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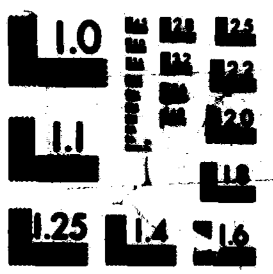

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Impact of Future Developments in Electronic Technology on Cockpit Engineering

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NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARD Report No.757

IMPACT OF FUTURE DEVELOPMENTS IN ELECTRONIC TECHNOLOGY ON COCKPIT ENGINEERING

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This Report was sponsored by the Aerospace Medical Panel of AGARD.

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PREFACE

This paper reports the results of the Cockpit Engineering subpanel of an AGARD workshop on "The Potential Impact of Future Developments in Electronic Technology on the Future Conduct of Air Warfare". The workshop was organized and sponsored by the Avionics Panel. In addition to the Avionics Panel members on the subpanel, there were also representatives from the AGARD Aerospace Medical and the Guidance and Control Panels.

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The paper reflects the views of the Cockpit Engineering subpanel, which was one of ten subpanels involved in the workshop. The subpanel treated the design and development of the cockpit in terms of the effects emerging electronic technologies are expected to have on aircrew mental workload, training, and crew station design at both the conceptual and display/control technology interface levels. Due to the time constraints of the workshop, it was not possible to develop fully the topics and issues raised by panel members. Consequently, this paper surveys the cockpit engineering problem and provides a limited treatment of the considerations and developments believed to be needed to ensure that the potential offered by new electronic technologies is realized in future weapon systems.

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CONTENTS

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SUMMARY

This paper considers the issue of how advances in Electronic Technology are expected to impact cockpit engineering for future airborne weapon systems. It briefly surveys aircrew functions in an effort to isolate peak periods of operator workload, and suggests ways new technology may be applied to yield improved aircrew, and hence system, performance. Accompanying this analysis is the presentation of a procedure that can be used in making decisions about what cockpit functions to automate. The implications of advances in avionics technologies on conceptual design practices regarding the crew station, aircrew training, and the development of new training devices are also reviewed. Finally, current and emerging interface technologies are briefly surveyed. Based on this survey and analysis, some general recommendations are offered.

LIST OF SYMBOLS

AI	Artificial intelligence
BDA	Bomb damage assessment
CAS	Close air support
CGI	Computer graphics imagery
CM	Counter measure
CRT	Cathode ray tube
Dels	Display elements
EC	Electro-chromics display
ECM	Electronic counter measure
EE	Electromechanic display
EL	Electro-luminescent display
EO	Electro-optical display
EP	Electro-phonetic display
EW	Early warning
F.C.S.	Flight control system
FEBA	Forward edge of the battle area
FLIR	Foward looking infrared
FLOT	Foward line of own troops
GCI	Ground control intercept
GPS	Ground positioning system
HUD	Head-up display
IFF	Identify friend or foe system
IFFC	Integrate flight and fire control super-system
LC	Liquid crystal
LED	Light emitting diode
LLLTV	Low light level television
LV	Light valve
PD	Plasma display
Pels	Picture elements
RF	Radio frequency
SAR	Synthetic aperture radar
TV	Television
VFD	Vacuum florescent display
WFOV	Wide field of view

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This paper reports the results of the Cockpit Engineering subpanel of an AGARD workshop on "The Potential Impact of Future Developments in Electronic Technology on the Future Conduct of Air Warfare." The workshop was organized and sponsored by the Avionics Panel. In addition to the Avionics Panel members on the subpanel, there were also representatives from the AGARD Aerospace Medical and the Guidance and Control Panels.

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INTRODUCTION

It is generally accepted that in many current military aircraft, particularly single-crew aircraft, pilot workload is excessive and can be a limit to the capability of the aircraft as an operational weapon system. Advances in on-board avionics systems have the potential for generating huge amounts of information, and considerable care will be required in optimizing the the man-system interface in order that the human pilot capability (which will be essentially unchanged) can be utilized effectively to enhance overall system performance.

Ideally the man and the aircraft systems would together be designed as a total system. This concept is difficult to achieve due to limits in our understanding of human information processing and other performance variability, the methods required to load information into him, and the selection/integration of input/output (information) channels. At the present time man has some important capabilities which, in the short term, are unlikely to be attainable with machines. These include:

- Complex pattern recognition
- Assessment and decision-making concerning complex situations
- Intuitive judgment.

Although computers currently excell in analysis and numerical computation, their capabilities in the field of artificial intelligence are developing to the point at which the man's capabilities in complex assessment and decision-making may be matched and even overtaken in limited domains. The implications for the design of man-machine interfaces have not yet been explored, and could raise some important and fundamental new issues.

Another difference between man and machine is in integrity and failure mechanisms. For the forseeable future, man is likely to have a unique capability to combine extremely high integrity with complex high-bandwidth operation. The integrity implications of artificial intelligence will certainly require much study. At the same time it must be recognized that the demands on pilots of modern aircraft are such that accidents happen far too frequently, and it should be an aim of overall system design to reduce the frequency of human failure. Better simulation and briefing prior to flying the aircraft may be an important development which will arise from new electronic techniques.

In this paper, the particular problems of the man-machine interface are explored, and some guidance is given to ways in which improvements can be effected compatible with system performance changes arising from advancements in electronic technology. Resulting from these, it is expected that overall aircraft system capabilities can be improved, for example in areas such as all-weather day/night operation, and operation in more hazaradous conditions and against a more capable enemy.

The paper is organized into several relatively independent sections. The first two sections provide a brief analysis of aircrew functions from two perspectives -- by mission and by system task. Functional areas where advancements in electronic technology may be applied to simplify or otherwise reduce aircrew mental workload are identified. The third section considers the issue of crew station design tools and methods needed to ensure the effective use of an ensemble of advanced electronic technologies. Section four considers electronic technologies in terms of the man-machine display interface. This is followed by a brief look at advanced automation techniques applicable to the cockpit. The focus of the paper then shifts to examine the impact of electronic technologies on aircrew training and the design of specialized ground equipment.

ANALYSIS OF AIRCREW FUNCTIONS BY MISSION

The purpose of this section is to identify periods of high aircrew task loading and to suggest an approach for selecting tasks to simplify through the careful use of electronic technology.

Close Air Support Missions

The mission is to provide close air support coverage to friendly forces in the vicinity of the forward edge of battle area (FEBA), on both sides of the forward line of own troops (FLOT). This mission is applicable to both fixed wing and rotorcraft (helicopters). Targets include a variety of enemy forces, generally mobile ground elements, operating in the vicinity of friendly forces. Coordination with friendly forces is therefore essential, and will involve cross-service communications. Survival requires defensive capabilities and may involve air-air combat with enemy rotorcraft. Weapons include air-ground "smart" precision-guided and "dumb" bombs, cannon, and guns as well as air-air missiles and guns.

In chronological order, the mission may be broken down into the following major phases, with major aircrew functions peculiar to close air support as indicated:

Mission Planning. Establish attack/re-attack plan, including coordination with flight members; review threat information, rules of engagement constraints, and formulate contingency plans.

Pre-Flight and Take-Off. Aircraft and communications checks, taxi, take-off, climbout and rendezvous.

Orbiting Contact Point Prior to Penetration. Checking the area for hostile air threats; navigation checks to maintain orbit position.

Low-Level Penetration. To the extent possible follow pre-planned route and time schedule; maintain low observability, minimize communications, avoid ground/orbit impact, and scan for threats; globally achieve and maintain situation awareness, including locations of other flight members.

Target Acquisition. Detect, recognize, classify, and identify target and align aircraft for attack; coordinate with friendly ground and air assets; maintain vigilance against threats.

Target Attack (Weapon Delivery) and Re-Attack. Execute attack maneuvers, perform bomb damage assessment (BDA), locate and avoid threats, plan reattack profile and coordinate with wing. If a rotorcraft, change firing position.

Egress and Recover. Execute planned exit or replan to meet check point/time through established corridors; transmit ID; scan for launch of both enemy and friendly threats; perform landing under battle conditions.

Air Defense and Air Superiority Missions

The mission is to attack enemy airborne targets including aircraft, rotorcraft (helicopters), cruise missiles and remotely piloted vehicles, generally on the friendly side of the forward edge of the battle area (FEBA). Targets are assigned by friendly ground control intercept (GCI) or airborne command and control centers, and therefore close coordination with these elements is essential. Survival requires defensive capabilities including ECM, flare and chaff. Weapons include air-air missiles and guns. This mission is usually thought of as applicable to fixed wing aircraft.

In chronological order, the mission may be broken down into the following major phases, with major aircrew functions peculiar to air defense and air superiority as indicated:

Mission Planning. Selection of an operating area, briefing on threats, rules of engagement, location of bases, order of battle, contingency plans.

Pre-Flight and Launch. Aircraft and communication checks, taxi, take-off, climbout and rendezvous.

Attack (Fire Control). Obtain target assignment and verify target/attack information against onboard sensor display information. Detect, recogn'ze and identify target aircraft and evaluate target data. Fly attack geometry according to displayed command. Arm and check weapons and perform fire control. During this period, the pilot must continuously check for electronic warnings of counter threats.

Recovery. Return to base, approach, landing, shutdown and operational debrief.

Electronic Combat and Interdiction Missions

The mission is to penetrate a moderate to deep distance beyond the FEBA/FLOT to interdict enemy lines of communication and to counter enemy air defense installations. This mission is applicable to both fixed wing and rotorcraft, but has been developed to a higher level for fixed wing aircraft that generally penetrate deeper and fly somewhat higher and therefore require more sophisticated electronic combat equipment. Targets include a variety of enemy forces, both fixed and mobile ground elements, industrial activities, roads, railroads, shipping installations, etc. During this mission, the aircraft will have to coordinate with other airborne assets and will have to clear friendly air defenses prior to and during penetration and egress. Survival requires defensive capabilities and may involve air-air combat with enemy fixed-wing and rotorcraft. Weapons include air-ground "smart" precision-guided and "dumb" bombs, cannon, and guns as well as air-air missiles and guns. Electronic countermeasures, including jammers and expendables in both radio frequency and electro-optical spectra, are key to success of these missions.

In chronological order, the missions may be broken down into the following major phases, with major aircrew functions peculiar to electronic combat during an interdiction mission indicated:

Mission Planning. Selection of a route and flight plan that avoids or minimizes exposure to enemy air defenses.

Pre-Flight and Take-Off. Aircraft and communications checks, taxi, take-off, climb out and flight in friendly areas.

Penetration of the FEBA/FLOT. Flying the planned mission using tactics, such as limiting audio, radio frequency (RF) or electro-optical (EO) observable emissions or reflections and/or terrain masked flight, to reduce the possibility of detection by the enemy's air defenses. These tactics may make it more difficult for the aircrew to obtain the information needed to perform penetration.

Transit in Hostile Territory and Penetration of Objective Area Defenses.

Threat Detection. Monitoring of electronic warfare support measures, including sensor systems operating over the entire spectrum (audio, RF, and EO), to detect active or passive enemy search and detection systems.

Threat Acquisition. Use of automatic or semi-automatic artificial intelligence (AI) threat and target recognition functions, including pre-processors for visual, thermal, and RF sensor video image exploitation and knowledge-based post-processors for information fusion of multi-spectral image features, digital map information, and other knowledge. Once acquired, threats may be handed off to other friendly aircraft or command, control and information centers and should be recorded for mission debriefing.

Threat Response. Making the decision to ignore, counter, avoid, or destroy the threat using automatic or semi-automatic AI decision-aiding functions, including pre-enabled functions with response times shorter than human capabilities, pre-enabled functions utilizing "command by negation" control, and responses requiring direct aircrew participation.

Egress Through Hostile Area and FEBA/FLOT, and Recovery.

Identification of Peak Task Loading Periods

Analysis of each of the missions considered, and comparisons between missions, indicates that there are certain activities, often common between missions, that are likely to stress the system and the pilot and which are therefore expected to drive the design of the cockpit and automation provisions.

For example, when an air defense/superiority mission is analyzed, the attack phase is found to impose greatest workload. When a typical attack phase is broken down into 42 individual tasks, 11 are associated with flight path control, 16 with weapons management, 10 with communications, command and control, 3 with threat management, and 2 with aircraft system monitoring.

Low-Level Penetration of Hostile Defenses. Crossing the FEBA/FLOT in the close air support and electronic combat/interdiction missions will generally be a high aircrew loading period because enemy air defense and other resources may be concentrated there and the level of their alertness will usually be very high. In addition, due to the activity level in this region, and the presence of large numbers of friendly forces, there will be an increased possibility of mistaken attack by friendly forces.

(For the electronic combat/interdiction mission, entering the objective area, which may be some distance from the FEBA/FLOT, will require a somewhat different form of penetration. Countering area and point defenses in the area of the mission objective will generally be a high task loading period because the objective of the interdiction mission will usually be of high value to the enemy and therefore well defended. Since we fly into the specified objective area to perform the assigned mission we may not be able to avoid these defenses and must therefore counter or destroy them.)

Obtaining Threat Assignment and GCI Vectors. This can be a high workload task involving communications, navigation and attack coordination planning. Aircraft must maintain formation while receiving threat information and setting up weapons for attack.

Threat Detection and Countermeasures. This will be a high task loading portion for all of the missions, but the preparation and responses may differ. For example, it will be particularly difficult for the electronic combat/interdiction mission when threats are detected in the area of the mission objective since, in addition to countering a high density of area and point defenses, we must accomplish the mission (e.g., destroy a specific target), which will certainly alert the enemy to our presence. For the other missions, over friendly territory and/or in the vicinity of friendly forces, we may have assistance in detection and countering of threats. However, in these areas, we may be threatened by mistaken attacks from our own forces.

Response also depends upon whether we are dealing with a surface threat or an airborne threat. Response to detected surface threats will be high task loading events since they may interfere with the planned mission and may require the aircrew to deviate from the planned flight path. Response is highly dependent upon the type of aircraft (e.g., fixed wing vs rotorcraft) and the type of mission (e.g., covert special operation vs major bombing raid). The pilot must decide, often in less than a few seconds, whether to ignore, avoid, counter, destroy or disrupt the threat. Responses to detected and acquired enemy airborne threats will often be even higher task loading events than surface-to-air threat engagement. Response choices are the same, but an airborne threat is generally more dangerous to ignore and more difficult to avoid.

Following detection and recognition of a threat, the aircrew must decide to:

a. Ignore it if the threat is not in a track mode, if it is beyond lethal range, and/or if it is behind us and we are already flying away from it.

b. Counter it by emitting and reflecting an absolute minimum of potentially observable energy, and, when a threat is detected, any active emissions (such as radar, radios, lasers, etc.) should be turned off, if possible, to reduce the likelihood that the enemy will be alerted to our presence and allow him to track and recognize us. If the threat is of a type that may be susceptible to active countermeasures, we may decide to invoke them. We may utilize expendable countermeasures, such as chaff, flares, or other decoys to deflect enemy radar or EO sensors. Active countermeasures, such as deception or jamming, may also be invoked, but these carry with them the possibility of further alerting the enemy to our presence and allowing him to recognize us.

c. Avoid it. If the threat is ahead of us we may be able to change our flight path and fly a clear path around it. If the threat is off to one side, we may be able to duck behind a hill to mask ourselves. Sometimes a reduction in altitude may provide sufficient masking, although this tactic may require a reduction in speed or perhaps a hover maneuver, which may impede the main purpose of the mission. In order to intelligently avoid a threat, we require knowledge of direction, range, and the capability to perform intervisibility calculations using a digital map.

d. Destroy or disrupt it. Given appropriate weapons and geometry, the best response may be to attack the sensor systems associated with the threat, or to destroy the threat itself. Defense suppression is particularly appropriate if other friendly aircraft are following and may have to respond to the same threat. One friendly aircraft may be assigned the job of provoking a response by enemy air defense systems so they may be located and destroyed.

Target/Threat Acquisition. Following detection of a threat, or arrival in the vicinity of a target, and a decision to possibly attack the target or threat, the airborne or surface target or threat must be "acquired" (i.e., we must classify/identify it, determine range, direction of motion, etc.). This requires use of direct vision plus multiple sensors operating in the electro-optical and radio frequency bands. It may also involve interfacing the pilot with automated target recognition aids that if properly designed should mitigate workload.

Air-Ground Attack/Re-Attack. In the CAS mission, high workload emerges from the need to rapidly assess the situation, decide if a re-attack is necessary and if so to coordinate it with the wing man and friendly ground forces. At the same time hard maneuvering is likely, and the crew must continuously scan the environment and instruments to detect threat status. Thus the crew will exercise all major crew station subsystems in rapid succession while trying to use "eyes-out" for as much time as possible.

Air-Air Fire Control. The difficult (high workload) tasks are to acquire the target, identify and evaluate it, select and arm the weapons, and bring the target within the firing envelope, while the target and other threats are attacking own aircraft. All the while, the pilot wants his eyes out of the cockpit to seek or maintain visual contact on the target and the other threats. Throughout, he needs to coordinate with the other aircraft in the flight to maximize the combined combat effectiveness.

Egress/Return to Friendly Territory. This applies mainly to the close air support and electronic combat/interdiction missions. These missions require transit through hostile area and FEBA/FLOT. This is similar to penetration and transit, with added threat of mistaken fire from own forces when near the FEBA/FLOT or over friendly territory. This requires careful execution of planned exit (or replan) to meet check point/time through established corridors, and transmission of ID and scan for launch of both enemy and friendly threats. Recovery may require landing at forward bases under battle conditions.

Air Crew Task Simplification

Tasks currently done manually or semi-automatically by the crew may be simplified by improving the crew/system interface (more appropriate displays, voice control, touch, etc.), by the judicious use of automation and/or AI, and/or by improving crew station integration through the use of holistic design techniques.

Single-Pilot Considerations

If there is only a single human crewmember in the aircraft it is useful to separate tasks into those involved with continuous control over the aircraft flight path as one part, and all the discrete system and mission management tasks as a second part. The percentage of workload required in the first part depends upon the degree of flight control automation and pilot acceptance and trust of that automation. The workload for the second part is determined by the sum of the times required to do each discrete task, including the overhead required to switch primary attention between tasks in each category.

When workload becomes high, as in the mission phases identified in the previous section, either flight path control must be made easier to free a greater percentage to the managerial tasks, or else the managerial tasks must be reduced or eliminated.

Even if flight control can be automated to the maximum extent, when flying near the ground, pilots require a "head-up" and "eyes-out" view of the outside world to reassure themselves that automatic flight control is working. This requires a cockpit design that allows control and display of managerial tasks while the pilot's head is up and his eyes are out.

This requirement causes a potential conflict of pilotage vs situation awareness: Pilotage certainly requires a conformal display of the direct view of the outside world plus any sensor imagery or flight parameter information, while situation awareness may require a plan view or "bird's-eye" view to allow the situation to be viewed beyond visual range.

Criteria for Selecting Tasks to be Simplified

In selecting tasks to be simplified, we must be careful to protect the pilot's prerogative to set the "what to do" and concentrate on "how to do it." The pilot is likely to accept all the automation help we can give him to monitor all the dials and gauges and do the tasks he considers to be "dogwork." He can also probably be convinced to allow the system to do tasks that are beyond human response time, and that could save his life. However, pilots may be expected to resist automation of other tasks unless we can convince him the automation is designed to help him do his job, not replace him.

Currently there is no accepted procedure for selecting what tasks to simplify or for specifying automation requirements. One approach, shown in Figure 1, emphasizes human response time, high demand periods, safety, and ease of automation as criteria for selecting tasks to simplify. These criteria, as applied to airborne weapon systems, are briefly discussed below:

<u>Tasks that Require Response Times Beyond Human Capabilities</u>. There are two key considerations in this area:

Aircrew Response Time. The fastest possible human response time is about 0.15 sec (1.5 alpha cycles), the time it takes for an attentive person to press a button in response to an unambiguous alert. If the person is concentrating his cognitive powers elsewhere, it may take five seconds, or more, for him to notice an alert, shift his eyes and mind to the new area, and begin to respond.

Threat Weapon System Reaction Time. Some weapon systems can acquire and shoot down an airborne target in 20 sec, or less. As these weapon systems become more and more automated, their response times may go down a few seconds, particularly for low altitude targets and air-to-air engagements.

Therefore, electronic combat tasks that should be simplified by automation/AI in the future include threat detection, threat acquisition, and threat response. In the battlefield of the future, it may be necessary to invoke pilot-enabled automatic release of chaff or flares, automatic deception or jamming, and/or automatic defensive maneuvers in response to automatically acquired threats. [Weapon system functions with aircrew tasks potentially in this category: Flight control, fire control, target acquisition, threat warning/CM, equipment management.]

<u>Tasks that Must be Performed During High Task Loading Periods</u>. In each of the periods identified in the previous sections, multiple tasks must be performed in constrained time intervals, which may overload the aircrew, particularly if a single-pilot vehicle is considered. These tasks include: (1) pilotage (short-range maneuvers within the line-of-sight of naked eyes or EO sensors to avoid terrain or obstacles),

(2) tactical routing (medium-range maneuvers to achieve the mission objective), (3) threat and target detection and recognition, (4) countering or avoidance of threats, and (5) destruction of threats and targets. [Weapon system functions with aircrew tasks potentially in this category: Flight control, fire control, target acquisition, threat warning/CM, navigation, communications, equipment management.]

Repetitive and/or Safety Critical Tasks that Might Not Get Done by the Crew Due to Fatigue, Boredom or Stress. Much of the time and effort of pilots in current airborne weapon systems is spent monitoring the hundreds of engine and avionics parameters and looking for "out of tolerance" conditions or trends so that corrective action may be initiated. When heavily loaded by mission considerations, such as an engagement with an enemy surface-to-air or air-to-air threat, the pilot may forget to monitor some key parameters. If a failure or battle damage occurs under these conditions, the aircraft may be lost. Alternatively, a pilot under stress may focus on an adverse trend such as rising engine pressure and inadvertently fly the aircraft into an obstacle. Even when not heavily loaded, a fatigued or bored pilot may not notice the effects of some failures or battle damage until it is too late.

For these reasons, monitoring of the airframe, engine, and avionics equipments should be considered prime candidates for automation. Whenever possible automatic corrective action should occur without even alerting the pilot (unless an executive decision is required or the equipment failure will cause a major change to the planned mission). [Weapon system functions with aircrew tasks potentially in this category: Flight control, fire control, threat warning/CM, equipment management.]

Tasks that Can be Cost-Effectively Implemented in the Time Frame Under Consideration. Current advances in control/display technology may be projected into the future, and we may predict that, by 2005-2010, we will be able to operationally field advanced devices within the constraints of tactical aircraft size, weight, and cost. In the time period under consideration, digital processing is expected to be many orders of magnitude less costly, in terms of size, weight, and dollars, than current equipment. In addition, we may confidently expect that AI languages and programming aids will make it much easier to generate complex computer programs that will be able to cost-effectively solve problems that currently require human intelligence. These advances will result in:

a. Head-up and eyes-out panoramic displays with large fields of view, high resolution, color, and, if desired, enhanced stereo depth cues.

b. Ability to synthesize "real world" imagery and pictorial tactical situation displays that recreate clear day visual perception under night and adverse weather conditions.

c. High quality voice synthesis and robust voice recognition.

d. Natural control of sensors, weapons system, aircraft flight, and display modes based on head and eye position, finger position, and other "body language" modalities.

e. Great simplification of tasks that require transfer of complex tactical situation information from the system to the aircrew, and rapid application of the aircrew's superior cognitive powers to management of the weapon system.

f. "Time shifting", an automation technique that can be applied with minimum processing and programming complexity to a large class of problems. With this technique, the aircrew makes decisions (and enables automatic actions) prior to takeoff, during the cruise phase of the mission, while hovering, or during some period when task loading is not a problem.

Performance Improvement by Task Integration, Holistic Situation Awareness, and Coordinated Control

Each of the tasks identified in the previous section (except those requiring response time beyond human capability) can individually be accomplished by a pilot; however, when many must be performed in restricted time periods, task load becomes excessive, particularly if the various tasks cross functional boundaries. A need exists, therefore, to reduce or to simplify the task constellation confronting the pilot.

Figure 2 illustrates a concept called the "virtual cockpit" that may be applicable as a scaffolding for visual integration of pilotage and system/mission management tasks while providing eyes-out posture for the pilot.

Task integration across functional boundaries should be used to give the pilot a holistic view of the current situation, and then to achieve simple, coordinated system control for each specific mission task. The following are most critical for a single pilot:

a. The pilot needs new aids to facilitate the adjustment of tactical and navigation planes enroute to meet the actual conditions encountered during a mission.

b. Flight control, target acquisition, and weapon delivery/fire control need to be integrated to yield maximum firepower and increase first pass kill probability. Rather than fly the aircraft in response to flight director command displays, the pilot should have the option of designating the target and having the flight maneuvers and fire control/weapon delivery done automatically (with manual flight override always available).

c. Inter-aircraft communications tasks for coordinated command and control of friendly assets need to be simplified.

d. Threat situation understanding and threat countermeasures tasks require integration simplification. Fusion of sensor data from multiple sources into one integrated picture should reduce the time directly spent in correlating the information from different displays, with different formats, scales, etc.

e. The pilot needs help in the rapid detection of objects that may be targets or threats. He also needs help in recognizing and classifying these detected objects and evaluating them. He is at great risk if he makes a wrong evaluation and is handicapped by the rules of engagement that require considerable information before committing to weapon use. A robust yet passive, automatic or semi-automatic IFF is badly needed.

f. The rotorcraft pilot needs more and better information to perform nap-of-the-earth maneuvers while navigating.

ANALYSIS OF AIRCREW FUNCTIONS BY SYSTEM TASK

During the next twenty years, we shall see an increase of the role of manned aircraft in warfare. Due to the development of new weapons, of new strategy and thanks to the sophistication of data link transmission and avionics airborne systems, the pilot of a combat aircraft will become more of a manager of his aircraft (through automatic functions) than a hands-on system controller. It thus becomes necessary to put at his disposal all the information which is required to help him to accomplish his mission successfully, and also to restrict his operations to the primary tasks necessary to accomplish the critical phases of his mission.

We know that a manager of a complex, multi-dimensional task like air combat often needs the aid of a well trained associate for helping him to watch and lead the aircraft. It is this image of the relation between the man and his associate which illustrates the man/machine interface problem in a combat aircraft. The man/machine assembly has functions to achieve, piloted by the man and accomplished by the machine: the aircraft has become the pilot's associate.

The object of the present section is to analyze the new functions allocated to the pilot and to deduce the implications on the cockpit engineering, in order to define some basic man/machine interface trends for the following twenty years.

Study of Basic Functions

The basic piloting functions which will be studied as they concern the trends for interfacing the man and the machine are the following:

- flying (control of aircraft maneuvers)
- navigation (localization and guidance)
- communications (voice and data link)
- utilities management
- mission management.

Flying. Modern aircraft are 'fly-by-wire' controlled. This has for the pilot a double advantage: first, the configuration of the aircraft (center of gravity location, external loads arrangement) need no longer be considered by the pilot in flying his aircraft, and second, all limitations (flight envelope) are automatically monitored, and the flight control system itself forbids any dangerous excursions.

This has involved within the cockpit a simplification of the control system (electrical side stick), but a complication of the display system. The normal flying is now "head-up", with all necessary information in the center of the pilot's field-of-view, integrated with other data.

As the reference for flying is now superimposed upon the external environment, new parameters for flying control have appeared:

- flight path (instead of longitudinal attitude)
- track (instead of heading)
- altitude
- speed.

This permits more accurate piloting, but requires high integrity of information in order to ensure flight safety.

Besides these basic flying modes (keeping the parameters at their initial value), additional modes are necessary to up-date these parameters, for instance to introduce a 2D horizontal navigation mode or a 4D flight profile management. More sophisticated modes are also integrated in the flight control system (F. C. S.) as terrain following/ terrain avoidance or automatic weapon delivery (e.g., integrated flight and fire control). Correct flying in these modes requires new dimensions for display. Whether these should be head-up or head-down is an important question, but it is essential for the pilot to have the best continuity between the head-up and head-down information.

Navigation. The navigation problem of an aircraft is in fact double. The aircraft is a platform moving in the sky in relation to ground references. Identification of the "state vector" of the aircraft is "localization" (4D position, speed, attitude); monitoring of this state vector to accomplish the different phases of the mission is "guidance."

As far as localization is concerned, it is only a utility function to initiate the flying and guidance functions; this function must be transparent to the pilot. The interface between the systems and the pilot requires very limited workload for vehicle guidance; selection of modes (sensors configuration: inertial, GPS, radio-navigation, ...) is automatic with a manual overriding possibility.

For guidance problems, if the mission does not run exactly as planned, the environment will be updated in the system either by consulting the airborne data bases or by data-link. A decision is then to be made by the pilot to choose a new trajectory with the aid of a three-dimensional display (pathway in the sky) concept. The optimization of this intricate pictorial display is critical in minimizing workload.

Communications. Without communications, no mission is possible, but with communications the data transmission flow can easily saturate the pilot. Problems of communications are:

- management
- processing of data transmitted or to be transmitted
- display to pilot.

Management must be as automatic as possible, with suppression of specific control panels. The indispensable controls will be made either by voice recognition systems, or by centralized multiplexed keyboards. For data link transmission, the pilot must choose information which directly concerns the present phase of the mission, and which must be displayed (after processing).

Utilities Management. For the pilot, the aircraft is a platform plus an operational weapon system. Utilities are the systems which ensure the availability of the platform to accomplish the different operational phases of the mission; they include:

- the engine
- electrical supply
- hydraulics
- air-conditioning
- aircraft configuration devices (gears, slants, flaps, external stores, ...).

The present trend is to introduce, for these systems, digital controls. For some of them, the integration is already nearly complete with the F. C. S. and engine, or partial with the avionics system.

The only problem for the pilot is to know the state of his platform; if a problem occurs on one system, the pilot has to be warned of the seriousness of the failure. If a reconfiguration cannot be made automatically, the pilot then needs some aids to make the correct decision (in this case, an expert system can then be used).

Mission Management. That is the essential function of the pilot. The true objective of cockpit engineering is to give to the pilot the best decision conditions to accomplish with success the successive phases of his mission. The less workload that is imposed on him to manage the platform, the more capability he will have to make the mission decisions.

The pilot has to manage more and more intricate sensors and armament. The mission environment is becoming more and more aggressive, and joint missions are more and more numerous, with the requirement of integration in complex tactical networks. In short, in spite of more and more efficient mission preparation, the pilot will be, during the major part of his mission, the only "brain of his mission." The manual workload can easily be reduced by new systems (voice recognition, multiplexed controls and keyboards, helmet mounted sighting systems, ...) but the "mind workload" will always remain great.

For the mission management function, the major problem is to select the information to be displayed, and to display it in a form which can be easily assimilated by the pilot.

A big part of the pilot's workload for mission management, whatever the mission is, consists of target designation (recognition and identification). For this function, automatic devices are available, but the final authorization of firing is always left to the pilot. The problem is then to display in the best possible form the information given by the sensor (radar, laser, FLIR, LLLTV, Helmet Mounted Sight) for use by the pilot. The pilot must be able to change the type of display he uses as easily as possible. It is above all in this domain that further research is required.

Conclusions

To achieve the increasing number of functions allocated to him, the pilot needs to have at his disposal a completely integrated flight panel.

Besides the problems of optimization and multiplexing of the control devices, particularly using new technologies like voice recognition systems, the major problem of new cockpit engineering is the display function. The primary role of the pilot (in his aircraft) is to make decisions after having quickly estimated the state of the situation.

Crucial developments concern essentially the display philosophy: "What to display? When to display? How to display?". A very big effort is required in this domain. A complete study and analysis of the tasks of the pilot is necessary, aided by in-flight recording and ground simulations.

When applying these concepts in a given aircraft, there will certainly be technological hardware problems (large field-of-view, panoramic flight control panel, flat screens, color display, helmet mounted displays ...), but also and chiefly software design problems. The major problem is to define a language between the man and the machine; the man gives orders to the machine (which is the more simple dialogue direction), and the machine must give the best aids to the pilot (which is the most intricate dialogue).

In the year 2005 aircraft cockpits will certainly have considerable improvements in instrument layout, but there will always remain a problem of language between the machine and the man. The machine will have more information and perhaps more knowledge than the pilot, but it will not always know what part of its knowledge is to be transmitted to the pilot or how to optimally transmit it. That is the problem which requires further major research.

CREW STATION DESIGN METHODOLOGY

The Problem of Crew Station Design

Three forces are at work that have implications for the design of crew stations. These forces are: (a) increased threat imposed by a technologically more sophisticated enemy; (b) increased amounts of information made available to the system by the transition to digital avionics; and (c) the emergence of software that can make increasingly more complex decisions, ones formally considered to be the exclusive province of the aircrew. Because these forces are not restricted in the individual component or subsystem that they affect, their impact on the crew station can be diverse and can be properly considered only at the level of the total, integrated crew station. In other words, at the level of crew station design synthesis.

Unfortunately, current design methods are weak in their ability to identify and evaluate system-wide attributes as part of the synthesis task. The current approach is to synthesize a crew station design out of a baseline system which has been augmented with emerging technologies believed to be necessary to meet the imposed mission requirements. This "synthesis", more often than not, occurs in a largely unstructured and undocumented manner that does not produce an explicit conceptual formulation of a total crew station. The current approach to crew station design cannot continue if workload is to remain manageable, as it is only capable of addressing workload on a local, subsystem basis and is "blind" to the need to control it on a crew system basis. Moreover, it limits the ability to infuse intelligent software in a manner that could offer maximal benefit to the aircrew.

The result is that more attention must be given to the synthesis of a uniform and global concept of a crew station. For this to occur, new methods, procedures, and tools are needed to aid the crew station designer with this task.

The advantages derived from placing more emphasis on design synthesis and the early formation of a design concept, or conceptual framework, are somewhat abstract and therefore difficult to appreciate. In an effort to clarify the matter, this section attempts to illuminate the idea through a brief discussion of the use of machine intelligence in an airborne weapon system. The basic concern is that a holistic crew station concept must be in place to guide the design of individual subsystems and components of the crew system if they are to satisfy higher-order system attributes that are made manifest only at the higher level of the total crew station.

The Man-Machine Partnership

One way aircrews view their current state and progress in a mission is captured by the expression "staying ahead of the system." This expression means that the pilot is in control of the vehicle, and that he has time to operate all subsystems and complete the tasks as they occur as the mission unfolds. As soon as a pilot perceives he is "falling behind the system" and that he cannot catch up by simply working faster, some tasks will go uncompleted. The pilot knows from training and experience that he cannot be behind the system for long before it will be out of control and he will be in a life-threatening situation.

The nature of staying ahead of the system is likely to change, when significant machine intelligence is incorporated in the weapon system. With machine intelligence, the system can think, learn and understand. Consequently, it will have the ability to anticipate pilot actions and make certain decisions. Accordingly, the pilot must be able to anticipate and understand these machine anticipations in order to work cooperatively with the system. This implies that a partnership must be formed between man and his system, one built on mutual understanding and trust. This is fundamentally different from the partnership that exists between a pilot and system that does not contain machine intelligence - here the partnership is based on control, not cooperation.

Trust and cooperation are higher order attributes of the system as a whole and are not tied tightly to any one system or component. The issue, then, is how does one build these attributes into a crew station? They are not likely to emerge from the mere integration of subsystems, unless, of course, the design of subsystems is guided by the desire to optimize these attributes in the first place. The point is, this cannot happen unless system and crew system level attributes have been properly identified and prioritized at the outset.

Machine Intelligence Example

To reinforce the point, it is valuable to review recent work in the development of digital avionics super-subsystems. For example, there is a major effort to integrate the flight control subsystem with the propulsion and fire control subsystems. In this effort, it has been recognized that a global architecture is needed, one that considers properties of the super-subsystem as a whole. For example standards have to be established for processing formats, bus structure and other things. By formulating a total architecture first, the integration of components can be made more complete. The entire super-subsystem, for example, could share processors, memory storage, and other components. As a result, the design of a super-system could be simpler and offer an improvement in system level reliability and maintainability (R&M), even though this advantage of the synthesized design may not show up in the current figures of merit used for R&M, since they are based on data from individual components.

What Methods and Tools are Needed?

At least four different types of aids to design synthesis are needed in the conceptual stage of development. The first consists of methods that can be used to formulate appropriate super-subsystem or higher level concepts, to identify the "system-level" attributes that capture salient aspects of the concept, and to critically analyze the concepts and attributes. The analysis method would permit the performance of sensitivity analyses with respect to different mission conditions, trade-off studies to prioritize the attributes, and other analyses that would help clarify what should be used to guide the design of subsystems and components.

The second type of methods focus on elaborating and representing the attributes, both local and system-level ones, in ways that facilitate the construction of a process architecture. This may include the use of both static and dynamic representational techniques that reveal inter-dependencies among attributes and suggests approaches that can be taken to handle potential conflicts. The representations must also demonstrate that system-level attributes emerge from the process network structure, and provide the material needed to evaluate alternative networks in this regard.

Another set of methods is needed to elucidate what standards (e.g., data format, timing codes, etc.) are needed and what form they should take. It is possible that part, if not all, of this task can be achieved with the aid of good representational methods.

Finally, a new class of evaluation methods is needed. In the area of crew station design, these methods must be able to assess things like decision quality, situational understanding afforded by the crew station, aircrew trust in the system, and crew workload. To be of greatest value, they should also identify the factors that most noticeably impact these "system-level" attributes.

Conclusion

The lack of a well-developed set of crew station design methods that focus on crew station synthesis in a holistic fashion is a severe short-coming. We are just now beginning to more fully appreciate that a holistic approach may be essential to the effective exploitation of emerging interface technologies; hence, a complementary development in this area of methods is needed.

MAN-MACHINE INTERFACE EQUIPMENT

Projected Capabilities of Display Techniques For Aircraft Use

Around the year 2000 aircraft displays will be not only windows on the status of flight but also vital in the decision making process during certain states of a mission. Especially during those phases with a high pilot workload, the mission and aircraft data must be formatted and displayed in such a way that the quality and the rate of information to be extracted by the pilot is sufficient to arrive at major complex decisions within 2 to 5 seconds without exceeding the pilot's peak workload capacity. In some cases this also implies that the pilot must delegate some of the lower priority (but still important) decisions to an automated device without risk of conflict. The displays should also enable him to evaluate such risks.

The display(s) must be ergonomically satisfactory, i.e., free from ambiguous artifacts pertaining to the display technology and capable of displaying static and dynamic information under strongly varying environment (especially visual) conditions. Presently the only programmable display device capable of meeting such requirements is the cathode ray tube, but its size is limited to about 100 x 100 mm. It is expected that the new generations of aircraft need display sizes affording medium field of view (e.g., size 300 x 200 mm) to wide field of view (panoramic). This excludes the conventional CRT, if only for bulk and weight. New CRT designs may emerge to satisfy the medium field of view requirement. Other flat panel display technologies are being considered for wide field-of-view.

Display Characteristics Required

Images coming from different sensors have different formats and resolution. As a result, there is a need for format conversion where the sets of picture elements (pels) are brought under a common denominator to be processed by the computer and shown on a display which is composed of a number of display elements (dels). The del density must match the highest (meaningful) local pel density.

The del density also must satisfy ergonomic requirements. Taking eyeball movement at plus and minus 12°, eye resolution at 0.5' and viewing distance 700 mm, the display size should be 300 mm at 3000 dels. Such a screen would comfortably accommodate maps, sensors data and images, systems status and other communications.

In aircraft applications, the image processing properties are mainly determined by acceptable errors in moving symbology. Fast moving lines break up in raster scan format, thus frame information must be frozen, and the accepted rate for fusion is about 60 Hz. This coincides with conventional TV rate, although interlaced fields may not be acceptable.

The bandwidth of a 3000 x 200 display, non-interlaced, refreshed/updated at 60 Hz, is greater than 360 MHz depending on a required pulse rise/fall times, a figure which 10 years from now will not present problems in operational systems. Even 100 Hz frame rate can be accommodated when required for (high light output) flicker suppression in peripheral view.

High del density displays are required for crew functions usually located in the instrument panel and that require high cognitive information. A lower degree of overall accuracy is needed when a crew member uses pre-attention perception capability, which is much faster than cognition but has very limited subject range (prefocussed). The display should be formatted to provide the required accuracy when and where needed by the phase of the mission, e.g., in the direction of view (head up), possibly collimated to match the outside viewing distance and providing necessary flight cues in the peripheral view.

Presently it is considered that such displays should have a very wide field of view; helmet mounted displays seem to be the only viable solution. The techological difficulties associated with such engineering options are enormous, considering the still very high del counts resulting from the large viewing field even at low del density, combined with the requirements of low mass and freedom of movement of the pilot.

Image Sources, Resolution and Processing

The resolution of imaging sensors depend on the nature of their operation (e.g., SAR vs FLIR) and on the intrinsic resolution afforded by the energy carrying medium (wave length). Presently the upper bound of any single sensor is 100 dels across the direction of flight; this bound is not expected to improve dramatically over the next two decades, except for sensors operating in the visual range.

However by intelligent fusion of different sensors, including 1-D sensors and on-board databanks, resolution improvement can be engineered to make full use of future display capacity. This requires large and extremely fast computing power. To a certain degree this is also true to make full use of artifically generated images (digital maps, mission scenarios) in combination with sensor driven graphics (e.g., new flight directors such as pathway in the sky, optical flow information).

Presently computing power is being increased through the use of improved technology which permits higher densities per chip area and shorter switching times per transistor. In image processing the computing power can be further increased by taking advantage of the 2-D/3-D nature of the data and using appropriate parallel computing methods. Also promising is the application of optical (both analog and digital) computers, although the interface to the display still remains a bottleneck.

At the display face itself one may engineer resolution improvement (by a linear factor 2 to 3) by the use of optically computed interpolation values, a method which would be very cost effective.

Display Technologies

Serious contenders of instrument panel displays with high del density (100 per mm^2) should be available for operational use by 1995. At present such forecasts are hazardous, given the limited funds allotted to their development for aircraft use. Large size plasma, light valve and laser displays are available for command and control rooms; it is doubtful whether the plasma display can meet the 10 del per mm objective. Table 1 lists the technologies under development with the estimated del density by 1995. Ratings are +:5, to 10, 0:2 to 5, -: lower than 2 per mm.

Table 1

Technology	del density
flat CRT	+
vacuum florescent (VFD)	0
laser display (LD)	+
light emitting diode (LED)	0
plasma display	0
liquid crystals (LCD)	+
light valve display	+
electro-chromic display	-
electro-phonetic display	0
high speed electro-mechanical	-
electro-luminescent displays	0

Apart from high del density, panel displays must provide a number (max 32) of recognizable contrast (mixture of brightness and tint) levels, with a minimum of five maintained under strong incident light conditions. The color palette can be small, e.g., five. Update rate must allow fusion of successive images of moving objects/images--recommended is an update rate >50 Hz. Light output shall be dimmable over a large range, say 10^4, while maintaining dominant viewing characteristics. Preferred sizes range from 100 x 100 mm^2 to panoramic, but in the next 20 years the maximum size of a single panel probably is limited to 300 x 200 mm. Operational useability of several flat panel technologies also depends on suitable device drivers.

The helmet mounted displays are in the trial stage using CRT and LED devices. Currently a 1000 x 1000 del image is possible. The WFOV requirement is easier to realize because of the more favorable optical arrangement. The del count should be increased by one order of magnitude unless variable resolution techniques are feasible and become realizable.

The HUD could be combined with the WFOV display. However the HUD, driven by a monochrome source and with extended field-of-view is judged to be satisfactory over the next two decades.

In the following Table 2 the major display parameters are compared for the 11 technologies.

Table 2

	del density	contrast	update rate	light output	dimm-ability	grey levels	color	size small	size large
FLAT CRT	++	+	++	++	++	+	++	++	++
VFD	+	+	++	+	++	+	+	++	-
Laser	++	++	++	++	++	++	-	++	++
LED	+	++	++	++	++	++	+	++	-
PD	+	++	-	++	-	-	-	++	++
LC	+	+	-	na	na	+	+	++	+
LV	+	++	+	++	++	++	+	+	++
EC	-	++	--	na	na	--	--	++	-
EP	-	++	--	na	na	--	--	++	+
EE	-	++	-	na	na	--	-	++	++
EL	+	+	-	+	-	-	-	++	++

The Use of Voice Systems in the Cockpit

Visual signals are spatially confined. One needs to direct the field-of-view to the mm. Moreover, in high workload phases of the mission, attention can be focused on some types of visual information such that other information which suddenly becomes important can be "overloaded." Also the amount of information may saturate the visual channel capacity. Aural signals have the advantage of being absorbed independent of visual engagement, while man's information acquisition capacity is increased by using the two channels simultaneously. Motoric skills are hardly affected by speaking. For information being sent from aircrew to other humans on the ground and in the air, speech is a natural and efficient technique which has been used for many years. Until now the process of aural communication between aircrew and systems has been usually restricted to a limited range of warning signals generated by the systems.

Digital voice synthesis devices are now widely available and have many commercial applications. There appear to be no problems technically in using them in aircraft to transfer data from aircraft systems to aircrew. The real difficulty is in identifying the types of message which are best suited to this technique. Warning messages currently appear to be a particularly useful application, although these will probably need to be reinforced by visual warnings as aircrews can totally miss aural warnings under some conditions. Feedback of simple numerical data is also being considered.

One of the main disadvantages of aural signals is that the intelligibility is greatly impaired by noise in the cockpit. However, the understanding of the mechanisms of speech synthesis and speech recognition has reached the point where voice systems in the cockpit can be considered. Although electronic voice recognition in the laboratory reaches scores of 95 to 98% (comparable with keyboard inputs), the vocabulary is still very limited and recognition tends to be personalized. But the prospect of logic manipulation in AI techniques can greatly improve the situation to depersonalize recognition in noisy environments. Actual data on such improvements are not available to this subgroup. These would also depend on how much redundancy is used in both syntax and semantics. Furthermore a coding "language" is to be preferred, just as in conventional A/C radio communication, to prevent the system responding to unvoluntarily uttered (emotional) exclamations.

Several commercial voice recognizer systems are currently available on the open market, but these have not been designed for airborne application, and considerable development will be needed before they can be regarded as usable for combat aircraft. Simulator and airborne trials in a number of countries using this early equipment have identified the following as key areas in which further investigation/improvement is required:

a. Size of vocabulary. At present this is very limited, but recognition performance is generally inversely related to vocabulary size.

b. Background noise/distortion. The cockpit environment is frequently very poor, and the aircrew oxygen mask and microphone are far from ideal.

c. Necessity for pre-loading voice signatures. Current systems have to be loaded with individual voice templates. Consequently, if aircrew voice changes (e.g., under stress), recognition performance is reduced. Moreover some subjects have a much greater natural variability in their voices than others.

d. Continuous speech recognition. Most early systems can only recognize isolated words, whereas in natural speech the speaker frequently allows one word to flow continuously into the next.

e. Recognition Performance. Even under ideal conditions, recognition scores are always less than 100%, and under bad conditions with poor subjects the scores may be only 50-75%. Thus it is currently necessary - and probably will continue to be so - to have some form of feedback to confirm to the speaker that the message has been correctly "captured."

In summary, trials with first generation voice recognizers have produced encouraging results, but the need for significant improvements has been identified and these are now being explored. It is really too early to give an exact estimate of the extent to which voice recognition techniques will be used in future combat aircraft, but there is considerable promise that a valuable new interface channel can be developed. First applications are likely to be in areas where 100% accuracy in data transmission is not essential, and where an alternative form of data input is also available to aircrew.

ADVANCED AUTOMATION TECHNIQUES

The Concept

Within the general scope of "advanced automation" is implied a concept of increased computational capability embedded in the systems suite of future aircraft, to the extent that computers are carrying out functions generally considered to be beyond the purely determinate processing of numerical data and are concerned more with judgment, assessment and decision-making. The U. S. "Pilot Associate" program is an example. Whether such computer-based systems are classified as "artificial intelligence" is a question of semantics which is not of real significance. What is important is that the availability of this new capability implies that the interface between it and the aircraft (which will generally consist of a single pilot) must be re-assessed and re-optimized.

Types of Interface

The two types of interface technology (visual displays and voice interactions) described in the last section are both potentially available for communication between a pilot and a pilot associate. The standard interfaces of the normal push-button computer input and perhaps touch-screen input must be added to the list. These are, of course, the types of interface which will already be available in the cockpit for use with existing types of avionic systems, and that provide information such as navigation, weapon aiming and other systems data. The pilot will be operating the aircraft using a mental model of the whole aircraft/outside world situation based on the displayed information. Thus the additional advices and warnings provided by the "pilot associate" are probably best overlaid upon the conventional systems so that they are perceived by the pilot as fitting naturally into his existing mental framework. Thus, for example, it may be envisaged that warning of some external threat, or advice to the pilot concerning a suggested route to minimize exposure to threats, would both be communicated to the pilot by appropriate symbology overlaid upon a map display or upon a perspective display of the route ahead. It will, however, be important for such displays to clearly distinguish between "hard" information, i.e., data known to be accurate or certain with a high degree of probability, and information derived from the "pilot associate" which may represent judgments based on inaccurate or incomplete information. Ideally it may be desirable to provide some indication of the estimated reliability of displayed data, and if possible an "explanation" of the rationale for some recommended action.

Currency of Data

One type of computer-based technique for constructing a pilot associate is the IKBS (Intelligent Knowledge-Based System) or Expert System, which forms judgments based on a knowledge of previous situations learned from interactions with "experts", together with a knowledge of the current situation. If the "pilot associate" is to make decisions or recommendations which are consistent and acceptable to the pilot, it is necessary that both the pilot and "pilot associate" should have knowledge which is itself as consistent as possible. This implies particularly that information updates generated by the avionics systems (e.g., navigation, EW, Comms, etc.) should be simultaneously displayed to the pilot and provided to the "pilot associate."

Initial Applications

Although opinions differ on the speed at which the techniques encompassed in the concept of a "pilot associate" will be incorporated into military aircraft, there seems little doubt that appropriate technology will become available and will be so used. Three separate considerations currently appear to be significant in attempting to estimate the speed of advance in this area. These are:

a. The development of appropriate computational hardware and software.

b. The build-up of knowledge bases sufficiently complete for practical application in the complex environment of a military scenario.

c. Acceptance by aircrew of the concept.

Of these three, the first is the only one in which it can be confidently predicted that sufficient progress will have been made to allow incorporation into in-service aircraft by 2005. Rate of progress on two and three depends essentially on investment in research and development programs which will be largely specific to the military aircraft application. For three in particular, a degree of trust must be built up which may well take several years. For this reason it appears likely that initial applications will be in non-critical decision-making areas such as cross-checking the performance and behavior of complex on-board systems. There is, however, the opposite view that pilots will be most ready to accept "pilot associates" in highly critical roles which are clearly beyond human capabilities, and where use of such systems is probably the only means of survival in very hostile situations. Three possible applications are currently identified as primary possibilities for on-board application by 2005:

a. Assessment of status of performance of on-board complex interactive systems (to be presented to the pilot by display).

b. Assessment of threats, external to the aircraft and within a complex tactical scenario, with possible threat avoidance action to be taken (to be presented to the pilot by display).

c. Assessment of threat situations in a time less than a pilot's response time, and initialization of response action.

It must be emphasized that c. above, being an essentially automatic task, would in general only be allowed if previously "enabled" by the pilot. In particular any coupling of the output of a complex threat assessment computer directly into a high authority aircraft flight control loop would be acceptable only in highly hazardous situations and with clear pre-enabling by the pilot. Indeed, a general rule for the application of this technology would be that in all circumstances a pilot must be able to override the automated system.

TRAINING AND GROUND EQUIPMENT

New Situation Techniques

Simulation is undoubtedly an effective and efficient method of training aircrew. However, not all learned skills transfer well from simulator to aircraft. Transfer of training is generally greater for procedure-loaded tasks than for perceptual-motor tasks. Many of the visual and kinesthetic cues required by pilots to perfect perceptual-motor skills cannot be reproduced with sufficient fidelity in state-of-the-art simulators.

The degree of realism required in a simulator will depend on the nature of the task and on the level of experience and expectation of the student. While high fidelity systems may be required to develop and maintain operational flying skills, relatively simple part-task trainers can be used effectively to teach basic procedures and routines.

Experience with current aircraft indicates that the impact of advances in avionics can have an adverse impact on crew workload, and when not properly applied, can result in capabilities being built into aircraft which the operators cannot use. The simulation of peak-workload scenarios may be the only effective means of enabling crews to practice and gain experience with all system modes of operation.

Recent improvements in motion platform performance (e.g., increased operational excursion limits and reduced time lags) have resulted from the introduction of hydrostatic-bearing and improved servo-valve technology. In the foreseeable future, it is not anticipated that system excursion limits, and hence motion magnitude or duration cues, will be increased further.

Future military simulation requirements for both tactical and strategic missions involving the simulation of natural terrain over extremely extensive gaming areas will utilize very large amounts of digitized source data. The associated on-line CGI system data bases will require highly automated transformation routines employing VLSI techniques, programs to generate curved surface fits to the terrain data, and sophisticated texture mapping systems.

Development of the area-of-interest concept appears to have potential for solving the problem of presenting high-resolution wide field-of-view displays. The technique is based on the fact that only a certain part of a visual field, that which is subtended by the central cone of the foveal retina and within which the observer has the greatest discriminatory capability and visual acuity, need be displayed with high resolution and detail at an instant. The detail and resolution of the remainder of the field may be degraded significantly due to the reduced discrimination capability of the peripheral retina. The imagery representing each of these portions can be manipulated in response to target location, head and/or eye movement. This approach presents challenges with respect to head and eye-position tracking.

The dynamics of the perceptual cues experienced during flight simulation frequently produce symptoms of motion distress: dizziness, disorientation, pallor, increased perspiration, visual flashbacks, nausea, emesis. Simulator sickness, as it is generally termed, has been experienced by pilots in both fixed-base and moving-base simulators. Experienced pilots tend to be more susceptible than inexperienced trainees.

Experienced pilots have a well established neural store based on observed relationships between manual control inputs, visual dynamics, and the orientation and inertial sensations produced by the vestibular and proprioceptive systems. To the extent that a flight simulator violates these sensory expectations, a sensory conflict results that is accepted as the primary contributing factor to simulator sickness. This conflict is probably reinforced by the more compelling visual sense of motion experienced with wide field of view displays and/or with greater scene detail, and particularly by large discrepancies in the temporal relationships between motion and visual cues.

Unpleasant symptoms experienced in the simulator may compromise training through distraction and decreased motivation. Behaviors learned in the simulator to avoid these symptoms (e.g., reduced head movement, avoidance of aggressive maneuvers) may be inappropriate for flight and result in a negative transfer of training. Also, simulator users may be reluctant to continue training because of the unpleasant symptoms. Moreover, the adaptation that may occur to a simulator's motion and visual display characteristics could be counterproductive in training-for-mission if simulator adaptation increased susceptibility to disorientation during flight for a period after a simulator session.

Embedded Training

Some of the problems described above may be alleviated by the concept of embedded training. This concept takes advantage of the extensive capacity for data-processing and data-transmission in modern aircraft, together with advanced, flexible displays in the cockpit, which can form the basis of a simulator for aircrew training. Thus with the aircraft on the ground, but coupled up to some additional data processing and possibly with some add-on real-world display for the pilot, a realistic simulation of many pilot tasks can be made. Recent developments in area-of-interest displays mounted on the helmet give promise that they could be used in this role.

Such embedded training methods would also be used in the air. An example of this might be the simulation of a fairly hazardous low-flying task with the aircraft actually flying at a safe height but using displays and data appropriate to flying close to the ground. This is an extension of a technique already used for crew-training in ASW aircraft in which synthetic target data is fed into the aircraft's data system during training flights.

Mission Briefing and Planning

The simulation techniques described in the above sections are generally aimed at generating crew skills for a generalized mission. In addition, it is essential that aircrew be provided with data which is specific to individual missions; this process is generally called briefing. But the briefing process is closely coupled to the iterative process of determining the optimum route planning for a specific mission task, and this in turn relates closely to the pilot's perception of his task during the mission.

The availability of modern simulation and data processing techniques provides an opportunity to re-examine this whole area of mission analysis and briefing. It is feasible that simulators (dedicated or embedded) could form a vital tool for optimizing mission routes, taking account of terrain profiles, enemy defenses, target positions etc., as well as pilot workload. Such a re-examination would need to take account of the likely NATO air warfare scenario in which very short briefing times may be required in order to minimize sortie rate. It should be taken into account the desirability that briefing data be rapidly transferred from the briefing equipment to the aircraft with the minimum of aircrew participation; solid-state digital storage devices and high-speed data links should provide suitable mechanisms for such data transfer.

CONCLUSIONS AND RECOMMENDATIONS

The consideration and analysis described in earlier sections of this chapter lead to the following primary conclusions and recommendations.

1. The new technologies have the potential to improve air warfare capability, but only if the crew-system interface is properly implemented. If the new technologies are misapplied in the interface area, an overall degradation of performance will occur. To prevent this, improvements in crew-station design methodology, including tools, are needed.

2. In the timeframe to the year 2005, most types of aircraft will require the presence of human intelligence and the ability it confers to exercise judgment and deal with unexpected situations. But because of the vehicle, system and operational costs of carrying crew in air vehicles, together with fundamental limitations in human performance, there are strong reasons to develop unmanned air vehicles. There is a need to examine the scope for such vehicles and to identify the scenarios in which they can be effective.

3. The technology of "Artificial Intelligence" will probably be sufficiently mature by 2005 to significantly improve pilot workload, if applied properly. Applications will include automatic decision-making and pattern recognition. It is clear, however, that the cognitive/behavioral sciences should have more impact on the development process to ensure that the technology is properly applied to the cockpit interface.

4. Automation is necessary in the attack phases of a mission to reduce the time from target/threat detection to weapon delivery. The pilot needs rapid assistance in the recognition and classification of threats. He should be able to designate targets, select weapons and fire without taking his eyes away from the outside scene.

5. An important improvement for the reduction of pilot workload at critical mission events is the fusion of sensor data from several sources into one integrated picture with common scale and compelling formats to provide situational awareness.

6. Eyes-out-of-the-cockpit display and control technology advances are critical to the success of future combat missions. Additionally, in the given timeframe, there is a requirement for color displays of improved resolution.

7. Attention needs to be paid to the automation of mission planning and to the use of embedded training either pre-flight or in-flight. There is a problem in maintaining a current real-time data base of terrain, target and threat information.

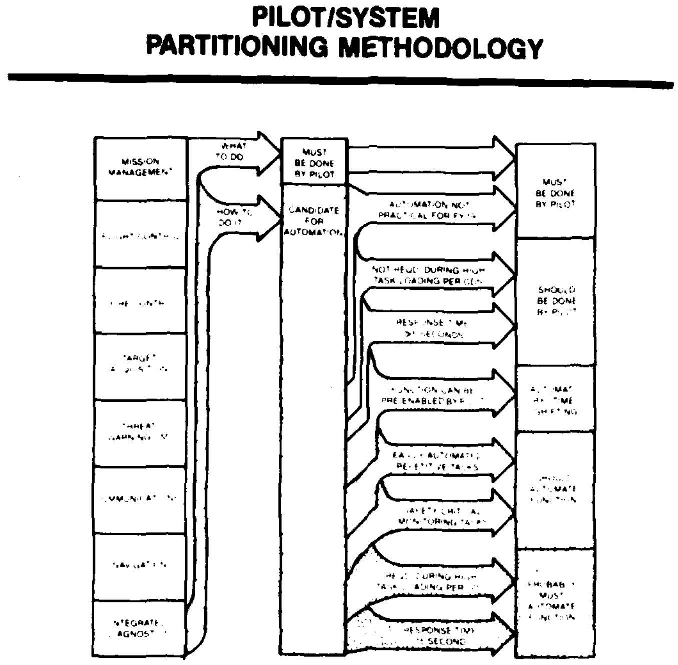

Figure 1. A methodology for deciding what cockpit functions to automate.

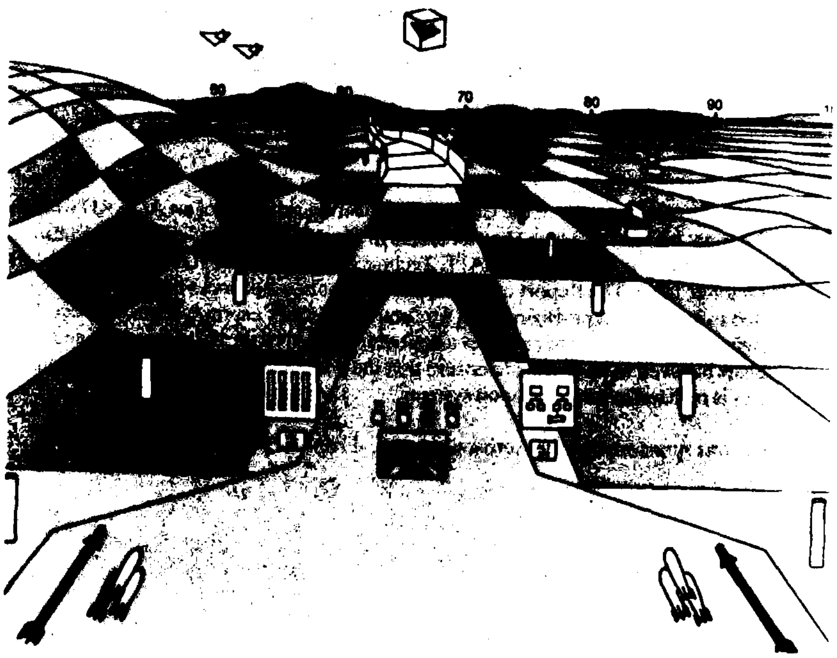

Figure 2. An example of a virtual cockpit. Mission, flight control and system status information are all available on a single virtual space display.

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14. Abstract

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This Report was sponsored by the Aerospace Medical Panel of AGARD.

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