE-DATA +)))
  IF     (SETQ NOA (ABS (NOSE-OFF-ANGLE *LEAD-PLANE* SAM-SITE)))
         (OR (> NOA (+ 90 *PERPENDICULAR-HEADING-DEVIATION*))
             (< NOA (- 90 *PERPENDICULAR-HEADING-DEVIATION*)))
  THEN   (REMOVE-ASSERT '(PARAMETER +))
         (SETQ HEADING (PERPENDICULAR-HEADING *LEAD-PLANE* SAM-SITE))
         (ASSERT '(PARAMETER HEADING ,HEADING))
         (SUGGEST)
  GOAL   ((UPDATE-DOPPLER-NOTCH-MANEUVER)))
```

Figure 2

```
(c-rule
 :name 'new-maintain-constant-distance
 :type :non-max
 :pattern
 '(<-
   (maintain-constant-distance
    (agent1 ownship)
    (agent2 ?sam-name)
    (interval ?cnst-dist-interval))

   (and
    (relative-ownship-position
     (heading ?heading)
     (interval ?int-x))

    (relative-track-position
     (track-id ?sam-name)
     (bearing ?bearing)
     (interval ?int-y))

    #f(intersect ?int-x ?int-y ?cnst-dist-interval)
    #f(nose-off-angle ?heading ?bearing ?noa)
    #f(abs-value ?noa ?abs-noa)
    #p(abs-diff-lt ?abs-noa 90 7.5))))
```

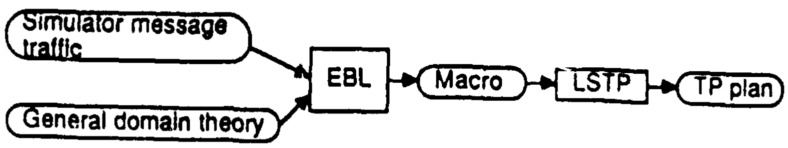

Figure 3

Doppler Notch Macro*

```
If (track-class (track-id ?id) (object-type 1))
   (track-status (track-id ?id) (radar-mode track))
   (relative-track-position (track-id ?id) (azimuth ?noa))
   (fctn (abs-value ?noa ?abs-noa))
   (pred (abs-difference-less-than ?abs-noa 90 7.5))

Then (safe-from-sam (target ownship) (sam-site ?id))
```

Figure 4

* temporal conditions are not displayed

MODELLING THE DYNAMICS OF PILOT INTERACTION WITH AN ELECTRONIC CREW

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SUMMARY

An approach to modeling complex interrelationships between cognitive and situational variables in pilot interaction with an electronic crew is described. The approach uses system dynamics to express and explore the interrelationships between such factors as how reliable the electronic crew is during mission performance, the pilot's estimate of how reliable the electronic crew is (how much the pilot trusts the electronic crew), pilot workload, pilot self confidence, task difficulty, and the amount of risk associated with decisions. A small mathematical simulation of these interactions has been developed to demonstrate how the model may be used to predict the overall performance of the human-machine system and the outcomes of individual decisions in a dynamic environment.

1. INTRODUCTION

Technology advances are enabling more pilot tasks to be automated, including cognitive tasks such as situation awareness and decision making. While there is a huge amount of literature on the psychology of interactions between people, there is very little data on the psychological issues of human interaction with automation. For example, the factors that influence pilot decisions to use or not use automation in a given situation are unknown, even though such decisions are critical to success and survival. To make intelligent decisions about how automation should behave, how it should be applied, how much authority it should have, and what the interface to the pilot should be, not only must these factors be identified, their behaviors must be understood.

Because the Electronic Crewmember (EC) is much more than automation, the importance of these psychological issues is enhanced. An EC capable of performing the pilot's cognitive tasks, inferring pilot intent, and dynamically reallocating tasks raises critical questions, such as: When should an EC take over pilot tasks or responsibilities? What happens if the EC incorrectly infers pilot intent or interprets the situation? How can responsibilities be gracefully transferred between the pilot and an EC? How can an EC be made "pilot-centered"?

Some of the issues implicit in these questions involve the psychological factors that contribute to coordination between human teammates. If interaction with an EC is more like interaction with another human than is usually the case with automation, the general conclusions that have arisen out of investigations in human psychology may provide clues to how pilot interaction with an EC will behave.

To identify potential factors, consider pilot decisions to rely on or override an EC in a particular situation. We may suggest that the pilot will choose to override the EC if he doesn't trust it to perform correctly. He may choose to rely on the EC more or less under conditions of high risk, and whether he relies on it more or less may depend not only on how much he trusts it but on his level of confidence that he can accomplish the task himself. In fact, we may suggest that if his level of self-confidence is higher than his level of trust in the EC, he will choose to take control himself in risky situations. He may tend to rely on the EC more under high workload demands.

In the real world, of course, all of these considerations and others will act in combination. Any given decision to rely on or override an EC may, in fact, be a function of complex, dynamic interdependencies between a large number of factors. In order to understand these factors, relate them in meaningful ways, and model them in a way that is useful for making design decisions, several objectives must be accomplished. First, factors of interest must be defined in a way that is conducive to both empirical investigation and modelling. Second, a modelling framework must be found that permits the expression of complex, dynamic interdependencies. Third, a research program must be designed that enables the development and testing of hypotheses in a particular human-machine system.

As a first step in this process, we have addressed the issues of pilot trust in an EC, pilot self-confidence, pilot assessments of risk, and pilot workload in a dynamic environment. We have formulated operational definitions of these factors which express them on normalized scales, and we have hypothesized some interdependencies and modelled them in the DYNAMO simulation language. The rest of this paper will discuss parameter definitions, the general structure of the model, a literature review to identify reasonable hypotheses about model behavior, and the model itself.

2. MODEL STRUCTURE AND DEFINITIONS

An initial model structure is shown in Figure 1. The figure depicts conjectured interrelationships between operator skill level, task complexity, workload, risk, trust in the EC, self confidence, and EC reliability. Each of these factors may be represented by variables expressed in terms of probabilities or percentages of a resource, permitting the depicted structure to be expressed in a mathematical model with normalized scales. Some moderator variables are also provided. For example, because humans are generally poor at probability judgments and own workload assessments, variables are provided for perceptions of risk, machine reliability, and workload. The directions of hypothesized effects between parameters are shown by the arrows.

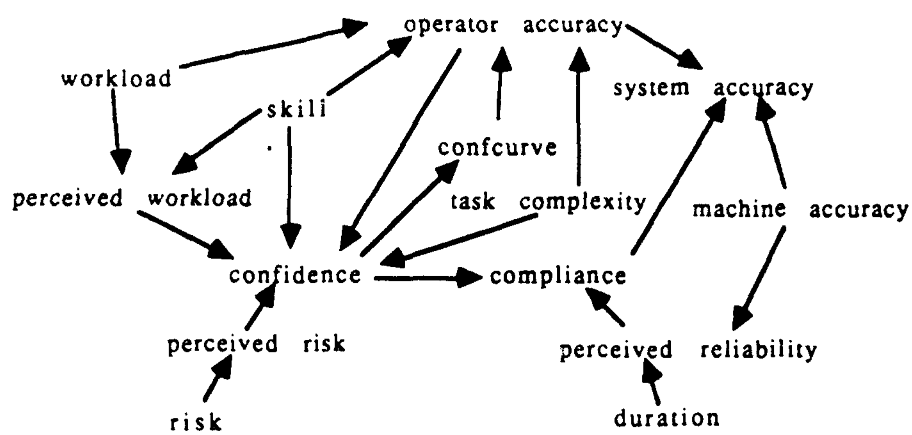

Figure 1: Hypothesized interrelationships between psychological factors in pilot/EC interaction

The following definitions are used in the initial model: Accuracy parameters are defined as percent of decisions or actions that are correct; Workload and Perceived Workload as a percent of workload capacity; operator trust in the machine (Perceived Reliability) as the operator's subjective estimate of the probability that the next decision or action made by the machine will be correct; operator Self-Confidence as his or her subjective estimate of the probability that his or her own next decision will be correct; Compliance as the probability that the operator will allocate responsibility to the machine; Risk as the probability of sustaining damage and Perceived Risk as the operator's subjective estimate of that probability; Task Complexity as the probability that an unskilled operator will reach a correct decision or make a correct action in a given instance; and Skill as the percentage of that skill required for perfect performance possessed by the operator. By defining parameters in terms of probabilities and percent of capacity, meaningful relations can be drawn between parameters, and parameter values may be set or determined in empirical studies. However, the definitions are necessarily quite restrictive and limit the applicability of the model. They also do not cover the possible multidimensionality of some of the parameters. Nonetheless, this level of restriction is necessary to achieve a tractable model.

3. LITERATURE REVIEW ON PSYCHOLOGICAL ISSUES IN PILOT/EC INTERACTION

To generate reasonable hypotheses about how these parameters might behave in pilot decisions to rely on or override an EC, a literature review was performed on human subjective probability estimates, trust, self-confidence, risk, and workload, with sources from experimental psychology, social psychology, engineering psychology, human factors, and sociology.

Studies of subjective probability have provided guidance for the behaviors of the associations between "risk" and "perceived risk", "machine accuracy" and "perceived reliability", and "operator accuracy" and "self-confidence". In general, the pilot model should tend to be conservative when assessing posterior probabilities (1), but overconfident in making predictions (2). It should be unduly influenced by small sample sizes (2), and relatively uninfluenced by independence of events (3), sample size, base rates, and regression toward the mean (4). Estimates should approximate the distributions of the events themselves, even among independent events (3), and be influenced by representativeness, anchoring, and availability (4). For model performance, these results suggest several behaviors. Pilot risk estimates should be influenced by existing perceptions of risk; that is, if conflict has occurred recently, the pilot's estimate of current risk should be higher. When developing an opinion about the trustworthiness of the EC, the pilot may be unduly influenced by early experience, making strong predictions with little data (5). Conversely, the pilot's opinion should be more resistant to change after more experience with the EC, suggesting a moderating effect of the "duration" parameter. Estimates of "self-confidence" (own predicted accuracy) and "perceived reliability" (predicted machine accuracy) should be unduly influenced by the immediately preceding outcome.

Trust has been an understudied topic in psychology, despite its ubiquity and importance in human affairs. Studies of trust in human psychology have failed to reach agreement on the dimensions of trust, but do agree that it is a multidimensional construct with both cognitive and emotive components. Although trust is influenced by individual differences, situational influences are independently significant (6). Trust that does not develop under conditions of low workload but does under conditions of high workload may be sustained under a later low workload condition (7). When trust is violated, a method of absolution is required or trust will not be regained (8). It is thought that trust is more easily destroyed than rebuilt, but this is untested (5). Operators with greater skill levels should have better calibrated trust in the machine (5). For model performance, the following behaviors are suggested. "Perceived reliability" should rise when it is less than the EC's "accuracy" and fall when it is higher. It should be less sensitive as a simulated scenario progresses, and should be better calibrated to EC "accuracy" with higher pilot skill levels. It should fall faster than it rises, particularly after an EC failure. Nonetheless, the pilot may rely on the EC more when subjected to high workload demands even if his trust in the EC is low. This can be accomplished in the model through the "self-confidence" parameter and its influence on "compliance". High "workload" may lead to low "self-confidence" (predicted own accuracy); if "compliance" is determined by the relation between "self-confidence" and "perceived reliability", it may be high even when trust is relatively low. This provides the method of absolution necessary for a stable system (8).

Risk studies have been performed in many areas of investigation. Some general results suggest that higher skill levels lead to lower risk estimates, but that people are generally overconfident in their assessments of own risk (9). Exposure to a risk tends to increase subsequent perceptions of risk globally (10). For modelling, the "perceived risk" parameter should be subject to the foibles of subjective probability estimates in general. It should be higher after recent exposure to a risk, even if the new risk is not associated with the old one. And it should be better calibrated to the "risk" parameter with higher levels of pilot skill. However, the issue of whether the pilot will tend to allocate more or less responsibility to the EC under high risk conditions remains unaddressed in the studies cited. For modelling, we assume that this will be determined through the effect of "perceived risk" on "self-confidence" and its subsequent effect on "compliance".

Most of the work on self-confidence examined for this effort addressed the relation between self-confidence and performance. In general, it appears that there is a positive relation between the two, but the direction on causality is unclear. While many studies indicate that higher confidence leads to better performance (11, 12), it may also be true that better performance leads to higher self-confidence. For modelling, the most conservative position at this time is that a two-way, positive linear relation exists between "self-confidence" and "operator accuracy". We also hypothesize a moderating function "confcurve" that modulates "operator accuracy" to account for errors due to over- or underconfidence, although no support for this was found in the current review.

The difficulty of defining and measuring workload makes its treatment in the proposed model a difficult issue. However, analytic workload models abound, and it is possible that an analytic tool based on the proposed model may be linked to such a tool to provide estimates of pilot/EC joint performance in the presence of the stated psychological factors and analytically derived workload profile. The definition of workload offered here suggests that a workload scale input to the model must contain a maximum workload threshold so percent of capacity can be determined. With regard to the effect of workload on performance, many investigators have conjectured that an inverted U-shaped curve exists, with reduced performance at one end due to underload and consequential reduced vigilance, and at the upper end due to overload, and some evidence for this has been found (13). For modelling, it seems appropriate at this time to treat this relation conservatively.

4. MODEL DEVELOPMENT

Many of the behaviors described in the previous section have been modelled in a small mathematical model of the interrelationships shown in Figure 1. We have used the DYNAMO simulation language which allows the expression of complex, time-based interdependencies between multiple parameters in simultaneously solved difference equations. Parameters are expressed as levels and rates, with delays, random noise, clipping functions, and other modelling features available.

As an example, consider a case where a reliable EC proves itself to a skeptical pilot until it fails for a short period. We assume that risk and workload are constant and the pilot is highly skilled. We hypothesize that the rate of change of trust is proportional to the difference between EC accuracy and the pilot's previous level of trust, that its absolute value is greater when the rate is negative than when positive, and that it is less sensitive with greater duration. Our equation for trust is: trust.k = trust.j + dt (trust.jk); and for trust's rate of change: rtrust.kl = delay (((macc.k - trust.k) / 20 clip (1.7, .3, macc.k, trust.k)) X (1 - duration.k)). Compliance.k = sqrt ((1 - confidence.k) X trust.k). System accuracy is: sysacc.k = oacc.k + compliance X (macc.k - oacc.k). Macc is machine accuracy, and some of the numeric constants are arbitrary, as are the time units. These equations produce the behavior shown in Figure 2 (14).

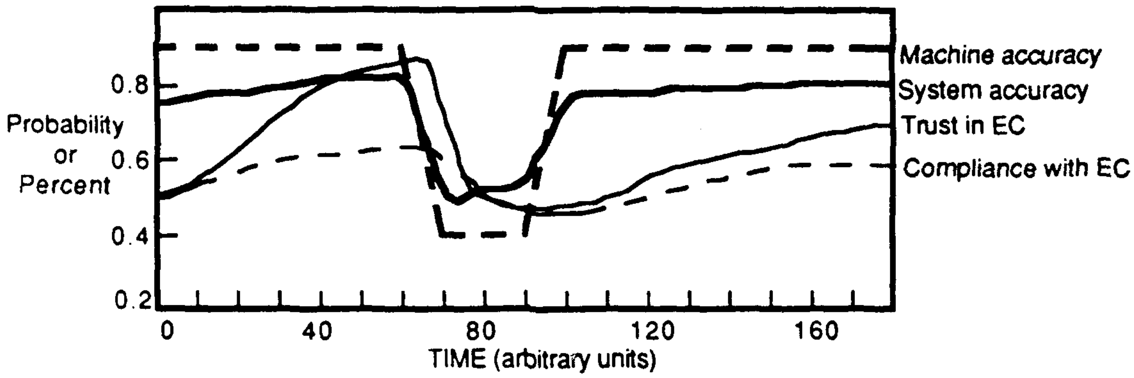

Figure 2: Sample output from DYNAMO model (hand-drawn replication)

Many complex behaviors can be observed by providing various profiles of machine accuracy, pilot workload, and risk, and different behaviors can be observed with different skill levels. However, not all of the hypotheses identified in Section 3 have been modelled yet, and empirical validation in a human-machine context remains to be done.

5. CONCLUSION

The model and literature clues presented offer a framework and initial hypotheses for addressing complex and dynamic interdependencies between cognitive and situational variables in pilot interaction with an Electronic Crew.

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Aircrew Acceptance of Automation in the Cockpit

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Abstract

The concept of human-electronic co-operation in the cockpit is synonymous with that of a team. Whether or not team members interact effectively will rely largely upon the pilot's acceptance of his electronic team mate. This paper reports on the attitudes of eight British Aerospace test pilots towards the future of such co-operation. Particular emphasis is laid upon the factors of system function, task allocation and trust. Pilots opinions are examined against a schema of 'Operational Relationships', recently proposed in the literature .

1 INTRODUCTION

The purpose of this paper is to address the issues of trust and acceptance in cockpit human/electronic teamwork. There is a legitimate concern that the strategy of automating all of the pilot tasks which it is technically feasible to automate is unlikely to provide the optimum design for the future human-electronic aircrew team (eg. Hollister 1986). A first defence against this can be achieved by developing a close liaison between the system designer and the pilot population. This should help in the identification of those tasks whose automation would, in the opinion of aircrew, be most beneficial and thus enhance the likelihood of pilot acceptance.

British Aerospace (Military Aircraft) Limited employ a number of pilots to perform test flying on aircraft such as the Harrier, Hawk and Tornado Aircraft. These pilots have many years of fast jet experience in the Royal Air Force or Royal Navy, Fleet Air Arm as well as in other NATO forces. This pool of experience offers BAe an opportunity to gather opinions and gauge initial reactions to the specific and general acceptability of automation.

Questionnaires and structured interviews were used to elicit the views of eight BAe test pilots regarding the functions and philosophies that should drive the integration of automated, semi-automated and human-electronic co-operative technologies in the cockpit. The pilots had a total of 31400 hours of fast jet flying experience (Details are given in Section 1.1). During these interviews reference was made to the concept of Operational Relationships (OR) as described by Krobusek, Boys and Palko (1988). In this schema ten distinct categories of Operational Relationship are defined. These range from OR'A', where the pilot performs the activity, to OR'G'3, where the system may perform the action autonomously. All 10 are listed below in Table 1, and were used after the interviews to categorise responses. During the interviews the concepts were used to prompt the pilots to consider the possibilities and potential for cockpit automation. Throughout this paper opinions are related to this schema.

Table 1 'Operational Relationship' Summary Table

OR'A' - The pilot performs the activity
OR'B' - The (relatively straightforward) activity is performed automatically by the system.
OR'C' - The system may remind the pilot if the pilot asks or has authorised such.
OR'D' - The system may remind the pilot.
OR'E' - The system may prompt the pilot (with unrequested information).
OR'F' - The system has been given authority to perform function, but with pilot consent.
OR'G' - The system may perform an action only if various conditions are met.
OR'G'1 - The system may perform the action, but must concurrently notify the pilot.
OR'G'2 - The system may perform the action, but must notify the pilot when first convenient for the pilot.
OR'G'3 - The system may autonomously perform the action.

The interview techniques required pilots to iteratively address specific elements and aspects of the piloting task, the aircraft's systems and it's operational role. This provided a flexible structure within which pilots could consider existing automation requirements as well as future possibilities. Four general areas were addressed, these were (i) the management of the aircraft systems, (ii) situation assessment, (iii) tactics and (iv) the man machine interface.

1.1 PILOT EXPERIENCE

Details of the fast jet flying experience of the eight pilots interviewed are given in Table 2 below.

Table 2 Approximate Pilot Logs

	Pilots								Aircraft include:
	P1	2	3	4	5	6	7	8	Tornado(IDS/ADV) Jaguar
Hours	4700	3500	3000	3500	4000	3500	4200	5000	Hunter Jet Provost Hawk EAP
	Total 31400 hours								Harrier (+Sea) F16 Phantom

2 MANAGEMENT OF AIRCRAFT SYSTEMS

2.1 Engines

In general the pilots welcomed engine automation, although they could not easily envisage the potential for automation beyond the fully digital engine controls current in GR5 Harrier or proposed for EFA. Nonetheless, further automation would be welcomed if it maximised opportunities for the pilot to assimilate higher level information by reducing engine system distractors. Particular emphasis was laid upon the desirability of the system performing all pre-flight checks and start-up procedures as there is considerable pressure upon the pilot at this stage in a mission, especially if 'scrambled'. At this stage in a mission pilots wished to only be alerted only if a significant[1] system failure was detected {OR'G'1} believing that self-correcting systems should self-correct autonomously {OR'B'}. Following a system failure it was suggested that details relating to the performance penalty of that failure would be required as the pilot may decide to fly in spite of the failure. Thus pilots welcomed decision aiding but did not wish the system to take a FLY/NO-FLY decision.

In general pilots believed that the aim of engine automation should be to provide 'care-free' handling particularly during periods of high mental workload as experienced in low level flight and during emergencies or combat situations. This could only be achieved if the system was of a sufficiently high integrity to engender a high level of trust.

2.2 Fuel and Hydraulic Systems

Current fuel system automation is considered to be at a fairly high level, although past experience has shown the importance of a 'transparent' system that enables the pilot to confidently assume control of the system in the event of a failure. Pilot opinion was entirely in favour of further hydraulic automation, although there was disagreement concerning the OR that should govern these procedures (ranging over OR'F';OR'G& OR'G'1). Pilots stated that they would wish to sanction {OR'F'} any automated procedure that would affect aircraft performance (eg. moving fuel may affect centre of gravity). It was suggested that pilots should not have to bother themselves with fuel or hydraulic system operations, although high level information was essential (eg. range, kg. left, undercarriage status)

It was recognised that the requirement for information and sanctioning may be part of the process of developing trust in an automated system.

2.3 Battle Damage, Faults, Malfunctions

In general, pilots did not want to be informed of the technical diagnosis of specific types of battle damage, fault or general malfunction. Rather, under these conditions they wanted the system to reconfigure following OR'G'3 with the qualification that should operational capabilities or flight performance be affected the system should immediately inform the pilot of these new parameters. Again this is an example of the need for decision aiding requirements to parallel those of automation.

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1 'Significant' in this context refers to factors that will affect flight performance or operational capability

2.4 Avionics

Automation of navigation systems, which involve many routine tasks, was believed to be a sensible goal although cautionary reference was made to the integration of early automated Inertial Navigation systems which were found to increase rather than reduce workload due to their poor reliability. Although opinion differed upon the level of autonomy (LOA, see also Krobusek, Boys and Palko (op cit.) at which specific navigation and other avionic systems should be set, there was general agreement that automated system functions should remain hidden until a pre-defined point at which the system would request authorisation to continue, thus in effect proposing a variant of OR'F'. The point was reiterated that if a function could be automated with high reliability and the effect of this automation had no effect upon the aircraft's performance then the fact of that automation should remain hidden from the pilot. However as recommended by Krobusek, Boys and Palko (op cit.) it was agreed that such events be recorded for later, in-flight perusal. This appears to support a special case of OR 'B', but with the qualification that such events be recorded in case they impact upon other factors later in a mission.

3 SITUATION ASSESSMENT

3.1 Automated Sensor Management

All pilots agreed that an automated sensor manager that presented an accurate tactical 'picture' was required, but were sceptical about how accurate such a system could be due to the number of variables that must be considered and the often stated requirement to retain flexibility. Although such flexibility may be achieved by pre-setting the 'goals' of a sensor manager's LOA (eg. be stealthy until x etc) pilots were in general unwilling to accept the concept of L'sOA at a more complex level than that of sophisticated tactical decision aider or mission management aid. Overall the concept of L'sOA as interpreted by pilots at the highest level of authority did not extend to that of dynamic re-allocation of function. The highest acceptable level was perceived to be that of pre-flight presets of the functions that would be performed by the pilot and by the system. The consensus appeared to be that L'sOA would not (and should not) be reconfigurable in flight. This view appeared to be driven by the realisation that dynamic re-allocation of function and in-flight LOA resets would occur during high workload periods and potentially contribute to confusion during highly inopportune phases of a mission. It seems likely that the most useful arrangement of pilot-system co-operation (LOA) will be predictable because it will be necessary to reduce the occurrence of variations in this relationship during periods when the pilot is integrating the tactical significance of many external variables.

Pilots did agree that a high integrity automated sensor suite would be extremely useful and afford a significant combat advantage for the pilot. Recent developments such as auto-scan centering and auto-scan volume, as used in radar target acquisition, have been enthusiastically received due to the accompanying large reductions in workload. Although pilots believed that automated sensor management and sensor correlation were priorities, they were concerned about the integrity of such a system. Pilots suggested that trust and confidence in such a system could only be brought about through repeated trials in which the auto-sensor's 'picture' was found to be more accurate than that which the pilot had developed from the usual sensor sources. It was suggested that it would be essential to attach confidence levels to the fused and correlated output of such systems. Thus sensed information could be presented in a form such as "I'm 70% sure this is a Flanker". Given these integrity and probability pre-conditions, pilots believed that they would accept sensor management, correlation and fusion at OR'G'3.

3.2 Automated Defensive Systems (DAS)

Defensive aids systems automation was generally considered a good idea, although pilots were concerned that the system could easily be spoofed (tricked into making an error of commission, a false identification of a threat). To cope with this eventuality most pilots believed that an OR'G'1 level would be required but also mentioned that the need to regularly monitor the system to detect spoofing might increase workload. As with most systems manual override was considered essential.

All pilots were unanimously opposed to the concept that the DAS should be linked to the flight control system (FCS) such that automated missile 'Break' procedures could be undertaken without forewarning. Although several rationales were provided, (including those of system error, spoof/annoyance factors and the potential for physical injury) opposition to this proposal was sufficiently strong to suggest that automated FCS intervention 'went against the grain' at a fundamental level. Missile 'Break' related automation was acceptable only at OR'E'(eg. BREAK PORT).

4 TACTICS

There was little agreement concerning the usefulness of automated tactics systems (ATS), but all felt that tactics would be the most complex pilot tasks to automate due to the inherent dynamic and flexible nature of combat. As discussed previously, pilots appeared reluctant or unwilling to conceive of a tactical level of human-electronic co-operation that exceeded that of sophisticated decision aid. Interestingly the point was made that a capability to vary tactical L'sOA (on the ground) may be useful as a pilot training aid for less experienced pilots, although it was stated that the logic and reasoning employed by the system must be very clear. Pilots felt that the optimum role for ATS would be the computation of target engagement paths, missile release zones and paths of egress. Most pilots believed that these functions should operate at OR'E' levels, although some pilots felt that they may wish to allow the system to carry out the engagement through sanctioning system control of the FCS {OR'F'}. All pilots agreed that regardless of the OR covering target engagement the pilot must perform the weapons release task himself {OR'A'}. One pilot could see the full potential for this type of automation stating that should the pilot delegate target engagement procedures to the automated system, this would -

> **".....allow one aircraft to almost have the capability of two, as the pilot will be able to cover against threats and check systems just as a second crew member would do."**

There was a general feeling amongst the pilots that although they could imagine the potential role of an ATS decision aid they would have difficulty trusting the validity of these displays or indeed the information upon which they were based. A typical comment concerned the auto-detection of a SAM site, it was believed that pilot's would wonder (a) is it really a SAM site ? (b) has the site run out of missiles? (c) is it just illuminating (spoofing) with it's radar ? Pilots felt on the whole that they would be reluctant to trust such a system or the data upon which it made its decisions. Two general accompanying comments were made, these were that :

(1) The most useful tactical decision aiding would be the identification of targets (Automated sensor management) together with details of <u>target</u> performance capabilities together with <u>own</u> optimum engagement parameters (eg. intercept speed and course).

(2) The tactical automation 'nightmare' is that the automated

aircraft provides lots of clear tactical information to the pilot, but that this information is wrong because the system is being spoofed.

5 MAN MACHINE INTERFACE (MMI)

All pilots agreed that the MMI of automated systems would be critical to aircrew acceptance of such systems. A major concern was that the pilot should be presented with an unambiguous display of 'who' was in control of 'what'. There was also concern that the pilot's desire to be told what the system was doing {OR'G'1} or to sanction automated actions {OR'F'} might actually increase his workload.

It was unanimously agreed that there is already too much displayed information in the cockpit for the pilot to reliably intake at periods of high workload and that the proliferation of sensor and weapon aiming systems will exacerbate this problem, particularly in single seat aircraft. Consequently an MMI priority is to reduce the amount of information presented in the cockpit by concentrating on the fused and correlated 'high level' information to be presented to the pilot (eg."port flap hydraulic failure" or "port flap stuck at 15 degrees" is less useful than "starboard roll reduced to **"etc) . Thus the pilot should immediately be aware only of the fact and the implications of significant changes within or outside his aircraft. The significance of an event will require clarification through further research, nonetheless significance appears related to the impact of events upon operational performance, tactics and safety.

Most pilots agreed that during periods of high workload it would be extremely advantageous if an automated system could prioritise information and present this at a time when this would not be distracting. This is similar to a special case of OR'G'2 in which the concept of 'performing an action' is changed to 'gathering information', rendering the nature of the human-electronic interaction closer to that of human co-operation rather than a simple shift of the locus of executive control.

6 GENERAL ISSUES

A number of general issues emerged from the interviews that have bearing upon the integration of the human-electronic team and the pilots ability to speculate upon such a relationship.

6.1 Operational Relationships

The concept of OR's was easily understood by all pilots, although the pilots varied in the level of the OR they were prepared to allocate to human-electronic teamwork. This in itself may support the concept of 'Pilot Tailoring' a process which would essentially customise a pilot's individual LOA requirements. It was suggested that the ten OR's proposed by Krobusek, Boys and Palko (op cit.) could in fact be simplified for the purposes of gauging pilot opinion to :

a) The system does it always {OR'B','G'3}
b) The system does it sometimes {OR 'G'}
c) The system does it and tells the pilot (either then or later). {OR 'G'1,'G'2}
d) The system asks the pilot to be allowed to do it. {OR'F'}
e) The pilot does it. {OR A)

Those OR's omitted from the original schema {OR 'C','D','E'} appear qualitatively different from the rest and as such may be better suited to a schema describing levels of decision aiding.

6.2 Levels of Autonomy

In general, pilots had some difficulty imagining functional models of LOA concepts. There existed a general resistance to the concept that human-electronic team co-operation could be redefined whilst in-flight. Although the concept of 'pilot tailoring' was welcomed it was believed unlikely that these parameters would be re-tailored' between missions due to the sheer complexity of remembering another set of variables. A point made throughout all the interviews was that reducing the complexity of aircraft systems must be the goal of automation. Pilots added that they may well not interact with systems that added significant complexity to their task even if those systems could buy an operational advantage. Although Krobusek, Boys and Palko (**op cit.**) argue that the end product of integrating an LOA approach within automated aircraft systems would buy a "**very dynamic range of performance**" for the system, pilots appear more concerned that they should understand exactly what the performance characteristics of all their aircraft systems will be throughout an entire mission, an assumption that does not allow for a wide range of in-flight variations to the co-operative human-electronic team relationship. The LOA concept did receive support from some pilots who suggested that it would provide a useful training and combat aid for the inexperienced pilot.

7) CONCLUSION

Overall, the pilots welcomed automation that *would relieve them of tasks during* periods of high critical workload and of carrying out mundane and routine monitoring tasks. Whilst there is a degree of mistrust and scepticism concerning the integrity and reliability of future automated systems, the development of such systems are enthusiastically supported as they are seen as the only means by which the pilot will be able to cope with the workload demands anticipated from forthcoming aircraft systems. However, it appears that an effect of this underlying mistrust is that most of the pilots interviewed wish to be presented with information on at least some aspects of the automated decision making processes, a requirement which might actually increase the workload associated with a given task. Interestingly, the pilots opinions were similar to those in the sample reported by Taylor (1988) in venturing that trust in automated systems would not actually develop through the presentation of premises and hypotheses upon which automated decisions had been made but that an individual's trust would develop when the system repeatedly 'got it more right' than the pilot. Ultimate acceptance of highly automated systems would be achieved only when the 'folklore' of trustworthiness generated by reliable systems is passed onto the next generation of pilots.

Many pilots expressed a strong concern that automation will be introduced without fully taking into account the tasks that the pilot performs, resulting in a system that will not be used or liked.

The sample of pilots interviewed in this survey was relatively small and hence their opinions should not be considered representative of the pilot population as a whole. Their experience and backgrounds may have tended to encourage a greater caution and apprehension of automation concepts than would be found amongst those pilots who are currently joining squadrons.

Finally, it should be recognised that pilot opinions are just that, they may be wrong, they undoubtedly differ and and they will probably change. However, ultimately pilot opinion will determine whether or not the human-electronic team members really do work together as a team.

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PSYCHOLOGICAL PRINCIPLES FOR HUMAN-ELECTRONIC CREW TEAMWORK

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1. INTRODUCTION

Human-Electronic Crew teamwork is the co-ordination of activities of human and machine components of advanced crew systems, employing both conventional and artificial intelligence computational techniques, where there is an orientation towards common goals and objectives. Paradigms and metaphors, such as Human-Electronic Crew teamwork, provide both guiding and limiting frameworks for structuring thinking about crew systems interface design. Traditionally, aircrew interface design has been guided by the manual control paradigm, involving a closed-loop negative feedback control system, with the human as the adaptive element. Improvements in flight technology and aircraft capability revealed limitations on manual control in IMC/IFR conditions, with the potential for loss of control in highly dyna⁻ 'c environments, unusual positions and high G. The introduction of automation technology gave curr... cy to the supervisory control paradigm, with the transfer of some human functionality to automation, and with the human operator allocated a system management role. Experience has revealed the unreliable nature of human monitoring performance, with problems of undetected degradation, and reduced operator intervention capability. Now, the prospect of utilising machine or artificial intelligence (AI) has encouraged the use of the problem-solving paradigm for interface design. This focuses design effort on how the interface can be created to help perform the mission (EGGLESTONE, 1988).

In 1988, participants at the 1st Joint GAF/RAF/USAF Workshop on the Human Electronic Crew broadly agreed that teamwork provides an appropriate metaphor for characterising the relationship between the human and AI system components needed to solve mission problems (EMERSON et al, 1988). In the military aviation environment, mission problems are characterised by uncertainty and ill-structure. They require flexibility in handling contingencies as they arise, rather than as planned. In dealing with this requirement, AI system interface design needs to reduce operator workload, improve operator situational awareness, and enhance decision-making performance by creating an improved integration or matching between the human and electronic crew capabilities. The difficulties that seem most likely to arise are in the areas of creating trust, maintaining goals and in achieving appropriate levels of autonomy in such a teamwork relationship.

The aim of this paper is to develop an improved understanding of the requirements for teamwork in the Human-Electronic Crew with reference to the literature on social psychology and computer aiding. Through this analysis, it is intended to identify key dimensions that characterise levels of maturity in teamwork, with particular regard to problem solving and decision making under uncertainty. We will attempt to incorporate these dimensions into a prototype audit tool for evaluating the quality and maturity of Human-Electronic Crew teamwork.

2. TEAMWORK MODEL

In order to examine the requirements for Human-Electronic Crew teamwork, we will be guided by a generic model representing the system of relationships between different aspects of teamwork. The model proposed, shown in Fig. 1, is derived from the social psychology of small group dynamics (McGRATH, 1964). Teams differ from small groups in the greater emphasis placed in teams on clear definition of goals, roles and structure. Teams have three distinctive characteristics:

a) Co-ordination of activity, aimed at performing certain tasks and at achieving specific, agreed goals.
b) Well-defined organisation and structure, with members occupying specific roles with associated power, authority and status, whilst exhibiting conformity and commitment to team norms and goals.
c) Communication and interaction between team members, which we refer to as team processes.

The system of relationships between the components of teamwork can be understood in terms of the team's goals, resources, structures, and processes, and their effects on individual team members, team development and team performance. Two system feedback loops can be identified, namely:

a) Feedback on performance of the team's task, compared with team goals, possibly leading to changes in team resources, e.g. recruitment of additional expertise.
b) Feedback affecting team structure as both individual members and the team develop, learn and adapt to changing goals and task demands, e.g. dynamic function allocation, initiative turn-taking, emergent leadership.

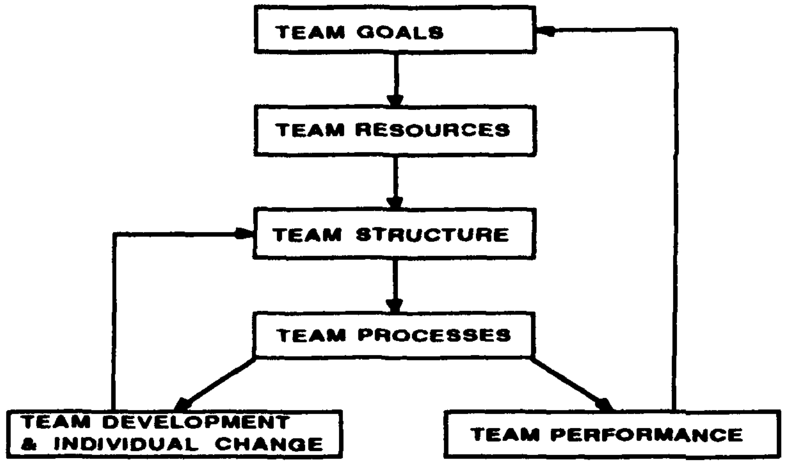

FIGURE 1 - Teamwork Model.

We propose to examine the requirements for Human-Electronic Crew teamwork in relation to the individual components of this generic model. Each component will be addressed in two parts. Firstly, we will summarise relevant heuristics and guidance on teamwork derived from a selective review of social psychology literature (PENNINGTON, 1986; EIMER, 1987a; WELLENS AND McNEESE, 1987; LARSON AND La FASTO, 1989). Secondly we will identify some of the principal issues raised for Human-Electronic Crew teamwork, based on current applications of decision support systems, with relevance to the teamwork model components.

3. TEAM GOALS

3.1 TEAM GOALS : SOCIAL HEURISTICS

Effective teamwork is strongly associated with a clear understanding by all members of the team's performance objectives. Effective teams are characterised by a commitment, focus and concentration on clearly defined goals. Team goals should be believed to be worthwhile, and personally challenging. Their pursuit should create a sense of urgency and progress. Achievement of team objectives should make a clear difference to the situation. Failure of teamwork is most commonly caused by the elevation of other goals, usually personal or political, above the team's performance objectives. Personal and political agenda threaten the clarity of team goals, leading to loss of focus and reduced concentration of team efforts. Achievement of objectives can be facilitated by the setting of high, but achievable, performance standards, which motivate and produce pressure on team members to improve both individual and team performance.

3.2 TEAM GOALS : HUMAN-ELECTRONIC CREW ISSUES

When considering the design of a goal-based team structure, it is necessary to make the distinction between goals, sub-goals, and meta-goals. Goals are the teams objectives, successful attainment of which are both necessary and sufficient for task completion. Sub-goals refer to the lesser objectives, attainment of which are necessary but not sufficient for task completion. Sub-goals are relevant where achievement of mission goals requires a staged or iterative process, with the sub-goals being the objectives of each stage (SIMON, 1978). Meta-goals refer to over-riding goals which, although not being directly related to the task, provide an infrastructure in which successful goal achievement can occur. An example of a meta-goal is the maintainance of pilot situational awareness. Although it is not part of the mission, per se, it is an important factor in the pilot's ability to reach task goals. Failure to achieve such a meta-goal will impact on task performance. Thus meta-goals are most relevant during the design stage, be it the design of systems or team structures.

When team structures are functioning in a dynamic environment, then sub-goals (and to a lesser extent task goals) will change (LIND, 1988). For effective team performance, all team members must be aware of any changes in their goals. Failure to communicate such changes will result in the loss of the common goal structure. The impact of this for the design of human-computer teams is that such communication must be bidirectional i.e. sufficient feedback must be given by both team members for the other to maintain his awareness of the new goals.

4. TEAM RESOURCES

4.1 TEAM RESOURCES : SOCIAL HEURISTICS

Team resources comprise all the relevant abilities and tools, skills, rules and knowledge available to perform the task, including both human and machine capabilities. The availability of resources is determined by the team size, i.e. the number of individual members, by the level of individual and team training, competence and expertise, and by situational factors such as fatigue, boredom and anxiety stress. Increasing team size may facilitate or inhibit performance on tasks, e.g. by generating more ideas on problem solving tasks, whilst increasing the time taken to generate each idea. Resources may be redundant or unique, through the team being composed of homogeneous or heterogeneous membership. Homogeneity for some resources may be more effective for performance than heterogeneity. However, resource variability, through heterogeneity may produce greater sensitivity to changing task demands. The resources must be willing and able to collaborate effectively. Compatibility can be achieved with different but complementary resources for dimensions such as the *need to dominate* or to control events. Teamwork is normally associated with the achievement of specific goals requiring specialised skills. For effective teamwork, the requisite resources should be available and appropriately distributed among the team members, in accordance with the task structure and load. In tasks where the performance of a team is limited by the weakest member (conjunctive task constraints), resource variability is undesirable. In tasks where team performance is determined completely by the best member's performance (disjunctive task constraints), a high degree of resource variability is desirable. Matching of resource characteristics to task demands, in terms of the difficulty of underlying operations, is the key to estimating the capability for effective teamwork.

4.2 TEAM RESOURCES : HUMAN-ELECTRONIC CREW ISSUES

The design of the human-computer team requires that knowledge be gained of the resources of each team member. This will allow the a priori allocation of tasks to that member best fitted to perform them (where expertise is limited to one member) or dynamically according to the situational demands (where both members have relevant expertise). Correct utilisation of unique and redundant resources will produce a synergistic team, thus extending the total resources of the team (MOSS et al, 1984). An example where unique resource allocation would be effective is in judgements under uncertainty. Humans are traditionally poor at integrating multiple sources of probabilistic information in a formal statistical manner. Computers are, on the other hand, good at such 'number crunching' activities. Thus a successful team would use the computer resource to achieve this part of the process. Humans are good, however, at accepting integrated advice and using heuristics to make judgements under uncertainty. Thus the team would use this human resource to complete the decision process. Where both team members have the expertise and resources to perform a function, then allocation of that function should be performed dynamically, with the choice of who should do the task being decided through consideration of meta-goals e.g. maintainance of SA, reduction of pilot workload etc. The design of suitable task structures to best exploit the available resources is discussed below.

5. TEAM STRUCTURE

5.1 TEAM STRUCTURE : SOCIAL HEURISTICS

Team structure concerns the relatively stable pattern of relationships between members that determines the communication required for co-ordination of activities, and that governs the distribution of functions, roles, status and power. The function of team structure is to implement access to task-relevant resources. Team structure and associated patterns of communication should be designed to facilitate rather than restrict access. Effective teamwork requires a structure driven by performance results. The required structure is that which is appropriate for achievement of the specific team performance objectives, with the minimum complexity of resources necessary and sufficient for successful functioning. Maintenance of organisational processes should not consume unnecessary resources. In an functionally effective structure, individual and team efforts always lead towards achievement of the team goal. Increasing cohesiveness and attraction between team participants leads to greater conformity to team norms, more uniformity of behaviour, improved performance and increased job satisfaction. Poor performance and morale are associated with poor cohesiveness and low membership attractiveness. Centralisation of communication structure affects membership satisfaction and team performance. More centralised communication networks (e.g. wheel versus circle structure) produce better team performance but lower membership satisfaction, except in complex tasks when the central elements become overloaded. *Decentralised networks allow a more* even distribution of workload.

Structure creates role differentiation. Status and power are affected by roles and functions. Discrepancy between the expected role, perceived role and enacted role of individuals introduces conflict between team members. The evaluation attached to a role determines the status of the individual and influences conformity to team norms. The perception that interactants have equal status facilitates communication. Function allocation is essential for effective co-ordination of goal- oriented activities. A high degree of rigidity and clarity in function allocation, with clear accountabilities, is beneficial for well-structured tasks, which follow a clearly defined plan, and for tasks requiring unique rather than redundant resources. Flexibility in function allocation is beneficial for tasks involving ill-structured problems, uncertainty and requiring good communication between team members. The communication structure influences the distribution of information, power and authority in teams. The member through which most information passes has the potential to exert considerable influence over the team (informational power). In a highly-centralised communication structure, the member in the central role acts as the information gate keeper. This member is most likely to be perceived as, and act as, the team leader. The distribution and locus of power depends on the ability to monitor the performance of members and to exercise reward, coercion and feedback (reward and coercive power), to generate a positive image that attracts emulation (referent power) and by the ability to internalise goal-relevant information and acquire knowledge (expert power). Effective teamwork is most likely to occur when assigned, legitimate power coincides with the locus of informational, expert, referent, reward and coercive power. The function of the team leader is to exercise authority and power in order to achieve the team's performance objective. Leadership is achieved by changing, directing and controlling the behaviour, attitudes and opinions of team members to conform with team roles, standards, norms, and goals. Leadership behaviour includes clarifying team objectives, making important decisions and taking initiatives, and identifying ways of achieving objectives. Leadership effectiveness is dependent on the exercising of situationally appropriate task-oriented and relationship-oriented skills. A strongly authoritarian, task-oriented style is not necessarily the most productive when dealing with ill-structured tasks requiring good communication and cohesiveness between members.

5.2 TEAM STRUCTURE : HUMAN-ELECTRONIC CREW ISSUES

The implementation of the structures described above in the human-computer team require consideration of the levels of autonomy to be assigned to the computer's functions. Several taxonomies of the levels of autonomy of human-computer interaction have been postulated (e.g. SHERIDAN & VERPLANCK, 1978). They describe the level of interaction as varying from the human performing all functions, through increasing levels of computer autonomy, to the computer performing functions independently with discretionary power to not inform the human. The level chosen is likely to be situationally dependent in that it will depend on the demands of both goals and meta-goals. This is since the requirement for autonomy is itself a dynamic function of the operational context. For efficient teamwork, the locus of power should be allocated to maximise goal achievement. An example would be the computer 'taking control' when the pilot suffers G-induced loss of consciousness. Also, where the computer controls data fusion and displays management e.g. Pilot's Associate, and hence information flow, then this necessitates, by implied consent, that at least part of the leadership role (traditionally associated with the human team member) will be performed by the computer team member.

Where task allocation is static, the level of interaction can be chosen a priori. Dynamic task allocation may require a variable authority gradient to exist in order to best exploit the resource distribution across team members. Where situational demands are high, requiring pilot mandate for all low level 'chores' may decrease the usefulness of assigning such tasks to the computer. When the demand is less, then less autonomy may be beneficial by maximising the degree to which the pilot is 'in the loop'. The degree to which this is relevant is likely to depend on the types of functions which the computer can perform, and also on the degree of trust in the computer exhibited by the human. Where a high degree of trust is available, task leadership functions may be shared or even transferred to the computer member. How such levels of trust can be produced are discussed in the next section.

6. TEAM PROCESSES

6.1 TEAM PROCESSES : SOCIAL HEURISTICS

Team processes of communication and interaction are affected by the structural characteristics of the team (roles, status, cohesiveness). Communications can be analysed for functional content and style. Content can be task oriented or social-emotional oriented. Task-oriented communication includes interactions exchanging information (repetition, confirmation, clarification), opinions (evaluation, analysis, feelings) and direction (suggestions, possible actions). Communication with social-emotional orientation involves positive and negative reactions concerning agreement (acceptance, concurrence, understanding), satisfaction (release of tension, humour) and solidarity (affirmation of status, help, reward). Social cohesiveness is important for team productivity and performance. Interactive styles can be characterised as affiliative-nonaffiliative, affecting cohesiveness and reflecting attractiveness; dominant-submissive, reinforcing power relationships and reflecting status; responsive-unresponsive, reflecting the expressive quality and effectiveness of communication. Communication has temporal and bandwidth constructs (channels, modalities) Un-restricted communication can be unproductive, distracting and an inefficient utilisation of resources. Broadening the communication bandwidth increases the psychological closeness of interactants. However, some psychological distance may be necessary for tasks requiring autonomy and independence of thought and action. Widening the bandwidth beyond that needed for audio communication does not improve performance on some problem- solving tasks. The communication bandwidth should be necessary and sufficient for achievement of team goals. Formal language can be restrictive, slow and inefficient for solving ill-structured problems. Conformity to dialogue protocols (e.g. rules for structuring turn-taking, transferring controls) should increase the efficiency of communication and maintain the goal-orientation of interactions. Effective communication requires knowledge of the functionality, meaning and goal of the communication. This is achieved by tracking both the goal and the context of the communication, using domain-specific information and information for the control of the communication process. Effectively communicating and collaborating teams are characterised by a high degree of trust. Trust requires predictability, dependability and faith in interpersonal relationships. Trust occurs in a collaborative climate characterised by honesty, openness, consistency and respect. Violations of trust have catastrophic, irredeemable effects on team functioning and performance. Full teamwork potential is unlikely to be realised when trust has been broken. Trust allows team members to stay problem-focused, it promotes efficient communication and co-ordination, improves the quality of collaborative outcomes, and it leads to compensatory behaviour. Compensation between individuals is necessary for performance standard to be independent of variability in team resources.

6.2 TEAM PROCESSES : HUMAN-ELECTRONIC CREW ISSUES

Communication between the human and computer team members is achieved through the design of the interface between them. An effective interface requires an understanding of the knowledge requirements of the team members with a consequent moding of input/output facilities to support these requirements. Again, both goals and meta-goals need to be considered in the design of the interface. If the computer is to control the flow of information, then an efficient model of the human's information processing abilities/ requirements is essential. Adaptive or learning interfaces have the potential for maximising teamwork (WEISBROD et al, 1977). The problem with such systems is that they can learn 'bad habits' (or sub-optimal behaviours) from the human if they are adapting to his behaviour without sufficient reference to the task and meta-goals. They need to be goal rather than behaviour driven, implying the need for the adaptivity to be bidirectional. In other words, the team efficiency will only be improved where human and computer are given sufficient feedback on goal achievement to both learn, and hence improve sub-optimal performance. Such feedback will not only allow compensatory teamwork to occur, but will also enable a suitable level of trust to develop and be maintained. Failure to provide it may result in over-trusting (EIMER, 1987b) or under-trusting (LERCH & PRIETULA, 1989), both of which impact negatively on task goal achievement.

7. TEAMWORK MATURITY AUDIT

It may be useful, on the basis of the foregoing analysis, to construct a tool for evaluating and auditing the quality and maturity of teamwork in candidate Human-Electronic Crew systems. Table 1 identifies potential audit constructs associated with teamwork maturity, derived from the teamwork model components. In conducting an audit on a candidate system, the aim would be to evaluate the extent to which the audit constructs are primary features, minor features, or not represented in the system. Additional constructs, from other domains e.g. systems architecture, software engineering etc would need to be included in a fully comprehensive analysis.

MATURITY CONSTRUCTS	DEFINITIONS
TEAM GOALS	
Clarity	Clearly defined performance objectives.
Common Structure	Shared understanding of meta/sub goals.
Tracking	Awareness of changing objectives.
Impact	Critical for mission success.
Achievement	High probability of success.
TEAM RESOURCES	
Sufficiency	Enough expertise/ability/competence.
Availability	Readiness for application to task.
Heterogeneity	Variability/uniqueness of expertise.
Compatibility	Ability to combine/integrate/match.
Enhancement Capability	Ability to add to expertise.
TEAM STRUCTURE	
Goal Driven	Governed by performance objectives.
Resource Accessibility	Facilitates access to resources.
Cohesiveness	Attracts conformity to team norms.
Dynamic Function Allocation	Real-time role/task distribution.
Levels of Autonomy	Degrees of independent functioning.
TEAM PROCESSES	
Wide Bandwidth	Multiple modalities for communication.
Bidirectionality	Two-way flow of information/feedback.
Shared Initiative	Leadership turn-taking.
Common Knowledge Base	Shared understanding of situations.
Trust	Willing to accept others' judgements.

TABLE 1 - Prototype Teamwork Audit Tool

8. CONCLUSIONS

This analysis demonstrates that there is substantial understanding, in social psychology, of the processes of teamwork, sufficient to generate a potentially extensive list of criteria for judging the quality and maturity of Human-Electronic Crew teamwork. The limitations of the model are that Human-Electronic Crew teamwork may have unique emergent characteristics that are not evident from analysis of human teamwork. A major problem with the model is that it is based on a high degree of trust. When distrust occurs, teamwork breaks down in a potentially catastrophic and irredeemable manner. This may result, in the worst case, in the human operator refusing to use any of the electronic crewmember's capabilities. The distribution of power raises the issue of leadership, with consequent moral and political implications if the locus of power is not to reside with the human. Such a prototype model is unlikely to provide a fully comprehensive analysis of the issues. However, the aim of audit is to judge the whole through a sample of relevant criteria. As such, this model may have some utility, at least, in conceptualising, designing, and validating candidate Human-Electronic Crew teams.

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Decision Support and Adaptive Aiding for a Battlefield Interdiction Mission

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SUMMARY

This paper discusses what we feel are some of the important issues in designing the interface between a pilot and an electronic crewmember, and describes some of the problems encountered in addressing them. We also describe some possible approaches to overcoming these problems.

1. INTRODUCTION

The past several years have seen a number of efforts to develop intelligent pilot aids. They may be called electronic crewmembers, pilot's associates, pilot's assistants, or something else. These projects differ in scope, with some designed for more or less functionality than others; in breadth, with some concentrating on entire missions and others on particular segments; or in application, with some intended for commercial aviation purposes and others tailored for military missions. *System similarities (such as functionality)* outweigh differences, however, and their developers tend to share a set of fundamental concerns. Goals of many of these systems include offering situation assessment advice, planning missions and tactics, monitoring system status, offering reconfiguration advice following system malfunctions, intelligently managing displays (presenting the right information in the right form at the right time without burdening the pilot with system management tasks), and recognizing when the pilot can use automation help (due, for example, to high workload) in order to allocate functions dynamically.

Pilot-Vehicle Interface concerns are of overriding importance in such a system. All this functionality will be just another black box if it is not implemented properly. The present paper describes what we feel are some of the important issues in interface design, as well as some of the problems encountered in addressing them. We also describe some possible approaches to overcoming these problems.

2. MISSION CONTEXT AND PILOT INTENT

One outstanding problem for an intelligent system involves determining operator (or pilot, in the context of electronic crewmembers) intent. The concept of determining intent is a source of confusion and controversy. The term is not meant to imply some sort of mindreading. There are realistic ways to determine pilots' most reasonable or likely actions in a given set of circumstances, and the challenge is to make them work. The potential payoff is high; there are many advantages to achieving a precise, robust, predictive scheme for inferring intent, particularly in the kind of dynamic environment a cockpit represents. These include likely improvements in system performance as a result of anticipating a pilot's information and function allocation needs, and reducing the need for direct pilot-system communication.

Most previous attempts to infer pilot intent have adopted traditional Artificial Intelligence techniques and knowledge acquisition methods, and depend on rulebases, scripts, and the like. It has never been clear that these adequately capture the subtleties of the environment sufficiently; sceptics (e.g., Dreyfus & Dreyfus, 1986) argue that procedural rules and scripts are insufficiently flexible to represent cognitive activities in complex environments. A rulebase may always need yet another conditional statement to handle new circumstances. In response to these problems, some electronic crewmember systems adopt the tactic of making relatively loose predictions about intent and relying for their accuracy on monitoring the pilot's actions to confirm or disconfirm and reconfigure predictions. In a sense, this approach can be considered as much reactive as predictive. It can also be very cumbersome and expensive to build a system based on this approach and difficult to modify or tailor it to individual preferences.

Alternatives are available, however, for acquiring and representing both the knowledge and the policy that pilot intent implies. We are exploring the feasibility of using statistical models (e.g., through discriminant analysis) of the relationship between the "mission context", expressed as a set of pertinent, measurable aspects of the mission environment (and perhaps, if necessary, some minimal set of observable pilot actions), and a pilot's probable physical and cognitive tasks. For example, a threat encounter might be represented in terms of the type of threat, the distance from ownship, assessments of its intent and capabilities, numbers and types of ownship defenses and countermeasures, and the like. Using expert judgments or data from simulated flight, the patterns these variables represent could be grouped and mapped onto a set of response tactics. The analytic component of this approach is very much like "cognitive task analysis" (e.g., Terranova, Snyder, Seamster, and Treitler, 1989), but the resulting model would be very similar, both conceptually and mathematically, to a "neural net", (Rumelhart, McClelland, and the PDP Research Group, 1986). (Indeed, a neural net might be used instead of discriminant analysis.) Similarly, regression equations could be developed from prioritized ratings of information requirements to support the tasks appropriate for each example context or group of contexts. An alternative approach to modeling the pilot's judgments about tactics and related decisions would involve using "policy specifying" techniques (Ward, 1977).

This context-based approach is promising, but has yet to be adequately developed and tested. If successful, it might offer several advantages over current methods, providing the system with a flexible representation of the pilot's likely actions and requirements in virtually any context.

3. DECISION SUPPORT/DISPLAY MANAGEMENT

Pilots are confronted with a numbing amount of information from sophisticated current avionics systems, and new avionics are planned all the time, especially for military applications. For the most part, professional pilots are able to pick out and absorb the information they require at any given time. But it's not made very easy. One frequent complaint is that to make the cockpit environment tolerable some of the avionics and warning systems intended as important and helpful in maintaining situational awareness must be turned off. The important point is that an electronic crewmember can't be viewed as just so much additional functionality.

One way of assuring during the design process that this doesn't happen is to view the electronic crewmember as a decision support system. This involves expanding upon the basic information requirements to systematically justify the functionality of the system. Zachary (1988), for example, has developed a complete framework for evaluating decision support needs by considering both the decision maker's objectives and the environment in which decisions are to be made. In other words, it is important to consider not just what information is required, but also what will be done with it. The process continues in order to determine how the information must be analyzed to be most useful.

Another way of aiding the pilot's decision making includes systematically determining when and how the system's products are presented. This allows the designer to implement intelligent display management techniques with the goal of reducing the system management tasks required to configure displays. Thus, when the pilot is performing some task, a display format would be selected to support the task with information, tailored in both content and modality according to his/her current workload level and other pertinent factors.

Conceptually, intelligent display management is a special case of dynamic function allocation, which is discussed further in the following section.

4. DYNAMIC FUNCTION ALLOCATION

Function allocation analysis is fundamental to the design of any cockpit, and frameworks for such analyses have become very sophisticated (e.g., Pulliam & Price, 1985). In general, though, three basic questions are typically asked when static systems are being designed: what does the person do best, what does automation do best, and what can either one do? General descriptions of tasks that fall into each category have been around for a long time. Building an electronic crewmember, however, allows for the possibility of dynamic function allocation (DFA).

Briefly, the idea of DFA is that an intelligent system can itself determine the need for automating more or fewer tasks without the pilot's explicit authorization. DFA is controversial and many pilots find the notion distasteful because they assume it will necessarily disrupt the basic understanding that a pilot has of his/her own responsibilities and the aircraft's. For proponents, however, it constitutes an absolute requirement for building a true electronic crewmember, or an "associate" for the pilot. The real issue appears to be whether DFA can be implemented so as to retain system predictability; the pilot must understand the system well enough to know what it will or won't do at any given time.

In addition, as Chinnis, Cohen, & Resnick (1984) note, it may not be sufficient to analyze how a job is presently done and allocate pre-existing cognitive tasks. First, adding an electronic crewmember can change the very nature of the tasks, so a simple allocation scheme can perpetuate an existing inferior approach. Second, the nature of how tasks are performed changes in a dynamic environment. For example, the decision-making process in stressful or time-constrained situations can be very different from that during more relaxed periods (e.g., Noble, 1989). Thus, people may be better than computers under one set of circumstances, but no better or even worse than computers under other circumstances. The lesson for someone making function allocation decisions is obvious. The first step should be to consider allocations in terms of what variables make a particular allocation desirable. The next step should be to consider how various mission events could affect those variables.

Fortunately, "dynamic" does not mean "chaotic"; of course we can't allow just anything to happen at any time. The goal is to emulate a perfect backseater or copilot, with whom the pilot has worked for a long time. Each knows what needs to be done and what each can decide to do. The backseater may not need to be told to do something, but instead can recognize the need, do it, and tell the pilot it's done with a brief message.

DFA will need to be applied very carefully, however, and only after investigation to determine the circumstances in which it should occur, how to let the pilot know it is occurring, and just how tasks should in fact be allocated dynamically. We are already working on a way of triggering and directing DFA based on a real-time estimate of pilot task demands; when completed, it will require calibration and development of a policy for its use. Other factors should reasonably affect allocation decisions as well, such as system workload and capabilities, and the time required for the pilot to absorb and understand displays. Although Chechile, Eggleston, Fleischman, and Sasseville (1989) have reported work on measuring the "cognitive content" of displays, making any such model useful also involves relating the model's outputs to actual performance or comprehension across a range of workload levels.

5. SYSTEM AUTONOMY

System autonomy is an issue closely related to DFA. The first comprehensive introduction of an electronic crewmember into the cockpit will also face critical issues of how much autonomy it should exercise, when it should take over tasks, whether it should override the pilot (and if so, under what conditions), and so forth. Wrapped up in these questions are the operational criteria an electronic crewmember must satisfy: it must be predictable, support the pilot's needs, require minimum communication and supervision, and not be disruptive by changing displays or modes or taking other actions against the pilot's wishes. But what should happen if the pilot doesn't recognize the need for assistance, such as during disorientation? What happens if the pilot's actions don't follow the crewmember's expectations based on its understanding of the current situation and plans? What happens if the crewmember can't form an adequate situation assessment or plan, or infer the pilot's intent with a high degree of confidence? How can confusion about pilot/crewmember responsibilities be avoided in a dynamic function allocation environment? Are system requirements for predictability compatible with the desired functionality?

One promising approach to resolving this dilemma is to provide the system with a small, discrete set of operational modes or autonomy levels. Within each level the crewmember's authority would be well-defined and bounded, facilitating predictability. In addition, a small number of well-defined rules could describe conditions under which the crewmember's autonomy level can change and how it can change. The philosophy could also allow the crewmember to provide safety functions to compensate for disorientation, impairment, or work overload. Finally, it could provide the pilot with an always-available "panic button" capability, whereby the crewmember could recover the aircraft to a safe situation while the pilot became reoriented, planned the next action, or prepared to take control once again.

Within this framework, we need to determine the number of levels that are suitable, and what the functionality within each level should be. For example, there might be an "Inactive" mode; at this level, the system could maintain all monitoring, situation assessment, and planning functions, but take no actions and initiate no pilot communications. In "Standby" mode, the system could also initiate communication with the pilot when some pilot-defined condition is satisfied, such as crossing a waypoint or encountering a threat. As an "Advisor" the system would provide assessments, plans and instructions, but take no actions. As an "Assistant", the system would maintain advisory functions and also assume responsibility for tasks explicitly allocated to it by the pilot. At the "Associate" level, full DFA would be in effect; the system would maintain advisory functions and responsibility for explicitly allocated tasks, but would also take over tasks as needed, based on mission events, the current plan, survivability and safety assessments, pilot task demands, task priorities, and pilot preferences.

Any framework also requires a clear set of rules regulating autonomy levels. For example, the pilot should be able to select any level at any time. In addition, if the system cannot perform at the selected level due to lack of information, low confidence level, or because of a fault, it might inform the pilot of the reason and assume the highest level it can. If control tasks are involved, they should be transitioned back to the pilot based on pilot preferences, task priorities, and system capabilities. The current autonomy level should always be displayed to the pilot, and perhaps a list of system-authorized functions should be available for display at any time, or constantly if the pilot chooses.

Of course, a lot of work is required, particularly developing techniques and performing studies to measure and benchmark pilot and system capabilities, establishing criteria and thresholds for changes in level based on these factors, and developing a pilot-vehicle interface concept appropriate for managing the crewmember's autonomy level.

6. GENERAL CONSIDERATIONS

Electronic crewmember concepts do not have to represent quantum leaps in development. Pilots already use and trust automated systems for a number of purposes. In an F-15, for example, if the radar is operating in long-range search mode and locks on to a target, an automatic display reconfiguration occurs; if missiles mounted on the right wing have locked on to a target but combat maneuvers bring the target around to the left side of the aircraft, the lock is automatically transferred to a left-side missile. The important point is that pilots accept and like these actions because they are the same thing they would do manually under the circumstances and the automation makes their lives a bit easier. They also involve a rudimentary form of dynamic function allocation. The question is whether we can extend acceptance and trust from these specific functions to systems that, for example, offer tactical advice or generally automate display reconfiguration and a wide variety of functions.

There is still a lot we need to learn about how people react to automated systems and about how people fundamentally interact with and use decision aids. In an interesting paper, Lehner, Mullin, and Cohen (1989) argue that it is important that users be given information to help them "identify contexts in which (either they or the system) is likely to be incorrect". They raise the concern that not doing so may result in the aid contributing to worse, not better, decision making. On the other hand, decision aids may be useful for the information they supply users quite apart from their advice. They may, for example, configure and present information in a useful way; the user is informed even if the ultimate advice is not accepted. This is our final point: efforts and development programs don't always have to work out as expected to be valuable.

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ADAPTIVE FUNCTION ALLOCATION FOR INTELLIGENT COCKPITS

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SUMMARY

The trend toward the automation of aircraft systems has increased as the threats and mission functions of modern tactical aircraft increase in complexity. Advances in computer technology and artificial intelligence systems have made the concept of cockpit automation a viable technology. This trend results from the common assumption that such technology will decrease workload, reduce error, and expand human capabilities. The use of these technologies is essential to deal with the ever increasing information processing demands of complex systems. However, several human performance issues need to be addressed to achieve the anticipated benefits of automated cockpits. The Cockpit Automation Program at the Naval Air Development Center (NADC) was developed specifically to examine the human performance aspects of the "intelligent" cockpit. This paper describes the program at NADC, focusing primarily on investigations planned during the first year's effort.

INTRODUCTION

The introduction of automation technology in aircraft has given rise to new human factors issues and concerns. For example, the ability of the pilot to intervene effectively when an automated subsystem fails is one of the key issues frequently discussed in relation to automated cockpits (1). Other difficulties that operators of automated systems may face include loss of system awareness and manual skills degradation (2). Another major issue involves the degree to which a system should be automated. Automation can be thought of as a continuum between total human control, and totally automatic control (3). A specific instance of automation may, however, include a degree of flexibility where the allocation of control changes in a dynamically changing environment. That is, the level of automation is dynamic and remains adaptive to levels of workload and/or critical mission events. This has been termed adaptive-aiding and has been shown to be effective in improving performance in many situations (4,5). The assumption underlying the implementation of these technologies is that with the automation of functions that were once relegated to human control, the processing resources of the individual will be freed to deal more effectively with other aspects of systems requirements (6). However, while the use of these technologies is essential to deal with the ever increasing information processing demands of complex systems, the long-term implications of these technologies on human performance are largely unknown (7,8).

Because of the complexity of the next generation tactical aircraft, the use of intelligent crew support systems is becoming an increasingly important design option. For example, several intelligent systems are being introduced into the air combat environment. The Advanced Tactical Fighter (ATF) and its Navy counterpart (NATF) both plan to incorporate automation concepts developed as part of the Pilot Associate Program. The use of such systems is a necessity because of increased crew information and control loading (9). Therefore, the question is no longer whether automation should be introduced, but *how* systems should be designed to optimize human performance in the use of these systems. However, the use of such systems could easily result in performance degradation if they are not designed to be compatible with crew requirements for advanced crewstation designs (10).

The purpose of the NADC Cockpit Automation Program (CAP) is to examine the human performance implications of the intelligent cockpit. One of the most important problem areas to be addressed is in determining the task conditions under which adaptive automation of aircrew support systems may be beneficial. Additionally, our program will examine how control passes between the crew and computer. The nature of the human-computer interface for adaptive systems is another area that has not received much attention. As a result, our effort will develop interface design techniques needed to maintain the crew's tactical awareness and give them the feeling of control over the aircraft mission. While many of these ideas have been discussed conceptually, most have not been systematically evaluated. It will be crucial to examine these concepts in a more dynamic aircraft/crew mission environment so that the principles resulting from this research can be operationally defined and validated. Therefore, the final products of the program will be cognitive engineering principles and guidelines suitable for documenting specifications for future Naval air platforms.

PROGRAM OVERVIEW

The CAP is a four-year effort, initiated in FY90, involving personnel at NADC and the Navy Research Laboratory (NRL) as well as technical support from both academic and private sectors. In general, the first year examined the conditions under which adaptive decision-aiding was effective. The emphasis during this year was to define and demonstrate adaptive processes under different conditions. That is, what tasks are suitable for adaptive decision-aiding and under what conditions are these technologies appropriate. The first experiment conducted this year was developed to obtain baseline performance measures. Factors such as workload level, event rate, and number of target classifications were factorially combined to determine appropriate parameter levels for the next set of experiments. The second experiment, based on input from the baseline study, will assess how individual task components (resource requirements) contribute to overall performance and interact in their impact on each of the other component tasks. The results of the first year's experiments will help to clarify the class of tasks that are amenable to adaptive processing. The second year will determine what adaptive control processes are most efficient under different tactical conditions. Here the main area of interest will be in examining the process in which information is "handed-off" between the human operator and the computer. The third year will include the development of principles for adaptive-aiding in the intelligent cockpit. Drawing on the database developed in the first two years, the third year will propose principles that can be used to develop the characteristics of adaptive-aids for use in a tactical environment such as air combat maneuvering or strike warfare. The final year will demonstrate a full mission simulation verifying the principles developed in the third year.

BASELINE EXPERIMENT

The purpose of the first experiment was to create a simulated environment that sampled the most important cognitive and perceptual/motor tasks present in a high performance tactical aircraft. The baseline experiment was conducted using the NADC's Reconfigurable Crewstation (RC). The RC is a two-seat, non-motion based weapon system simulator designed to be able to simulate current and next generation display and weapon technology. The study consisted of two core tasks that were presented on two separate multi-function displays in the RC cockpit: the Tactical Assessment Task (TAT) and the Tracking Task (TT). The TAT consisted of a top-down view of a tactical situation evolving about the owncraft (see Figure 1). The TAT display showed multiple target symbol types (e.g., friendly, hostile) that were acquired via datalink. Superimposed on the display were two concentric range circles centered about the owncraft. The outer circle represented the limit of the owncraft onboard sensors. The inner circle represented the minimum range that an enemy aircraft was permitted to penetrate. The primary task required of the subject was to monitor the TAT and respond to "events" with the proper button press. An "event" was defined as the time at which a datalink target appeared within the area between the two concentric range circles. The targets may cross over the outer circle from a starting location outside the circle, or a target may simply "pop-up" in the middle of the display. One of two button presses were required of the subject as different tactical events occurred on the display. A "CONfirm" button press was used for friendly type symbols, while the "DESignate" response was used for hostile type symbols.

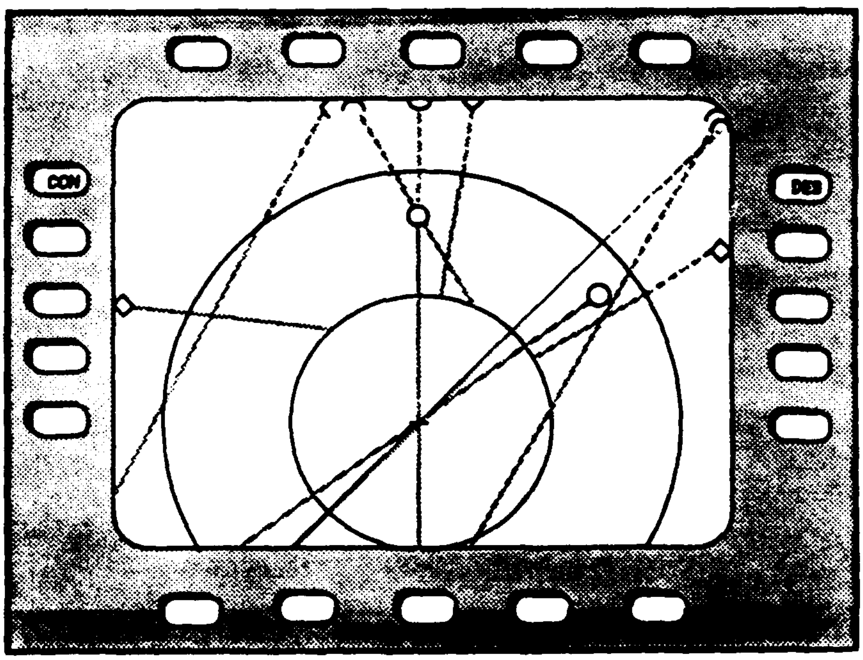
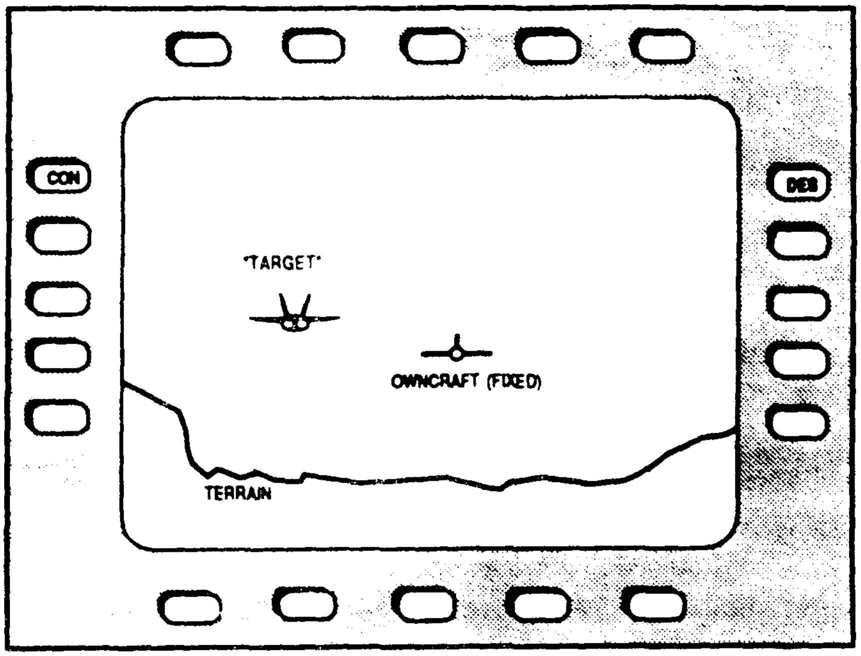


FIGURE 1

TACTICAL ASSESSMENT TASK

As the tactical situation unfolded, subjects were required to "fly" the aircraft via the TT. The TT required that the subject perform compensatory tracking in two dimensions. The TT presented a computer-driven "target" for the subject to follow via control stick inputr (see Figure 2).



I-2

FIGURE 2

TRACKING TASK

For the TAT, there were two primary experimental variables: (1) number of different types (classes) of symbols presented, and (2) the event rate at which targets became eligible. Variation of the number of different symbols that appeared presumably affected the memory load of the subject. Display load was varied through different event rates that governed the number of stimuli presented on the screen at any one time. The primary measure of performance for the TT was RMS error between the owncraft and the target. Subject performance for the TAT consisted of mean reaction time for all target events. Results were presented in terms of correct and incorrect responses, missed targets, and false alarms. Again, the primary purpose of the baseline study was to determine appropriate levels of workload as design considerations for the next set of studies.

ADDITIONAL EXPERIMENTS PLANNED FOR FY90

The goal of the next group of studies was to investigate which *types* of tasks would most benefit from adaptive automation, i.e., where will adaptive automation result in the most improvement in pilot-aircraft performance. Secondly, we also wished to study potential performance deficits (the "automation deficit") associated with automating cockpit tasks. The rationale for this work relies loosely on Wickens' multiple resources model, which decomposes tasks according to the classes of processing resources used by the tasks. The experimental approach is based on a generic multi-tasking context consisting of a communications task, the TAT, and the TT. Each experimental condition consisted of three serial segments, such that the first and last segments required the subject to perform all three tasks concurrently. The first segment in each condition was the baseline segment, enabling a baseline measure of performance to be obtained on each of the three tasks. The second segment in each condition was a test segment, in which the difficulty of one of the tasks was increased with or without automation. The third segment repeated the baseline segment and allowed the estimate of the "automation deficit," a deficit in performance level due to the prior use of automation. This basic structure allowed investigation of: (1) the effects of resource competition (by comparing across conditions with low common resource requirements with those of high), (2) automation benefit (by comparing Segment 2 automated vs. nonautomated), and (3) automation deficit (by comparing Segment 3 following an automated segment with the baseline Segment 1). Space limitations do not permit detailed specifications of the procedures to be followed in this experiment; however, a restatement of the study's hypotheses should prove informative:

H1. Cognitive tasks show a greater automation deficit than perceptual-motor tasks.

H2. Cognitive tasks show a greater automation benefit than perceptual-motor tasks.

H3. The greater is the resource competition, the greater is the automation benefit.

Another experiment is planned that will compare automatic versus adaptive-aiding in a typical monitoring situation. The question to be answered here is in determining under what conditions adaptive processes should be invoked. This study will examine the relative efficiency of fully automated and adaptively automated systems under various levels of workload and time-on-task. That is, how will various levels of time-on-task interact with workload level to affect the aircrew's ability to monitor automated as opposed to adaptively aided tasks (such as responding to changes in the status of different aircraft systems). The effects of emergency events and some measure of overall tactical awareness will be important experimental factors to consider when analyzing the effectiveness of various levels of automation. Another important consideration to be investigated in this study is how the aircrew uses adaptive and automated systems after they become a familiar part of the flight routine. That is, will subjects become over dependent upon automation with extended practice? Moreover, it will be important to assess whether subjects demonstrate an increase in tactical awareness with adaptive as opposed to fully automated systems.

CONCLUSION

For the time being, the human operator will remain an integral part of any intelligent cockpit, if only to serve as a redundant element. Additionally, we believe that ultimate decision-making responsibility must lie with the aircrew. The design of human-computer interfaces along with the development of suitable models to predict human performance under multi-task, high workload environments, will undoubtedly prove to be the challenge facing the engineer and human factors specialist as they work together to design advanced combat aircraft of the future.

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MISSION MANAGEMENT IN GROUND ATTACK OPERATIONS

THE HUMAN COMPUTER INTERFACE

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ABSTRACT

The Mission Management Aid Joint Venture (MMA JV) is a collaborative research project between British Aerospace, GEC Ferranti Defence Systems, GEC Avionics and GEC Sensors, Secretary of State for Defence (RAE) and Smiths Industries Aerospace and Defence Systems. The management organisation for the Joint Venture is shown in figure 1. The Joint Venture is a three phase programme, the objectives of which are to:

i) Establish the functional requirements and feasibility of the MMA.

ii) To prove the techniques for accomplishing this in a rapid prototyping environment and produce a set of functional specifications.

iii) To optimise the MMA functionality and develop the MMI on a real-time Mission Capable Simulation (MCS).

With the ever increasing trend towards complex integrated avionics systems and the increased level and capability of threat anticipated in future hostile scenarios, the requirement for the pilot of the single seat aircraft to maximise his situational awareness at all times is one of the prime issues in driving the development of such systems.

This paper outlines the requirement for the MMA and introduces the major functional areas of sensor fusion, situation assessment, dynamic planning and the Man-Machine Interface. The paper also discusses some of the Human Factors issues associated with the introduction of an intelligent Mission Management Aid (MMA) and the increasing need to promote situational awareness. Issues relating to the design requirements and evaluation of such systems are also discussed.

1. INTRODUCTION

It is undoubtedly true that the operational requirements for future military aviation, and especially the future single seat fighter, are becoming progressively more demanding. Traditional roles are being extended and the scenario in which aircraft will be required to operate is likely to be characterised by increasingly hostile and capable threats. In addition changes in the perceived threat to NATO are likely to result in an emphasis on a rapid response to threats developing outside the region which has been the core of NATO's thinking for forty years. In an effort to meet these requirements avionics systems are becoming increasingly sophisticated and integrated and the pilot is required to manage these more capable systems in an increasingly difficult and unpredictable scenario (Powell & Adams, 1986).

In contrast to these requirements we seem to hear more and more about the failures of sophisticated and highly integrated systems not so much because the system fails to function but because it does not produce the performance expected of it. The pilot is often cited as a major or contributory factor in the failure.

In reality this may be as much a reflection of the design process as an indictment of either human or operational aspects and it is in this sense that the requirement for 'situational awareness' is a fundamental aspect of system design. Unless the designer can identify the requirements of the pilot, it is difficult to define the detailed functional specifications for a device such as the MMA. This problem is exacerbated in the initial stages of system conception by the difficulty in obtaining coherent and consistent views from pilots in response to fairly open questions about the operations of future systems.

We may define situational awareness as the pilot's overall appreciation of his current 'world'. This implies both sensory processing and inferencing on the part of the pilot. An awareness of his own state as well as the state of his aircraft systems, stores etc, and the current mission situation are all components which contribute to his overall situational awareness. An implication of this is that it is difficult to measure as a global metric and is limited in its utility as a tool to predict performance. Indeed, this ties in with reality. It is difficult, even for the pilot himself, to predict situations which will result in a loss or partial loss of situational awareness. A number of factors such as an individual pilot's susceptibility to various stressing tasks/incidents, his physiological state, current level of training etc. will all affect the way in which he allocates his attention and the amount of resource that a particular situation demands. This, in turn affects the speed and accuracy with which he perceives the word.

Nevertheless, pilots put increasing importance on their ability to maintain an overall situational awareness and there is an undoubted requirement to understand what factors contribute to this state, to identify their relative importance and thus to ensure that the system enhances the pilot's situational awareness at any instant in time. This, in turn, reflects on the design process.

There is a fundamental need to understand what information (as opposed to data!) the pilot needs in a particular mission context, how that information is perceived and how it contributes to his overall situational awareness.

2. MMA APPLICATION

The overall objective of the prototyping phase is to demonstrate the major functions of the MMA in an integrated form. A top level view of the MMA is shown in figure 2.

After consideration of a number of possible missions and scenarios it was decided that to most fully exercise the MMA's functionality the initial prototype should operate in an Air to Ground role although the capability to carry out air-to-air-missions will be incorporated in a later phase. Within the air-to-ground scenario the MMA will carry out several missions within the current NATO structure and demonstrate its ability to respond to intelligent hostile threats. These are primarily OCA/CAA (offensive counter-air/counter air attack) and AI (air interdiction) missions.

They are ideally carried out by a small group of aircraft and are similar in that they are principally stealthy missions demanding minimal uxse of active sensors, co-operation between aircraft, and a high degree of pre-planning of all mission phases to and from the target. The importance of group operations in future scenarios is unquestionable and an important aspect of the MMA's operation will be to interact with other MMAs to allow intelligent target hand-off, attack sequencing and communal planning of resource deployment.

The scenarios are based on a 100 x 200 km area located in the European Central Region and it is intended that the MMA should demonstrate the ability to produce a single view of the outside world through its sensors and a mission plan(s) which is capable of inspection. In addition, the MMA will demonstrate the ability to 'repair' the plan as a function of information updates or unforeseen events.

3. FUTURE SYSTEM REQUIREMENTS AND THE MMA

System design and development often follows a top down approach (Meister, 1976; de Neufville & Stafford, 1971). From initial concept, therefore, the design and development process generally proceeds as in figure 3.

In practice this is typically an iterative process where evaluation may result in a revisiting of any of the stages above it (as illustrated in figure 3) - even to the extent that it may sometimes modify the objectives!

It is also evident (Rouse & Cody, 1988) that this is not a completely tenable approach since the implied dependency of each stage on its predecessor may be only partially true. It is difficult to predict the effect on performance of allocating pilot authority to specific tasks/functions without an understanding of the pilot information and control requirements.

This, in turn, may require significant evaluation or research. The inadequacies of a Top Down (or Bottom Up) approach are largely caused by the need for a 'man-in-the-loop' system. Thus a flexible mixture of approaches is required with a significantly greater emphasis on the Human Factors aspects of the system early in the design process. This should result in a product which has a greater prospect of satisfying the customer's needs and also minimises the iterative design/redesign process. This approach is reflected in the MMA design process.

4. MMA CORE FUNCTIONS

Recognition of the need for a more pilot-orientated approach has been embodied in the MMA in that the Man-Machine Interface (MMI) development has been identified as a separate activity which can proceed in parallel with the prototyping of the major functions. Thus the human factors design considerations are seen as important drivers in the design of the MMA itself rather than vice-versa. Consideration of the MMI and information display requirements have included examination of fundamental human factors aspects such as the pilot need and benefits of processed sensor information; potential problems associated with knowledge databases of tactics and assessed threat values; the display of optional plans including advice on tactical routeing, the use of resources etc.

This approach has led to the production of a series of Human Factors guidelines for the MMA (Brydon & Stanger, 1986) and to the derivation of the four major functional areas, as illustrated in figure 4, viz: Sensor Fusion, Situation Assessment, Dynamic Planning, Man-Machine Interface.

These core functions of the MMA provide a tactical plan to the pilot, which he may, wholly or partially, accept or reject. This tactical plan is designed to satisfy the mission objectives. It addresses every aspect of the mission and is visible to the pilot through his cockpit display suite. Alternative (and presumably less favourable) plans are produced, and displayed at the pilot's request. There are four main processes involved. Sensor fusion takes data from a number of sources including the on-board tactical database and combines it to produces a single fused view of the outside world - the Alpha scene. This is combined with intelligence data from the pre-mission brief database to produce an assessed view of the situation - the Beta scene, taking account of the objectives of the current and future mission phases. This assessed view and the overall mission objectives are used to produce a number of tactical options - the plans (or gammas). Finally, the MMI function prioritises the information presented to the pilot and manages the displays and multi-function controls.

The core areas of the MMI which have been prototyped to date are illustrated on figure 5.

The organisation of the computer equipment used to prototype the MMA is illustrated in figure 6. The Symbolics Work Stations are used to develop and host the MMA core functions whilst the Silicon Graphics are used for the Man Machine Interface. The Meiko Computing Surface, a transputer based machine hosted on a Sun, is used for the development of real time software for the full scale Mission Capable Simulation of the MMA.

4.1. SENSOR FUSION

The sensor fusion is provided with data from the aircraft sensor systems, communications systems, and the tactical database. This information is processed in two stages to produce an alpha scene, which is the view of what the aircraft can see in the outside world, together with associated confidence intervals. The two stages in the sensor fusion process are sensor report and track correlation and object attribute fusion.

4.2. SITUATION ASSESSMENT

The Alpha scene is passed to the Situation Assessment function to produce a Beta scene, which contains a threat-prioritised list of objects. This is a multi-stage process in which firstly the known friendly objects are filtered for separate processing.

The remaining hostile and unknown objects are evaluated for threat and target potential.

It is apparent that the pilot will need an overall view of the assessed scene whereas the subsequent functions will require a more detailed view of specific parts of the scene.

4.3. DYNAMIC PLANNING

This is the heart of the MMA planning which constructs tactical plans (Gammas) including a Gamma* option (the most favourable gamma). The plans are built from the Beta scene input, which provides the planner with the "current situation" and from the mission objectives provided by the pre-mission brief. The final Gamma* produced contains much more than just a proposed route, for example, the proposed employment of weapon and countermeasure systems, and a 3-dimensional tactical route generated by the threat avoidance function, which are fed to the appropriate aircraft systems.

The Planner evaluates options for an Attack-Defence strategy. These options take account of the mission objectives, potential target and threat values and the current status of the aircraft's weapons and countermeasures.

Small scale tactical re-routeing in the air, for threat and terrain avoidance is incorporated at a low level in the Gamma(s). The output is in the form of a list of threat-avoiding waypoints for utilisation by the navigation system.

4.4. MAN-MACHINE INTERFACE

The man-machine interface for the MMA is centred around the Pilot Interface Manager (PIM). The PIM may be considered as a number of functions which "organise" the information required to be presented to the pilot at any time.

The core functions of the MMA will provide information relating to the current situation, proposed MMA actions/solutions, status of systems and cues to the pilot, and the PIM will prioritise this information according to the pilot's current objective. The information required for display is scheduled according to the pilot's current tasking, which will be monitored by the MMA.

Another important aspect of the MMI, will be in ensuring that apart from the level of information displayed automatically to the pilot, he can easily and naturally access lower levels of information to explain, or qualify MMA advice/plans etc. This will be particularly important in the evaluation of the MMA, and in pilot training in order to boost confidence and acceptability of the system.

5. THE RELATIONSHIP BETWEEN THE MMA AND THE PILOT

A team of fifteen have been working on the MMA over the last three years. Of this number three have a significant human factors background and one has had some thousands of hours fast jet experience as a pilot.

Early work on the Man Machine Interface convinced the team that knowledge elicitation from experts was a very difficult task unless the experts were asked well defined questions. It was determined that the best way to define the questions was to prototype the pilot interface and its displays and controls so that aircrew could be asked to choose between alternative approaches early in the programme. The organisation of the Work Station Equipment used in prototyping is shown in figure 5. The results of these researches will be developed in the real time mission capable simulation of the MMA and this will enable more exacting evaluation of the pilot interface with operational aircrew. This environment will allow investigation of situational awareness in high workload phases of missions.

Refinement of the distribution of function between the pilot and the MMA is a primary purpose for this development and evaluation work and the pilot's capabilities versus those of the machine are fundamental to this distribution.

The overall task has three levels which may be described as based upon:

a. Skills

b. Knowledge

c. Inference

A postulate for the division of function for these three levels might be as follows:

a. Skills - Give the machine the routine and allow the man the time for the highly skilled tasks.

b. Knowledge - Include a wide ranging knowledge base in the machine and provide the man with an intelligent, context dependent access to this knowledge so that he can quickly access relevant information.

c. Inference - Provide inference capability in the machine but organise the MMI so that the man's inherent capability for inference can complement the mechanistic process used by the machine.

Patently these postulates are imprecise and require to be developed in detail during the simulation and evaluation of the MMA.

6. CONCLUSIONS

Situational Awareness is the key to the improvement of mission effectiveness in future combat aircraft. Enhanced levels of intelligent automation of the mission avionics of these aircraft raise the possibility of improved situation awareness. This improvement will not be achieved unless the balance between the capabilities and needs of the pilot are carefully balanced against the potential capabilities of the enhanced mission systems at every stage of the development.

It is particularly important that this balance is established at the earliest stages of the development of systems such as the MMA and is a primary area of concern at each major review evaluation and experimental trial thereafter.

7. ACKNOWLEDGEMENTS

The author wishes to acknowledge the contributions to this paper made by the Joint Venture Team, particularly Chris Gibson of RAE and Alison Garrett of BAe.

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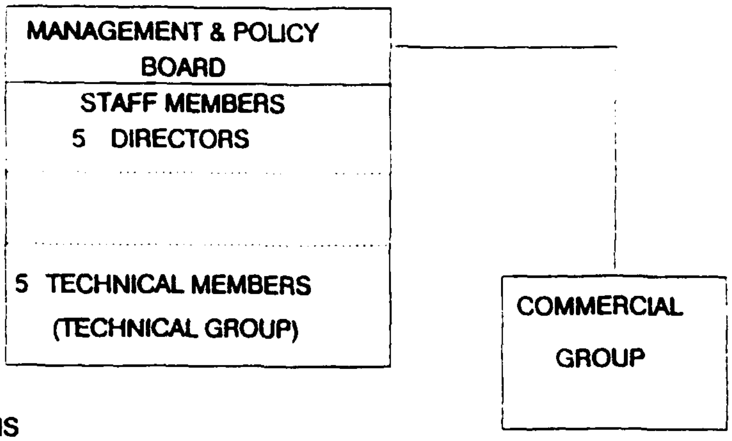
Fig 1

MMA JOINT VENTURE

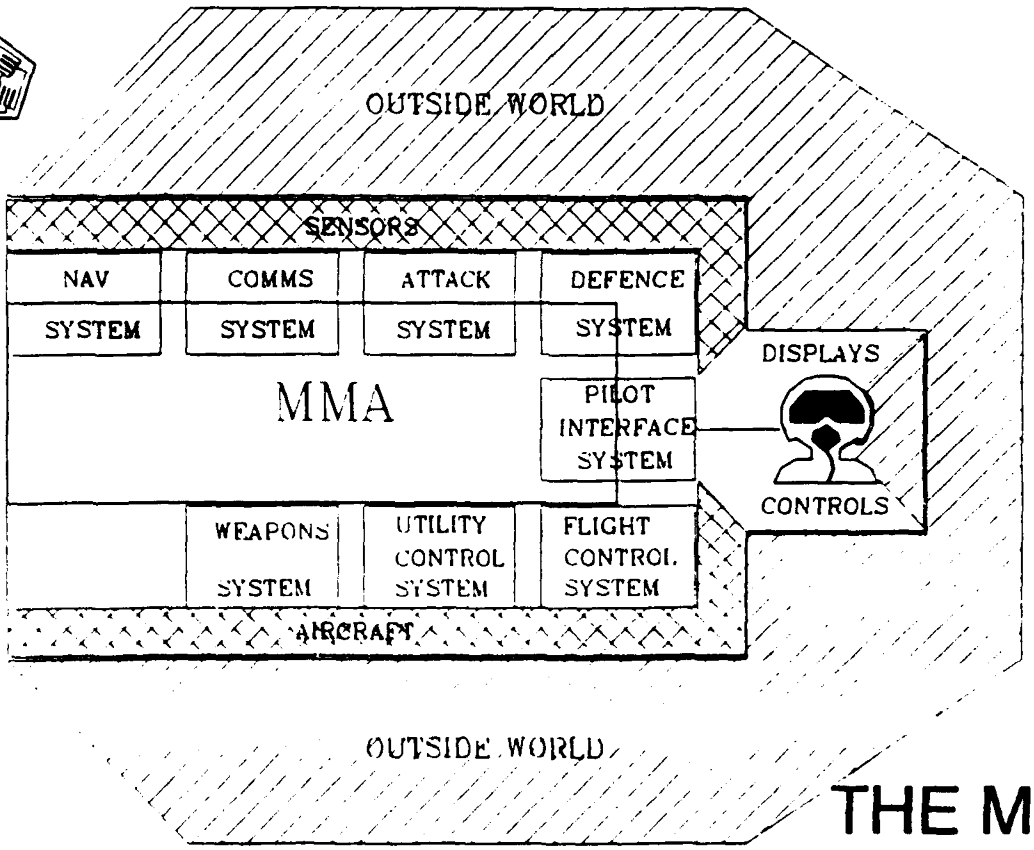
MANAGEMENT ORGANISATION



PARTNER ORGANISATIONS

British Aerospace(MAL)
GEC Avionics & Sensors
GEC Ferranti Defense Systems
Smiths Industries Aerospace & Defense Systems
Royal Aerospace Establishment, Farnborough

Figure 2



THE MMA

TYPICAL DESIGN PROCESS

Figure 3

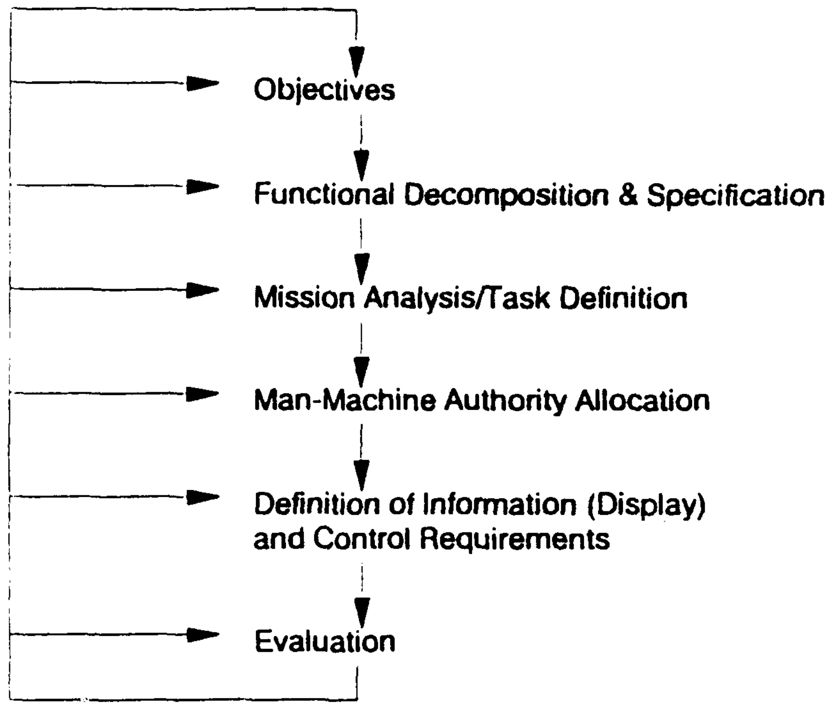


Figure 4

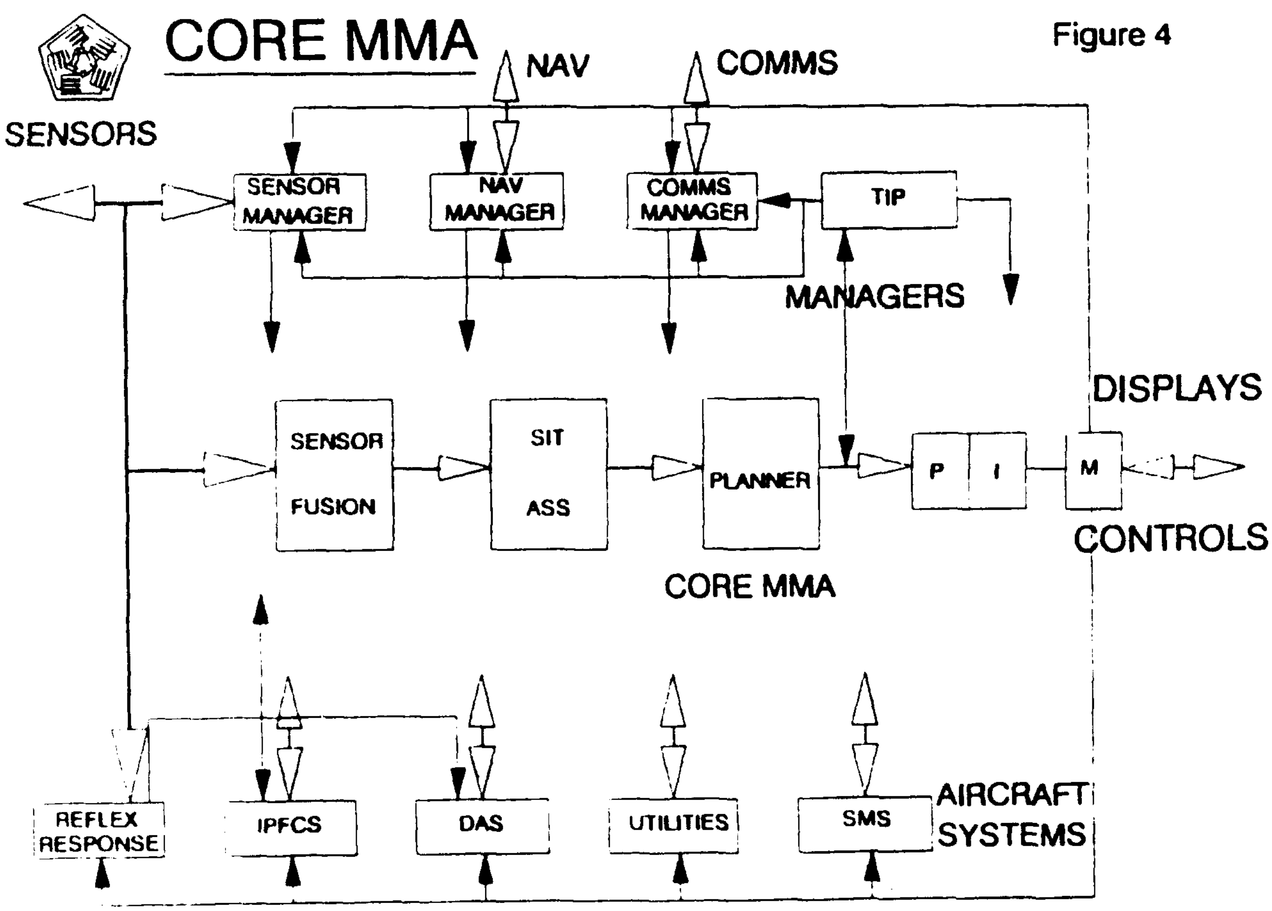
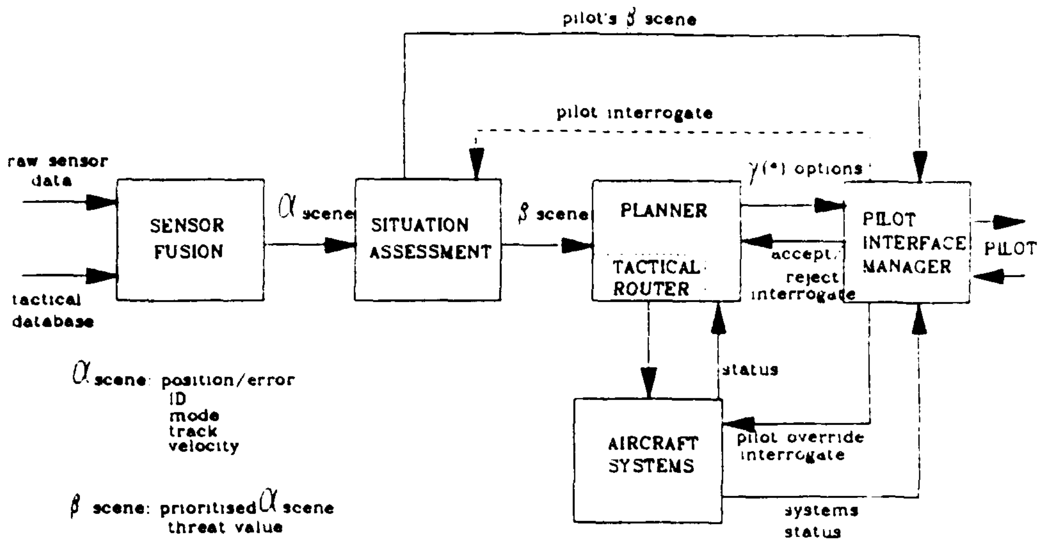


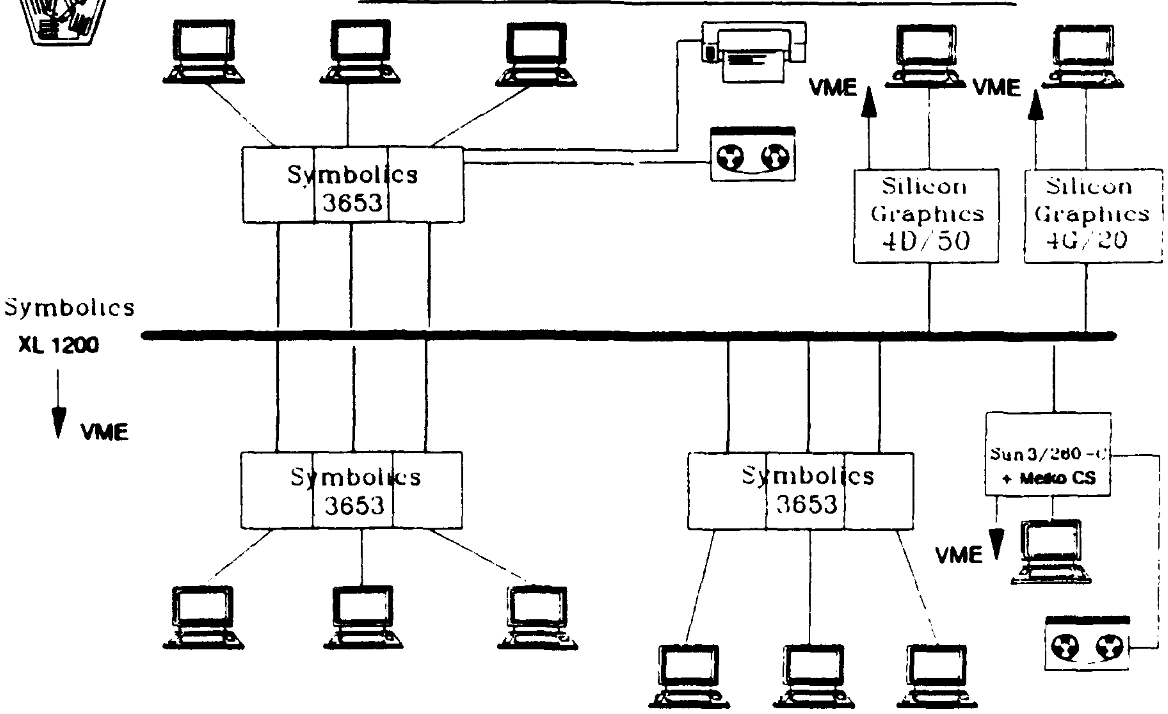
Figure 5



MMA Core Functions and Interfaces.

Figure 6

WORK STATION NETWORK



DASSAULT AVIATION

René AMALBERTI, Gilles CHAMPIGNEUX
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MAN MACHINE COUPLING: A KEY FOR ELECTRONIC COPILOT ARCHITECTURE

WORKSHOP THE HUMAN-ELECTRONIC CREW

Date **September 25, 1990**

DASSAULT
AVIATION

ABSTRACT

Because of the battle field complexity, pilots will face critical situations. They need assistance. However, for complex situations no fully proved solutions are computable.

Therefore, decisions have to be elaborated in a cooperative process combining the system viewpoint with the pilot intuition. The system has to be aware of the pilot's intent, as well as the pilot needs a coherent understanding of the system reasoning.

This man-machine coupling perspective constrains the Electronic Copilot architecture (such as type and presentation output results, type and nature of reasoning) but also allows to reduce the classical burden of embedded software (such as security constraints, decision optimality).

As a result of these advantages and limitations, the man-machine coupled architecture is the solution for successful Electronic Copilot. DASSAULT-AVIATION and CERMA are currently working on this line.

INTRODUCTION

In order to maximize the mission efficiency and the cost effectiveness of future fighter aircraft operations, it is desirable to plan for a good management of the limited and valuable crew time. This requires a good allocation of functions between the crew and automatic systems, and an effective Man-Machine Interface (MMI) design.

Automatic systems should eventually significantly reduce the pilot workload. They are even necessary for actions that require fast and highly accurate responses, fastidious and repetitive tasks. However, humans should be kept in the loop when the actions require judgment, multi-sensory information, correlation of data. This makes humans irreplaceable for unplanned and contingency tasks, and for complex critical operations that require supervision.

For example, pilots in combat should be relieved of routine monitoring tasks and system operations to devote more time to tactical operations and high level actions. They would then become true "managers".

With an effective overall MMI design, benefits can be expected in the following areas:

- Systems management
- Tactics management
- Mission management

This MMI perspective for future avionic systems in combat aircraft design is now possible with the emergence of Artificial Intelligence (AI) techniques. A complete integration of these technologies, in an overall MMI design is necessary to provide the best operational capabilities. The application of this integrated design principles is well illustrated by the concept of the Electronic Copilot for future smart cockpit.

Starting with a state of the art of terrain experience in the MMI domain by CERMA, a general presentation of DASSAULT project of the Electronic Copilot shows the importance of the Man Machine coupling perspective relative to the system architecture.

COGNITIVE ERGONOMICS AND THE DESIGN OF AN ELECTRONIC COPILOT

Human factors evidences from the aviation history and the literature

When a computer system is always able to select the best solution for a problem, current aviation policy is to couple this aid directly to the plane and keep the pilot out of the loop. The picture changes considerably when men are coupled to imperfect aids: this is the present (and most likely future) case for AI systems applied to tactical real time analysis. Here solutions need to be proposed rather than executed, and the pilot's ability to judge them must be maintained. The pilot also needs to be in the loop of reasoning to avoid "magic" behavior that can arise from blind belief in the aid.

Recent studies on human-decision support system coupling all point to a general principle of coupling that has obvious bearing on these solutions: the less the operator experience has, the more interactions he will have with the system. Similarly, the less the pilot's experience, the poorer the quality of his interactions with decision support systems with optimal reasoning (Roth, Bennett and Woods, 1987). Lehner (1987) frames this principle in similar terms: the greater the user naiveness as regards a support system, the greater the required commonality of knowledge and reasoning between system and user (glass box necessity).

However, the glass box concept can be applied to different levels of requirements:
-the basic level consists in displaying informations in a natural way for the operator. "Natural" means quick understanding and resource free for the user. This level perfectly fits the concept of "Representation aids" as proposed in the Zachary's taxonomy. Example are now numerous in the technical domains, e.g. modern cockpits whose respect this principle are termed "glass cockpits" (Airbus A320, Boeing 767/757).
-the second level is more demanding. It consists in respecting same reasonings than Human when elaborating a decision. Thus, in contrast of level 1, this level severaly constrains the type of decision the system could propose. Nevertheless, this restriction could serve better the final user (namely the novice user) in dealing with the problem than any else optimal calculations.

However, it is clear that a decision aid cannot be strictly identical to Human behaviour. This could not take sense as well for computer reasons as for respective abilities of Human and computers (speed of calculations...). Rather than imitating pilots reasonings, the true challenge for successing in coupling an electronic copilot to pilots is much more to be capable to tune system solutions according to the users' degree of qualification, the flight context, and possibly other Human factors dimensions. Thus, the software architecture of the electronic copilot becomes largely influenced by the complex requirements the system has to respect. Anyway, this challenge cannot be reached without a preliminary good representation of pilots reasonings and cognitive needs. This is the reason why the CERMA and DASSAULT AVIATION have developed extended field studies of pilots cognitive behaviours before defining system architecture.

Results from field studies

The studies were conducted on pilots cognitive activities during high speed-low altitude penetration missions over a four year period. The mission consists in flying from an allied air force base, towards a target designated in advance, and when reached (after sometimes, approximately 1/2 hour flight) treat it (reconnaissance, bombing). The flight has to be as fast as possible and as low as possible to avoid being detected. The flight back to the base is also at low altitude and different from the ingress. The detailed results are presented into Amalberti & al. 1989, 1990.

On ground mission preparation

Mission preparation is a necessary prerequisite to mission execution. All the pilots spent more time in preparation (50 to 65 minutes) than in execution (45 to 60 minutes). Thus special attention was paid to the cognitive processes involved in this stage.

The differences between expert pilots and novices in mission preparation are mainly related to metaknowledge. The pilots defined their trajectories as a function of their internal competency models. Pilots with greater experience can define smaller navigation points and have more candidate points to choose from. Novice pilots have a good representation of the kind of navigation point they can reach. They tend to look for large points, which places a number of severe constraints on their itineraries and gives them higher overall nautical mileage than expert itineraries. Beginner pilots plan fewer way points than experts, in particular between entry into enemy territory and the target (high speed-low altitude conditions). They are less able to assess relief points than experts and thus plan more direct trajectories calling for fewer way-points.

This analysis of flight preparation has a number of implications for a cognitive model :
-when a pilot takes off, a large set of potential problems have already been solved.
-pilot strategies elaborated during mission preparation are fully dependent on their MK (internal representation of competences). The flight plan is designed to be compatible with the pilot know-how. Thus flight plans for the same mission order can differ substantially between experts and novices (although the operational result can be acceptable in both cases).

Analysis of pilot activities during flight

It is clear that the key to rapid process control is resource management. Because of risks and the high dynamicity of the process, priority is given to flight control, i.e. short term activities. Pilots can only invest in medium and long term activities -navigational and tactical *anticipation- when the flight is stabilized* for a sufficiently long period of time with correct parameters.
Inflight activities during normal operating conditions can thus be broken into three categories :

(i)short term engine and navigation handling :
Pilots make a series of systematic checks at the start of each leg to make sure they have reached the required parameters (route, speed, altitude)

(ii)coherence and confidence assessment:
The risks pilots take in short term evolutions when they invest in long term activities is closely related to the degree of fit of their mental model of the situation to the actual one. This mental model can lose validity because of interface faults or because of unexpected changes in the environment. Pilots are aware of these risks but cannot invest all their resources in redoing system calculations or doubling the actual situation. They thus develop operative strategies to enhance confidence in their short term predictions with minimal risks so that then can devote time to long term activities as soon as they consider the situation will remain stabilized for a period of time. These strategies rely on logic that differs considerably from the mathematical and physical logic of the system. The pilot checks that the situation is coherent with low altitude flight by equating engine temperature (in degrees celsius) with speed (in knots). This equation is purely local and only holds for on-going flight conditions. The pilot is aware of this contingency and uses the observation to make an assessment of system normality. These confidence enhancement strategies are applied systematically at the end of a series of short term actions. Since these are reinitiated every 20-30 seconds, they can be seen as prerequisites for allocating resources to medium and long term reasoning.

Data gathering and confidence assessment are also greatly facilitated by what can be termed a polysemiotic trait of expert knowledge: a pilot can deduce much more information from one dial than the flightbook indicates.

(iii)Navigational and tactical anticipation

During inflight operations, the flight plan was never executed as defined during ground preparation. Deviations in route, timing and/or altitude were observed in and out of the context of the incident phase. These deviations occurred systematically (but ranged in magnitude) between the takeoff leg and entry into enemy territory. The magnitude of the deviation was inversely proportional to the pilot's experience.

Protocol analysis and interviews indicate that novice pilots plan a detour at the beginning of the flight because they are afraid of being late for takeoff (mission preparation is very demanding). Thus if they are late they can easely recover their timing by taking a short cut. This points out the crucial importance of MK in the regulation of behavior; as we saw earlier, novice pilots' flight plans are longer because of the nature of the way points they select; it is also longer because young pilots allow themselves more degrees of freedom than expert pilots.

Similar strategies were observed at other phases in the mission. Some pilots believe that they will be detected by radar because of the context, and consider that the best solution is to accelerate. They thus decide to slow down at some distance from the radar in order to be on time over the target.

When considering the approach to the target, comparison between novices and experts clearly show the differences in terms of logic of reasoning and the possible handicap due to systems guidance. All pilots deviated from the planned route just before the target because of a radar threat. Then, only experts recovered the planned axis of target approach. Novives made a direct trajectory to this target because they flew the system guidance which permanently indicate the direct heading to target without tactical considerations. Inversely, experts had to ignore the system informations during a period of 10 to 30 seconds in order to recover the planned trajectory. Thus novices attitudes can be termed system driven although experts attitudes are more self based driven. In this case an intelligent assitance in guidance would have been probably profitable to novices.

Anyway, it results from these studies that an electronic *copilot would largely gain in* benefit by taking into account the cognitive limitations of Human, namely these of novices. Another pragmatic consequence of these studies is expertise elicitation which directly serves the content of the knowledge base of the system. Because of tactical complexity, interviews of pilots refering to concrete missions they have carryied out are often good departure for expertise elicitations giving to field studies a multiple interest in the definition of the future electronic copilot.

THE ELECTRONIC COPILOT CONCEPT

Conducting penetration missions in hostile territory has always raised problems of workload on a single Pilot, regardless of the aircraft configuration. These problems have generally been solved by applying strict mission control rules or by adding a second crew member. However, in a single seater aircraft, even if the Pilot is relieved of routine and repetitive tasks, mission control can be unacceptably complicated. Considering that Artificial Intelligence could provide answers to these problems DASSAULT is working on this approach for the aircraft of the 2000-2010 decade.

Cognitive aspects of the Electronic Copilot

Man in the loop as a mission manager

Our concept is clearly putting the Pilot in the loop. The Electronic Copilot will only propose decisions to the Pilot or present information pertinent for the Pilot decision process. The Pilot will be free to accept or not the proposition and no automatic decision will be taken.

This implies that relevant information should be managed in order to minimise the divergence with the Pilot line of reasoning. For instance a particularly important point in Pilot aid is filtering of the alarms and management of emergency procedures. The Pilot must be able to supervise control of the various aircraft systems in all situations, including failure situations.

Our first results confirm that the Electronic Copilot will increase the importance of the man machine interface as it will generate a real dialogue with the Pilot. This will require Artificial Intelligence not only to generate displays or messages but to manage the pertinence of information depending on the mission phases and the history of the Pilot activity. It will be a central task for the Electronic Copilot to infer continuously the Pilot activity, and to exchange with him suitable synthetic information in order to assist the decision process.

Synthesis of diverse classes of expertises

The Electronic Copilot will address a very large range of expertises. In our alarm filtering development, expertise included the knowledge related to the engines, the electrical generation, the hydraulical generation, and the braking system. A dozen of experts were involved including not only engineers but Pilots and ergonomis.

In the overall Electronic Copilot expertise will cover not only system management but also tactical reasoning, strategic mission planning and man machine dialogue. To tackle these difficulties we are implementing a full mission simulator on which the expertises can be globally elicited and refined using on-line interactive software.

This situation is much likely to be the common case in large projects of Operator assistance.

Constantly evolving expertise

Most of the systems we design today will require knowledge that has not been experienced yet.

The new design by itself can modify the way operators will perform the task or even more drastically it may change the task itself. Sometimes problems that used to be very difficult to solve become routine and other reasoning fields regain emphasis. For example in the Electronic Copilot the navigation burden of the pilot will decrease, leaving more time to handle complex tactical management.

In combat domain the dynamic of knowledge evolution is even greater. Competition creates the need for constant refinement and creation of new strategies. For example in multiple aircraft engagement, it has proven necessary to create expertise without collecting rules from human experts as the game of defence vs attack leaves an open field for strategic behaviour.

This constantly evolving expertise is often the case when the assistance concern future projects with no "real life experience".

Interface constraints (media available)

Crew don't like to be given important amount of data, they only wish to get the information they need at the time they need. That is the reason why our Company is working for many years to find best appropriate ways to display information, taking in consideration that "a picture is still worth a thousand words". This work has led us to develop in fighters head-up flying using velocity vector and energy rate for all the mission phases and adding very powerful high order guidance symbols in many other modes, for example the synthetic runway with associated guidance box.

We are now thinking that AI techniques can be very helpful in this quest for best interfaces. The idea is to continuously adapt the display contents to the situation and to the Pilot preoccupations. Moreover AI driven cockpits are foreseen as natural extensions of our present know-how.

The importance of MMI design has led our Company to make an always increasing use of simulation techniques. Several tools are used to define the cockpit and all the software-driven interfaces. Final assessments and adjustments are made with an important participation of flight-test teams in our simulation facility named OASIS (for Outil d'Aide à la Spécification des Interfaces Systèmes i.e. Man-Machine Interface Design Tool) located in Istres.

We also conduct studies concerning on-board use of voice processing and its relationship with other means of dialogue : displays, keyboards, dedicated or soft-keys...

The Electronic Copilot project is now trying to merge our knowledges of the many possible dialogue means, realistic for fighter aircraft of of the next century. Some directions appear as very promising in order to simplify from the Pilot point of view the use of all the aircraft functions.

CONCLUSION

- Humans will still be heavily and directly involved in future missions therefore human factors will be an important design driver for new systems.
- Advanced technologies to assist humans will have to be integrated early in the design process.

Artificial Intelligence will be strongly linked in the future with Man Machine Interface design. This seems to be a necessary step in order to allow efficient management of complex missions with man in the loop.

The Electronic Copilot concept will be a major breackthrough for modern MMI design of futur fighter aircraft, and is a good example of this approach.

The project is now moving from a feasibility study to an exploratory development phase. This will give us many interesting experiences about the proper knowledge engineering for such complex MMI design.

"Pilot's Associate: An Evolving Philosophy"

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Abstract and Introduction

The technology to insert an artificially intelligent decision aiding system into an aircraft is developing rapidly. The existing Pilot's Associate program, a cooperative effort between the Defense Advanced Research Projects Agency and the U.S. Air Force, will likely lead to an advanced development program and flight test within the next five to seven years.

This paper describes the state of the technology in terms of its mission functionality, and addresses issues that will impact the use and operational acceptance of intelligent systems. The paper also discusses the potential impact of the technology on aircrew training and selection, and identifies issues regarding the integration of the system into the daily mission routine. Finally, we discuss some of the philosophy and psychology of the relationship between the pilot and the electronic crewmember.

Pilot's Associate History, Successes, and Status

The Pilot's Associate (PA) program is a two phase effort to develop a single-seat fighter pilot decision aiding system that runs in a real-time, piloted simulation (Fig. 1). Phase One was a dual-award contract with McDonnell Aircraft Company and Lockheed Aeronautical Systems Company as prime contractors. Specific PA descriptions that follow were derived from the Lockheed system, but philosophies and issues are generic in nature.

Phase One used rapid prototyping development with major demonstrations of the PA system at the midway, Demonstration 2, and completion points, Demonstration 3. The Demonstration 2 software ran on general purpose symbolic computers in about six times real-time and showed the success of the cooperating knowledge-based systems approach [1, 2]. The Demonstration 2 mission was realistic, but, being a narrow mission slice, it did not present PA with the usual range of mission events. Rather, it presented a subset of events designed to show PA breadth, but not necessarily depth.

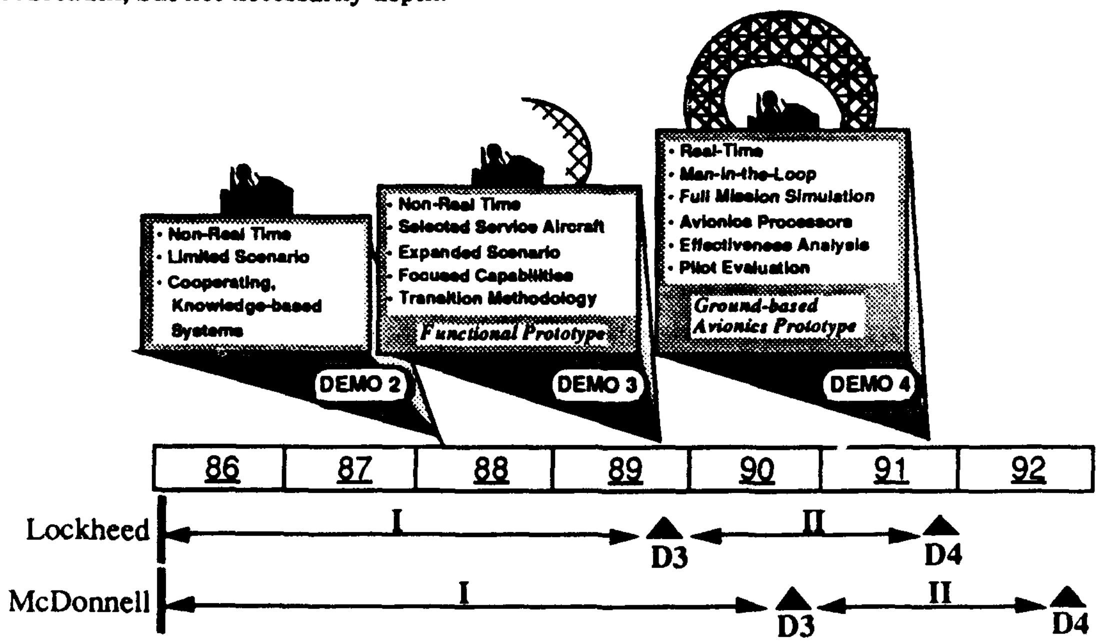

Figure 1: Pilot's Associate Schedule

Demonstration 3 employed PA in a more complicated mission, with deeper knowledge-bases, and still had performance of about six times real-time. It again used symbolic processing computers and a medium fidelity cockpit simulator. A front-end Mission Support Tool allowed pilots to set parameters and defaults in determining whether the pilot or PA would perform various tasks at different mission stages. This tool is the primary means for a pilot to initialize the PA for a particular mission, and forms the baseline for pilot expectations of PA behavior. Since expectations and predictability are keys to building trust [4], the Mission Support Tool provides a mechanism for establishing the associate relationship which is crucial to pilot understanding of the PA.

Phase Two began in early 1990, and will culminate at Demonstration 4; a piloted, full-mission, real-time demonstration of a PA with similar functionality as in Demonstration 3. Demonstration 4 software is being developed in C++ (a structured, object-oriented programming language) and will run in a hardware configuration to include avionics processors. A clear path of transition to the Ada programming language and a full avionics environment will be defined at the conclusion of Phase Two. The Demonstration 4 PA will be tested in several fighter aircraft scenarios to quantify the operational utility of a pilot decision aiding system.

The success of the Phase Two effort may lead the Air Force to fly a pilot decision aiding system in an advanced cockpit flight test demonstration. Once the benefits of PA are measured and validated, decision aiding systems of this type may be adapted to cockpits, crew stations, and missions of a variety of aircraft and other vehicles.

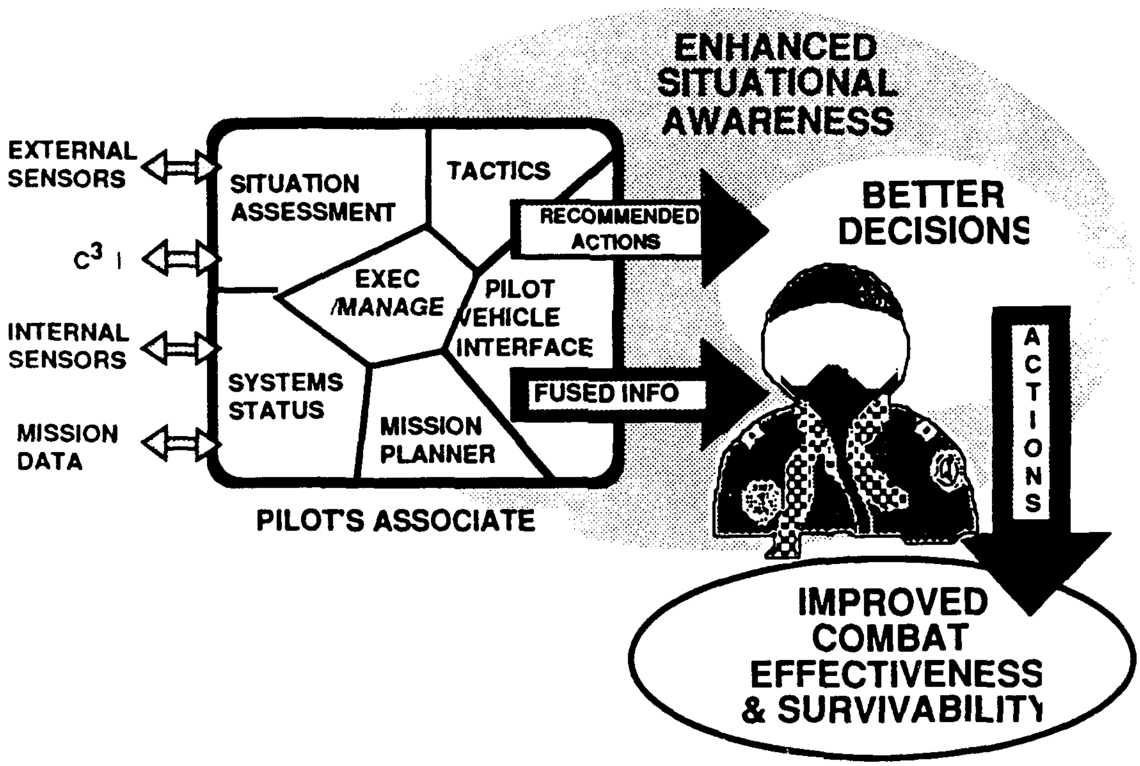

Figure 2: Pilot's Associate Concept

Functionality and Operational Utility

The PA was broken into six major subsystems roughly approximating fighter mission responsibilities: **situation assessment, system status, mission planning, tactics planning,** pilot-vehicle interface, and an executive coordinating the other subsystems' actions (Fig 2). The Pilot's Associate must give the pilot the information needed to accomplish the mission -- when it is needed and in a manner consistent with his needs. It must present a coherent picture of the combat situation in an intuitive format on a display medium selected to help him focus his attention with minimal interference. Further, the PA must not impede the pilot's innovativeness, rather it must free the pilot from mundane tasks allowing innovative ideas and actions to develop fully.

In essence, the Pilot's Associate revolutionizes the cockpit by monitoring pilot actions and adapting its activities to support them, rather than the typical automation approach that requires the human to monitor the machine's performance, sometimes with disastrous results [3]. The synergy to be achieved -- by designing for the computer to do what it is best at; by allowing the human to think, evaluate, act and innovate; and, by encouraging a smooth overlap of responsibilities based on the human's preferences -- is only now beginning to be evaluated.

While experimental validation of the Pilot's Associate will not be performed until Demonstration 4, some preliminary utility studies and subjective evaluations already indicate significant potential benefits. Some of the functions most promising in terms of operational utility and payoff include: assimilating aircraft systems information and evaluating the effects of failures on the mission; calculating and inferring the potential mission impact of enemy air and ground threats; coordination and communication of cooperative tactics between multiple aircraft; facilitation of quick formation rejoins to maintain mutual support and force integrity; accurate route replanning for high-probability-of-success contingency plans; intuitive information presentation for quick pilot assimilation and enhanced situational awareness; and adaptive aiding for pilot/machine task management.

User Acceptance

All the demonstrated benefits mean nothing if pilots ignore or shut off their Pilot's Associate. A sense of trust must develop during ground training, flight training, and operational use, if the PA will be used as intended. That is why users (pilots) must be involved from the beginning in the system design and development. The program managers, engineers, and developers must build the PA to be flexible enough to adapt to the preferences of individual pilots, just as human backseaters and pilots work out a teaming relationship, known as crew coordination. The evolution of this relationship between humans does not happen overnight. One should not expect more from intelligent systems, but pilots may have high expectations. They may not have the tolerance for error that they do for fellow humans, even if they have a good mental model of how their PA behaves -- including its limitations and strengths. Preparing for PA errors and graceful degradation may mitigate some of the usual human intolerance of machine error [4].

Emergence of the "Associate"

Since user acceptance is crucial to Pilot's Associate success, emphasis on the teaming relationship between pilot and PA is warranted. This emphasis is manifested in the Operational Task Force (OTF), a group of aviators who provide a link to the end users and who routinely answer PA designers questions not only about what PA should do, in terms of operationally valuable functions, but how it should do it. The OTF fosters a pilot's trust in the system by influencing PA design to be predictable to, and compatible with, the pilot [5].

The PA designers and OTF have addressed many early development issues. Some of these issues are:

> *1) Using the concept of adaptive aiding, the PA will assume tasks based on the pilot's workload and pre-authorization. This implies that the pilot will not necessarily know who is responsible for what actions at any particular time. Is this potential source of confusion tolerable?*
> Current crew coordination is initially based upon written flight manual instructions. Details usually evolve during flights when the crewmembers develop an unwritten "contract" that determines the timing of actions and individual responsibilities. The Mission Support Tool and a newer concept, Principles of Interaction, may foster the development of teamwork between the pilot and PA [6]. Real-time testing should determine our success in fostering the desired level of teamwork and should reveal any remaining sources of confusion.

2) How does one manage the tailorability of the PA in a standardization context? May each pilot set display preferences and tactics, or is the pilot limited to a subset, or prohibited from tailoring displays and tactics entirely?
A goal is to allow pilot tailorability in the belief that it is a necessary feature for user acceptance. However, it is more likely that tailoring will be done at the squadron or flight level rather than by individual pilots. The amount and control of tailorability is an open issue, though, currently determined more by program schedule and cost than design philosophy.

3) How do the pilot and PA grow together? Does the pilot really need to develop a relationship with the PA like that between a pilot and human backseater?
To be an effective combat decision aiding system, the PA must be robust and flexible. It must actively support the pilot in all flight phases and throughout the spectrum of fighter aircraft missions. PA must work synergistically with the pilot, doing tasks for which it is best-suited, and freeing the pilot to concentrate on pilotage and mission success. An important attribute for the PA, like the human, is also to know when its activities are inappropriate. Pilots often tell of forcing an inexperienced or less-than-capable backseater to go "cold mike" -- to keep doing the job but to keep their mouth shut. A Pilot's Associate which constantly needs to be brought up-to-date by the pilot during or after mission events is the antithesis of an associate. It must also know enough to be quiet, perhaps regardless of the value of pilot-input information, if the interaction could detract from the pilot's attention to the mission.

We cannot over-emphasize our assertion that a team relationship must develop between the pilot and the PA for mission success. The Principles of Interaction [6] and Mission Support Tool helps build the requisite teamwork by giving the pilot a window into the PA and laying the groundwork for the crew coordination "contract" mentioned above.

The principles assure pilots that they are in control of the mission -- that the machine supports and monitors the human, not the reverse. The Principles of Interaction define the guidelines for the pilot-PA relationship, and help the pilot build a mental model of how PA works. Some example principles are:

1) The pilot is in charge.
2) Plans may be:
   - Approved or rejected explicitly, with little effort;
   - Approved or rejected pre-mission;
   - Approved or rejected implicitly by pilot action; or,
   - Ignored, with predictable results.
3) The effort required of the pilot to control the PA must be less than the effort saved by the PA.
4) The PA must operate in a predictable manner.
5) The PA is required to monitor the pilot, not the other way around.
6) The PA must notify the pilot of key (as defined and set by the pilot) mission events.

The Mission Support Tool enables pilot experimentation with different adaptive aiding schemes, tactics tailoring, and display preferences. This tool allows the pilot to exercise *a priori* control over PA by explicitly establishing some details of the crew coordination contract.

Training and Pilot Selection

Having addressed the pilot-PA relationship, what is the potential impact on pilots of these relationship assumptions. Questions and possible answers that arise are:

1) Will PA change the nature of the individual suited to be a pilot? We do not believe so. In fact, by allowing the pilot to concentrate on pilotage and weapons employment, the addition of the associate may reinforce the value of the traditional qualities commonly associated with a fighter pilot. A guiding philosophy is to have the machine adapt to, and work for, the human, not *vice versa*.

2) Will pilots need to be more managers than warriors? One early concept of artificial intelligence in aircraft was to view the pilot as a systems manager -- monitoring and approving/disapproving recommendations. This philosophy has been reversed entirely in the Pilot's Associate. A goal is to reduce human monitoring and managing of aircraft systems for which they are ill-suited and poorly motivated. Rather, by developing an associate to support the pilot's strategic and tactical skills, he will regress more toward the warrior state than his systems management tasks allow in today's aircraft.

3) How important will training become to acceptance of the technology and for tuning performance? We assert that training will be crucial because training builds trust. Extensive training is also required because the Pilot's Associate human-centered design philosophy is such a radical change from the traditional aircraft-centered philosophy. Ultimately, less training should be required because of the intuitive and intelligent interface. In fact, one of the Principles of Interaction demands that pilot control of PA require less time and effort than PA saves the pilot in executing the mission.

The previous discussion, the Mission Support Tool, and the Principles of Interaction provide a framework for developing a successful teaming relationship between the pilot and the Pilot's Associate. One logical evolution, however, takes the argument one step further, and hinges on the fact that Demonstrations 2 and 3 required little pilot action to accomplish difficult missions.

Do We Need the Human Pilot at all?

A fully-developed Pilot's Associate would likely include a capability to take over the aircraft, if the pilot is disabled, and do more than simply recover to straight-and-level flight. Since the PA conceivably understands the situation and mission context, it could keep the aircraft safely in the mission pending pilot recovery. This capability could potentially render the PA aircraft autonomous.

Does this obviate the need for some or even all pilots? Possibly in some aircraft roles and missions but not generally. The guiding philosophy of the program has been to support the cognitive and decision-making abilities of the human. This philosophy evolved out of the fundamental recognition that computers and humans are each better at specific tasks, especially when supported by the other. There are also technical limiting factors such as sensors and data fusion/interpretation algorithms which would severely affect the capabilities of an autonomous system. Another scenario is perhaps more likely -- a cooperative set of piloted and semi-autonomous platforms. Whatever the eventual application of the technology, it is only through insightful, educated discussion that we will we identify critical questions and answers before the Pilot's Associate and related systems become operational.

Conclusion

We have argued strongly for research into the psychology of the associate relationship between humans and "intelligent" computer systems. Unfortunately, data for analyzing such a relationship may not be readily available until such systems are fielded. Relationships analogous to what we expect for the pilot and PA should be studied extensively in the interim to insure functional utility, and to avoid user rejection. Reliance on basic principles, such as keeping the user in the design loop, testing and training extensively, and keeping PA as robust and flexible to individual pilot preferences as possible can only help build the required trust and teamwork for a successful mission.

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EXPLANATION OF WORKSHOP TEAM ACTIVITIES

(LAST TWO DAYS)

TEAM TASKS

The meeting call notice identified a series of issues relevant to human-electronic crew teamwork. These issues set the focus for the workshop team discussions conducted during the final two days of the meeting. The five guiding issues were as follows:

1. What is the status of the technology needed to support the human-electronic crew teamwork concept?

2. What are the interface issues?

3. What technical areas should receive increased emphasis in the near future?

4. What will be the impact on pilot selection and training?

5. How far are pilot aiding concepts likely to be pursued, i.e. are we moving along a path towards replacement of the human pilot?

In addition, specific technical issues, which had arisen repeatedly during the workshop presentations, were identified as potential topics for further detailed discussion. The specific technical issues were as follows: trust/confidence, functional description standardisation, representing uncertainty, real time AI, levels of autonomy, dynamic function allocation, and goal tracking.

In order to enable the workshop teams to address these issues in a systematic manner, an outline structure was proposed for the discussion, described on the form overleaf. The two key factors of the meeting - AI and the cockpit - were identified as the primary topics. Each of these primary topics was further divided into three different discussion areas - state of knowledge, unresolved issues, and potential directions.

The workshop participants were divided into five multi-national teams. Each team was tasked to address any or all of the issues raised by the workshop, using the proposed structured framework for guidance as far as possible. In the event, after a series of lively discussions, each team came up with an independent set of conclusions, structured in a variety of ways, representing the diversity and richness of their interactions. The team chairs presented their conclusions in the final plenary session of the meeting, and prepared the written summaries provided in the following section.

THE HUMAN-ELECTRONIC CREW : IS THE TEAM MATURING ?

WORKSHOP OBJECTIVE. To identify the state of knowledge, unresolved issues and potential directions in aircraft applications of AI technology and the impact on the cockpit of the Human-Electronic Crew.

FORMAT OF WORKING GROUP ASSIGNMENTS

AGENDA	TOPIC	
	AI TECHNOLOGY	COCKPIT IMPLICATIONS
1. STATE OF KNOWLEDGE Levels of understanding. Current practice methods and techniques.	1.1 ?	2.1 ?
2. UNRESOLVED ISSUES Areas of uncertainty. Research and development requirements.	1.2 ?	2.2 ?
3. POTENTIAL DIRECTIONS Alternatives, Choices, Priorities Costs / benifits.	1.3 ?	2.3 ?

N.B. All groups to address all cells in the order indicated.

SAMPLE ISSUES

(1) What is the current state of the art needed to support the concept of the Human/Electronic Crew?
(2)What technical areas should receive the most emphasis in the immediate future?
(3)What sort of schedule for operational application of this concept are the experts willing to predict?
(4)How far will the concept be pursued i.e. are we moving along a path toward replacement of the human pilot?

USEFUL QUESTIONS

PRIMARY - What? Which? Why?
SECONDARY - How? Who? Where? When?

POTENTIAL REQUIREMENTS AND CONSTRAINTS

PRIMARY - Operational (Enviromental)
Technical (Physical, Computational)
Psychological (Social, Emotional, Moral)
SECONDARY - Economical, Political, Physiological, Biological, Sociological, Philosophical.

WORKSHOP TEAM REPORTS

TEAM No 1

We began our discussion by taking a vote of interest in the topics that had been presented for consideration. We took the vote merely to determine the most productive starting point for our discussion with the understanding that the discussion would be free to roam into the other areas as it might. The topics of pilot trust in an EC, dynamic function allocation, and levels of autonomy each received three votes, real time performance received two, and representing uncertainty and functional standardization each received one, from the subgroup of people who would be present on Friday. Regarding the four questions posed, pilot selection and training received five votes, interface issues four, and whether the pilot would be replaced two. Because the subgroup that remained on Friday was composed mostly of human interface people, we decided to concentrate on cockpit implications and generally ignore the AI technology issues, feeling that we would have little to contribute to that topic and that concentrating in the one area would enable us to go a little deeper into it than other groups might.

Trust

On Friday, we opened our discussion on the topic of trust. The point was made that we are already facing issues of trust (both under-reliance and over-reliance) in existing automated systems, and that some over-reliance problems bring up training issues. In order for the pilot to know when to trust the automation, he needs to understand the system's modes and to recognise when its safety processes are or are not operating correctly. We can already see the issues cropping up in the use of the "open descent" mode in the A320 and autoland in the 757 and 767. It was suggested that we might learn something from process control displays, as people working in that area have had to devise concise representations of complex system states. Clear system status displays that promote better understanding of the system state may help calibrate reliance on the system.

It was suggested that a set of metarules for automation for all systems might be devised. These would establish rules of behaviour that apply to all highly automated systems. A uniform treatment of automation, with standard constraints on its behaviour, would do much to promote predictability.

Another factor that would promote predictability is a standard, transparent interface. As flexibility increases, the potential for memory loading and confusion also increases. This makes the need for a good pilot-vehicle interface design all the more imperative.

It was also suggested that continuous confirmation of correct operation would promote trust, even though some theorists say that trust only develops under conditions of risk. Fly-by-wire was brought up as an example.

FUNCTION ALLOCATION

With regard to dynamic function allocation, we had an extensive discussion of the need for pilot confirmation of task reallocations. It was suggested that single seat cockpits were developed largely because of the potential for confusion about and usurpation of responsibilities. It was also suggested that the Associate concept doesn't fit within the military command structure, that there were no "associate"-like relationships in the command hierarchy. This point was disputed during the presentation.

The point was also made that dynamic function allocation is a large step from the current state of the art. Such a large step requires a carefully considered approach. One participant wondered if dynamic functions allocation occurred between human crews, and another responded that it did and was a necessary attribute of the job. However, the point was also made that there is much implicit and gestural communication between human crewmembers, and that "a glance is a high bandwidth channel" not available between a human and an EC.

Finally, it was suggested that automation is currently technology-driven rather than human factors-driven, and that a great need exists for structured guidance from the human factors community on how automation should be applied. However, this is in part a selling job, as automation developers and implementers may not be aware of the human factors issues associated with it.

V.A.R.

TEAM No 2

We started by identifying a number of issues that should be considered. These issues were discussed at some length and a set of key technical issues were defined. These topics were as follows:

a. Trust/Confidence

This area has been poorly researched and is an area that will need further work if we are ever to achieve the full benefit of the electronic crew member. The lack of research effort in this area is a major concern.

b. Representation of Uncertainty

Both the electronic crew member and the pilot will make 'soft' errors. Thus systems must be designed to allow for the facts that errors will occur. Therefore, both the machine and human must monitor for errors. It is critical that systems are designed to be robust in the face of errors.

In terms of current technology, it is possible to represent the nature of machine and human error. However, there needs to be work to match the two sources of error representation. There also needs to be work on the matching of error levels to the needs of the task.

The final question is to define a relationship between the high level mission objectives and the error levels that are acceptable for the human and the machine.

c. Goal Tracking

It is a fundamental aspect of the concept of the Pilot's Associate (or Electronic Crew Member) that the machine component has some view of the pilot's intention. There is a basis of theoretical research in terms of plan recognition, but this has not yet been applied to the problems of the aircraft. In particular, there is a lack of understanding of how to cope with the multiple goals that the pilot maintains.

d. Real Time AI

Many of the Issues in real time AI applications have been solved. The major need is to achieve good applications experience to develop a base for the development of systems. The major area of endeavour should be the development design methods.

e. Levels of Authority

This is an area that has not been addressed with any success so far. There is a natural concern amongst aircrew that they will not be in control. However, a review of the performance and functionality that will be required shows that we cannot expect the pilot to be in control in all circumstances. This is an area that needs to be addressed at a policy level as much as at a research level.

Function Description/Standardisation

The workshop included a paper on standardisation for the pilot interface. The key aspect of this paper was the development of an agreed approach to the description of functions that a pilot undertook. This is in contrast to the more frequent approach to standardisation which is to consider the specification of symbology, display layout and control placement.

The working group felt that this approach was the basis for solving a fundamental aspect of the relationship between the human and electronic crew members. Without a basis for description of functions, it is impossible to consider how roles are allocated, on both a static and dynamic basis. Until there is an agreed and coherent description of functions, it will still be the case that the electronic crew members are technology led rather than satisfying a clear service need. For this reason, it was felt that this topic should be singled out by the participants of the meeting as the area into which further collective effort should be invested to ensure that appropriate attention and resources are allocated.

Conclusion

In addition to directing attention of the conference to the final item of the technical issues, there was a general comment. It was felt that there was a lack of continuity between the two conferences, there could have been a scene setting session at the beginning, summarising the issues raised at the previous conference, this would have defined a basis for monitoring progress and identifying trends in the development of the electronic crew member.

Finally, this workshop group would like to thank the organisers of the conference for a stimulating and successful meeting.

J.C.

TEAM No 3

The viewgraphs used during the summing up by the session chairman utilised the previous workshop format for summarising the issues and problems to the Workshop. The categories encapsulated by the matrix sometimes obscured the salient details which emerged during the discussion sessions using the evaluation criteria laid down by the Organising Committee. The findings reported and views expressed were generally related to the scale of activity undertaken and the level of appreciation of relevant disciplines and related technologies involved in producing computer based advisors.

Technology Status to Support Electronic Crewmember Concept

Technology development has been uneven with large advances in some narrowly focused software areas resulting in unfulfilled potential due to lack of consideration of wider integration issues. Individual demonstrators still do not approach general human reasoning capabilities where shortcomings still are evident in such areas as conflict resolution, and reasoning in uncertainty in dynamic environments so exposing the limitation of rule based, Bayesian reasoning. Means of presentation of visual information and verbal input/output devices are being developed in isolation without adequate consideration of integration with or maximising capabilities of the electronic advisors potential. Sadly, this indicates the all too familiar experience of the unsystematic approach typically associated with the introduction of a new technology when Human Factors personnel have not been involved during the appropriate phases.

Interface Issues

Communications and interaction between the Human and the Electronic Crewmember were identified as the crucial interface issues. The resultant and often experienced mismatch between technology potential and demonstrators' limitations were often a manifestation of the insufficient attention given to an overall, systematic approach discussed under technology status. Conventional textural or graphical outputs associated with computer systems have been found to be grossly inadequate in conveying information when required by aircrew and massively underscores the information technology potential of the electronic aircrew systems.

Technical Areas Requiring Increased Emphasis

A more systematic approach is required to exploit and usefully combine the individually demonstrable potential of interface media. Voice interaction technology was an example discussed of an available technology which ought to be effectively combined with the electronic crewmember to produce the near symbiotic relationship which is often found between effective front and rear human crewmembers. Due to the heuristic nature of much of the reasoning employed together with the exploitation of incomplete data then more attention needs to be applied to developing evaluation techniques and validation procedures to cover these novel, and sometimes unique systems. In step with the need for the development of specialised validation procedures, as a preliminary to airborne certification, the requirement for implementation of military software in Ada would require a significant effort in incorporating the unique software structures used in intelligent systems.

Impact on Pilot Selection and Training

The exploitation of the educative effect of close association with intelligent systems technology was seen as a positive effect, especially when coupled with aptitude tests to determine computer numeracy during selection. Intelligent systems were seen as raising the competence of the aircrew and the explanation facilities provided feedback of performance and re-enforced learning during training.

Redundant Aircrew?

General agreement that the research aim was not to replace the pilot but to make him more effective by exploiting the technology to produce an electronic advisor and maximising human-electronic crewmember capability.

Advances to date have been substantial but what is required is for researchers, managers and requirements specialists to be less parochial in order to fully realise the potential of the technology as outlined by the Keynote Speaker.

H.H.

TEAM No 4

Current Status

Question 1 What is the status of the technology needed to support this concept?

This was addressed in the following ways:

Artificial Intelligence and Technology (Fig 1)

The academic and scientific community are now more confident of the ultimate feasibility of implementation. Various software and methodologies have been established and evaluated in the laboratory.

The levels of understanding of the enormity of the task are now starting to filter down to the engineering design and build community.

The academic and scientific communities confident view that this is now merely a question of building an engineering implementation of their concepts, is not presently shared by the engineering community.

Cockpit Implementation

The academic and scientific community are now more aware of the pilot's problems. The understanding of pilot interaction and needs with regard to the AI interface has been greatly improved in the last 2 years. The concept of a scientific/engineering/pilot workshop/forum such as this conference is invaluable and should be encouraged.

The status of the various sub-systems making up a Pilot Associate program was evaluated as follow:

System Status Expert (Fig 2)

The most simple to implement in terms of engineering effort. Very well advanced. No problems anticipated in terms of final implementation.

Mission Manager Expert (Fig 3)

Moving map displays and navigation systems using latest technology together with extensive digital data bases such as DMA DTED and DFAD are presently implemented.

Automatic navigation reversion and route planning is very well advanced using simple AI techniques and extensive processing. No problems are anticipated in following through this work.

Situation Assessment Expert (Fig 4)

Long Range Radar, Forward Looking Infra Red, and Millimetric Sensors are here now. Acoustic sensors are presently well advanced. The outstanding issues are how to present this plethora of sensor data to the pilot in a readily assimilated manner. (The so called "Sensor Fusion"). Automatic Target Recognition is progressing but is at present not as successful as was anticipated. However, this problem is thought to be solvable with advances in technology.

Tactical Expert (Fig 5)

The decision maker or evaluator of the total situation is presently far behind. It is in this area that the academic/scientific community is presenting a whole series of conflicting opinions which, until these are resolved, the engineering builders will not progress. What are the rules? How are they learnt? How are decisions communicated to the pilot? Until these questions are answered this expert will stay unbuilt.

Pilot Executive Expert (Figs 6)

This sub-system which was originally conceived as being an overall executive manager residing between the individual system experts. This expert being the source of the pilot/AI interface. This concept, of a separate executive expert, now seems to have been quietly dropped.

Question 2 What are the Interface issues? (Fig 7)

Interfacing to the pilot is straightforward in low workload situations. In high workload situations the pilot is so busy he may overlook/ignore the associate unless the information is timely, relevant and clearly presented. The former should present no problem. However, the relevance presents more of a problem in a complex scenario and until this is fully defined it is difficult to envisage the precise implementation of presentation.

Unresolved Issues

At present there are single seat aircraft and two seat aircraft. Does one gradually increase the capability of the single seat operator by means of Pilot Associate techniques until in the final analysis one has an effective 2 seat aircraft or does one gradually replace the second seater in a two seat aircraft until the two seater becomes a single seat?

At some time before the next generation of one or two seat aircraft are laid down, this qestion must be resolved. One cannot have a one and a half seat aircraft.

Pilot feedback suggests that in addition to being a systems/mission manager, the rear seat operator is invaluable as an additional pair of eyes in close air-to-air engagements. History suggests that this situation will always be with us, despite untold predictions that long range standoff weapons will eliminate this threat. In this case the requirment exists to develop a close air-to-air engagement 360^{o} solid state visual sensor with the capability of identifying and reporting any necessary immediate evasive action to the pilot, e.g. "break right now!"

The Future

Question 1 — How far will the Pilot aiding concepts be pursued? Is it thought that we are moving along a path towards replacement of the human pilot?

It is not expected that the human pilot will ever be replaced in the foreseeable future for the following basic reasons:

1. Flexibility - In a combat scenario the basic mission can be planned to the last detail. However, between the time of planning and execution, the situation can change. A human operator can assess the now situation and replan and re-execute in a flexible manner.

2. Trainability - A human is capable of learning without being taught. This process is imperfectly understood. At present we are still struggling on the concepts of the best methods of teaching AI machines and establishing that they have learnt correctly; far less enabling or even allowing them to learn on their own experiences.

3. Responsibility - At present the pilot is responsible for the actions of his machine. Everyone is fully aware of the irksome habits of, initially, banks, shops, airlines (and now in virtually every sphere) for lax or poor performance to be laid at the door of computer breakdown or error. The infamous "Sorry it's not my/our fault, it's the computer".

Envisage a combat or war scenario with an unmanned attack aircraft with full artificial intelligence making autonomous, self taught weapon released decisions. Who would be responsible?

The user - Squadron Commander
- Airforce Chiefs
- President

The manufacturers - Designer
- Tester

"None of our other ones has done this before! It was a healthy, well adjusted intelligence when we shipped it from the factory, you must have taught and treated it badly to create this situation".

M.L.B.

Team No 5

AI Technology

1. State of Knowledge

Hardware developments have outstripped software progress.

Availability of rapid prototyping greatly helps the exploration of new ideas.

Not enough time is spent with the software tools we already have available.

The current belief is that one cannot originally write AI software in Ada.

Direct porting from AI code to conventional code may lead to computationally inefficient code being produced.

We need to begin with a better understanding of requirements.

We need to distinguish between real time as it applies to avionics and as it applies to human time frame (give response on time for the pilot to use).

No learning systems are as yet available.

Conclusion

Industry is in a strong position to build good operational Intelligent Knowledge Base Systems for well defined, narrow applications.

2. Unresolved Issues

How do we determine pilot intentions? Through the sensing of the pilot's overt actions?

In the human/machine relationship who adapts to whom? In the past, the human adapted; now we are moving to systems where the machine can adapt somewhat.

What does validation and verification mean in the context of AI? We should not expect the AI system to perform 100% correctly. It should be sufficient for the AI system to perform X times better than the all-human crew.

How do we build progressive confidence in the AI system? How do we build in safety checks for bounding the AI decisions?

3. Potential Directions

We need to become more realistic in our expectation of AI systems.

We need to define the goal of including AI in a system. Are we trying to build a perfect crewmember or are we just adding another piece of equipment on board the aircraft?

Cockpit Implications

1. State of Knowledge

Displays are much more efficient than controls for communication between the human and the EC.

The symbology and formats on the displays are much too complicated and cluttered.

2. Unresolved Issues

There is a need for better/additional means of sensing pilot intentions.

What will give the machine the capability to adapt and/or learn?

3. Potential Directions

We need to develop better models of pilot performance.

We need to learn more about pilot preference.

We need to balance the technology, to identify the best tasks for the pilot and best tasks for the EC.

We need to identify when unpredictability in pilot or EC is deliberate (predictable uncertainty).

We need to develop criteria for assessing pilot acceptance and trust of the EC.

We need a better assessment of pilot workload in order to determine dynamic function allocation between the pilot and the EC.

J.R.

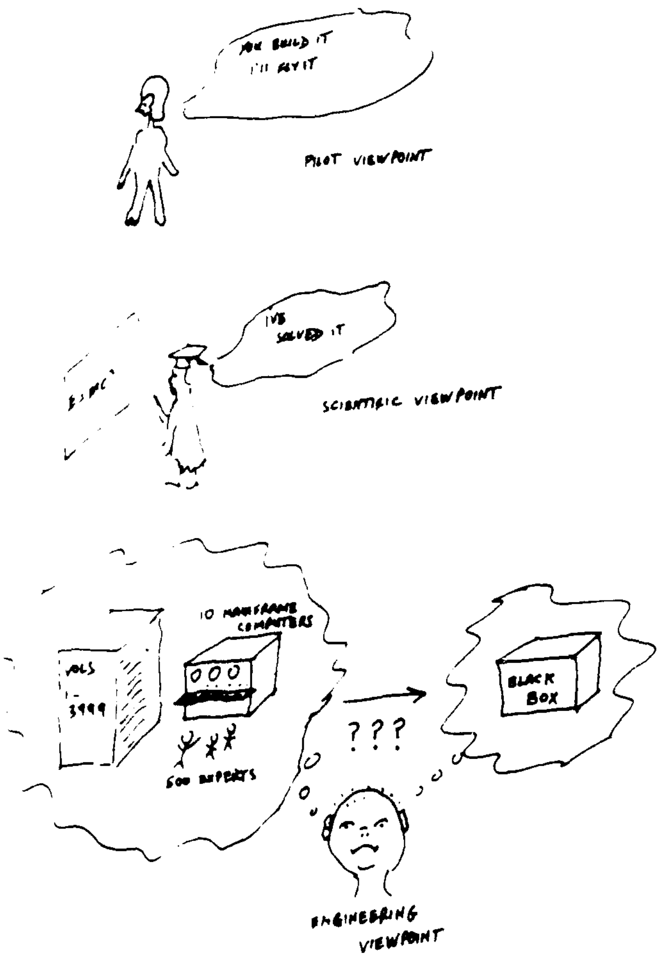

FIG 1 STATUS

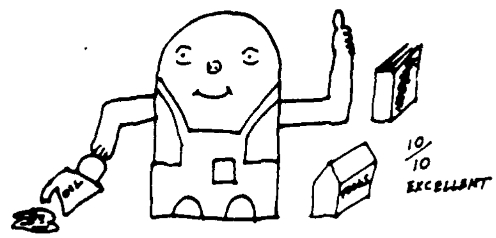

FIG 2 SYSTEM STATUS EXPERT

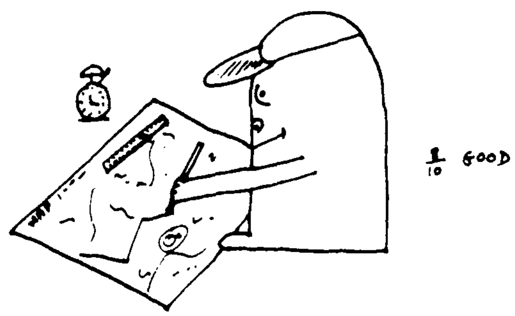

FIG 3 MISSION MANAGER EXPERT

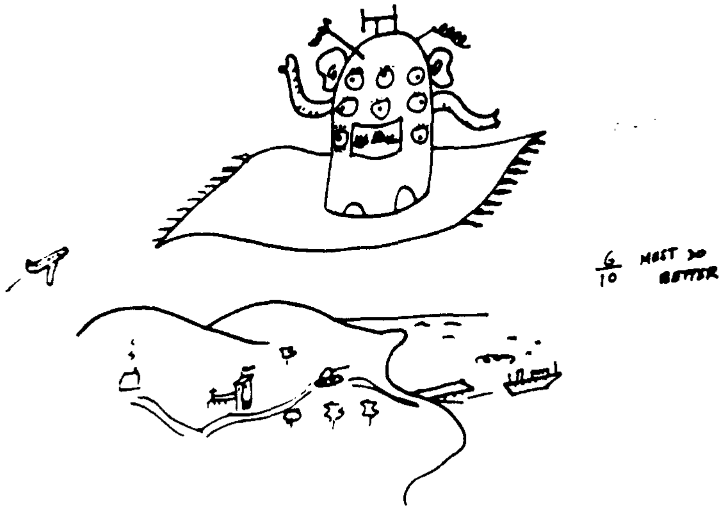

FIG 4 SITUATION ASSESSMENT MANAGER

FIG 5 TACTICAL EXPERT

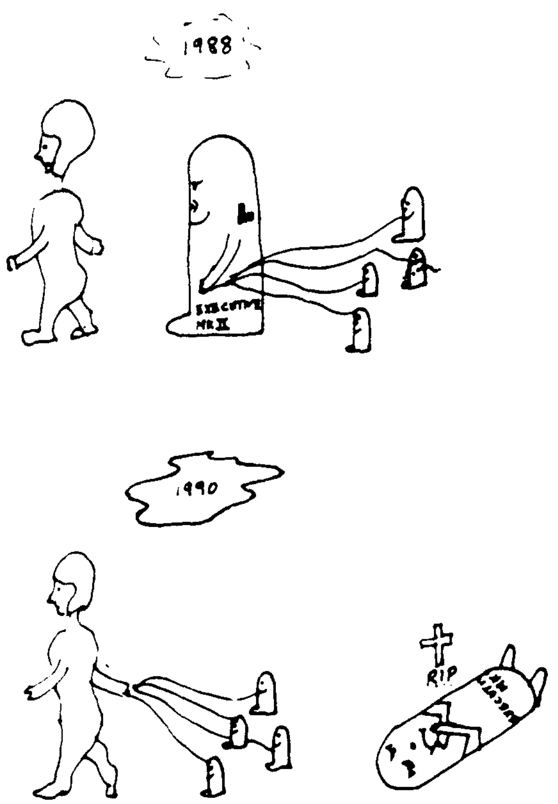

FIG 6 PILOT ASSOCIATE PROGRAM

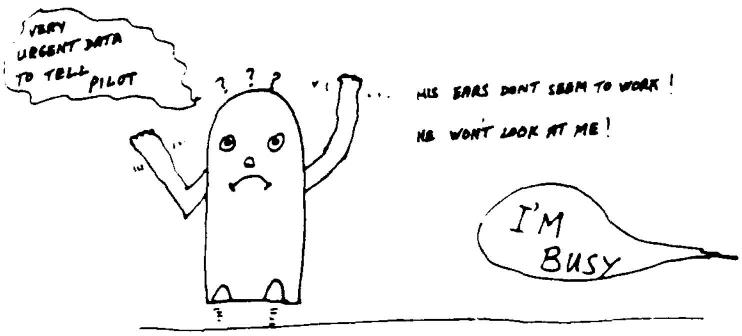

FIG 7 PILOT/AI INTERFACE

TEAMS

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CONCLUSION

This workshop's main thrust was to aid in the development of a more efficient cockpit for future attack/fighter aircrews. Pooling together the knowledge of the artificial intelligence specialists, cockpit designers, and aircrew members, this workshop provided a forum for the exchange of ideas about hardware and software architecture which will make up the human-electronic crew member combination. Such a combination will allow pilots to more safely and efficiently navigate in hostile areas, attack enemy targets, or land in poor visibility. The electronic part of the crew is there to aid the human aircrew, not to take over the mission. In the human-electronic crew, the human will still maintain overall control. The goal of the human-electronic crew is to increase the crew's efficiency, while optimizing workload and safety.

One of the main goals of this workshop was to determine how far technology and design concepts have progressed for artificial intelligence in the cockpit and papers presented reflect that significant progress has been made. Also examined was the teamwork issue of pilot inferencing and how information could be efficiently conveyed between the pilot and the electronic component. It is the conclusion of the workshop teams that for the near future the pilot will have to adapt to the electronic member's formats, as there are no current artificial intelligence systems that can truly learn. In the mean time, workshops such as this one will continue to provide a medium in which ideas may be shared among specialists to further the development of the human-electronic crew.

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