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Final Report On Biotechnology Research Requirements For Aeronautical Systems Through The Year 2000

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PREFACE

The purpose of this study session was to identify basic and applied life sciences research needed to support Air Force aeronautical systems that could be in development or operation in the year 2000 and beyond. This research should serve both near and far term goals.

Technological advances applied to vehicles and their weapons, the quantity and rate of information flow through the cockpit, and the environment in which the pilot will operate can all be expected to produce high stress missions which will call for extending human performance. These same technological advances may aso present new burdens on elements of the command and control system, posing new demands on ground or air based command systems due to increased information flow and the necessity for command decisions in real time.

A mission can be considered high stress when the demands imposed on the crewman approach his capacities; this generalization applies to such diverse demand-capacity relationships as strength, sweat production, maximum cardio-respiratory fitness, cognitive processes and visuo-motor reactions. When high stress occurs as a result of a mismatch between the capacities of an individual and the demands imposed upon him, there are really only three classes of solution:

(1) Modify the man,
(2) Modify the equipment, and
(3) Modify the task demands.

The biotechnology chapters of this report treat all three of these approaches, as appropriate. The purpose of the study is to identify those key areas in which research is required concerning human protection and capability enhancement, and to suggest the questions to be asked and some approaches which appear promising.

The answers to these questions will guide the matching of pilots to vehicles and influence the very nature of the Air Force pilot's role in the year 2000 and beyond.

This study brought together engineers and biotechnologists to discuss the problems of the year 2000 aircrewman. The engineers in their Engineering Core Committee, examined the trends and possible developments in airframes, power plants, weapons, avionics and threats that could be in operational aircraft or included in aircraft under development by the year 2000. The Engineering Core Committee prepared, as a result of these discussions, a set of mission profiles for tactical, strategic and other missions. These missions, discussed in Chapter 1, were presented to and discussed with the Biotechnology Core Committee in a joint meeting at Southwest Research Institute in September, 1981.

The Biotechnology Core Committee, after study of these recommendations, identified six (later expanded to seven) areas of biotechnology that would be most affected by hardware developments and the changes in mission requirements. The Biotechnology Core Committee selected additional experts to serve on study groups for these six areas of biotechnology at a Study Session held in San Antonio in January, 1982.

These study groups were charged with identifying the specific research issues that must be addressed by the Air Force to meet the biotechnology requirements of the year 2000 aircrew. Further, a plan for pursuing these research topics was to be developed. The results of these study groups' efforts constitute this report.

Biotechnology is such a diverse and complex field that any one of the selected study areas could have warranted its own, individual report. To best serve the aircrew, however, they must be considered together so that a properly integrated system of support, control and communications can be provided that enables the aircrew to optimally perform its mission.

Because of the volume of material needed to fully address the recommended research, this report is presented in two parts. Volume I is a summary overview of the aeronautical systems of the future and the biotechnology research required to meet the needs of the aircrew. Volume II discusses each of the study areas in the detail needed to justify the commitment of resources to the solution of the identified problems.

ACKNOWLEDGMENTS

This report is the result of the efforts and enthusiastic participation of a diverse group of biotechnologists and engineers drawn from academia, private business, government and the military. We gratefully acknowledge the following committee members for their contributions. The full names and addresses of these participants can be found in Appendix A.

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ABSTRACT

This report discusses the basic biotechnology research problems that require solution by the year 2000 to ensure optimum performance of manned Air Force aeronautical systems. The projected aeronautical systems for strategic, tactical and support systems are discussed, with emphasis placed on the roles of increased automation and information processing, as well as the increased physical stress of higher performance aircraft, extended mission durations and new weapon threats. Six generic areas of biotechnology are considered along with the research needed to address the needs of the year 2000 aircrew. First discussed is the human-machine symbiosis needed in systems that will become extraordinarily complex in the future. This is followed by the related needs in developing improved human-machine information interfaces that avoid overloading the human operator or pilot. Many missions of the future will be unforgiving and of high intensity. The problems and research needed to deal with the increased stress and to protect and enhance the aircrews' performance during these missions are discussed in detail. The report discusses how simulators can be advanced to provide not only better training for aircrews but also how they can be used in the development of new systems for optimizing the human-information-machine relationship. The increasing complexity of aeronautical systems discussed early in the report is complemented by a chapter on crew selection and enhancement. More care and better techniques are needed for selecting candidates for each aircrew position and for enhancing their capabilities in order to maximize their potential for successfully accomplishing their missions. The report is completed by chapters on the problems and research issues facing the aircrew who must operate in chemical and biological warfare environments and in radiation environments.

The breadth of topics covered in this study required that the report be published in two volumes. Volume 1 is a very brief summary of the research issues and the proposed research plan. Volume 2 provides, for the interested reader, a more detailed discussion on the background and proposed solutions of each of these research issues.

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INTRODUCTION

From the beginning of recorded history to the present time, man - in one fashion or another - has played a key role in the performance of the weapon systems at his disposal. Initially, his physical capabilities were the critical factors in his role in the weapon system; now, however, his decision-making abilities have become equally important. This change has been evolutonary, therefore, existing systems do not necessarily take full advantage of man and his unique skills. This shortcoming has been triggered in part by the absence of a sufficient biotechnology base to allow informed improvements in system design to be made in concert with other technological advances. Acknowledging that there are no truly unmanned weapon systems and that it is vital to have the proper data base to prescribe the correct role of the human element in emerging weapon systems, the Air Force Office of Scientific Research established a study group to examine the state-of-the-art and to forecast the biotechnology research requirements for aeronautical systems that could be in development or operation by the year 2000 and beyond.

Definition of the Problem

Stated simply, technology threatens - in its present form - to outstrip man's ability to cope on both a physical and mental level. For example, new power plants and materials have made possible aircraft that can sustain high G-loads that exceed man's tolerance; protection of man from various threats produces physiological stresses that overwhelm the body's normal defense mechanisms; and avionics technology has produced the capability to generate information with a data rate that easily saturates the comprehension and decision-making ability of the human system's elements.

An understanding of these overloads, implicit in future engineering developments, and definitions of those research strategies required to make maximum utilization of both human and technological capabilities in future aeronautical systems are the concerns of this study.

Scope of The Study

Biotechnology requirements are, by their nature, broad. In order to establish some limits, these requirements have been bounded by consideration of engineering technologies thought to be available by the year 2000 and by consideration of the various types of aeronautical mission scenarios that these engineering technologies would make possible. The following topics will be addressed:

(1) Complex automated people/machine systems,
(2) Information interface,
(3) High intensity, unforgiving missions,
(4) Simulation,
(5) Crew selection and enhancement,
(6) Chemical/biological threats, and
(7) Radiation environment.

Space systems *per se*, while they will be extremely important in the time under consideration, are excluded from consideration in this report.

I. AERONAUTICAL SYSTEMS PROJECTIONS
1990-2020

I. AERONAUTICAL SYSTEMS PROJECTIONS 1990-2020

This section summarizes the conclusions of the Engineering Core Committee(1) that were used by the Biotechnology Team to define areas of emphasis for new Air Force programs.

The Engineering Core Group made special presentations on possible future weapons, propulsion systems, control systems, electronic systems, total aircraft concepts and new potential missions.

A series of mission and crew interface matrices (Table 1) was developed assuming that new aeronautical systems would use the known or contemplated technologies available within the next several decades. These matrices provided a basis for the new research emphasis outlined in this volume.

Since many of the missions shown in Table 1 and the burdens on crew and support personnel are similar to those now in being, no major deletions are suggested from the programs now being pursued by the Air Force. The new aerospace systems technologies, primarily in electronics, permit better and more nearly real-time target acquisition. This, coupled with more capable communications, computation and presentation techniques, presages a glut of "needed" information. The man-information interface is probably the single most important future challenge since this potential mass of information promises to overwhelm present concepts of decision making to support Air Force missions. This prime problem, plus others noted as new or growing crew burdens on the matrices, suggest that:

(1) Biotechnology programs will be needed to determine the most useful presentation and training techniques to handle more and higher data rates than in the past for real-time decision making. It seems clear that support from crew members, other than the pilot, must be defined and substantially augmented for many missions.

(2) Information presentation techniques must also be explored so that quick, useful decisions can be made in a minimum time. These presentation schemes should not be limited to the cockpit. To be effective, command and control centers (whether airborne or on the ground) must include advanced data displays with computer created alternative responses to enemy actions and system degradation. Massive expansion in the ability to acquire and present information will require new ways to present this information to the air crew; also, it will involve new concepts and research for ground (command) data presentation. Nuclear, radar, I.R. and defense mechanisms of all varieties will increase dependence on unmanned or standoff systems. This will require presentation of battle status, target location and condition, and the identification and location of friendly forces to command control elements. The ability of the presentation to maximize the use of command judgment should be the target of a thorough biotechnology effort.

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(1) See Appendix A for members.

TABLE 1

Aeronautical Systems Mission Profiles
1980 - 2000

TACTICAL SYSTEMS

Mission Function	Duration	Alt.	Exposure	Environment	Mental Burden	Special Notes
<u>Offense</u> Deep interdiction	< 5 hrs (max. penetration time ≅ 1.0 hr)	< 10,000'	Air-air & grd-to-air weapons, EMP, CW, dirt in air, radiation laser*	Low-alt weather	Self-defense Target acq. Weapon selection	Adequate intelligence & 3rd party direction* Man-info interface*
Battlefield interdiction	< 4 hrs	Minimum to 10,000'	Same as above plus guns	Same & CW, laser*, intense G, radiation*	Same plus mobile target acquisition	Same except smaller moving targets
Close air support	< 3 hrs (multi-mission)	Same	Same as above	Same as battlefield interdict. plus air dust	Same as in interdict. plus multi-mission fatigue	Same plus friend & foe decision
Counter Air	< 5 hrs	Minimum to 60,000'	Air to air, EMP, radiation, laser*	Weather	Self-def. target acq. friend & foe	Potential 3rd party direction & automation*
<u>Defense</u> Counter Air	< 3 hrs (multi-mission)	Minimum to 60,000'	Air to air, EMP, radiation, laser*	Weather	Self-def. target acq. friend & foe	Potential 3rd party direction (AWACS-like)* automation*
Air battle direction	12 hrs airborne*	40,000'	Air to air, EMP, radiation, laser*	Weather	Boredom + complex game coordination	Developing mission: performance shown utilizes near term technology
Air mission direction (data link platform)	60 hrs airborne*	30,000' to 80,000'	Air to air, EMP, radiation, laser*	Advanced fuels	Boredom, physical sustenance	Developing mission: peformance shown utilizes 1990-2000 technology
<u>Reconnaissance</u> Normal concept	< 5 hrs	< 10,000'	Same as interdiction	Same as interdiction	Self-def. target acq.	Potential automation except self-defense*
<u>C^3I</u>	< 10 hrs	50,000' to 90,000'	Benign, but radiation possible	Benign	Adverse takeoff/ landing conditions	Source of requirement for chess player: performance shown utilizes 1990-2000 technology

*New or growing impact on crew.

TABLE 1 (CONT'D)

Aeronautical Systems Mission Profiles
1980 - 2000

STRATEGIC SYSTEMS

Mission Function	Duration	Alt.	Exposure	Environment	Mental Burden	Special Notes
C^3I data link platform	60 hrs airborne*	30,000' to 80,000'	Hi priority target Air to air, EMP radiation, laser	Advanced fuels	Boredom, physical sustenance	Performance shown utilizes near term technology
Offense Crew readiness (simulation)	Waiting limit daily-hr's	Simulu-lation	CW/BW base attack nuc. attack, simu-lation of readiness	Controlled	Complex learning, boredom, motivation	Present problem
Standoff	≅ 50 hrs: no relief*	1500' to 40,000'	Air to air intercept	Complete silence* or loss of communication Refueling	Indep. hi-responsib.* Self def.* Return base question-able*	Long duration*
Penetration	24 hrs: no relief* (actual pene-tration ≅ 2 hours)	0-400' & 60,000' & above, pop-up maneuver semi-orbit	Air to air, ground to air, guns, radiat., laser, *Terrain* avoidance	Refueling, Complete silence* Rough ride	Same as standoff plus terminal navigation recognition*	Roughness & maneuver after long duration*
Ballistic missile launcher	50 hrs: no relief	30,000' to 50,000'	Radiation, EMP	Benign	Same as stand-off	Long duration*
VTOL: ballistic missile launcher	< 2 hrs in air, 12 on ground*	0 to 30,000'	Benign EMP & RAD (escape)	Benign	Responsibility, boredom	Potential unusual pilot position.* (Standing for takeoff & land, supine cruise)
Reconnaissance	24 hrs: no relief	Same as penetration	Same plus solo mission	Same as penetration	Same as penetration	Same as penetration
Reconnaissance	Sub-orbit and multi-orbit	>100,000'	Space based laser	Hi-G, long dur. launch & landing	Automated	Same as Space Shuttle

*New or growing impact on crew.

TABLE 1 (CONT'D)

Aeronautical Systems Mission Profiles
1980 - 2000

SUPPORT SYSTEMS

Mission Function	Duration	Alt.	Exposure	Environment	Mental Burden	Special Notes
Defense Advanced early warning	≅ 50 hrs*	30,000' to 70,000'	Mild	Completely silent	Self def.* Hi responsib.* Commands intercept*	Automated intercept* Manned t.o./landing
Intercept readiness	Max. 12 hrs alert	30,000' 70,000'	Normal intercept	Normal intercept	Normal intercept	Present problem
Tactical airlift	< 10 hrs multiple missions	50' to 30,000'	Radiation, laser*, small arms	Heat-dust, CBW,* enemy ground forces	Navigation Rough fields Mult. missions	3rd party direction change
Strategic airlift	> 10 hrs	1,000' to 40,000'	Benign-potential interception	Benign, long duration	Duration, loss of comm., hazardous cargo	Communication loss
Rescue	< 4 hrs multiple missions	0 to 10,000'	Max tactical	Max tactical	3rd party guidance* or none	Multiple unknown tasks
Training & simulation	Long missions*	-	Simulation of exposure complex sys. & weapons*	Simulation & realism	Battle dir. simulation (training & update of "chess team")	Stress simulation

*New or growing impact on crew.

(3) The probable increase in automatic control of airborne systems, even though manned, suggests a new subtle impact on the crew member's physical and mental capabilities. This is the impact of surprise responses of the aircrew's vehicle. Under automatic control, vehicles can be expected to avoid programmed hazards, to produce changes in mission plan, to respond to external third party commands, and to "find" enemy targets without warning to the crew that may be on board for specialized reasons (go/no-go nuclear, friend or foe identification, weapon selection, return to base decisions, etc.). Although the actual physical impact may be no more severe than past history has determined to be sustainable, the new element is surprise. The crew must decide whether the automatic maneuver or change in status is normal or emergency and must be informed sufficiently to prevent loss of effectiveness.

(4) Advancing aeronautical technologies promise to make feasible many useful missions with extreme durations. This capability suggests new crew roles which should be explored to determine the limits to crew performance. These roles include the following:

(a) Act as custodian of an automatic airborne system. The new airborne systems could have durations of two to five days serving as "Airborne Jr. Satellites" for specific tactical or strategic purposes. These platforms would be data gathering and transmission bases or links in constant communication with (or dedicated to) ground elements. The crew member(s) might only monitor the performance and assure the orderly takeoff and return to base of the vehicle. This system would essentially be a man monitored, ground commanded, drone. Man's presence in the ultimate application of this concept is to assure that a multiplicity of normal and emergency bases can be used and that the vehicle is a "normal manned aircraft" when viewed from the standpoint of routine base support systems. This will avoid the necessity of creating special bases like those demanded for missile or drone launch and retrieval. The man also provides the last stage in the graceful degradation of the system, thus saving it for future use.

(b) Supervise the complete command and control of major battle situations from an airborne platform utilizing the information available from all data gathering systems, either on board, on the ground, or in separate aerospace platforms.

(c) Operate the ultimate "stand off" weapon system where ballistic missiles are carried in long duration aircraft, some of which are airborne continuously. These systems may have durations measured in days.

There are, of course, many variations of these mission scenarios; but all such concepts demand knowledge of rest cycles, presentation of data to crews whose attention is not focused, life support for day-night cycles of duty and the limits of human performance when demands for maximum mental performance is interspersed with hours of tedium.

(5) Technology will continually increase Vertical Takeoff/Landing (VTOL) capability. This will permit several mission scenarios. One alternative basing option for small ballistic weapon systems suggests a VTOL aircraft of modest range initially based on protected bases. On notification of "tension," the aircraft, with one small missile, deploys to a previously located but secret destination (radius approximately 250 miles) where it

lands. Its missile is protected by random selection of these peripheral bases and can be launched on command or returned to the home base. The pilot and copilot (if any) may be on alert in order to accelerate the initial departure. Takeoff attitude may be standing (similar for landing) whereas flyout position may be prone. The wait at the remote missile launch site may be long and the minimum crew may have go/no-go responsibility in the event of "no command received." The physical requirements are unusual but not severe, the cockpit attitude is substantially different, and inactive time on station may be long. The decision to move to an alternate (pre-planned) site may be made by the crew alone. This unique mission should be explored for "biotechnology" research demands.

(6) All such mission concepts imply special burdens on the learning and training process. The specialization of the crew members, the automation of the mission, and the inevitable revolution in the display process, all impose new tasks for the developers of crew and total mission simulators. The simulation process and equipment may be as essential to success as the mission equipment itself.

(7) Stealth techniques which impart low observability to aeronautical systems flying in the earth's atmosphere may become an integral aspect of systems design in the immediate future. Low observability will be manifested in a reduced total aeronautical system signature. Reducing the aerovehicle's detectibility by reducing the optical, electro, acoustic and infrared signatures beyond the capabilities of known or anticipated detection devices may place additional mental and physiological demands on the aeronautical warrior(s) of the future. The management of designed-in and on-board stealth supporting subsystems will demand greater sensory perception than in today's modern stability augmented aircraft. In the "ATARI" cockpit, there will be little dependence on kinesthetic (seat of the pants) cues for a significant part of the mission profile, primarily the attack or target rendezvous. However, there will be normal demands on the pilot's human perceptions during takeoff, landing and low altitude terrain avoidance.

(8) Crew personnel in future combat operations can be exposed to the following kinds of radiation in increasing quantities:

(a) Residual and acute ionizing radiation from conventional nuclear or enhanced radiation (neutron) weapons. Duration of the hazard exposure can be from a few hours to up to two or three days in long duration loiter missions. Crews must also be able to return to bases which may contain radioactive fallout.

(b) Pulsed, high and medium laser threats obtained from both ground and air-based lasers. Crew vision re-radiation/flash blindness and disruption of optical devices require consideration.

(c) Other electromagnetic radiation threats are possible - Electromagnetic Pulse (EMP) nuclear weapons which can seriously disrupt the operation of electronics equipment; microwave weapons, which are not likely in the time period of interest, partly because of the limitations due to the atmosphere and partly because other threats (ionizing radiation, lasers and EMP) appear to be more cost effective. Crew member hazard limits must be determined, however, when exposed to microwaves flying over enemy radars or bathed with emitted energy from on-board equipment.

Summary

Man has played a vital role in systems operated by the United States Air Force. He has been asked to perform tasks of ever increasing difficulty in an offense and defense environment which is becoming substantially more complex. This trend will continue and in some cases the sophistication may remove the human from the cockpit, but the human element of the systems will continue to be challenged to improve performance under more and more stressful conditions. Knowledgeable planning must be augmented with research and simulation to probe and understand human element limits and alternate means of enhancing performance.

II. HUMAN-MACHINE SYMBIOSIS WITH EXTRAORDINARILY COMPLEX SYSTEMS

II. HUMAN-MACHINE SYMBIOSIS WITH EXTRAORDINARILY COMPLEX SYSTEMS

A. Introduction

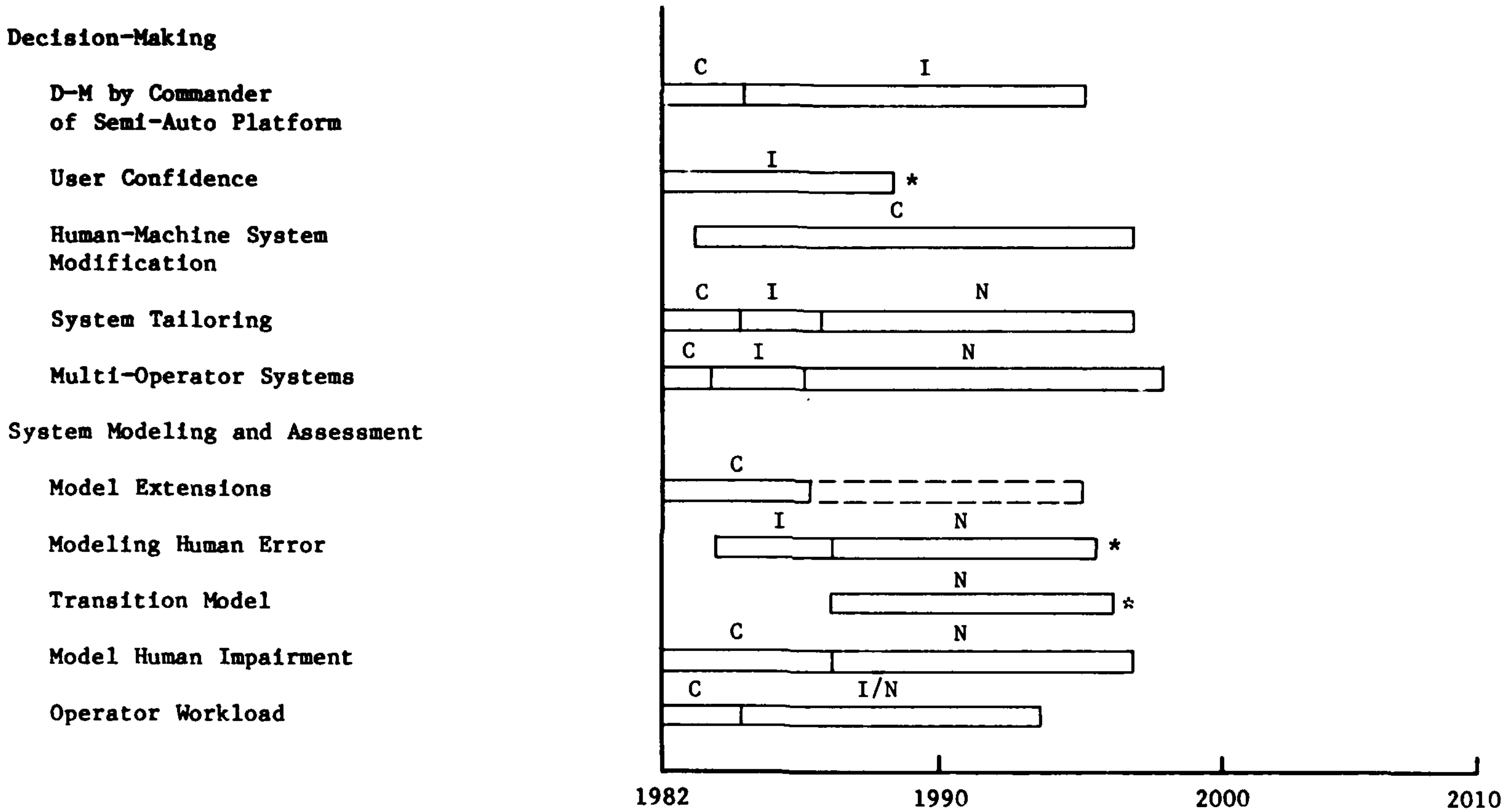
Projections of future aeronautical systems exhibit a common trend toward more complexity on the machine side, with a concommitant shift in human roles toward monitoring, situation synthesis, supervision and decision-making. This trend is illustrated in Fig. 1. Increased automation - more reliance on computers and automatic control - has been adopted as the basis for the solution of many existing and anticipated problems. While more automation does sometimes promise salvation, it is not an entirely unmixed blessing. Almost all tasks that can be defined in sufficient detail can be automated; but the results may be so costly and overly complex, or executed so inflexibly, that they become self-defeating. Thus, in some cases, the automation of functions can impair rather than improve human and system performance. What is good, or even essential, for the human may be inconvenient or inefficient for the machine. Allocations of roles between humans and machines and questions of cost and effectiveness are critical.

The aeronautical community has long experience in dealing with automation symbiosis. Automated guidance and control of manned aircraft through a complete trans-Atlantic flight, from brakes off at takeoff through roll out at landing, was achieved by the Air Force C-54 Robert E. Lee in 1947. Similar operations are now commonplace for jet transports of commercial aviation. In fact, in the next generation of transports, automation has been responsible for a crew reduction by one-third, as well as for improved efficiency and reduced operating costs. The F-102 included a completely automated fire and flight control system in the late 1950's, and today the F/FB-111 has many automatic modes, including terrain following. Active control technology, fly by-wire, and multiple redundancy concepts have been combined in the F-16 to create a highly automated, effective vehicle. Similar functions are done digitally in the F/A-18. Perhaps the most extensively automated system so far is the Space Shuttle, which can be flown from launch pad to landing with automatic guidance, control and navigation.

When any of the numerous components of a complex automated system fails, the whole system can become drastically ineffective, or even fail totally. This problem can be reduced by adding redundancy, automatic maintenance and automatic monitoring, but these options can be expensive and heavy, and can themselves add unreliability.

The symbiosis in our title refers to what we conceive is going to be a thrust in future systems - using human operators as integrated components for what they do best. Such integration cannot be designed a priori, but needs instead a continuing evolution of abstract ideas and concepts applied in collaboration with operational realism. Such collaboration might, for example, allow a pilot or commander to override every automatic subsystem in order to deal with contingencies. Human flexibility is still the best way of combining realiability with versatility.

Future aeronautical systems will have the current operational capabilities as solid starting points - that is, a well-tempered, effective vehicle



*Interacts with simulation

C = Continuation of ongoing research
I = Considerably increased effort
N = Major new initiative

FIGURE 1. HUMAN-MACHINE SYMBIOSIS - FUTURE TRENDS

for nominal and preconceived off-nominal flight profiles, complete with supporting subsystems. Designers of future systems will consequently try to provide this starting point even more effectively and, more importantly, will also try to solve problems that are now solved either poorly or not at all. Current weakpoints in fighter operations, for instance, include excessive-workload (e.g., nearly simultaneously operating the fire control system, mode selection and switching, monitoring and management of aircraft state variables - both short term variables such as attitude and longer term quantities such as fuel and control, etc.), and inadequate pilot appreciation of the air situation (status of closely associated friendly and enemy operations, identification of target status, threat warning). Similar workload excesses and incomplete situation appreciations occur for at least some phases of all Air Force roles and missions. There is an imbalance between the human and automation roles; our automation efforts must redress this imbalance.

For symbiotic automation to remedy these kinds of weak points, many improvements are required in all aspects of the interactions between the human and automation elements of aeronautical systems.

B. Desirable Properties of Automation Systems

1. Introduction

The predicted use of extraordinarily complex human-machine systems raises a large range of questions about the management of their development and of the training of the human participants. Furthermore, in a very real sense, the automated or machine components of such systems must be trained in the analogous ways; which is to say, training has a degree of overlap with continuing system development, both for the parts and for the system as a whole.

Although fully automated procedures for executing many of the missions projected in Chapter I will be feasible in the time interval 2000-2020, we will treat all of these missions as if they were executed by systems comprising automated mechanisms with symbiotic human components.

In this period, a number of platform level decision-making tasks can be foreseen. The term, platform-level decision tasks, refers to those which, in the contemporary Air Force, would be made by an aircraft commander. We do not specify whether, in 2020, the decision-maker would also have other responsibilities such as flying or managing the platforms and, indeed, whether the decision-maker would be in the platform, in another remotely located platform, or on the ground. The kinds of decisions and operations contemplated are not primarily concerned with platform management, yet they are nonetheless major factors in workload. They include appreciation of the air situation status and ordering of priorities; choice of whether to fire a weapon and, if so, when; selection of targets; and choice among sortie missions.

Why may such important decisions need to be made at platform level? Presumably, they will seldom, if ever, be made without extensive previous consideration and analysis on the ground; and often that ground analysis will permit pre-specification of appropriate action for each platform situation. But, such pre-specification may be inadequate, and even if it is fully adequate, two inescapable classes of decision-related problems will remain.

Consider the latter point first. One class of decision-related problem that goes with pre-specification is situation recognition, e.g., target identification. Even if the rules specify carefully what should be done in a given situation, someone must determine whether or not that situation exists. Furthermore, in the 2000-2020 era, time pressures may be such that definitive information may not be obtainable.

Inadequate pre-specification can arise because a possibility has been overlooked. A likely source of such an analytical error is excessive reliance on intact communications. No amount of doctrine may be enough to tell a platform decision-maker what to do if, after a launch under Fail-Safe rules, communications failure occurs under circumstances strongly implying that the intended source of communication has been destroyed by hostile action.

A special case of inadequate pre-specification arises if either machine or human elements of the system have been impaired without being destroyed. Machine impairment might leave the platform capable of weapons delivery, but not of communication. Human impairment, e.g., by CBW agents, could place time constraints on system operability never contemplated by the original mission design.

The argument so far has simply been that decisions will need to be made; next comes the question of what that implies.

2. Decision-Making

The task of decision-making can be divided into five subtasks:

(1) Identification of options available, including information-gathering options.

(2) Identification of relevant values, goals, or objectives.

(3) Determination of the degree to which each available option serves each relevant value.

(4) If uncertainty exists, it will normally refer to the answer to (3). In that case, obtaining and processing information to reduce that uncertainty may be appropriate.

(5) The results of the above steps need to be aggregated into selection of an option.

All steps except (4) can often be done well ahead of decision time. Consequently, many decisions can be pre-programmed, except for step (4). In such cases, step (4), often called diagnosis of situation recognition, becomes equivalent to decision-making and needs to be done at decision time.

Significant advantages to the human/automation system arise from the ability of the mechanism and the human operator to compensate for the other's reduced performance in a variety of circumstances. For example, although the diminution of system effectiveness because of machine or operator impairment caused abort of the primary mission, selected secondary missions might still be feasible. Thus, a total loss of effectiveness because all missions of the platform were aborted, or the loss of the platform and pilot may be avoided. Another advantage deriving from this symbiosis is that the human can elect, because of changes in conditions, to deliberately abort an otherwise prespecified mission and direct the weapon system to a different mission of greater value.

Quantifying the foregoing capabilities and achieving the advantages they can confer on the platform system and on Air Force planning are desirable goals for the 2000-2020 time span.

This quantification requires research in a variety of scientific and technical areas, such as behavioral science for decision-making, training, and multi-modal communication, with particular emphasis on adaptive interaction in training excerises so as to exploit the possibility of user-originated expansions of the capability of this man-machine symbiosis. In what follows, the objectives and approaches of the needed research are presented separately under the following research areas:

(1) Decision-making by commanders of semi-automatic platforms;

(2) User confidence in automated functions;

(3) Development of tools for understanding, describing and managing human-machine system modifications;

(4) Longitudinal management of the development of very complex systems (VCS);

(5) Tailoring for individual differences;

(6) Optimizing multi-operator and multi-machine effectiveness; and

(7) Role of automation in communication.

C. Research Issues

1. Decision-Making by Commanders of Semi-Automatic Platforms

a. Objective

The objective of this research is to improve various components of the intellectual task of decision making. The five specific decision-making task components are:

(1) Improve the technology for option derivation. What computational aids need to be developed to embody complex value systems and to help humans use these systems in devising new options?

(2) Determine the relationship between value structures and command hierarchies.

(3) Improved decision-making under uncertainity in apocalyptic situations. Technologies such as event trees and fault trees now serve to extend the range of probabilities with which humans can work effectively. But, these tools need more development and have not been studied in the context of possible apocalyptic consequences.

(4) Evaluate decision-making of impairments caused by various forms of stress, and of mechanisms for alleviating them. These forms of stress include physiological, divided attention, time pressures and high stakes.

(5) How can distributed decision-making be designed most effectively? How should such multi-head management be handled?

b. Approach

Empirical research is required to investigate several of these research objectives. For example, a special form of the divided-attention stress problem arises when failure of an automated portion of a system adds to a decision maker's workload. Can a pilot decision-maker do as good a job of making decisions after the autopilot fails as he could before? This problem has been studied to some extent in aviation contexts but not in contexts in which the pilot is a situation recognizer and/or weapons manager.

Other approaches to these research objectives require simulation studies. For example, to study dynamic decision allocation in response to systems impairment by loss of human or machine components requires constructing hypothetical environment and configuration simulations (probably low fidelity) as well as exploring ad hoc techniques for managing them under various conditions of initial capability and configurations of degradation.

2. User Confidence in Automated Functions

a. Objective

The overall objective is to explore and verify techniques of providing the human user with the appropriate confidence in system functioning. The main problem is under-confidence, so that system capabilities are not fully exploited, but over-confidence can have more severe and unforgiving consequences. Particular issues are:

(1) In training users on automated systems, will certain kinds of stress help the student over the hump of feeling that every automated function must be checked?

Example: In updating data files from natural language text, the analyst must be discouraged from reformatting the whole file and inspecting it visually after every modification or update.

Example: Do data communications to a pilot always need verbal verification?

(2) What kinds of reward structures perceived by the users are most effective in increasing their confidence? Compare penalties with immediate rewards for system use; should the system require increasing work from users if they do not take appropriate advantage of system capabilities?

(3) In some circumstances involving the highest level of human judgment, we see a natural tendency to rely on any automated assessment. Examples are vast increases in computerized personnel forms, the use of polygraphy in security clearances. How can such overconfidence be recognized and corrected?

b. <u>Approach</u>

This issue is part and parcel of development and training. There are two clear needs:

(1) To measure/assess the user models of user-machine operation; in particular, estimates of (a) confidence, (b) reliability, and (c) familiarity.

(2) A clear scenario of optional operational use.

As was remarked above, the goal is not purely unbounded user confidence in automated functions, but an <u>appropriate</u> confidence. Furthermore, as situations and priorities change, the appropriate levels of confidence can be expected to change.

3. <u>Development of Tools for Understanding, Describing and Managing Human-Machine System Modifications</u>

a. <u>Objective</u>

Human-machine systems are almost continuously being modified; sometimes by changing hardware, but more often by changing operational doctrine, content of training, software, or all of these. Such modifications, usually initiated by under-documented perceived needs, are usually ad hoc. A formal structure is needed to serve the following purposes:

(1) Recognize when and why a system modification is needed.

(2) Specify the nature of the modification.

(3) Describe and integrate related aspects of the modification, e.g., doctrinal changes almost always imply changes in content of training.

(a) Any such formal system should be able to determine systematically whether a particular human factor is understood well enough so that it can be completely automated, automated subject to human approval, or partly automated.

(b) How do we categorize the modifications to the man-machine interface? Such modifications include:

- Modifications in the style/format of information displays.
- Modifications in the content of information displays.
- User tuning (i.e., checking the effect of small changes) of system parameters.
- Addition of new user manipulations.

Examples: Instead of constantly displaying a system parameter, display it only when it strays from some limits; display a vector as a bar graph instead of as a set of numbers; provide the user with override capabilities for system defaults.

(c) How do we classify and evaluate modifications to software, such as addition of new functions, addition of new constraints, software "patches" for implementing the previous two, and elimination of unused or superseded software?

b. <u>Approach</u>

The methodology here clearly has a broad impact on many other issues, such as the R&D environment as a whole, or the tailoring of systems to individual operators and specialized applications. The approach stresses the point that the key to good systems is flexible and responsive changes in the functioning and priorities of man-machine systems, rather than the attempt to write a perfect system specification followed by a structured implementation, and finally by human user participation. This effort should help system designers make more rational and realistic plans for system development.

The work can be conducted both retrospectively and experimentally. There is much to be learned from seeing what kinds of modifications have been made to complex systems as a result of, say, (a) redefining priorities; (b) human engineering; (c) operational stress, as in combat; and (d) user tinkering and/or extemporaneous adaptation, and (e) failure of part of the system.

4. <u>Longitudinal Management of the Development of Very Complex Systems (VCS)</u>

a. <u>Objective</u>

If a VCS needs methods of development that differ from the current conventions of structural programming, new management tools are needed to handle the developmental problems. Such tools must incude:

(1) Standard functions such as schedules and budgets, both historically and projected, including bottleneck identification, e.g., a dynamic PERT.

(2) Simulation facilities for operational users so that machine configuration options can be compared, and machine interfaces projected so that human roles can be compared. In many instances, mathematical models to aid or replace such simulation exist, e.g., for many kinds of piloting, adequate engineering models of both pilot and platform have been developed for some

time. Most such models do not, however, allow for developmental modifications like learning or reprioritization.

(3) Intermediate evaluations, so that modules and submodules can be assessed not merely on a binary basis (go/no-go), but as they contribute to the (evolving) system priorities.

(4) A library of standards and examples. The manager must check the submanagers' estimates and projections by comparing them with history.

(5) Techniques of estimating this developmental robustness of subsystems and modules under (a) functional modification; (b) reprioritization; (c) new interface procedures or manipulations; (d) changing environments, both developmentally and operationally; and (e) failure of subsystems, both internal and external.

(6) Status monitoring of all system components with respect both to developmental progress and also to operational performance.

b. Approach

Large and complex software efforts have often been failures; current approaches seem to assume that if we could but make the correct initial specifications, the resulting implementation would be ideal. This has led to rigidities of architecture, procedures, functionalisms and interfaces that remain mostly as unperceived obstacles to later development.

An underlying theme is that a modification is not per se a confession that the system used to contain an error. Another is that much of what a manager does that is often termed maintenance, ought properly to be considered as continuing development. Another is that, since development relies on change, an initial function does not have to be performed superlatively at first, but only perceptibly well, for improving it will then be recognized as valuable. That implies that the manager ought to be given some models of evolving submodule collaboration, together with a model of system manipulability.

5. Tailoring for Individual Differences

a. Objective

The overall objective of this research need is to optimize the design of automation systems by adapting the automation configurations according to the individual differences of the human operator. This overall objective has the following specific implications in automation:

(1) Determine individual decision-making styles which require various decision-aiding schemes to accommodate these styles.

(2) Determine information processing characteristics which determine the most appropriate form and content of information to be provided to various users of automated systems.

(3) Determine the appropriate systems function allocation between the automated system and the human operator considered as a function of individual differences.

(4) Determine how individual differences can be used effectively in training human operators in automated systems. For example, learning strategies can be tailored to the appropriate learning styles.

b. Approach

In order to tailor the automation of systems to individual characteristics, an initial effort is required to determine the critical parameters relating to individual differences in terms of cognitive styles, decision-making styles, information processing capabilities, and system functions which are amenable to individual characteristics of the human operator. The set of critical individual difference parameters must be mapped into appropriate user models. These models can then be used to tailor the automated system to accommodate the individual differences of the human operator. In the process, we should use and apply what we now know about tactical decisions and their consequences.

6. Optimizing Multi-Operator and Multi-Machine Effectiveness

a. Objective

The overall objective of this research area is to improve systems that need many human operators. This has specific implications concerning:

(1) What roles will the various human and machine components be required to perform and how will the roles be allocated?

(2) How can operators in automated systems be trained to handle crisis management situations more effectively?

(3) How can the decision load sharing be distributed among the individuals and machines in the automated system, and what are the rules that need to be established for unburdening?

(4) What channels of communication should exist among these various human operator and machine components? How do these channels of communication need to be restricted in order to maintain the appropriate level of workload?

(5) How can cooperative distributed decision-aiding be provided in these multi-operator, multi-machine automation systems?

b. Approach

To accommodate multi-operators and multi-machines in automated systems, additional advances are needed in existing techniques for human-machine description and rule-based systems. These applications are most appropriate to complex platforms that consist of several operators working interactively, rather than the pilot/copilot situation. Specifically, development and advances of expert systems are needed to optimize decision load sharing and cooperative distributed decision-aiding. Improvements in the procedures for crisis management are needed so that they can be implemented in rule-based systems. Empirical research studies need to be conducted to evaluate the efficacy of these various improvements. These studies must be conducted in simulated environments representing the complexities of multi-operator environments.

7. Role of Automation in Communication

a. Objective

The overall objective of this research area is to explore ways of improving the receipt and cognitive handling of auditory received information. This is considered to be a relevant area of future research because the current approach to voice communication as a part of military operation carries significant liabilities. Linguistic and lexical incompatibility between sender and receiver can confuse or misrepresent meaning, resulting in delays and errors. Channel competition can result in missing or delayed transfer of information. Human memory limitations can result in uncertain recollections during high activity periods. Furthermore, the need for a crew member to transform information between modalities may not be facilitated due to poorly integrated voice and visual display systems. These effects are important in the sense that they are not peculiar to communications into and out of the immediate operating environment, but within it as well (teleconfer).

b. Approach

Because of the limitations of existing approaches and expected increases in information densities, vigorous research in the following areas is required:

(1) Communications management - Better ways of handling distributed voice communications involving multiple sources and channels must be formulated and evaluated. This includes the ability of the automated system to be readily altered upon human command and and provide nonrestrictive intervention. The ultimate goal is to improve the single channel auditory efficiency while reducing operator workload.

(2) Visual display integration - Speech recognition must be incorporated into visual display presentation. The questions are in what form should the speech be presented and how will it be controlled? Practical limitations regarding display spatial density suggest that key word displays could be an effective way of reducing human memory burden without displaying the entire transcription. Extensions of speech recognition technologies are needed such that key words can be extracted from continuous speech for automated display enhancement.

(3) Communication translators to optimize force interoperability - The concept of interoperability of strategic and tactical forces requires specific consideration for minimizing the feasibility of confused or

misrepresented meaning. Future automated systems, therefore, must be viewed as potential translators to improve transfer between sender and receiver.

D. Modeling and Assessments of Systems of Humans and Machines

1. Introduction

A large number of engineering models of human behavior, while working in concert with mechanisms or independently, have been developed, tested and applied over the last three decades. These models have been in the form of detailed or approximate analytic descriptions or as programs for computer simulations. The major behavioral functions described by such models have included: activity which is primarily sensory, such as visual search and visual or auditory detection; cognitive functions, such as decision making, risk taking and target identification; and, most prominently, the perceptual-motor behavior which characterizes the manual control of vehicles. For most of these applications, adaptations and extensions have been made of the models to include the effects of operator impairment by stress, drugs, long duration missions and other deleterious conditions, and particularly for visual search, field condition factors have been developed to extend laboratory studies to operational reality. Such extensions of the basic models are not adequate to assess many current man/machine systems and fall far short of what will be required for the development and evaluation of USAF automated weapons systems circa 2000-2020.

Paradoxically, human operator models acquire an increased complexity without an accompanying decrease in importance when they characterize the pilot or operator of an automated airborne weapons platform. The operator, without necessarily acting directly in many of the phases of the performance of an automated weapons system, <u>may</u> be compelled to assume any one of a large repertory of functions in order to insure the viability, effectiveness and reliability of the automated system. If the human operator's inanimate companion is degraded due to enemy action, component failures, environmental hazards or whatever, the human must be ready to expand his role in the joint venture. Human behavioral functions will also emerge for which no models were previously required. For instance, transistions in human behavior which were not of practical significance prior to the advent of complex automated weapons systems now must be included in the modeling of complex automated systems.

The technology that has made the inanimate components of the man/-machine automated system possible also serves to enlarge the repertory of skills which the pilot can achieve. Pursuit and precognitive modes of behavior become feasible when displays can be constructed from information gathered by sensors, both on the automated weapons system platform and on other platforms which may be positioned in the air, in space or on the ground. Advanced display and information sensing and transmission technology, which can enable higher human performance either in planned manual modes or in back-up manual modes under circumstances when the automated system is degraded, places a new demand on man/machine models when it fails, partially or totally. Although such failures may not be catastophic for the weapons system, they may convert what might have been graceful impairment of the man/machine system to precipitous degradation as the pilot's skill level regresses rapidly and unexpectedly. Impairment of the pilot by enemy action, stress, workload, long duration missions and so forth may also impair his ability to exploit the skill-enhancing technology available and result in performance degradation through regressive behavior. Thus, either impairment of the operator or failures of the machine can create conditions under which human errors develop and persist because previous levels of skill can no longer be obtained. It is as if the pilot, losing his sophisticated support in displays and information, slips and stumbles - but does so in a near-predictable manner. Such human slips and stumbles have been modeled so as to describe regressive behavior and errors in the control of relatively simple vehicles such as automobiles, and as such are part of a developing theory of human error. The automated weapons system circa 2000-2020 requires an expanded understanding and modeling of these near-predictable departures from skilled performance so that technology, training and doctrine may all be used effectively to minimize the impact on system performance of this class of human errors.

In order to model human error production and propagation in the automated weapons system of the future, the missions, primary as well as those secondary missions which must be considered when one or both of the symbiotic companions are impaired, will have to be divided into temporal components. These activities will have durations ranging from those long enough for adverse environmental effects to be demonstrated to intervals sufficiently short to capture transitions in skill levels.

Although adequate human behavior models for design, development and evaluation are in hand for some of the circumstances that have arisen and might be expected in future automated man/machine systems, there are large areas where knowledge is absent. Since these weapons systems can be expected to be expensive and not very numerous, the performance of each one can be of crucial importance. It is for this reason that modeling which can lead to an understanding and control of human error generation is a primary objective for the supporting biotechnology research for these systems.

The development of models is in progress right now, and should be strengthened immediately so that development of design and performance assessment support for the USAF can proceed before, during and after the design and development of the circa 2000-2020 weapons systems. These model developments should be interactive with the design process. In this fashion it will be possible to change the roles allocated to man or machine as the system evolves so as to achieve the most effective system performance. Together with this prescriptive function of the models there is a descriptive character which is of direct value to USAF planners. The planning scenarios with their assumptions of probabilities of success and exchange ratios will be used for force allocation, primary and secondary target allocation, mission assignments, manning schedules and cost/effectiveness measures. These two uses of the models interact in that the scenarios used in planning will be modified by the experiences acquired in the design exercises, and the design exercises will be influenced by the needs of the planners.

2. General Objective and Research Issues

All of the research issues below share the general objective to improve and elaborate the quantitative and qualitative models needed for design, assessment and understanding of complex human-machine systems.

a. Model Extensions

Extend current man/machine modeling research so as to create a model of the symbiotic man/automated machine system from which predictions of system performance and reliability can be made under conditions in which neither, either or both symbiotic companions are impaired due to such causes as hostile enemy action, adverse environments, excess workload, fatigue, machine or communications failures and so forth. This model, really a family of models, will emerge from continuing experimentation, validation and incremental improvements in the weapons systems.

b. Modeling Human Error in Very Complex Man/Automated Systems

(1) Create models of human error based on behavioral procedures, information handling, and motor skills so that design, pilot selection, doctrine and training can all contribute to the diminution of human error and to the increase of system reliability. This model is different in concept and construction from the well-known statistical descriptive methods or their surrogates based on expert opinions of procedures and human behavior.

(2) Starting with a detailed scenario for pilot behavior in primary and secondary activities, together with his inanimate companion in the automated weapons system, the theory of human error should be used to indicate where regressive behavior or grievous errors are to be expected. Following this planning, simulator studies will be used to refine, extend and validate this model. These results will feed into the system design process and will be iterated throughout the development of the weapons system.

c. Models for Transitions from Mode to Mode

(1) The human member of the man/automated machine system has the capability of assuming different roles in the weapons system as he or his symbiotic companion become impaired. It is important that methods be available to maintain operator proficiency in the many behavioral modes he must generate when needed. Although some information is currently available on changes in behavioral modes, this material is not adequate to the problems to be expected in the weapons system circa 2000-2020. Developing adequate information, models and application methods is an objective of this reseach.

(2) Mission scenarios presenting primary and secondary pilot activities will be the starting point, since from these, possible mode shifts can be determined. A point of departure for description and experimentation is the precognitive model for highly skilled human performance. This approach is natural to man/automatic system interactions in that the stored repertory of preprogrammed precognitive responses and their appropriate release by the human is a mimicking of the computer directed automated activity of his symbiotic companion.

d. Models for Human Impairment

(1) Impairment is an umbrella term for the deterioration of such human functions as judgment, decision-making, manual control and vision.

The objective of this research program is to understand if and how such impairments can be prevented, delayed or compensated for.

(2) Identifying mission scenarios and possible hostile actions, and the generation of normative base line performance data are the first steps in this approach. The next step is to examine in-flight proficiency maintenance: devices for informing the human when he is impaired in some subtle or gradually degenerative fashion. The effects of training, doctrinal responses, and intervention by speech or otherwise from C^3 facilities must be examined.

e. Operator Workload

(1) Improved measurement and quantitative evaluation of operator workload is needed. The objective is to address two considerations: peak or transient workload, and multiple workload measures.

(2) It is expected that the scenarios for the circa 2000-2020 weapons system will be characterized by long periods of boredom and near fatigue and abrupt, frenzied periods of activities. Within the active periods, crucial decisions and changing modes of behavior are to be expected subject to high peak workloads. The emphasis of past research has been on measures of average, not peak workload. Procedures will be explored for measuring and controlling such peak workload episodes so that levels remain within operator tolerance for successful system performance. Methods will be developed to explore multiple measures of workload so that the necessary set of measures can be obtained for establishing data bases for representative scenarios with which to develop behavioral models.

E. Facilities

A variety of research facilities will be required to investigate the diversity of research issues dealing with the characteristics of automation systems. In general, both special purpose laboratory and simulation facilities will be required. The laboratory facilities will necessarily be computer-based, time-sharing systems using interactive displays. The interfaces required include voice input/output, color CRTs, touch input, multifunction keyboards, trackball and joystick control. Depending upon the specific research issue being investigated, special laboratory enhancements will be required. For example, various decision-aiding algorithms and expert system implementations will be needed. Additionally, special pattern recording and retrieval systems, as well as multi-channel, multi-source capabilities will be required for communications research.

The second major research facility required to conduct this research is a complex simulation facility in which all components of automated systems can be integrated, tested and validated in a more operational context. This simulation facility should have the capability of representing the diversity of C^3I platforms envisioned for the time interval 2000-2020. The variety of missions performed in these simulations should be representative of those described in Chapter I. Initially, simulation facilities at FAAMRL and AFWAL could be used, but incremental upgrades will be necessary as the research on automated systems progresses.

Upgrades to existing simulation facilities are primarily of three types: online operator and systems performance assessment, implementation of various automated system enhancements, and flexibility to provide a variety of prototype operational systems.

III. HUMAN-MACHINE INFORMATION INTERFACES

III. HUMAN-MACHINE INFORMATION INTERFACES

A. Introduction

The previous chapter addressed the overall issues of the human-machine symbiosis with highly automated systems from a perspective which focused on the desirable properties of such systems and the descriptive models needed for assessments and role assignments. This chapter is a companion which emphasizes the more parochial "ins and outs" - the interface issues. Because both chapters deal with similar issues from a different perspective, some duplication in the discussions is inherent and even desirable.

A functional model of an information interface for advanced automation must consider the representation of the real world and the effect of that representation in a goal-oriented task structure. An effective interface requires a performance-oriented understanding of the types of information involved and the roles of humans and machines.

Situational information available to the human is an active integration of background data (e.g., intelligence reports, targeting data), and real time event data (e.g., target and threat verification, etc.). Process-related information has similar real time and priority data needed to navigate to some point on the earth, maintain appropriate vehicle states, acquire targets and deploy weapons.

In C^3I battle management missions, background and real time information have situational and process features which are becoming more dense and complex. Data bases are large. Sensory, communication and processing systems are complex and distributed; and system time constants may be large; yet the disturbances may be very dynamic and transient in nature.

Because of the increasing complexity of both real time and background data environments permitted by technology, the demands being placed on the human are certainly changing and may be increasing. Depending on the quality and content, greater amounts of information can either ease or increase the ability of humans to process it and make decisions. The greatest technological driver has been, and will continue to be, increasing automation. The great challenges are using, controlling, understanding and, in some cases, defeating automation. Necessarily, the role of the human is and will continue to change in that:

(1) The role of the decision-maker will become increasingly more complex and stressful for those functions where response times shorten and/or information to be assimilated increases.

(2) The role of the pilot as a controller will continue to evolve in the direction of a system or process monitor/supervisor and decision-maker.

Because the roles of humans are changing and the evolution of systems and "systems of systems," both friendly and hostile, are tending toward increased complexity, future research efforts must focus on the biotechnological issues associated with the information interface. Some existing interfaces exhibit such problems as:

(1) Ill-suited sensory-motor transformations,

(2) Highly restrictive human/computer dialogue,

(3) Limited filtering to reduce operator saturation,

(4) Poor aiding of data base searches,

(5) User/system unfriendliness,

(6) Lack of uniformity when interfacing with multiple subsystems, and

(7) Little provision for task modification and operator off-loading.

Significant improvements are needed to reduce this list and its operational consequences. The overall objective of this section is to identify those research needs which can provide a biotechnology basis for the design and development of enhanced information interfaces for the year 2000 and beyond.

B. General Considerations

The research approaches for enhancing the information interface in future, highly automated systems must consider the increasing demands on battle managers, pilots and crew members who perform in an information intensive environment. Consequently, several key issues germain to the current roles of the human require careful consideration and, in some cases, reevaluation. The relevant issues are:

(1) Use of natural abilities and psycho-physiological functions needed to produce a compatible user/system interface;

(2) Expanded emphasis on the development of embedded training techniques that include idiosyncratic effects associated with both man and machine;

(3) Techniques for increasing accuracy while reducing response time in cognitive task structures;

(4) Better treatment of uncertainty and complex forms thereof associated with the engagement, the process and the human (i.e., perceived, biased);

(5) Performance tradeoffs in interface design and system interaction based on individual differences (e.g., dialogue and information transferral, decision styles); and

(6) Approaches to flexible growth systems which offer real time modification based on changing missions and evolutionary enhancement of overall system capability. The approaches must necessarily address levels of human proficiency and needs in both of these circumstances.

C. Enabling Technologies - Year 2000

In this area, particular emphasis is placed on those biotechnological research issues which either offer potential for enhancing the human as a controller, information processer, and decision maker or improving the human role in light of extrapolating observed problems in the context of current systems. It is a necessary planning constraint that those technologies which offer the most improvement or enhancement be considered. For the sake of organization, six major enabling technology categories (i.e, displays, control and input, non-invasive physiological measuring devices, information systems, communications, and avionics) have been reviewed for this biotechnological impact.

1. Displays

Current trends in display development suggest that this technology will be characterized by further advances in packaging, technique and application. Advances are required both in the technology of display media, computer-driving of display, and in the psychological integration to determine what sensory data are most effective dependent on current task demands. It is fully expected that these advances will have a demonstrable impact on biotechnolgy in terms of both driver and approach. The most important types of display are:

a. Medium and Large Scale, High Resolution Visual Displays

(1) Liquid crystal
(2) Electro-luminescent (EL)
(3) Plasma
(4) Flat tube CRT
(5) Diffractive optical projection systems

b. Wide Field-of-View Displays

(1) Canopy projected
(2) Head-up display unit
(3) Binocular
(4) Helmet-mounted displays

c. Tactile Displays

(1) Force/pressure feedback devices
(2) Spatio-temporal prompting and orientation devices

d. Natural Language Displays

(1) Integrated with other visual data
(2) Auditory input, especially in dialog mode

2. Control and Input

Although it is difficult to functionally separate this technological area from the preceding, these are some features of this category that will impact on future biotechnological research.

a. Improved manipulator subsystems for fly-by-wire or fly-by-light flight controllers

b. Adaptive control/input systems

c. Voice actuated control

d. Head/eye positioning systems

e. Motor interactive display surfaces

f. Advances in tactile input and control

3. Noninvasive Physiological Measuring Devices

The consideration of adaptive man-machine interfaces logically demands further development of this technology. Specific categories that offer ways of enhancing the human role are:

(1) Advanced sensors - Monitor overt body behavior, such as eye, gaze, lips, arm movement, etc.;

(2) EMG techniques;

(3) EEG techniques - Auditory evoked response potentials, visually evoked responses and ongoing EEG monitoring of current brainstate; and

(4) Task monitoring techniques - Embedded workload measurement and vigilance monitoring schemes.

4. Information Systems

This particular area presents an enigmatic situation in that advances have been rapid and future limits in the development and application areas are difficult to predict. This is further complicated because the system analytical methodologies which are being developed (e.g., hierarchical approaches to modeling distributed processing systems) somewhat lag the advances being made in processor architecture (i.e., software, hardware and firmware). However, several major areas are important because of their probable enhancement features. These are:

(1) Very High Speed Integrated Circuits (VHSIC),

(2) Very high density, non-volatile memories,

(3) Natural language systems,

(4) Complex instruction set computers,

(5) Expert and knowledge based systems, and

(6) Distributed processing architectures.

5. Communications

For reasons of force reconstitution and positive control of forces at strategic and tactile levels, current investments in communications technology will continue. The major areas for planning future biotechnology research must consider the following technologies:

a. Communications Handling and Processing

(1) Voice/speech recognition
(2) Advanced signal processing and signal reconstruction

b. Links and Networks

(1) Satellite relay systems
(2) Laser communications
(3) Ground wave systems
(4) Millimeter wave systems

c. Reliability

(1) Detection of spoofing
(2) Avoidance of jamming
(3) Ability to delegate decisions to appropriate modes
(4) Decision-making in face of multiple, incomplete and conflicting data

6. Avionics

Specific technogical developments in this area will in some cases, and probably most significantly, serve as research drivers for biotechnological planning. In other cases, future avionic advances coupled with advanced automation and information interfaces will appropriately serve as biotechnology enablers. The most significant technologies include:

a. FLIR AND LLTV

b. Advanced Navigation and Targeting Systems

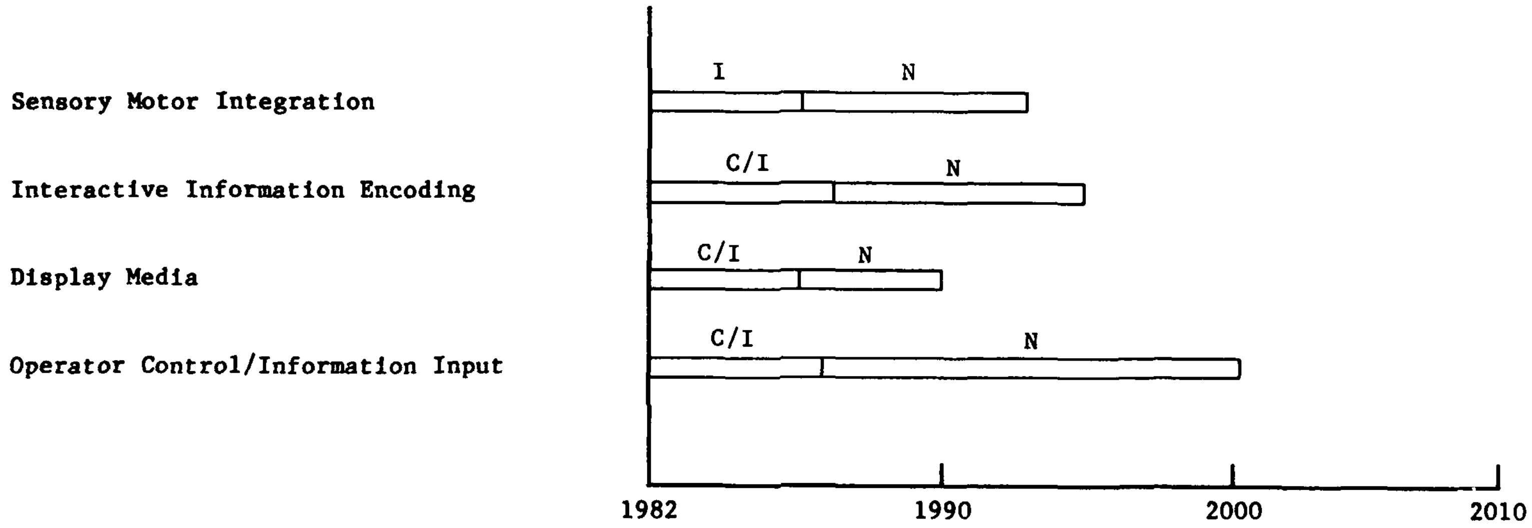
(1) SAR systems
(2) GPS and JTIDS
(3) Laser radar
(4) Terrain recognition systems

c. Automatic terrain following/terrain avoidance
d. Advanced controls for control configured platforms

e. Multi-redundant fail-operate avionics

D. Research Issues

Future trends of the first four research issues listed here (Sensory-Motor Integration, Interactive Information Encoding, Display Media, Operator Control/Information Input) are charted in Fig. 2.



C = Continuation of ongoing research
I = Considerably increased effort
N = Major new initiative

FIGURE 2. HUMAN-MACHINE INFORMATION INTERFACE - FUTURE TRENDS

1. Sensory-Motor Integration

In the past, much work in neuroscience, cognitive science and human factors has separated study of sensory systems from study of motor systems. Consequently, each sensory system has been studied separately and as a low-bit-rate channel. Future research in these areas must increasingly address the way in which all the senses are used in an integrated way to update the human's "model of the environment" within an ongoing performance of action and decision-making. Basic research in this area will integrate artificial intelligence (AI) research with neuroscience and cognitive science to provide better models of interacting subsystems within the human to allow effective automation of certain subsystems, and to enable effective interfacing (both sensory and motor) of man with machine. The proper development of more efficient man-machine interactive systems requires, of necessity, the determination and quantification of the innate and learned sensory motor transfer motions in humans.

a. Sensory-Motor Transformation and Parallel Processing

How are spatiotemporal sensory patterns coded to yield temporal patterns for coordinated control of multiple effectors? What hierarchical structures are involved, e.g., when posture provides a platform for arm movements which position the hand for delicate manipulation? Because it has been demonstrated that both reliability and speed of response can be enhanced by multiple sensory inputs (same information simultaneously presented to several sets of sensory systems), this is probably the most useful new avenue of sensory research. Associated research will involve the information capacity of single receptors and sets of receptors.

b. Multisensory Coordination and Conflict

When do audition and touch enhance the effectiveness of a visual input, and when do the senses conflict? What patterns are most effective - which most distracting? A given stimulus will produce a set of signals ranging from motor reflexes to long term responses, including high level discrimination activity. Responses which should be investigated for their utility as commands and/or monitors include:

(1) Short term reflex responses
(2) Evoked responses at different sensory levels
(3) Evoked responses at perceptual and premotor level

c. Motor Planning

The study of motor planning requires analyses of overall representations of action-situations (schemas), as well as of the postural frame within which specific movement sequences unfold. The motor responses are most reliable when posture and actively coordinated movements are taken into a single motor unit. Studies in three areas will ultimately result in a better understanding of the sensory motor integrative activity of pilots.

(1) Schema theory - An analysis of task and context-dependent recognition of complex situations, with special emphasis on identification of relevant perceptual parameters for (1) schema activation (situation recognition), and (2) action within the schema assemblage.

(2) Motor sequences in postural context - The pilot may be forced to operate under conditions where muscle tone has been altered by stimuli to, for instance, the vestibular, neck afferents or somesthetic systems. Under such conditions, some movements are facilitated while others are inhibited or deeply modified. Some of these motor responses, e.g., eye movements, lid movements, tensor tympani activity, can be directly related to sensory input. In addition to global coordination and response time, motor attitude may also change long term perception.

(3) Adaptation and learning - Each of the above studies needs to be augmented by studies of adaptation and learning, both to determine human characteristics and to determine what forms of machine learning can augment the human without degrading the man-machine interface.

For problems about which insufficient knowledge exists to permit the design of adequate problem-solving methods, adaptive or learning techniques are required. Issues to be addressed include pattern recognition, search, conflicts of interest, cooperativity, and the adaptive construction of local performance evaluation centers. The resultant associative sensory networks should not only have loss and damage resistance, but also the ability to use a generate-and-test procedure to automatically search for optional associations.

2. Interactive Information Encoding

a. Symbolic Interface Languages

Situation/assessment requires compact symbols capable of encoding a large number of variables and of a morphology such that the situation as a whole (gestalt) can be grasped from them at a glance. To minimize interpretation effort and learning difficulties, the pattern recognition capabilities built-in or overlearned by the visual system should be used. This leads to two approaches, referred to as respectively as mimetics and iconics.

(1) Mimetics - This is the topographic representation of geographic (space) by spatial perspective on the display, for example, using grids and silhouettes to communicate attitude and altitude with respect to terrain and ground features. This concept can be enlarged to cover multiple vehicles and large operation theaters.

(2) Iconics - This covers the dynamic use of icons (symbolic figures) whose separate features each encode one parameter of a situation. Images that are already overlearned present distinct advantages. Among these, sketches of human faces, as well as stick figures of hands and/or bodies, are prime examples. Faces in particular have been shown to be suitable for inducing effective gestalt discrimination over sets of 5 to 15 variables, and to

offer "natural" encoding of information such as attraction/aversion, (eye) direction, balance between sides, etc.

These graded (rather than discrete) and integrative methods of situation display can greatly enhance and streamline the overall interface in combination with the conventional discrete iconics and dials. Color, of course, remains an essential coding dimension at all levels.

b. Natural Language Interfaces

To provide an enhanced ability of the human operator to (a) determine the situation, and (b) obtain detailed parameters of human, machine and environment status to initiate, continue, modify or abort a given course of action, integrated multimodel (e.g., visual, auditory and tactile) are appropriate. In addition to natural and enhanced "environmental" information, and the use of conventional symbols to flag places and conditions of importance, natural language can play a vital role in compact descriptions of complex conditions. Two facets of man-machine dialog are involved: "natural language processing" per se which can translate natural language to and from a computer query/answer language; and "expert systems," the construction of data bases structured for access via dialog rather than explicit query.

From the standpoint of software architecture, managing very complex systems will demand the full integration of cognitive psychology into interface design. This could include the development of intelligent interface agents acting as intermediaries between user and system. Such systems could become effective boosters for learning and lead to the development of machines aimed at raising human performance and general intelligence.

(1) Dialog access to expert systems

(a) Research objectives

To formulate dialogue structures and evaluate their syntactical composition for optimizing interactive, human-controlled, computer assisted data base searches and problem solving; and to identify standards for specifying query languages and relational natural language development for interactive computer programs.

(b) Approach

Under those conditions where an operator must access large data bases of information and infer relationships, future user friendly automated systems must be able to interpret operator inputs, conduct relevancy searches, and produce a meaningful response. To make this dialog effective, one can assume that the most complete and compatible representation of the operator's request with its logical constraints for the search is contained in a syntactical dialog structure. Furthermore, for the operator to understand the system's interpretive logic, the system's response should also match the input dialog.

Current trends in natural language parsing suggest that future generations of automated systems will be able to parse dialog entries for relational processing and unparse inferences from knowledge data bases for operator use. The parser must be developed as a model of the human interface between an external language and an internal representation of concepts and ideas. Quantification of human performance using the dialog syntax as the independent variable will help define syntax standards for the future natural language band systems.

(2) Natural language enhancement of visual displays

(a) Research objective

To use spoken or written output to highlight salient aspects of signal situational changes in complex visual (or multi-model) displays.

(b) Approach

Carefully directed research on human cognition can determine what aspects of a visual display are most salient (a) within a given situation, or (b) in reevaluating the overall situation. Coordinated machine vision research can then provide semantic representations (semantic networks; schema-assemblages) of visual scenes that can be tagged for saliency. Natural language research then enters to develop techniques for combining conceptual and linguistic knowledge in generating sentences in priority-ordering. This research should be integrated with dialog-access research to ensure that currency reports are integrated within status-reminder reports.

(3) Expert systems and learning

(a) Research objective

To configure expert systems to update user models and learn from experience.

(b) Approach

With each mission, new data are accumulated about a variety of combat situations. Ways must be developed for recording these data and integrating these into expert systems available to all pilots and other personnel. In addition, data can be accumulated on individual pilots. Prompts from the expert system which are ritual for one pilot may be an irritant to another. Thus, an expert system must be able to structure its dialog according to the long-term model of the pilot. Finally, ways are needed for monitoring short-term factors (e.g., current physiological state or direction of gaze) and to determine appropriate messages, whether linguistic or visual, either data base or environment driven.

3. Display Media

a. High Performance Visual Displays

Specific technology and research efforts should be directed at providing a wider field-of-view display medium in which information from various information sources can be represented to the visual sense of the operator. This medium should use, to the greatest extent possible, the visual perceptual abilities of the operator, such as binocular, peripheral and color vision. Maximum use should be made of virtual image projection technology to produce displays which minimize the physical size to achieve wide field-of-view image representation to the eyes. The use of eye and head position sensing can be used effectively to position high resolution area of interest information within the visual field of the fovea, while motion cues and other cues may be presented in the periphery. Methods for encoding information in three-dimensional visual space using binocular displays should also be considered. Information sources for these displays may be derived directly from sensors or consist of processed or synthesized information provided by digital computing elements and represented as encoded information (as discussed above). Biotechnology research must address the issue of display configuration (e.g., field-of-vision, image overlap, accommodation/projection) and spatio-temporal interaction of display images and the operator's visual sense (e.g., resolution, contrast, color fidelity, etc.). Display performance and operator visual capabilities should be considered in a common methodological construct, such as describing the overall capacity of the display to convey visual information of the operator using spatio-temporal transfer functions.

b. Non-Visual Display Media

Anticipated technology advances will provide unique tactile and auditory displays. Research should identify the methods for coding information using these sensory modalities. The use of arrays of stimulators can provide direction cueing or vehicle state information. The value of such a display must be assessed considering the dynamic environment in which these systems may be operated. Auditory displays using computer synthesized speech or other encoded aural languages may also provide direction and/or attention cueing.

c. Multi-Modal Display Integration

The real impact of non-visual displays may be greatest when used with visual displays. Operator visual attention may be directed using tactile or auditory stimulation. Response time and accuracy performance with multi-modal displays should be assessed in both vigilance and high workload tasks. Algorithms for governing the interaction of these display media should also be derived.

4. Operator Control/Information Input

a. Conventional and Non-Conventional Input Modes

Conventional operator controls have been limited to hand and foot motions used for tracking (joystick, rudder) or discrete switching. These manipulators and their associated signal conditioning and shaping still require significant improvements as subsystems of fly-by-wire or fly-by-light flight control and guidance systems. Unfortunately, the baseline of comprehensive research data on manipulators in context with the modern systems is inadequate to current needs; accordingly, new flight control system manipulators tend to be developed on a very expensive AD HOC basis.

Voice input is the object of much research in other man-computer interfaces. Special work is needed to determine its proper share of the input load in the present environment.

More fundamental work is needed for non-conventional input modes. These subdivide into:

(1) Detection of movements using advanced contact or remote sensors, for instance, dynamic detection of eye gaze and saccades; body gestures, e.g., pointing; mouth shaping (lip reading); body posture (e.g., "seat of the pants" helicopter control); etc.

(2) Control by muscle groups (such as temporal or masseter) using EMG electrodes.

(3) Direct tapping of brain signals in the form of EEG or ERP (Event-Related Potentials). These techniques offer potential both for direct control and for the monitoring of cognitive events in the brain. Present approaches to EEG and Evoked Potential Signals have reached their limit. The next round of research must take advantage of the emerging fast processors to reduce multichannel data in real time and capture the rapidly changing correlations between channels. Bringing the time windows of analysis to the level of significant mental microevents will allow biodata to actively interact with ongoing cognitive procedures.

For all of the above approaches, work is needed for the development of advanced sensors integrated in VHSIC array architectures.

b. Augment Adaptive Input Modes

With either conventional or non-conventional control interfaces, modern adaptive processing approaches offer improvement possibilities. Adaptive control filtering using the Kalman techniques has overcome some spurious error factors related to individual operator dynamics and environmental situations. The use of EMG or ERP in conjunction with adaptive controllers may provide more viable control elements for high performance platforms. In this application, these physiologically derived potentials may be processed and used to dynamically adjust model parameters to increase control fidelity.

5. Robotics and Machine Vision

With the modern multimode automatic pilot, the automation of navigation in "calm" environments is substantially complete, including developments in terrain-following which enable point-to-point navigation in near-ground altitudes. Major developments are still required in dog-fight conditions, especially when flight control must be integrated with control of multiple weapons systems. Automation of these functions must be integrated with research on (a) high-level supervisory control by on-board crew, and (b) remote piloting from ground stations or distant airborne command platforms. Automation will be needed for refueling and weapon-loading in high-radiation or CBW environments that might impair or remove ground crew, yet might not penetrate cockpit defense systems.

a. Visual-Tactile Coordination for Robot Control

New tactile sensors must be developed and algorithms devised to best combine data derived from these sensors. The areas of research interest include: static and dynamic vision, static and dynamic tactile sensation, the interactions of multimodal sensory data in the creation and maintenance of environmental models (schema-assemblages), and adaptive control structures using a knowledge-directed approach.

b. Integrated Machine Vision System Development

Systems are needed which symbolically represent the three-dimensional world depicted in the two-dimensional image. This includes the naming of objects, their placement in three-dimensional space, and the ability to predict from this representation the rough appearance of the scene from other points of view. Research will include: an analysis of color images of outdoor scenes, from segmentation (or partitioning) of an image through the final stages of symbolic interpretation of that image; and knowledge-directed interpretation via schemas.

c. Processing Dynamic Images from Camera Motion

Research is needed on the basic algorithms for determining segmentations from stereo and time-varying images, developing algorithms for determining optic flow image sequences, and developing algorithms for effectively extracting environmental and control information from image sequences produced by moving vehicles and robot assembly environments. Basic issues must be understood in order to develop computer vision systems for terrestrial and airborne motion using a sequence of images obtained from a sensor in motion, and changes in the sequence of images must be used to establish a consistent environmental model over time. The key scientific issue to be addressed is the recovery and effective representation of information concerning the physical environment, such as surface distance, extent and orientation, relative to a moving observer. The necessary techniques should be developed using simulated and actual scenes with restricted forms of sensor motion, leading toward analysis of actual scenes with smooth, but arbitrary, motion.

E. Facilities

Three levels of facility are envisioned as desirable to address the research elements discussed above:

(1) Individual laboratories for basic research in universities and research communities,

(2) Regional research resource centers, and

(3) All Air Force centers for development.

The facilities for development do not need detailing here. The proposed regional research resource centers will support three kinds of activity:

(1) Complex flight-simulation facilities to be used to test results after they have been explored in the laboratory environment. Researchers would sign on for use of this facility much as physicists sign up for experiments at Brookhaven or Fermilab. Such experiments would also encourage intergroup cooperation.

(2) Foundries: much of the research proposed will involve highly-parallel computation of the kind that would swamp conventional computers beyond the initial exploratory phase. Research groups will thus need facilities to transform parallel algorithms into integrated circuit chip designs and have these fabricated promptly and reliably.

(3) Host nodes for computer networks to ensure rapid intergroup communication, remote experiments where practicable, and experiments in internode coupling to simulate the distributed C^3I environment. Such nodes may also support research in computer software, including network protocols, AI programming languages and visual display languages.

The facilities for individual laboratories will be highly variegated. A common need will be computer facilities for data processing, network communication, interfaces with VHSIC test-modules, and interfaces for on-line control of experiments. Specific laboratories will include:

(1) Robotics laboratories with multiple arms and multi-modal sensor arrays,

(2) Neuropsychophysiological laboratories for animal experiments on sensory-motor integration,

(3) Neurophysicological laboratories for monitoring and modulating human neural activity during sensory-motor tasks,

(4) High-resolution interactive graphics facilities with combined computer and camera input, and

(5) Human factors laboratories for cognitive and psychophysical monitoring.

F. Applications

1. Super-Cue Displays

It is well-known that "optic flow" vectors provide enhanced cues for display of a runway for purposes of landing. For some tasks the "best" cues may have no natural counterpart, but instead may have to be "manufactured." The study of sensorimotor integration will isolate what sensory cues are most salient in different decision-making and motor tasks. These kinds of considerations will guide the choice of "super-cues" to be enhanced in visual displays.

2. Multi-Sensory Semi-Virtual Displays

The normal correlation between auditory, visual, tactile and vestibular cues is severely disrupted in high-G, high-stress conditions. The study of the normal temporal correlation of multi-modal inputs in coordinated control of motor tasks can be factored into the design of multi-sensory displays that retard, advance and enhance environmental inputs to optimize pilot control.

3. Biocybernetics - Enhanced Platform Crew System

a. Integrated multi-user systems with biocybernetics enhancement of input (combining monitoring of movement, eye gaze and voice) with real time cognitive assessment of brain wave. The level of automation and task sharing between operator and automated control is linked to both system and operator wave.

b. Development of mimetic displays from combined stored terrain data and sensor input.

c. Built-in tactile displays in flight units.

d. Integrated training simulators for situation recognition and decision-making using biocybernitics enhancement - automatic activation of help systems from combined overt behavior of brain wave assessment integrated to main systems for pre-mission rehearsal as well as training.

G. Advanced Biocybernetic Crew Systems

With the research described in this chapter, a biotechnology foundation is laid for an advanced crew system based upon biocybernetic interfaces. Such a crew system would exploit the natural perceptual and motor control abilities of the operator to provide better man-machine interfaces on high workload and information intrusion platforms and C^3I systems. It is envisioned that the information needed for a crew member will be encoded, simplified (using, for example, the mimetics and iconics symbolic languages described above), spatially organized and represented as virtual images in three-dimensional space in geometric and/or pictorial formats. Visual display presentations can be enhanced by synthesized auditory and tactile displays which provide alerting and directional cueing to the operator. Feedback of sensory and cognitive functions via event-related potentials can provide enhancement of selected display properties (such as display luminence). This display approach effectively places the pilot or operator perceptually within the battle situation with displayed information encoded to reduce response time and increase accuracy. Automatic decision aids will assist the crew member in isolating faults, reducing uncertainty and prioritizing decision options. Machine vision can provide target detection information to the operator. Rapid control of cockpit functions or input of C^3 systems can be implemented through combining and coordinating eye, line-of-sight, voice commands and hand controllers. EMG techniques and improved natural dialog with computing subsystems will quicken those control inputs and considerably reduce crew workload by eliminating the constraints imposed by conventional manual controls. These control interface models will also provide a more direct means of communicating visual line-of-sight and other encoded information between operators. It is anticipated that implications of these interfaces will revolutionize the interfaces in crew systems and can be applicable in a broad range of command strategic and tactical aircraft platforms and C^3 systems. Another implication of these enhanced interfaces is a reduction in the requirements for training and experience of operators when natural abilities are exploited.

IV. HIGH INTENSITY, UNFORGIVING MISSIONS - MISSION STRESS, PROTECTION AND PERFORMANCE ENHANCEMENT

IV. HIGH INTENSITY, UNFORGIVING MISSIONS - MISSION STRESS, PROTECTION AND PERFORMANCE ENHANCEMENT

A. Introduction and Summary

This chapter analyzes the new mission requirements and stresses anticipated in aeronautical systems and addresses the problems of operator effectiveness and degradation, and potential means of increasing mission effectiveness, and safety and crew biodynamic protection. Primary new factors foreseen are long duration missions (over 60 hours), severe six degree of motion exposure in low-level, high-speed mission phases and variable duration missions in altitudes in excess of 100,000' (30,480 m).

The chapter discusses research requirements in two major areas: performance and protection. Although these areas, and particularly the subareas analyzed, overlap to some extent, they were used to organize recommendations and plans. Under the heading "Performance," the following subareas are discussed:

(1) Noninvasive monitoring and enhancement of aircrew performance
(2) Predictive modeling of aircrew performance
(3) Prevention of motion sickness
(4) Prevention of spatial disorientation
(5) Performance augmentation in HSLL flight
(6) Exploration of unconventional man-machine interphases
(7) Enhancement of communication
(8) Definition and modeling of multiple stress effects

Under the heading "Protection," the following areas were considered important:

(1) Enhancement of tolerance for multi-stress environments
(2) High G protection for tactical missions
(3) Innovative head-interacting devices
(4) Integration of protective clothing ensembles
(5) Assisted escape initiation
(6) Extended escape envelopes
(7) Occupant crash protection

Specific recommendations for research efforts in the listed subareas include the following:

Performance:

(1) To develop the capability to monitor aircrew performance without interference in order to alert or assist aircrew in case of unacceptable performance degradation.

(2) To develop predictive modeling of human performance. (This parallels for man the present capability for designing aircraft in order to achieve the best possible match between aircrew and aircraft characteristics.)

(3) To prevent motion sickness through crew selection, cockpit environment design and drugs.

(4) To prevent mishaps and performance degradation resulting from spatial disorientation through development of improved training methods and improved cockpit presentations of orientation information.

(5) To diminish the effects of biodynamic cross coupling in high-speed, low-level flight and augment aircrew capacity through passive and active performance mediation or assistance devices.

(6) To improve the crew member's afferent and efferent information handling capacity under extreme conditions of informational and environmental stress by developing alternative modes of information transfer.

(7) To provide a reliable, effective jam-proof aural communication system and to develop optimum systems for audio warning and for voice activated controls.

(8) To acquire the capability to model and predict aircrew performance under combined simultaneous and successive mission stresses.

Protection:

(1) To extend aircrew tolerance for future operational stresses, singly and in combination, by the methods of acclimatization, crew selection and/or pharmaceutical agents.

(2) To develop a protective system that will enhance aircrew's ability to successfully maneuver in a high G, tactical environment.

(3) To develop "head interactive devices" which integrate the multiple functions and requirements imposed for the human head, replacing obsolete helmet concepts.

(4) To take advantage of new fibers, fabrics and active control of the crewman's microenvironment to design integrated protective assemblies which are fully functional and comfortable.

(5) To develop alerting, warning and actual escape initiation systems that will decrease aircraft loss rates and assure that escape occurs within potentially achievable envelopes.

(6) To implement new separation, deceleration and recovery techniques, and fully capable escape systems, allowing confident aircrew training and operation over the full range of aircraft performance.

(7) To achieve new techniques for restraint, limitation of forces and egress that will significantly increase occupant survival in both military and civil transport systems.

Research plans at the end of each major area indicate the time frames for initiation and completion of the initiatives envisioned and addressed by the above recommendations (see Figs. 3 and 4). The plans also indicate if continuation of ongoing research, considerable increased effort or a major new initiative are required to achieve the capabilitites desired.

B. Performance

1. Monitoring and Enhancement of Aircrew Performance

a. Introduction

By the year 2000 aircraft will be specialized both in terms of avionics and the types of missions that they will fly. Although many of the stresses that will be experienced in these flights are similar to those encountered in current aircraft, new missions will add the stresses associated with extremely long duration flights and chemical, biological, electromagnetic and nuclear environments. For these reasons the pilot will have both a greater physiological strain associated with advanced aircraft design and an enhanced psychological demand associated with maintaining and operating a complex avionics package laden with visual displays. Current technology and research in both the psychological and physiological areas have given us a number of parameters which can assess pilot performance and performance degradation during a mission. These parameters and others, which may also provide a reliable index of pilot degradation, could be monitored in an aircraft using onboard avionics computers, and when critical levels of pilot degradation are found, appropriate corrective action could be taken. Since individuals are inherently different and since performance and performance degradation may in fact vary under different circumstances between men and women and individuals of various ages, the critical limits for pilot degradation could be carried on a personal characteristic card (PCC) by each pilot which could then be plugged into the plane before takeoff. In this manner the onboard computers on the plane would know the performance limits for each individual pilot and use these in the decision-making process. It is likely that no single parameter will provide a reliable index of degradation in pilot performance. In fact, it will most likely be a combination of factors used today and parameters that can be developed over the next 20 years that will monitor and predict degradation.

b. Objectives

In order to meet the needs outlined above, research must be conducted to devise methods of monitoring physiological and psychological parameters which index the status of the operator and alert the aircrew or ground control personnel of impending performance degradation so that appropriate corrective action can be taken. Four objectives must be met by this research. First, metrics must be developed that accurately and reliably predict performance degradation in a non-invasive and non-interfering manner. Second, research must be conducted to determine the interrelationships among these metrics. Third, criteria must be developed for acceptable deviation in predictive parameters as a function of the duration and type of mission being performed. Finally, computer algorithms must be developed to make decisions based on such monitoring.

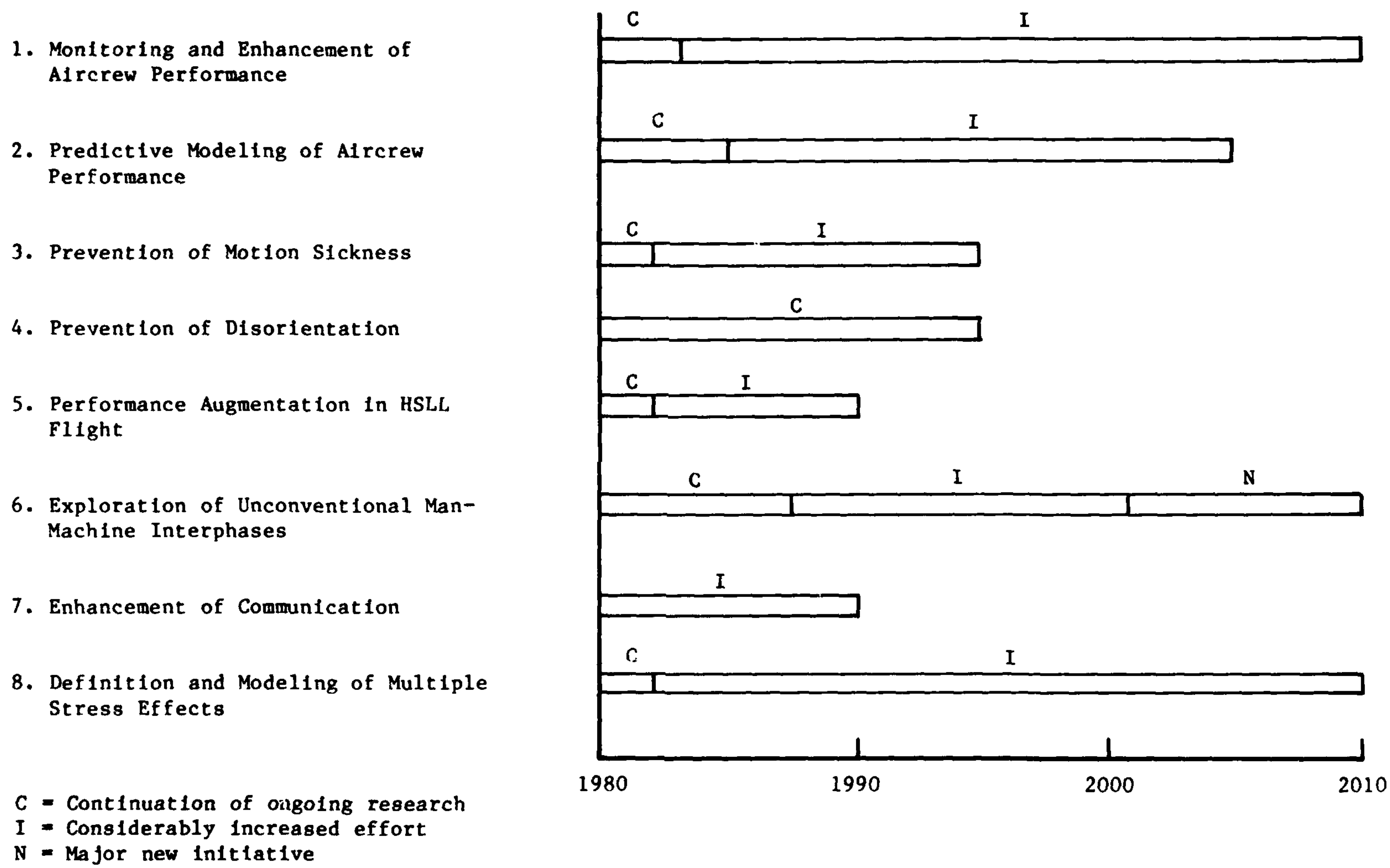


FIGURE 3. HIGH INTENSITY, UNFORGIVING MISSIONS - PERFORMANCE

1. Enhancement of Tolerance for Multi-stress Environments

2. High G Protectin for Tactical Missions

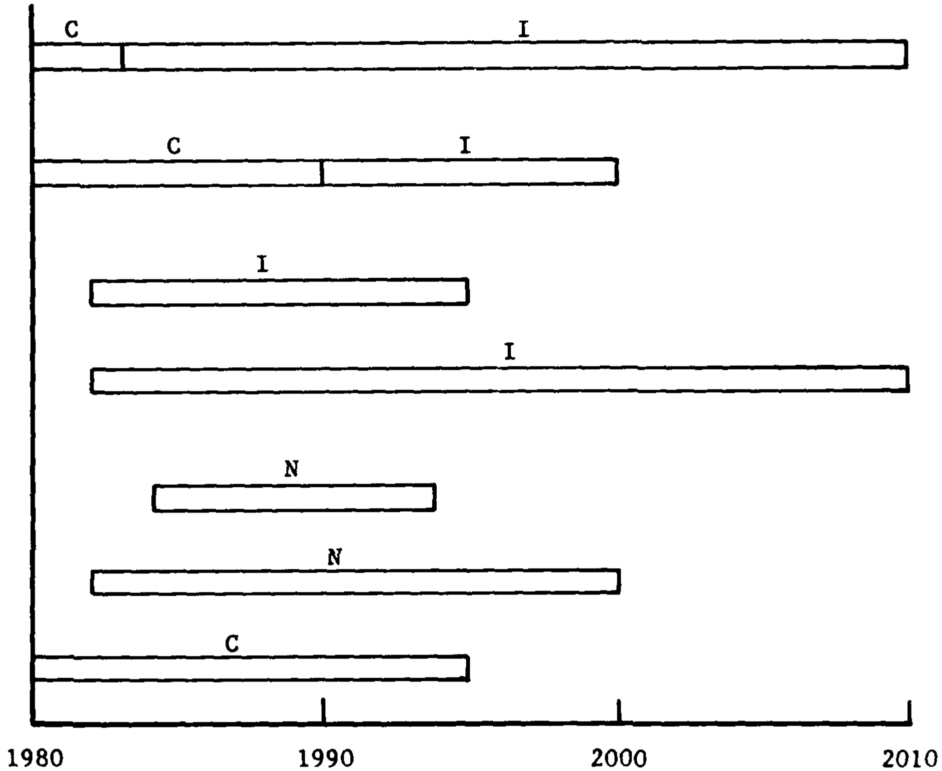
3. Innovative Head-Interacting Devices

4. Integration of Protective Clothing Ensembles

5. Assisted Escape Initiation

6. Extended Escape Envelopes

7. Occupant Crash Protection



C = Continuation of ongoing research
I = Considerably increased effort
N = Major new initiative

FIGURE 4. HIGH INTENSITY, UNFORGIVING MISSIONS - PROTECTION

c. Approach

The types of parameters that can be monitored to meet these objectives can be sub-divided into physiological and psychological parameters. These two categories can be further divided into those types of metrics which are currently under state-of-the-art development and those types of metrics which we would recommend for future development. Those presently available in the physiological area include:

(1) Electromyogram - The electromyogram, recorded above specific key muscles in the body, can be used as an index of the tension exerted by the muscles and impending muscle fatigue by doing a Fourier transform to determine the amplitude and frequency components of the EMG.

(2) Tremor - Muscle tremor has been shown to change under a variety of physiological stress parameters. Since avionic controls onboard the aircraft are becoming increasing fly-by-wire, it would be a relatively simple matter for the computer to monitor the tremor induced by operator pressures on the controls in the physiological frequency range of either 8 or 16 Hz. From this data, tremor could be quantified.

(3) Target and acquisition error - During flight, the ability of the pilot to make rapid corrections from inputs induced artificially by the flight computer could be assessed. The rate at which the pilot is able to move the flight stick would give an index of muscular degradation. Research must be conducted to develop appropriate tests of muscular degradation.

(4) Hypoxia - Hypoxia is a parameter which has been known to result in the degradation of many parameters associated with pilot performance. For example, the visual field is reduced markedly as the pilot becomes hypoxic. With current technology, it is now possible to transcutaneously measure either hemoglobin saturation, pO_2 or pCO_2. These sensors could be developed further so that the oxygen state of the body could be measured noninvasively. If a PCC card is then used for each individual pilot, the aircraft avionics would know the tolerable limits of hypoxia for a given pilot before a significant reduction in performance took place.

(5) Temperature - Since both shell and core temperature can alter pilot performance, both of these parameters should be measured.

(6) Flight control error - During the operation of a jet aircraft, as a pilot's performance begins to fall, turns are entered into with improper coordination. The slip that results from this action can easily be monitored by the computer through the use of the plane's turn coordinator. As the pilot becomes more and more physiologically fatigued, there will be a greater tendency to allow the aircraft to slip in turns. Therefore, such indications as turn coordination and the number of course corrections and errors a pilot produces while following a flight vector may provide a good performance parameter.

Future parameters that could be developed to aid in the physiological assessment of pilot performance degradation might include:

(1) Magnetoelectrocardiogram and electromyogram - Current technology allows us to measure the electrocardiogram and electromyogram through the use of surface electrodes. It would be much more convenient if this could be done noninvasively so that nothing would be attached to the body.

(2) Voice tremor - Current research and technology has enabled the measurement of low frequency tremor components in the human voice and the use of these components as an index of whether a person is telling the truth. It is possible that the frequency components, especially in the low frequency range of the voice, may also provide an index of degradation of performance. It is recommended that a series of work experiments be conducted with both dynamic and static exercise where voice frequencies are analyzed throughout the duration of fatiguing work of known intensity to see if this is possible.

(3) NMR - Nuclear magnetic resonance can be used to measure many parameters noninvasively, such as high energy phosphogens. In the last year or two, several laboratories have begun to use whole limb NMR to analyze changes in the energy state of tissues during fatiguing work. If this type of technology is applied to aircraft, an accurate assessment of energy reserves available for muscles and the current energy depletion rate of the tissue can be done as the pilot flies the aircraft.

(4) Cardiac output - As an index of the physical workload placed on the pilot, noninvasive techniques such as impedance cardiography can be expanded to see if they can be used as an index of the degradation in physiological pilot performance.

(5) Tissue oxygen uptake and blood flow - Research should be advanced in laser doppler diffraction techniques to measure blood flow and energy utilization by specific tissues such as muscle and brain to see how they are related to performance.

(6) Catecholamines - Research should be conducted to develop laser operated noninvasive methods of measuring tissue catecholamines to assess physiological and psychological stress transcutaneously.

In the psychological area, parameters presently available to the Air Force for assessing alertness and pilot workload include the transient and steady-state cortical evoked response, eye movement metrics and embedded secondary task performance. Within the next five years, several of these measures will be transferred to the cockpit and may then be developed for real-time monitoring. Future work must be done to examine new metrics which are less invasive and more sensitive than those that are presently available. Of particular interest among these are measures such as the magnetoencephalogram. The magnetoencephalogram could provide noncontact measurement of brain activity more sensitive than present techniques. Another method on the horizon that may be used to monitor performance in order to predict degradation would involve the assessment of strategy changes on the part of the pilot. It is widely recognized that human operators do not passively respond to increased levels of mental workload or stress. Instead, considerable evidence suggests that they tend to adjust the strategies of information processing that they employ in an effort to minimize or optimize psychological cost. Such strategic variation could present critical problems in future Air Force systems where high workload, fatigue and boredom are likely to confront airborne and ground based crew members. Strategies such as perceptual filtering, attentional focusing, and criterion adjustment that may be adopted by the stressed operator can be maladaptive with respect to system goals. Since degradation in operator performance is often preceded by such a subtle shift in strategy, it is likely that the ability to detect and assess strategy changes will provide a predictive index of overload and subsequent performance breakdown. Research must be conducted to identify specific strategy changes and the stressors that produce them, and to develop methods of assessing strategies in aircraft environments.

For both the physiological and psychological parameters described above, it would then be necessary to conduct a series of experiments to determine the interrelationships among these parameters. This would involve finding the relative weighting of each parameter as an accurate index of degradation in pilot performance and finding how the weightings might change with combinations of various psychological and physiological parameters. A third research area that must be pursued in relation to the monitoring problem concerns the selection of criteria for these measures. Because many workload and stress metrics do not yield obvious indications of maximum tolerance or operator capability for specific systems or missions, one approach to answering the question of "how much is too much" would be to apply standard decision theory methods to the problem. This would be accomplished by generating distributions relating measured stress or workload to system criteria-oriented states of the world (for example, target destroyed or target missed). Normally these distributions would overlap and the problem is to set a fixed maximum workload or stress level. Decision theory offers a method of solving this problem by combining the criterion distribution information with the results obtained from values assigned to a payoff matrix by decision makers at the command level. The outcome of an application of the method would be a single value on the stress or workload metric scale representing an absolute maximum for the mission under investigation. Once this work is done, the final research which must be accomplished would involve developing the appropriate computer control algorithms to make decisions based on the monitored parameters. This could take the form of a conventional logic tree type of computer program or involve the use of artificial intelligence. The development of artificial intelligence programs would offer the advantage of allowing such parameters as the duration of the mission, the integrated workload that was accomplished by the pilot during that mission, and such factors as age and circadian rhythms to be considered in the final decision as to whether the pilot has reached that critical point at which his performance will be unsafe and mission failure may result.

d. Facilities

The facilities to conduct this type of research are available. Obviously, this type of research relies heavily on computer research using artificial intelligence as a mode of computer operation. A data base must be established for the trade-off in pilot performance associated with centralizing visual displays and with changing control pressures and other such parameters in the aircraft as a means of making the aircraft more adaptable to the pilot. Once the trade-off can be weighed in modifying aircraft performance as a function of pilot performance, computer control programs must be written to implement trade-offs. Obviously then, the research would involve heavy use of high fidelity Air Force simulators to develop and verify the operation of these programs.

e. Applications

These monitoring technologies predicting pilot performance degradation will be applicable to a broad range of high stress missions predicted for the year 2000 and beyond. These missions will include the high physiological and psychological stresses of low level missions in bad weather, high altitude long and short duration missions for strategic reconnaissance and tactical purposes, and orbital flights. The three levels of specific applications methodology are as follows:

(1) Operator cueing - The simplest application of the monitoring that was described in the previous section would be to send some type of visual or audible alert to the pilot of an aircraft during a mission to alert him that if he continues at the current level of effort he is likely to compromise his mission performance. The pilot would then modify his behavior to overcome this problem.

(2) Off-line adaptation - A second and more sophisticated way of approaching the problem would be to use a technique that might be called off-line adaptation. In this technique, each pilot would be examined at some point in his career and possibly re-examined on a weekly, monthly or annual basis to measure such parameters as his muscular strength, endurance, reaction rates, etc. This would then be put onto a personal characteristics card that could be inserted into the aircraft so that aircraft systems could be modified to make them more usable by each individual pilot. For example, working at very low levels of strength allows the use of slow twitch muscle motor units. Using these types of motor units during exercise permits precise control of movement. Considering individual differences in the physiology of each pilot, flight controls could be adjusted to offer the same physiological stresses for each user while maximizing control. A similar approach would be to use off-ine adaptation to deal with individual differences in information processing capabilities. Once monitoring techniques are used to determine the individual's strength and weakness in information processing and responses to stress, this data could be applied in an off-line method using a personal characteristic card or profile to modify any given aircraft in order to compensate for these deficiences in terms of display and control functions.

(3) Biocybernetics - The most complex, but possibly the best mode to approach the problem would be with biocybernetic control. In this mode of operation, the avionics on the aircraft would make intelligent decisions about modifying aircraft operation both from a display and control standpoint, for better operation in the face of pilot performance degradation. If, for example, the pilot's visual field is reduced, the aircraft could shift critical visual displays to displays in the center of the console and avoid using the displays in the periphery. For example, if the pilot was exposed to extreme vibration, the rudder controls might be made stiffer such that a light isometric contraction might have to be applied with the leg muscles to maintain aircraft position. This light isometric contraction, while causing

some fatigue in the leg muscles, might have the effect of reducing or eliminating hand tremor. In this way, the aircraft avionics would make intelligent decisions and tradeoffs of how to modify control pressures and display of information to enable better mission performance in spite of pilot degradation.

2. Predictive Modeling of Aircrew Performance

a. Introduction

Predictive modeling is useful in determining the degree to which new tactics or equipment can resolve performance problems. Modeling of human capacity for physical work is well advanced, as are predictions of thermal comfort, discomfort, performance decrements and tolerance limitations for acute (1-2 h) and extended (2-12 h) effects. Models are available for acceleration, for some drug effects, hypoxia and other stressors. Such models are extremely useful in identifying problems, in assessing solutions (e.g., varied work/rest cycles), in minimizing costs of test and evaluation, and in reducing risks of human testing.

b. Objectives

Coordinate the various models and identify gaps [e.g., chronic effects (days) and repeated exposure effects (acute, extended or chronic)]. Integrate the individual models, including interactive effects of drugs, acceleration, thermal factors, pressure, vibration, circadian rhythms, nutrition, dehydration, sleep loss, etc. Physical, physiological and psychological models should all be included.

c. Approach

Provide increased support for such studies; encourage national/international symposia on models of human response to stress. Carry out studies on the work (energy cost) demands of nap-of-earth flights, high G flight, various mission profiles (strategic, tactical, etc.), and of pilot turn-around of aircraft with minimal assistance at remote/secondary bases. Study the effects of self-induced stress (smoking, drinking, partying) on formance under the various stressors in the flight environment. Explore various feeding supplements and regimens (including conditioning to periods of fasting up to three days. Most importantly, model the interaction between stressors and among individuals in small groups. Such studies must be oriented toward: (a) developing data bases for modeling approaches; (b) developing empirical or theoretical models to fit available data; (c) validating models across conditions other than those used to develop them; (d) extending models until they are valid across the range of USAF concern; and (e) modeling the effects of motivation, leadership, training, etc., as these factors become amenable to such modeling. The primary focus of this work must be on human studies, although animal studies may be required for some stressors (e.g., radiation).

d. Facilities

A list of facilities carrying out such research needs to be developed. An AGARD panel may be useful. An inherent part of this effort is the need for continued upgrading of models using information and expertise from widely varied sources not ordinarily in communication with each other.

e. Application

All life support development programs and tactical, strategic and transport scenarios.

3. Prevention of Motion Sickness

a. Introduction

Motion sickness in flight is not a new problem in military aviation and much is known about the etiology of the condition. However, it is still a cause of impairment of performance and with projected scenarios, in which the aviator will be exposed to motion environments and tasks which are more stressful and provocative than those now extant, the problem is likely to become more significant.

There are a number of drugs of proven efficacy that prevent motion sickness or increase a subject's tolerance to provocative motion stimuli. Unfortunately, these drugs are either sedative or have other side effects that impair performance and hence cannot, or should not, be used by operational flying personnel. As certain projected roles of the military aviator will place increased demands on his capacity for visual work in the presence of changes in the force environment likely to produce motion sickness, there is a need for effective drugs or other therapeutic measures, without deleterious side effects, to be developed.

In addition to the requirement for better therapy, improvements in selection should also be made. Measures of individual susceptibility are in existence, but as yet there are not reliable techniques for predicting which individuals will develop and retain protective adaptation during training, and hence will not suffer from air sickness during operational sorties.

b. Objectives

(1) To develop a procedure which will reliably exclude those individuals who will not develop adequate protective adaptation to the provocative motion of projected flight missions.

(2) To develop drugs or other therapeutic procedures which will prevent motion sickness in flight without side effects which will degrade operational efficiency.

(3) To optimize the cockpit environment so that provocative visual and whole body motion stimuli are minimized.

c. Approach

(1) Basic research - The neurophysiological processes underlying the development of the motion sickness syndrome and the site and

mode of action of anti-motion sickness drugs are poorly understood. A logical development of new therapeutic procedures is probably dependent upon the elucidation of these basic physiological and pharmacological mechanisms. Thus, work would, of necessity, be carrried out on experimental animals and would employ conventional neurophysiological, neuropharmacological and histochemical techniques. Initial assessments of new drugs that may be developed as a result of a better understanding of the mode of action of existing drugs, or of other drugs that are tried empirically, would also be conducted on animals.

These studies would be complemented by laboratory experiments to determine:

(a) The effectiveness and duration of action of new drugs in the control of motion sickness induced by simple (e.g., cross-coupled) provocative motion stimuli.

(b) The mechanism of action of these drugs.

(c) Whether drugs that control motion sickness degrade performance of psychomotor and other mental tasks of operational significance (e.g., logical reasoning, decision-making, vigilance, etc.).

(2) Applied research - Improvements in selection procedures will depend upon longitudinal studies in which the results of tests carried out on student aircrew are compared with subsequent histories of motion sickness in flight training or operational duties. Test procedures will have to be elaborated which assess aspects of vestibular function, adaptability and retention of adaptation, as well as other individual characteristics and dimensions of personality that may have predictive validity. More than one type of provocative stimulus may have to be employed because of the known low correlation between measures of susceptibility in different motion environments.

Current techniques for desensitizing and rehabilitating aircrew, whose training or performance has been compromised by intractable motion sickness, should also be improved and validated.

Analyses of the tasks of aircrew in projected aircraft and missions should be made to identify those situations in which motion sickness is likely to be provoked. New display configurations, in particular helmet mounted displays, that engender conflicting visual and whole body motion cues should be investigated and appropriate remedial procedures and techniques (e.g., space stabilization of the visual display) developed.

d. <u>Facilities</u>

Initial studies should be carried out in a conventional laboratory by staff experienced in relevant neurophysiologic and neuropharmacologic techniques and who have research experience in the study of emetic mechanisms. Simple angular and linear motion devices for the generation of controlled provocative stimuli in both experimental animals and man would also be required. More complex equipment, capable of producing low frequency

(< 0.3 Hz) linear acceleration stimuli of > $1 ms^{-2}$, preferably in two or three orthogonal axes, would be of assistance.

e. Applications

Control of motion sickness would be of value in the following operational areas:

(1) Training.

(2) Low-level penetration. The changing force environment associated with terrain following and turbulence of HSLL flight are provocative. Sickness of non-pilot aircrew degrades performance and may jeopardize the mission. Pilots may also be affected when not in active control of the aircraft as during automated terrain following.

(3) Reconnaissance. Projected sub-orbital "skip" missions will expose the aircrew to fluctuating hypo/hypergravity and are likely to induce motion sickness.

4. Prevention of Spatial Disorientation

a. Introduction

Despite continuing efforts to educate pilots about the mechanisms and hazards of spatial disorientation in flight, despite significant alterations of cockpit instrumentation to provide more assimilable orientation cues and to eliminate vertigo traps, and despite modifications of flight procedures to lessen the likelihood of disorientation, the U.S. Air Force continues to lose valuable aircraft and aircrew in mishaps caused or contributed to by spatial disorientation. Over the past three decades, between 4 and 10 percent of Class A aircraft mishaps and between 10 and 20 percent of fatal aircraft mishaps in the Air Force would not have occurred had the pilot not been spatially disoriented at some time during the mishap sequence. In 1979 alone, the Air Force lost 10 aircraft and several times that number of lives because of spatial disorientation, at a reported cost of 40 million dollars and at a replacement cost of far more than that. With aircraft becoming faster and more maneuverable, cockpit displays becoming more complex, and the flight environment becoming more hostile as a result of requirements to fly low, fast, at night and in weather, the orientation information processing task for the pilot necessarily becomes more and more demanding. For these reasons, orientation-error mishaps will become more likely unless further efforts to minimize the pilot's susceptibility to disorientation are pursued.

b. Objectives

The two major objectives of spatial disorientation research should be to obtain a better understanding of the mechanisms of susceptibility and resistance of aircrew to spatial disorientation, and to develop means by which spatial orientation can be assured under all conditions of flight.

c. Approach

To improve our understanding of the causes of disorientation mishaps, we must obtain psychophysical and control-behavioral measurements and conduct neurophysiologic investigations. In the former area, we should not only address the question of what visual and mechanical motion stimulus conditions result in orientational illusions, as has been the classic approach, but concentrate on identifying conditions or factors that lead to actual degradation of control responses, whether through deterioration of perceptive, cognitive, or motor abilities. In the latter area, neurophysiologic studies of orientation information processing schemes, with emphasis on neural information prioritizing mechanisms and orientational decision strategies, would add immensely to the appreciation of behavioral manifestations of spatial disorientation.

To contribute to the ultimate objective of preventing disorientation mishaps by developing and instituting preventive measures, a twofold approach seems most likely to be productive: (a) improvement of spatial disorientation training for pilots, and (b) improvement of cockpit displays of orientation information. Spatial disorientation training technology presently is capable of providing compelling demonstrations of various orientational illusions. What is needed is a means of convincingly demonstrating to a pilot the severe challenge which an episode of spatial disorientation presents to his ability to control a vehicle. Making such a demonstration readily available to all pilots through improved ground-based simulation is presently feasible and would represent a significant improvement in our ability to attack disorientation accidents through education and training.

The approach involving improvement of cockpit displays offers several attractive opportunities. Chief among these is the possibility of presenting orientation information through more natural sensory channels than foveal vision, thus making spatial orientation a more efficient process and sparing foveal vision for tasks requiring a high degree of discriminatory capability. Work should be done to determine how orientation information can best be presented to the pilot through his peripheral vision, his auditory system, his nonvestibular proprioceptors, and his cutaneous exteroceptors. As a goal, we should try to present all pertinent information about aircraft motion and position through non-foveal sensory channels in a natural, easily assimilable fashion.

d. Facilities

Studies of sensory functions and their relations to orientational mechanisms can be carried out at a number of institutions having strong research programs in sensory psychology. Studies of control behavior under conditions of competing orientational cueing would best be accomplished at a facility having heavy involvement in flight simulation technology (e.g., MIT Man-Vehicle Laboratory or AFHRL). Neurophysiologic studies of orientation information processing should be done in laboratories well equipped for the most advanced methods of observing, recording and analyzing neuroelectric activity.

Advancement of antivertigo training technology requires the acquisition of one or more relatively small devices capable of incorporating the trainee into the motion-control loop while providing strong but conflicting orientation cues, both vestibular and visual. The USAF School of Aerospace Medicine should develop and/or evaluate any such device for Air Force use. To evaluate existing novel attitude displays and to conceive, develop and test in-cockpit devices designed to provide maximally assimilable orientation information requires motion platforms of several levels of complexity, up to and including instrumented aircraft (AFAMRL, USAFSAM, AFHRL, NADC, AFFTC and MIT Man-Vehicle Laboratory).

e. Applications

As spatial disorientation causes aircraft mishaps in all major operational commands and during nearly all types of missions, making it less likely or less lethal would have a salutary effect throughout the Air Force. The tactical forces would derive the most benefit, however, because of their need for high maneuverability. All phases of offensive tactical operations, especially night and weather air-to-ground and low-level air-to-air, have a critical need for artificial orientation-enhancing mechanisms because of the extremely limited margin for orientation-error-induced performance perturbations in such operations. Strategic penetration, because of ground proximity, presents problems with spatial disorientation similar to those of low-level tactical missions. Strategic reconnaissance at very high altitudes and high speeds presents special orientation and control problems under conditions of sudden distraction of the pilot, because of the need to operate strategic reconnaissance aircraft at the limits of their performance envelopes. Increased use of V/STOL aircraft, whether in support of tactical, strategic, or other missions, will also exacerbate the problem of spatial disorientation and orientation-error-induced loss of control; this is because of the instability of such aircraft and the concomitant demands on the pilot to monitor simultaneously and precisely multiple critical motion parameters.

5. Performance Augmentation in HSLL Flight

a. Introduction

The expansion of aircraft capability into advanced forms of low-altitude, high-speed, terrain avoidance, along with motion involving six degrees of freedom (both translation and rotation), presents a new set of control and restraint problems for the designer and the pilot. The problem definitions and solution methods can be defined only through a rational structuring of the situation stress dynamics and an equivalent model developed for the biological system involved, i.e., the pilot. This section outlines the major directions for research into the mediation of pilot performance in the multi-stress environment, both near and far term.

b. Objectives

A comprehensive program of research and development is needed to improve aircrew tolerance and performance in cockpits undergoing severe biodynamic environments such as maneuvering G, G on G, vibration and buffet. The biodynamic forces are accompanied by thermal, atmospheric, and psychologic stressors. The purpose of this research area is to provide the background information which will allow exploitation of the optimal performance of the man-aircraft system. This can be done by providing both passive and active performance mediation or assistance devices for application in the multiple stress biodynamic environment. The specific objectives can be enumerated as follows:

(1) Provide seating and restraint devices which will minimize adverse biodynamic coupling into the pilot's control behavior and provide for injury free escape.

(2) Provide controllers and control methods for manual, voice, pedal, neuromuscular, or neuro/myoelectric systems that will passively and/or actively input the pilot control intent without compromise.

(3) Provide protective equipment design limits to minimize adverse equipment-pilot interfaces.

(4) Provide biodynamic-physiologic models of the human in the face of six-degree-of-freedom acceleration stressors. In the long term, the models must be composites of the physiologic, psychologic and dynamic responses to such stressors and will partially define dynamic frequencies of maximal stress.

(5) Provide performance assessment or measurement methodologies which exhibit the required sensitivities for comparing different devices or techniques.

(6) Provide for performance sharing and performance enhancement through the use of model-directed artificial intelligence/biocybernetic systems in a pilot-vehicle symbiotic relationship.

c. Approach

(1) Investigation must be extended for passive and active restraint methods for multiple sequential acceleration vectors to provide safe body alignment along with seat angle variation. Techniques for time sequencing of the seat position and optimal instantaneous positioning must be developed. Techniques for safe active body alignment and reduction of displacement with adequate mobility must be explored.

(2) Vibration free control devices based on biodynamic models and active controllers must be evaluated. Voice control input devices should be developed. Techniques for application of neuro/myoelectric signals as control and monitoring methods under stress must be developed.

(3) The strength duration capability of the human under complex acceleration, particularly G_y, must be delineated for connected body segments. The head is a particularly weak member under side load. Design limit information must be developed to establish equipment weight limits and mass distributions.

(4) Structured biodynamic and physiologic model development should be explored based on large scale system paradigms, application of

binary weighting matrices, and linear system theory. Simplified linear system models of biodynamic response, vestibular response and physiologic system response (i.e., visual, cardiovascular) must be explored.

(5) Refined performance assessment models must be evaluated in the context of sensitivity of measurement. Simple measures and task development is required based on control theory as well as psychophysiologic measures. Sensory measures which provide predictive capability are also required. The measures must provide sensitivity such that enhancement through cybernetic systems application is enabled.

(6) Integration of the pilot and vehicle to provide for performance sharing requires the extension of artificial intelligence, pattern recognition, distributed problem solving, sensory processing (human and machine) and hierarchical control methodologies. Under severe stress conditions pilot performance changes must be evaluated to provide for automatic task partitioning with on-board intelligent machines.

d. Facilities

Current simulation facilities for environmental stresses must be upgraded to encompass the wider range of mission stresses.

e. Applications

(1) Low profile seating with interactive restraint system.

(2) Vibration free control for any dynamic system where control intent may be degraded by force cross coupling.

(3) Appropriate size limits and configurations for protective equipment.

(4) Models of the human which provide biodynamic/physiologic stress frequencies and provide band rejection filters for flight control systems.

(5) Sensitive techniques for assessing performance and optimizing pilot-vehicle interface system design.

(6) Artificial intelligence/cybernetic advances which allow for pilot-vehicle interaction capability under stress conditions. This will maintain optimal application of the weapon system by automated sharing of mission requirements in the presence of intrinsic, extrinsic and physiologic stresses.

6. Exploration of Unconventional Man/Machine Interfaces

a. Introduction

Projected mission requirements place great demands on the information processing capacity of the weapon-system operator. The ability to meet these demands could be enhanced by the use of unconventional means of transferring information into and out of the human operator. Information saturation of specific sensory and motor channels can, under some circumstances, be avoided by invoking parallel rather than serial means of information transfer. The ongoing revolution in computer technology, including very significant advances in large-scale integration and miniaturization of electronic components, yields new opportunities for the practical application of novel means of such information transfer.

b. Objective

The objective of this effort is to improve the afferent and efferent information handling capacity of the human operator by developing alternative modes of information transfer.

c. Approach

Information can be received through a wide variety of biological sensors. From the standpoints of utility and practicability, however, only those sensory systems which project into consciousness are likely to be amenable to receipt of meaningful alternative stimulus patterns. Vision presently handles by far the greatest volume of relevant information, and nearly all of that information is processed foveally. By assigning some types of visual information, such as spatial orientation information, to peripheral visual channels, total visual processing capacity is enhanced. The auditory system can receive acoustic information at a higher rate than is currently employed in aeronautical systems, and research on compressed speech and other novel stimulus modes should be undertaken. Translation of aircraft and weapon motion and position parameters into acoustic information should be explored further. In flight, the vibrotactile system is a vastly underutilized sensory system which offers tremendous opportunities for receiving information relating to the status of aircraft and weapon systems. This is true because of the capacity of the skin for spatial, temporal and stimulus-intensity resolution in a number of separate sensory modalities. Even the olfactory system could be used for information transmission requiring low volume and limited complexity of information, such as warning of malfunctions.

A special area of interest should be in direct neural stimulation, either of peripheral nerves through skin electrodes, or of the central nervous system through more complex neuroelectric induction systems such as electromagnetic transmission. Electrical skin surface stimulation could serve the same purposes as direct mechanical stimulation of the vibrotactile system (e.g., the monitoring of motion and position of weapons) and is relatively feasible. A great deal of development would be required for techniques of noninvasive, or even invasive, stimulation of the central nervous system to reach fruition. It appears, however, that if microminiaturization of data-handling hardware reaches a level of physical structural resolution to match that of the nervous system, much could be gained from developing and exploiting a direct interface between the external, physical world and internal, neural structures. Even now experiments with direct electrical stimulation of cranial nerves and cerebral cortical projection areas have begun and appear promising for aiding patients with sensory defects.

Special attention should be given to the problem of determining the limiting mechanisms involved in information processing. Artificial preprocessing of required sensory information, involving optimal coding strategies for each sensory channel, will be necessary; but the ability of the operator to actually process and make decisions based on the additional information made available by the expanded sensory interface needs to be quantified, and techniques may have to be developed to ensure that the operator's ultimate information handling capacity is not exceeded.

Perhaps potentially more practical is the prospect of coupling biologically generated information to mechanisms for monitoring the operator's status or for translating his desires and intentions into effects. Of the wide variety of biomechanical effector mechanisms available for development, those involving myomechanical, myoelectric and neuroelectric effector mechanisms are the most promising.

The first category includes all mechanisms involving direct control of mechanical devices through voluntary movements of muscles not routinely used for such tasks. For example, one could activate weapons by voice, by tensing facial or scalp muscles, or by biting a piezoelectric dental implant. Less easy to implement and requiring more sophisticated signal analysis is myoelectric (electromyographic or EMG) activation and control. Myoelectric signals could, for example, be used to guide an aircraft or deliver a weapon. Manipulation of flight controls by voluntarily generated muscle potentials under conditions of incapacitating G stress would be especially useful. Another example would be a power-assistance device based on neck-muscle-potential activation for head turning under high G forces. Least easy to implement and requiring the greatest amount of computational processing would be the use of neuroelectric signals to effect control, guidance, detonation, or other functions requiring rapid responses by the operator. One example of this type of interface would be the use of corneoretinal potentials to visually guide a weapon to a target. An example of a more exotic application of this technology would be the use of the electrical manifestations of brain activity (electroencephalographic or EEG signals) to translate thought processes into desired effects, through employment of scalp-mounted electrodes and associated computational hardware located in the helmet.

d. Facilities

AFAMRL and USAFSAM, as well as many university psychology, physiology and bioengineering laboratories, have adequate personnel and equipment to do research on alternate modes of presenting and receiving information. Two special types of facilities are needed, however, for accomplishing the basic research and development of the effector technology discussed: neurophysiology laboratories with research emphasis in the area of information content of observable neuroelectric signals, and bioengineering laboratories in which biochemical and bioelectric activation mechanisms are developed for prosthetic devices. No major new facility or unusual research investment is required at this time, but promising leads may require additional investments. Use of higher-order experimental animals - even subhuman primates - is absolutely essential in the early phases of development of this technology and cannot be compromised or sacrificed.

e. Applications

The technology involved in developing unconventional man/machine interfaces applies to all mission conditions in which information processing loads threaten to become overwhelming, and also to those particular conditions in which mechanical forces or other environmental factors limit or degrade the operator's physical mobility. Tactical air-to-air missions will entail both of these conditions and would benefit most by providing the aircrew with additional sensor and effector modes. Strategic penetration could also involve some degree of operator impairment by mechanical forces as well as high task loading. Certainly, the tactical air-battle-direction mission will at times place heavy demands on information processing by a human operator, and distributing the afferent and efferent information interfaces more widely over the operator's total capacities would be beneficial.

7. Enhancement of Communication

a. Introduction

Aural communication is at present the primary link for intercrew communication and communication of the crew with the command structure. Present communications systems are marginal or inadequate because of noise, environmental effects on speech (e.g., acceleration or buffeting), and most critically because of enemy jamming. Unsatisfactory communication is implicated in many peacetime accidents.

Although jam-proof communications systems are under development and should be in service in the near future, their basic technological process employs synthesized speech at the receiver terminal and it provides, at present, no recognizable individual voice characteristics of the speaker. In multistation conferencing, individual speaker recognition is hardly possible.

Voice activated controls to assist the aircrew in high workload and high stress situations is technically feasible today, but its incorporation into a reliable system of controls and into the inflight communication system requires expanded knowledge of speech sounds, speech recognition and speaker identification.

b. Objectives

(1) Allow optimum and reliable employment of the auditory communication channel under all electronic warfare conditions.

(2) Allow multistation conferencing under all operational flight phases and conditions with high speaker fidelity.

(3) Allow communications systems design with noise-cancelling characteristics to increase reliability of communication and to prevent hearing loss in the aircrew.

(4) Provide automatic or semi-automatic communication/voice channel selection based on priority.

(5) Use one and the same communication system for voice activated controls and for voice feedback.

(6) Identify optimum means for reinforcing or unloading auditory information transmission through the visual and/or vibrotactile channel.

(7) Allow secure speaker identification and monitoring capability of his or her emotional/stress state.

(8) Determine an optimum audio warning/visual warning system using voice and tone audio components.

c. Approach

Speech characterization, machine analysis and synthesis is a rapidly expanding field which is dependent on the close collaboration of the communications engineering and psychoacoustic disciplines. The specific military objectives listed above (1-8) require directed team efforts to result in the desired military capabilities and their reliable validation and testing. Voice analysis for stress monitoring requires basic research advances and analysis of operational mission communication under all (primarily biodynamic) stress conditions.

Potential effects of low level chemical agent exposure on speech formation as well as hearing capability must be evaluated. Speech reception and information processing in the auditory channel must be understood to counteract effectively all potential jamming interaction, as well as to devise offensive jamming capability.

d. Facilities

Well-equipped acoustics laboratories with expertise in audiology, physiology and radio engineering are required, with capabilities for speech analysis, synthesis and recognition. There is no requirement for major new facilities.

e. Applications

The applications are, in effect, listed under "Objectives." All projected operations using voice communications will benefit.

8. Definition and Modeling of Multiple Stress Effects

a. Introduction

The operational environment can expose the aircrew to multiple stressors in various combinations and with various time histories. These stressors arise from two distinct aspects of the mission environment: intrinsic factors due to the aircrew functioning within the aircraft system and extrinsic factors due to threats from hostiles. Further, the operational setting itself can impose unusual and demanding work-rest cycles, altered sleep patterns, a requirement for prophylactic/therapeutic pharmacological agents, irregular dietary habits, etc. These effects of the setting modify the baseline psychological and physiological substrate of the aircrew, which can also influence the effects of the environmental stressors and can thereby result in still more severely impaired mission performance and degraded effectiveness. Finally, the environmental stressors, both intrinsic and extrinsic, acting in various combinations on variable baseline conditions of the aircrew, can interact in a non-linear manner, either diminishing or exacerbating the debilitating effects of the stressors taken individually. Thus, the effects of intrinsic environmental stressors such as vibration, thermal extremes, glare, work-load demands and information processing loads, combined with extrinsic stressors such as laser-induced mottling of the windscreen, high G maneuvers to avoid missiles and ground fire, exposure to chemical and/or biological agents, and exposure to ionizing and nonionizing radiation, may be quite different from the sums of these effects as studied individually under laboratory conditions. These multiple stress effects are poorly understood, and a considerably increased research effort, including systematic and parametric analyses, theoretical modeling of results, and operational or full-scale simulation validation, appears to be warranted.

b. Objectives

Three fundamental objectives must be met to solve the problems imposed by the multiple stress environment anticipated in future aircraft systems. First, the stressors encountered should be delineated, classified, analyzed and studied empirically. Second, data derived from experimental studies should be incorporated into theoretical models that account for linear and non-linear interactive effects. Finally, the theoretical models should be validated under operational conditions or in full-scale simulations. Thus, the overall objective for these research efforts is nothing less than to achieve a full and comprehensive understanding and knowledge of the effects of multiple stressors on human functioning in the aviation environment. Ultimately, this knowledge should be employed to develop optimal countermeasures against the multiple stressors encountered under operational conditions.

c. Approach

(1) The intrinsic and extrinsic stressors anticipated for the projected missions should be determined.

(2) The variables influencing the psychological and physiological substrate of the aircrew should be delineated.

(3) Criteria for human functioning in the aviation environment should be defined.

(4) A taxonomy for combining the stressors, the psychological/physiological substrate, and measures of human functioning in the aviation environment should be established.

(5) Empirical studies, investigating specific, highly probable and operationally realistic combinations of the above parameters should be conducted, and these data should be incorporated into large scale systems

models derived from complex systems theory. These systems models can be explored by use of techniques such as binary intent matrices, binary weighting systems, and linear systems theory with appropriate application of non-linear systems modeling.

(6) Interaction modes must be based on an integrated complex biodynamic-psychophysiologic system structure of the human. The structural model must link the actions of the three basic stress parameters (intrinsic, extrinsic, psycho/physiologic substrate) using equivalent dependent variables. The interaction paradigms must be dynamic in nature and must account for variable time sequential effects on temporal responses of the subsystems themselves.

d. Facilities

A large scale biodynamic research simulation facility which allows for application of the three stress parameters is required. Either significant upgrade of the active multistress centrifuge facilities is required, or a new approach through the development of a national combined stress facility should be undertaken.

e. Applications

The multistress model will be used to derive potential countermeasures to reduce stresses imposed by the operational environment. The model will provide the design basis for environmental requirements, cybernetic performance augmentation systems, and minimum stress/maximum effectiveness mission planning.

C. Protection

1. Enhancement of Tolerance for Multistress Environments

a. Introduction

Humans vary in ability to tolerate physical, physiological and psychological stresses. The tolerance of USAF aircrews can potentially be enhanced by selecting resistant individuals. Tolerance can also be enhanced by acclimatization, i.e., by altering responses as a result of scheduled, repeated stress exposures. In many cases, the benefits of such acclimatizing exposures are significant; in others, they are insignificant and for some stressors any exposure is harmful. A variety of pharmaceutical agents may also extend tolerance, though side effects must be considered.

b. Objectives

Evaluate the possible benefits/drawbacks to controlled exposures of humans to the range of operational stresses projected for the year 2000 time frame, including physical stresses (see flow charts on pages 54 and 55), such physiological stresses as fasting and dehydration and also the more difficult areas of psychological stress accommodation. The possible benefits and drawbacks of drug enhancement of human performance under stress (single and multiple stressors) also should be explored.

c. Approach

Identify the stressors to which human acclimatization is theoretically possible, and where the acclimatizing exposures are not harmful. Evaluate techniques for induction and maintenance of acclimatization to the physical, physiological and psychological stresses of aircrew missions. Examine possibilities of drug enhancement and potential problems of interaction and "cross acclimatization." Studies should be human oriented but some animal studies may be required. Work/rest cycle adjustments and altered feeding regimens and schedules all should be considered.

d. Facilities

Such studies are being carried out in a variety of DOD and academic facilities. A listing of such facilities needs to be developed and support provided.

e. Applications

The increasing demands on the aircrew can best be met by a combination of maximizing performance potentials, improving equipment and matching the mission demands to the best available equipment and human capacities achievable.

2. High G Protection for Tactical Missions

a. Introduction

The manned mission scenario for a high G/sustained G environment can be divided into five separate areas. The first will be air superiority which will involve high G maneuvering and air-to-air combat using both missiles and guns; a second will involve a stand-off loiter condition in which the aircraft will come on station and remain at 1 G for long periods of time or loiter at 2 G sustained for periods up to 24 hours; a third manned scenario might involve a pilot who is simply serving as a mission launcher in a ground station. In this instance, he must recognize the target, identify it as an enemy and be in a decision-making capacity in order to launch a missile. Fourthly, the mission scenario could be an air-to-ground mission in which the pilot engages high density ground targets using both missiles, guns and bombs on targets as close as 500 yards. Finally, the mission may involve a near-earth orbit in which the pilot would periodically be near his potential target. On command he would re-enter the atmosphere using a skip-in, skip-out technique to decelerate to achieve maneuvering speeds in the dense earth atmosphere. In the above situations (except for the ground-based controller), the pilot will require some form of anti-G protection.

Anti-G suits were developed as counter pressure garments in the early 1940's, finally standardizing on a five-bladder interconnected suit that used pneumatic pressure for inflation. This unit, combined with an anti-G valve to meter air into the suit, offered about 1.5-2.0 G protection, which was entirely adequate during WWII to give the U.S. pilot a combat advantage over his adversary. The use of an M-1/L-1 straining maneuver increases tolerance even more, up to levels of 9 G when used in conjunction with the anti-G suit. The use of a tilt-back seat in the Swedish AF DRACHEN or the U.S. Air Force F-16 has been reported to give pilots a 2 G advantage; however, this is only true with an increased angle of attack. Both the prone and supine positions have been experimentally investigated as potential positions for improving pilot tolerance to high G forces. All of these protective devices and maneuvers have been quite effective in improving a pilot's ability to perform in a high G environment for short periods of time. On the other hand, the use of the anti-G suit with muscular straining to improve tolerance is extremely fatiguing and can be a factor in limiting the duration or intensity of an air combat mission. It is the purpose of this task to identify research areas which may achieve G protection to a fighter pilot up to levels of 12 G.

b. Objectives

(1) To develop and test protective devices that will allow a pilot to engage enemy aircraft up to $+12G_z$ without having a significant effect on either his ability to perform tasks adequately in the cockpit or on his basic physiological defensive mechanisms.

(2) To perform research and development to determine the optimum inflation schedule (comfort, physiology, protection) of a pressurizing device that inflates during high G onset maneuvering environments in aircraft up to levels of $+12G_z$ for sustained periods of time (30 seconds). The potential benefit of a pulsating anti-G suit is to improve venous return, thus G tolerance would be investigated.

(3) To develop an optimum counterpressure garment for long term, low G loiter missions that may involve levels not greater than 2 G but for periods up to 24 hours.

(4) To evaluate the integration of: (a) physiological protection (positive pressure breathing; infra-sound techniques to improve pulmonary ventilation; CO_2 pre-breathing; use of pharmacological agents whether they be therapeutic, incidental or warfare; M-1/L-1 straining maneuver); and (b) mechanical protection (new concept anti-G suit employing the ECG triggered pulsatile counter-pressure combined with chest counter pressure when using PPB, upgraded anti G valve, tilt-back seat High Acceleration Cockpit (HAC), risk maneuvering sequences for obtaining optimum G tolerance with minimal pilot performance distraction or degradation).

(5) Selection criteria should be established to select super high $+G_z$ tolerant aviators based on both anatomic and physiologic parameters. Based on these criteria, retention standards must also be established to assure continued optimum performance and aviator safety. The optimum situation will be the proper protection of a fighter pilot who would have the capability of performing adequately for completion of his mission in an air superiority situation (air-to-air) or in air-to-ground missions, and a pilot who would be able to achieve and maintain tactical superiority over his adversary. Within the framework of this high G protection would also be included the introduction of training scenarios that would improve the pilots' ability to perform in these sustained high G maneuvering environments.

c. Approach

The identification of limiting factors in a high G maneuvering environment would be the first approach in developing a research program that allows improved G tolerance to fighter pilots. For example, in existing aircraft it is felt that 9 G for 45 seconds, using standard anti-G equipment and performing a maximum M-1/L-1 straining maneuver, may be the highest level a pilot can achieve without further advances in the state-of-the-art for anti-G protection. Thus, it is necessary that a research program identify those systems that could be improved that would enhance a person's tolerance to air combat G forces. It is well known that the use of positive pressure breathing, pre-breathing of 5-7 percent carbon dioxide, the incorporation of a tilt-back seat and the proper performance of a maximum straining maneuver all enhance a person's ability to perform in a high G maneuvering environment. At the present time, none of these singly-applied enhancements have been integrated such that they can be used simultaneously to improve a person's tolerance. A research endeavor should be developed in which the operational scenario of the year 2000 fighter may be involved and can be reproduced in simulators that are currently available or can be quickly developed within the foreseeable future.

Human subjects should be used in experimental situations to test and develop prototypes of these anti-G protective devices. These subjects should test the anti-G systems on simulators that can simulate the year 2000 scenario. Adequate monitoring techniques should be available that would allow the investigator a positive and objective means for determining the validity of the protective devices and techniques that are used to improve the maneuvering G tolerance of these subjects.

Quantitative measurement of the physiologic mechanisms responsible for enhanced tolerance must be developed. This would serve to assure safety and to more thoroughly understand the basic mechanisms responsible for the enhancement. This requies that noninvasive state-of-the-art techniques developed by the medical and scientific communities be specifically adapted to aeromedical laboratory experiments and actual inflight investigations. These techniques should be cockpit acceptable and highly reliable.

Finally, fighter pilots should be made available for serving as volunteer human subjects during the final test and development period of the equipment/techniques that will subsequently be used in fighter aircraft for improving tolerance. A prototype test bed such as the AFTI-F-16 aircraft should be made available for testing the final product(s).

d. Facilities

In the 1990's a new Tri-Services human centrifuge is mandatory for research and testing. The centrifuge should have the capability of high G onset (6 G per second or more); high G capability up to 15 G; methods for controlling the pilot's environment such as temperature, altitude and gaseous breathing mixtures; and be a closed-loop system "flown" by the pilot. Centrifuges such as the Dynamic Environmental Simulator (DES), the projected FY-1983 centrifuge at the USAF School of Aerospace Medicine and the U.S. Navy centrifuge at Warminster, Pennsylvania are all capable to a certain extent of simulating a fighter pilot's environment. The utility of these devices as fighter simulators is somewhat restricted by the short radius of the centifuge arms (i.e., 20 feet in the instance of both Air Force centrifuges and 50 feet in the instance of the U.S. Navy centrifuge). It might be more feasible to develop a long radius centrifuge capable of holding a fighter aircraft cockpit, thus allowing the pilot to fly a total mission from take-off to landing - one that would include engaging in a high performance maneuvering environment. One can envision a long radius track on which a large gondola or car would move rapidly around this circular, inclined track. Visual projections of figher environments would be available to the pilot for tracking and shooting in order to determine his physiological status/decrement and to determine his ability to perform while testing the anti-G protective devices and techniques outlined above. The device would not stand alone, however, and must contain advanced computerized data collection, manipulation, retrival and storage. State-of-the-art instruments for physiologic monitoring must be available for continual data and feedback for control of aircraft.

e. Applications

The tactical mission of the U.S. Air Force is to obtain and maintain a tactical superiority over any enemy aircraft within a combat theater (mission requirements are broken down in Fig. 5). In order to achieve this, the defensive fighter aircraft of the enemy must be engaged and eliminated from the area. This is required before air-to-ground fighters can engage and successfully eliminate ground targets such as tanks, Surface to Air Missiles (SAM's) and high density troop movements in tactical corridors. A fighter pilot that can maintain a high G advantage over his enemy can achieve a tactical advantage over him. Although anti-G protective techniques can be encumbering, it is envisioned that the final end product will not interact with the pilot's ability to perform his flying mission, which includes physical maneuvering of the aircraft, identification of the target, decision-making, and maintaining adequate surveillance of the enemy once he has been visually located. The techniques should not be counter-productive, i.e., serve as a distraction to the pilot. Thus, they must be devices or techniques that can be easily taught, installed adequately, and will not interfere with the cockpit environment.

3. Innovative Head Interacting Devices

a. Introduction

Conventional helmet design techniques cannot meet future needs. Required head-associated devices must supply oxygen and pressure to airways, optimize visual inputs, allow voice communication and eye command modes, protect from threats (see flow chart on page 55), allow intake of food and liquids, permit monitoring of aircrew status and minimize head injury in emergencies. Man's ability to support head weight is severely limited in the high G environment.

b. Objective

Develop non-encumbering head devices which are comfortable for the required modes and duration of use and which permit all necessary aircrew functions.

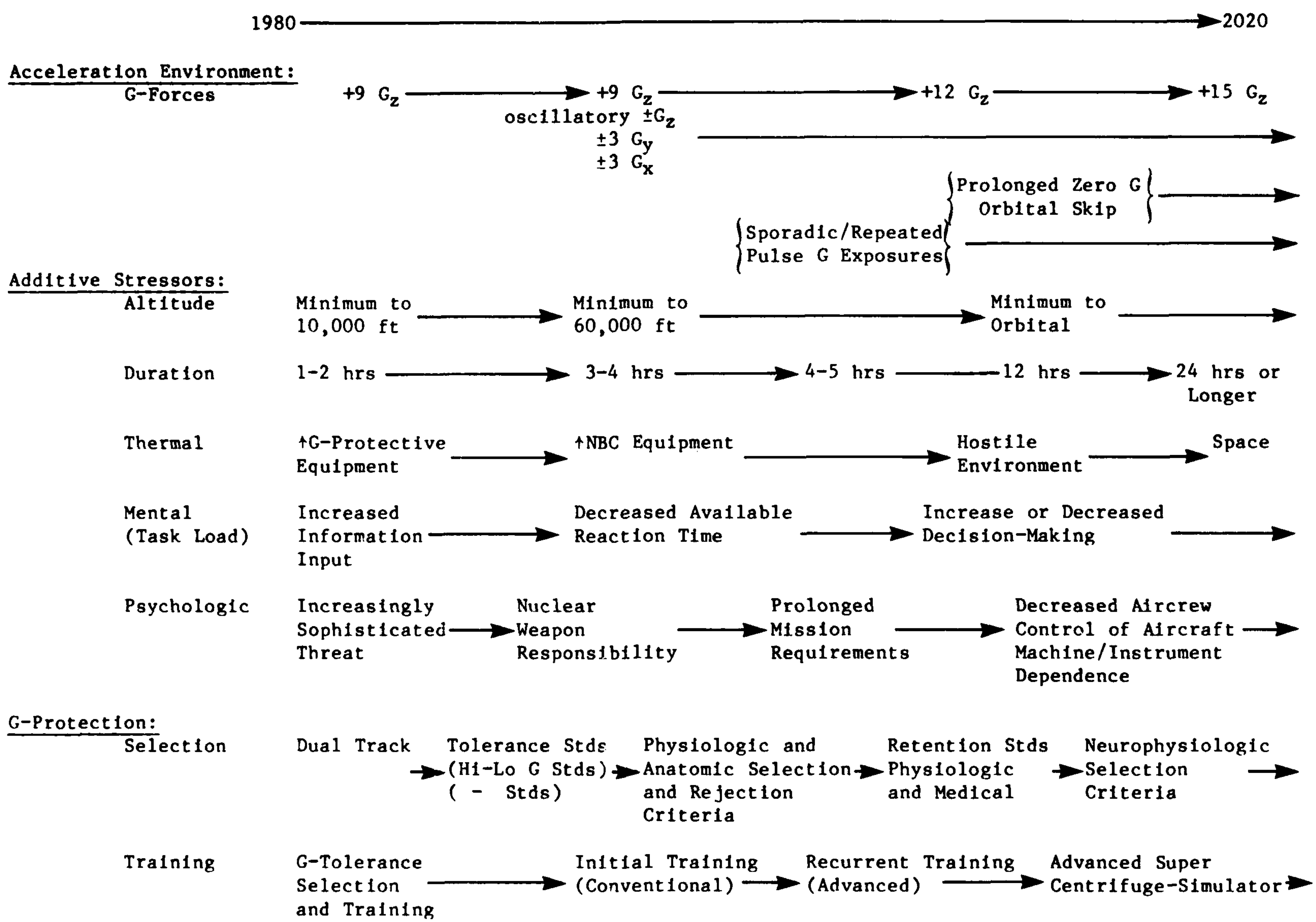


FIGURE 5. TACTICAL MISSION REQUIREMENTS (ACCELERATION)

Area	1980 →				2020
G-Protection (Cont'd): Devices	Improved G-Valves, G-Suits, Seat-Cockpit Configuration, and Helmet →	Physiologic Loop Assist Devices →			
Physiologic	G-Tolerance Selection and Training →	Physiologic Assist Techniques (PPB, etc.) →	Physical Conditioning Specificity →	In-Flight Activities (Long Missions) →	Circadian Rhythm-Optimization →
Pharmacologic	Decremental G-Tol Drug Effects (CB Agents, Advanced Fuels) →	Enhanced G-tol Drug Effects →	Combinational Pharmocologic Challenge →		
Radiation	Increased Cockpit Avionics Exposure Levels and Threat Exposures (Microwave) →	Increased Nuclear Threat (Sublethal and Lethal) →	Nuclear, Microwave, and Other Combinational Effects →		
Facilities: Centrifuge	Long Sustained G_z Rapid to Instantaneous Onset $+G_z$ →	$\pm G_x$, G_y, G_z Simultaneous (Closed Loop Control) →	Combined Stress Thermal + Hypo, Hyperbaric →	Complete Inflight Simulator →	
Instruments	State-of-the Art Medical-Physiologic Instruments →	Rugged, Nonbulky Noninvasive, Highly Reproducible Techniques/Devices →	Kinetics of Physiologic Changes →		
Automation	Computerized Collection, Manipulation, Storage, and Retrieval of Data →	Closed Loop Physiologic Feedback →			
Objectives/ Applications:	Air Superiority →				
	Aircrew Safety →				

FIGURE 5. TACTICAL MISSION REQUIREMENTS (ACCELERATION) (Cont'd)

c. Approach

Identify the major functions of head devices for each mission (fighter, VTOL, reconnaissance, platform). Evaluate conventional and new technologies for performing each head-interacting function and integrate them into non-encumbering equipment. Special emphasis should be given to interfacing head devices with the aircraft and providing active components which deploy only when needed. Progressive prototyping will be required.

d. Facilities

A center of expertise is needed which includes engineering and fabrication personnel, aerospace oriented physicians/physiologists, and aircrew experience. Support must include fabrication shops, bench testing facilities and environmental stress simulators (e.g., chambers, centrifuge), and flight-test capabilities.

e. Applications

Current headgear is a major problem in many Air Force missions, combining too much encumbrance with marginal or inadequate function. New head enclosures should greatly enhance both environmental stress tolerance and C3 functions.

4. Integration of Protective Clothing Ensembles

a. Introduction

Industry is now able to produce fibers to meet almost any specification of size, weight, bulk density, durability, compression regain, wickability, tactility, etc. New weaves (e.g., triaxial), fabrics (e.g., microporous) and materials (e.g., armors, films) are also becoming available. Functional clothing design is rapidly replacing conventional tailoring for mountaineering and extreme cold weather clothing. New handwear, headwear, restraints (e.g., air bags, take-up harnesses) and body supports are becoming available. A variety of high technology protective systems are coming into the inventory (e.g., anti-NBC).

Protective equipment is needed for the aircrew in high stress missions; 10 of the mission functions for strategic and tactical systems call for operations at altitudes above 50,000 feet and 7 of these may include G stress. Nearly all missions may involve thermal stress, whether from heat during ground checkout, cold survival (immersion, arctic terrain), or stewing in CBW clothing. High energy power sources in aircraft may call for special protection. Combinations of current protective gear are generally uncomfortable, restrictive and unwearable.

b. Objective

From new materials and advanced active modes of protection, devise combinations of protective functions into assemblies which are wearable, fully functional and minimally encumbering.

c. Approach

A tri-service lead laboratory (DOD or other) should be identified for encouraging industry-to-government transfer. One of its functions would be to match industry capabilities to military needs. It should develop test methodology and evaluation techniques (see Fig. 6, items 5 and 6). Most importantly, it could focus on interactions between various protective functions and design for improved integration.

In addition to new materials and fabrics, active functions in clothing, as listed under item 3 in Fig. 4, would be integrated in one ensemble.

It seems unlikely that any single ensemble can satisfy the needs of all missions. Proceeding from mission-specific stresses, with clear definitions of physiological capacities and tolerances, sensible combinations of protective functions should lead to prototype ensembles which are evaluated for function and wearability. Improved prototypes would follow in sequence until integrated ensembles appear which meet design goals and have good crew acceptance.

d. Facilities

A comprehensive facility is needed to develop and evaluate prototype clothing assemblies. Skills needed range from textile and mechanical engineering to physiology, anthropometry and clothing design. Finished prototypes can be man-tested in existing facilities, altitude and thermal chambers, centrifuges, and dynamic motion simulators.

e. Application

Protective equipment is necessary both for maintaining crew effectiveness and for mission completion in the event of less-than-catastrophic damage in combat.

5. Assisted Escape Initiation

a. Introduction

For a brief period of time, escape system operating envelopes matched a significant portion of the operating flight profile of the aircraft in which they were installed. However, since escape systems were designed for operation within well behaved profiles, out-of-envelope ejections still occurred in association with severe flight profiles at the time of the emergency. The trend is now clear toward strategic and tactical missions involving more severe planned flight profiles (high speed, low altitude, high maneuvering loads) and more capable aircraft with failure modes involving dramatic departures from controlled flight. As this trend has become established, fatality rates have steadily risen, averaging 25 percent in the U.S. Air Force over the last five years. This increase has largely been driven by escape initiated out-of-the-envelope. Given the projected requirements for increasingly severe manned missions in aircraft of greater sophistication, significant advances in escape system technology must also take place in order

1. Materials
   a. Fibers
   b. Fabrics
   c. Clothing

2. Special Items
   a. Headgear
   b. Handgear
   c. Footgear
   d. Harnesses
   e. Body Support

3. Ensembles: Active and/or Passive Protection
   a. Thermal Environment (Heat, Cold, Flame)
   b. Nonionizing Radiation (UV, Microwave EMR, Laser, Flash)
   c. Dynamic Forces (Acceleration, Vibration Impact)
   d. Altitude (Hypoxia, Hypobaria)
   e. Threat (Chemical, Biological, Nuclear Projection)

4. Test Methodology
   a. Flat Plate
   b. Sweating Plate
   c. Air Permeability
   d. Moisture Permeability
   e. CB Agent Permeability
   f. Non-Ionizing Radiation

5. Evaluation Techniques
   a. Heated Manikin
   b. Copper Hands & Feet
   c. Load Profile Analysis
   d. Dynamic Force Tests
   e. Subjective Scales
   f. Performance of Special Functions

6. Interactions Among Stressors/Protective Devices

7. Body Functions
   a. Eating/Drinking
   b. Elimination
   c. Hygiene

8. Performance/Encumbrance
   a. Reach
   b. Vision
   c. Function
   d. Other

9. User Acceptance
   a. Sampling Techniques
   b. Standardization
   c. Interoperability
   d. Sizing
   e. Basis of Issue
   f. Wear Life

FIGURE 6. PROGRAM ELEMENTS FOR DEVELOPMENT OF AN INTEGRATED PROTECTIVE CLOTHING SYSTEM

to avoid an escape system performance experience even more dismal that that currently being accrued. When major injury rates among survivors are considered, an undesirable result is achieved about as often as not in the current inventory.

Historically, the cost of research, development, production and maintenance of expensive escape systems has been justified on the basis of lives saved. However, it could also be argued that more lives are potentially salvageable through the diversion of some of these millions of escape system dollars to be used instead for the purchase of aircraft and munitions. The real justification for the provision of capable escape systems should lie in the mission performance implications. Achievement of available mission and aircraft performance in a manned weapons system requires confident and capable crew members, willing to train and operate "at the edge." The sure and certain knowledge on the part of the crew member that a necessary portion of his aircraft operating envelope constitutes a "dead man zone" will affect his willingness to train and operate there. Conversely, confidence in an adequate escape system may allow the performance level required for survivability in future manned missions.

Recognizing this, the problem remains of defining a "capable escape system." Historically, this has been difficult due to the insoluble problem of defining an adequate operating envelope. No matter how broad the envelope, escape could be, and often was, initiated outside that envelope. Future mission requirements dictate an approach to escape system technology which solves this quandary. Such an approach will involve attention to assuring that escape initiation occurs within an achievable envelope.

b. Objective

The objective of this effort will be to develop techniques to allow assisted escape initiation using automatic systems for alerting, warning, and, in extreme cases, actual escape initiation. Automatic escape initiation would take place only in situations in which aircraft recovery is clearly impossible and in which short time intervals, or the imposed accelerations of unstable flight, preclude voluntary initiation. In conjunction with efforts described in a separate topic on extending escape envelopes, this effort will result in an escape system capable of covering the entire operating envelope of future aircraft.

c. Approach

Accomplishment of this effort will require better definition of human response times within realistic mission profiles for the onset of likely failure modes. The response time should include perception, recognition, decision, recovery attempts and assessment when appropriate, and escape initiation. The utility of warning information to speed this process should be assessed. These determinations will require measurements within the multistress mission environment as simulated using biodynamic research facilities.

Concurrently, research should explore the feasibility of unequivocally defining unrecoverable conditions using information such as aircraft accelerations, ground proximity and closure rates, attitude, speed, and aircraft performance data. Advances in aircraft avionics are presupposed in order to allow things like all-aspect radar altimetry. These information sources should also be used to define those flight profiles which appear to indicate undesirable deviations from planned mission maneuvers. Criteria could then be defined to construct, for example, a staged alerting, warning and automatic escape initiation system. When the system detected an undesirable condition, an aural alert could be sounded such as "LOOK OUT." Such an alert could serve, for example, to direct the attention of a pilot to an unnoticed loss of altitude in a turning maneuver. Should the condition deteriorate further and the escape system operating limits be approached, an audible warning would sound such as "EJECT, EJECT." Such a warning would likely be of benefit in situations in which attempts to regain control have been inappropriately prolonged. Finally, in the clearly unrecoverable case, ejection would be automatically initiated prior to exceeding the operating envelope of the escape system. This presupposes an operating envelope which extends to the appropriate points.

The severity of the conditions required before escape could be considered mandatory and assuredly initiated would define the required escape system operating envelope. Cost tradeoffs could then be applied to the definition of appropriate levels of effort devoted to assisted initiation and expanded envelopes.

A special consideration in the future may be the initiation of sudden emergency escape from long duration missions in multi-crew battle-directing aircraft. In these situations, some crew members may be engaged in activities such as sleeping, eating and moving about, which may preclude typical escape postures. The provision of emergency escape for a comfortably sleeping crew member, for example, may or may not be a reasonable endeavor, depending on risk-benefit analyses which must await better mission definition.

d. Facilities

This effort would require sophisticated centrifuge facilities with realistic projected low altitude full-field visual displays in which aircraft dynamics and realistic failure modes could be faithfully simulated and crew member responses assessed (see Fig. 7). The utility of warning information and the risks and benefits associated with automatic or novel escape initiation techniques could then be evaluated. Furthermore, such a facility would be useful in demonstrating the reasonableness of assisted escape techniques to operational crew members. It is not envisioned that a facility of this complexity be dedicated to escape system development efforts alone. Instead, other multiple uses suggest themselves in the area of performance evaluation and tactics development. In addition, the training utility of the device in imposing the visual and biodynamic inputs to be expected under various aircraft failure modes should not be ignored. A facility with similar capabilities is described in section III.C.2.

e. Applications

This effort would define a reasonable approach for the provision of capable escape systems for projected USAF aircraft and missions.

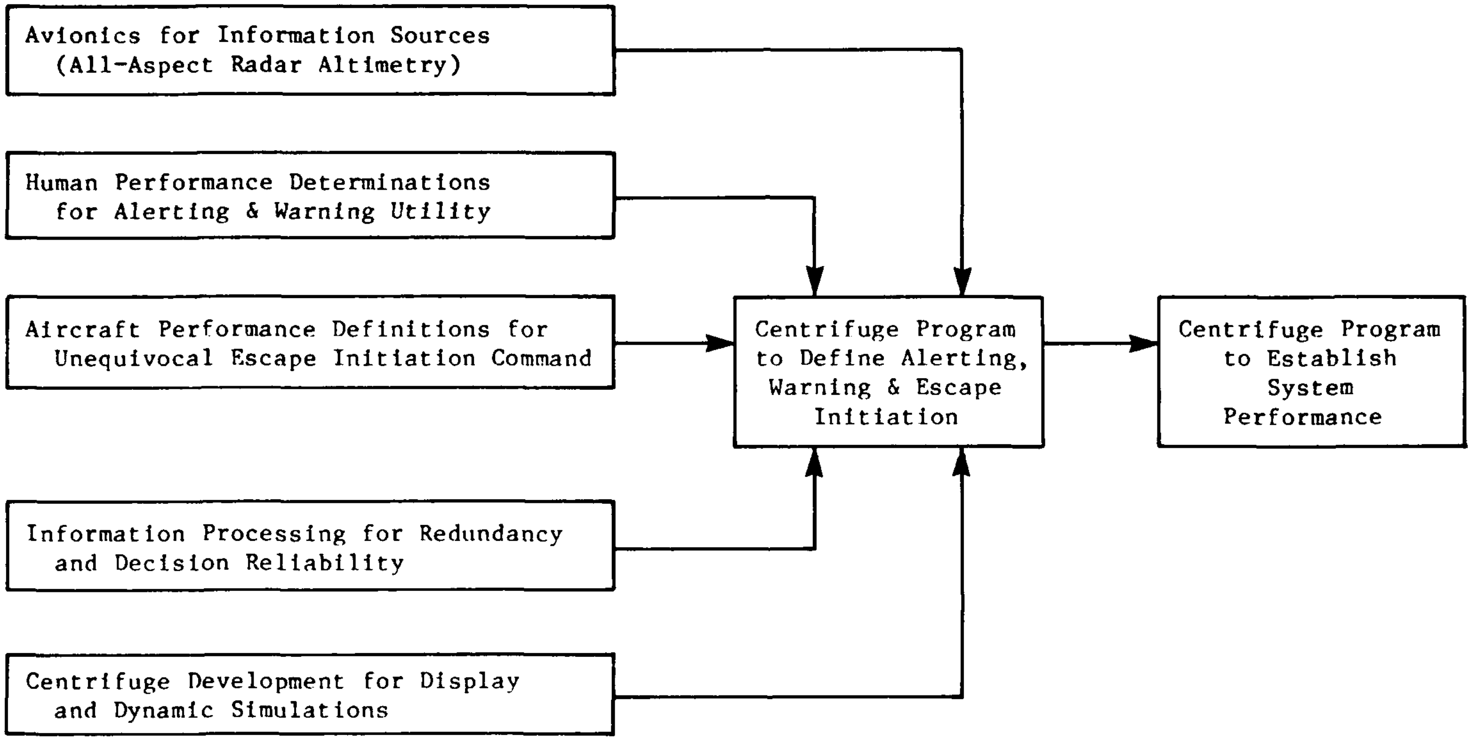


FIGURE 7. ASSISTED ESCAPE INITIATION FLOW CHART

It would also define the cost effective balance between efforts in initiation and efforts to broaden the envelope. It avoids the insoluble problem of attempting to provide over-capable envelopes which can never address worst case conditions brought on by delayed initiation. Capable escape techniques will be required for peace time training in realistic environments to assure performance for the USAF mission.

6. Extended Escape Envelopes

a. Introduction

Over the last five years, the USAF ejection fatality rate has averaged 25 percent. The largest contributor by far in this fatality experience has been ejection out of the escape system operating envelope. Over the next 20 years, it is anticipated that the escape system envelopes will continue to be challenged by high speed, high altitude and low altitude missions. Given the continued requirement for increasingly severe manned missions in aircraft of greater sophistication, the solution to the escape problem will require earlier initiation of an escape system with a broader performance envelope. The initiation problem is addressed in a separate research topic, the results of which will define the practical envelope required.

The envelope of current escape systems is limited primarily by air speed, by ground proximity, or by a combination of the two. Extending this envelope will require significant departures from current ejection system techniques. Current systems rely on either open ejection seats or ejection modules in which the crew station is separated from the airframe and separately recovered. Historically, a third technique has been used which involved the provision of a capsule around the crew member prior to ejection. The open ejection seat offers substantial benefits when ground proximity is a problem. This derives from the fact that the open seat is light in weight and the crew member can be rapidly decelerated and placed under a recovery parachute. However, windblast protection, even with active and passive limb restraint techniques, cannot easily handle very high speed ejection conditions. The module, on the other hand, provides improved windblast protection, but performs miserably near the ground with imposed aircraft sink rates. This derives from the fact that sink rates continue to take place during the long period of time required for deceleration and deployment of the large descent systems.

b. Objective

The objective of this effort will be to define techniques to allow the tolerable imposition of forces required for crew member escape from severe flight profiles. In conjunction with the effort in assisted escape initiation, it will be possible to establish an escape system capable of operating from all anticipated flight environments.

c. Approach

The escape sequence may be resolved into the following problem areas:

(1) Separation from an airframe which may be accelerating - The separation problem will require greater displacement-time performance from the escape system. This requirement may be somewhat relieved by deployment of aircraft systems to ease the severity of the flight profile at the time of escape. However, to achieve simultaneous separation and ground clearance from anticipated ejection initiation points, departures from current ejection system techniques of force application will be required. Dynamic preload techniques have been identified in current human biodynamic research which promise improved displacement-time performance and decreased injuries by application of force-time profiles optimized for human characteristic responses. These must be developed and applied. Ejection seat steering techniques may find application under restricted circumstances. They should only be utilized when they are clearly beneficial since they unfortunately delay parachute opening in attempting to accomplish ground avoidance trajectories. High sink rate ejections with reasonable altitude at ejection can benefit more from rapid deployment of a parachute. Finally, escape in the face of high maneuvering loads still poses a dramatic challenge both from the standpoint of biodynamic response to the required ejection forces and from the point of view of vehicle clearance in an accelerating or tumbling environment. Multiple crew members complicate the problem even more. Likely far-term solutions include delaying escape, when appropriate, until velocities and associated aerodynamic forces decay to acceptable levels, deployment of aircraft systems to ameliorate the problem, and multidirectional escape path choices to allow utilization of aircraft accelerations to assist escape clearance. It should also be noted that adaptive escape techniques can allow very soft "rides" under benign conditons and very severe "rides" when the chips are really down.

(2) Controlled deceleration while providing protection from the hazards of windblast - The deceleration problem will require equivalent developments, probably in body encapsulation and optimum deceleration force application techniques. Conventional open ejection seat techniques cannot be extended much further toward higher dynamic pressures. Dynamic pressure rises as the square of the velocity, implying greater and greater expenditures to achieve smaller and smaller increases in velocity envelope. Future systems will be required to provide the benefits of a module for windblast protection without the accompanying weight penalty. Such techniques will require body encapsulation which takes place as a part of the ejection sequence. Accompanying improvements in stability, divergence and windblast control such as flow diversion techniques and skip-flow generators may be useful. When altitude and the inciting emergency conditions allow, escape should be delayed while the aircraft is decelerated. When this is not possible, deceleration forces should be applied to the body transversly to allow maximum deceleration within human tolerance. An interesting logical sidelight to this issue is the observation that relatively low speed ejections allow virtually immediate parachute or recovery system deployment. When low altitude escape is encountered at a higher speed, precluding recovery system deployment, the higher speed implies the potential use of aerodynamic techniques rather than propulsive ones to accomplish terrain avoidance.

(3) Deployment and operation of a descent system prior to ground contact while providing environmental protection as appropriate - It is likely that the descent problem will continue to be solved by parachute

devices, at least over the next 20 years. However, improved deployment techniques and novel techniques for an assisted terminal phase could decrease the morbidity and mortality currently experienced during parachute opening and ground landing impact. Furthermore, encapsulation techniques deploying for windblast protection could also be adapted for protection against environmental hazards associated with altitude or extremes confronted upon return to the earth's surface. As we look to the future, design of recovery subsystems appears feasible even as we confront the problem of escape from extremely high altitudes, including the altitude and speed combinations associated with orbital flight. The descent system would have to subserve functions as a space capsule, re-entry vehicle, descent device, landing system and survival module. On a more mundane level, the significant morbidity and occasional mortality associated with conventional parachute landing falls of crew members has not yet been satisfactorily addressed .

d. Facilities

This topic is admittedly broad and will therefore require a number of sub-efforts and facilities. Existing impact test facilities can be modified to pursue a dynamic preload applications investigation for improved displacement-time performance. A reliable human mechanical model will be required, having reasonably soft tissue, and aerodynamic and three-axis acceleration characteristics comparable to that of the human body. This will require advances in our knowledge of human biodynamic response to combined environments (accelerative and aerodynamic), as well as advances in instrumentation. Such research will require use of existing facilities such as wind tunnels, sled tracks and computer facilities. The resulting mechanical model or dummy should be utilized in realistic escape system profiles. Current escape system testing is accomplished in relatively benign 1 G conditions on a rocket sled track. The development of systems capable of operations within broader envelopes will require testing in those envelopes. This implies the development of an escape system flight test vehicle for exploration of performance in severe flight profiles. A suitable test vehicle should be developed from an existing high performance two seat aircraft. Extended escape envelope research requirements are listed in Fig. 8.

e. Application

Escape systems are relevant to virtually all future manned weapon system applications. The problem of escape from high performance aircraft or space vehicles is an emotional one. The costs of achieving performance commensurate with future aircraft and missions is high. However, the costs of not achieving this level of performance may be greater still. Successful mission performance may depend upon crew member confidence sufficient to allow training and operations that take full advantage of future vehicle performance capabilities.

7. Occupant Crash Protection

a. Introduction

The science of occupant crash protection has been applied primarily to those vehicles not equipped with escape systems. Ejection seat equipped aircraft also occasionally crash and restraint systems are designed

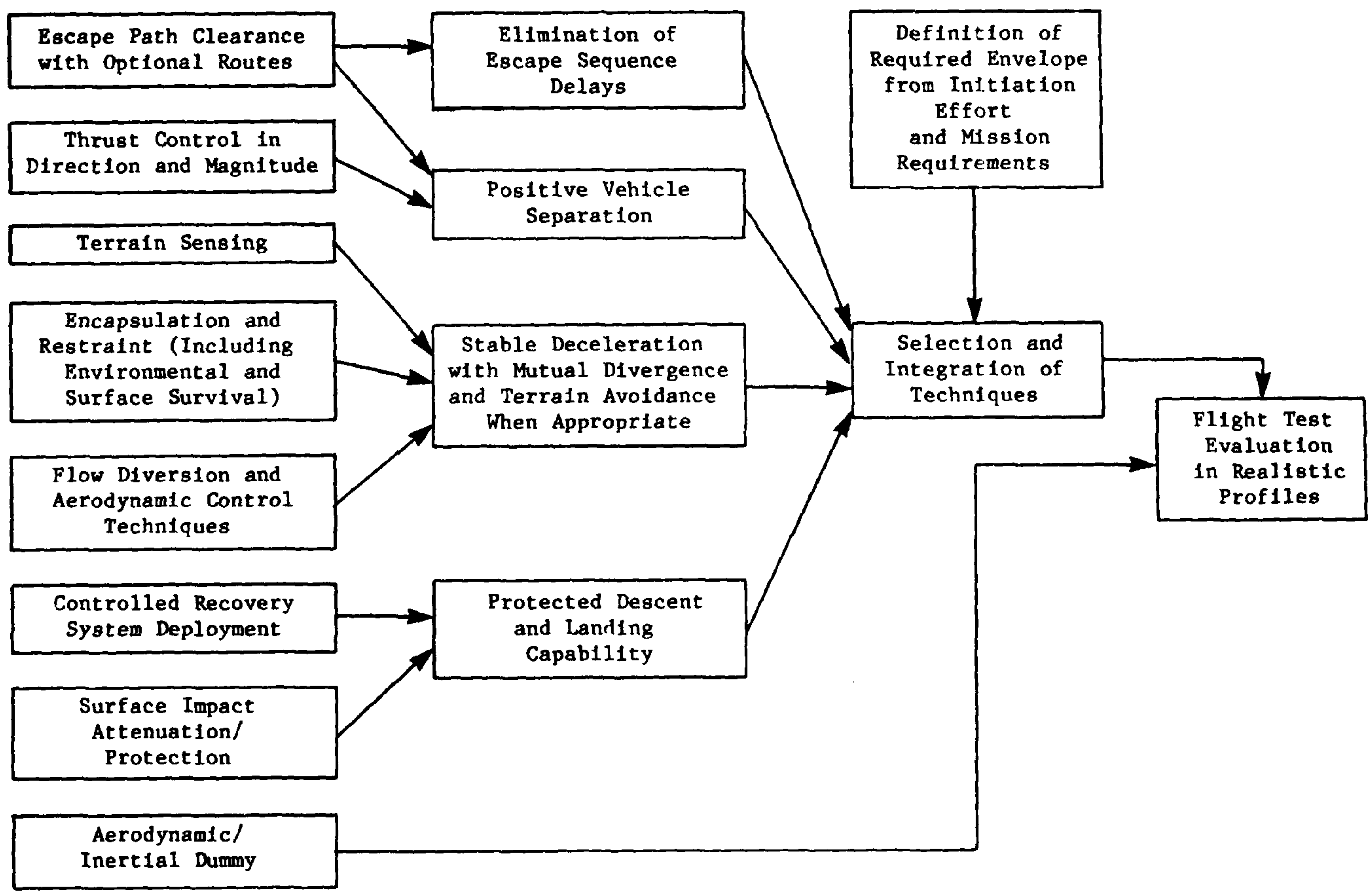


FIGURE 8. EXTENDED ESCAPE ENVELOPE FLOW CHART

to promote survivability under these circumstances. However, in survivable crashes vertical loads are typically rather low and transverse loads are generally less than those encountered during escape. Therefore, future restraint provisions suitable for the escape problem are likely to be adequate for crash survival. In all vehicles, the crash survival problem tends to place greater demands upon the airframe designer than upon the restraint designer. This has been true because intrusion into the occupant's "living space" has typically been the limiting factor. Restraining an occupant within a space which collapses around him provides no benefit. The problem is particularly severe in helicopter crash conditions because of the heavy transmission often located above crew members in a vehicle which experiences relatively severe vertical loads. Another significant concern has been fuel containment, without which fire provides a further limiting factor. Passengers in transport aircraft confront these difficulties, as well as that of accomplishing rapid and orderly egress. Escape systems for helicopters are feasible and have been considered. Future escape developments may prove them to be practical within the next 20 years. However, escape systems for transport aircraft carrying large numbers of passengers would not appear likely during this period.

b. Objective

The objective of this effort is to define techniques to allow tolerable imposition of forces for occupant protection in all circumstances in which airframe characteristics during crash allow the potential for survival.

c. Approach

The issue of occupant crash protection may be divided into the following problem areas:

(1) Living space - The provision of occupant living space is a demand upon the vehicle designer. Aircraft developments may allow the design of a habitable shell within which the occupant may be protected from intrusion of structure, debris or fire. Having this capability, further occupant crash protection techniques become feasible.

(2) Force limiting - The mechanical problem of occupant crash protection is simply to accomplish the velocity change which is necessary in order to come to a stop, while imposing only tolerable forces in the process. Since crashes may require very large velocity changes in very short periods of time, techniques for protection generally center upon the provision of additional time for the occupant to decelerate by allowing displacements with respect to aircraft structure. Typical of this technique are the stroking seat developments for crashworthy helicopter seating. More time allows lower accelerations but requires greater distances. Advances in this technology are possible by utilizing improvements in sensing and timing to accomplish anticipatory acceleration of the occupant. This would involve, for example, stroking the occupant's seat up just prior to the crash and then stroking it down during the crash. If an equivalent displacment of upward stroking can be added to a downward stroking seat, the beneficial effect of the downward stroke can be effectively tripled. If a downward stroking seat effectively halves the acceleration severity of a crash, such an upward-downward stroking seat would potentially attenuate the crash accelerations by a factor of six.

(3) Restraint - Typical restraint techniques involve combinations of lap belts and shoulder harnesses which are locked against extension by crash acceleration-sensing inertia reels. Improved restraint can be reasonably accomplished by pretensioning of restraint systems for major torso segments and provision of restraint to prevent flailing of head and extremities.

(4) Egress - Following a crash, egress from the aircraft is typically required. In the presence of fire, provision must be arranged for oxygen and for thermal protection. Furthermore, fuselage cutting techniques in association with automatically deployed egress aids may be utilized to assist and expedite the evacuation of passengers from large transport aircraft.

d. Facilities

Facilities required for this effort primarily devolve upon the airframe manufacturers. Development of biodynamic restraint techniques, including force limiting, may be pursued using existing impact test facilities. Other possible developments are shown in Fig. 9.

e. Application

Application to Air Force mission aircraft is clear. In addition, efforts in this area can be anticipated to have significant applications in civil aviation and automotive industries. Substantial human cost benefits have historically accrued from application of aerospace medical research in occupant protection. Similar applications may be confidently anticipated in the future and may serve as additional motivation for this research.

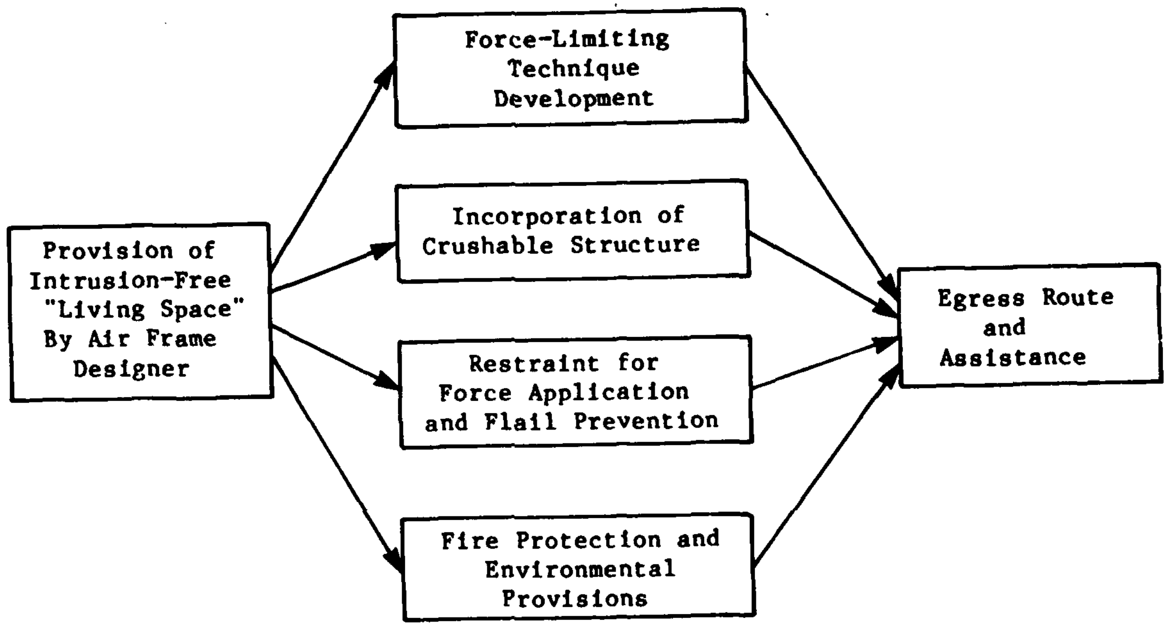


FIGURE 9. OCCUPANT CRASH PROTECTION FLOW CHART

V. CREW SELECTION AND ENHANCEMENT

V. CREW SELECTION AND ENHANCEMENT

A. Major Conclusions

(1) Selection and enhancement are highly interactive processes and should be treated as such.

(2) A major effort should be made to build aircraft which are capable of being flexibly and interactively designed using simulator data on multiple cognitive, personality, motivational psychomotor and physiological responses of the individual pilot. This could be achieved by a software fitting of the aircraft parameters to the individual characteristics of that day and that particular time of day.

(3) A major basic and appplied research effort on the mechanisms of fatigue, sleep, and circadian rhythms could have multiple payoffs for performance in the 24-hr/day, 365 day/yr environment. This requires the support of special facilities and multidisciplinary programs.

(4) Basic research on the enzymatic and neurotransmitter mechanisms underlying mood, emotional state and addictive behavior is a high priority.

(5) Data management between aeromedical groups and engineers should have a common language and adequate communication channels.

B. Crew Selection

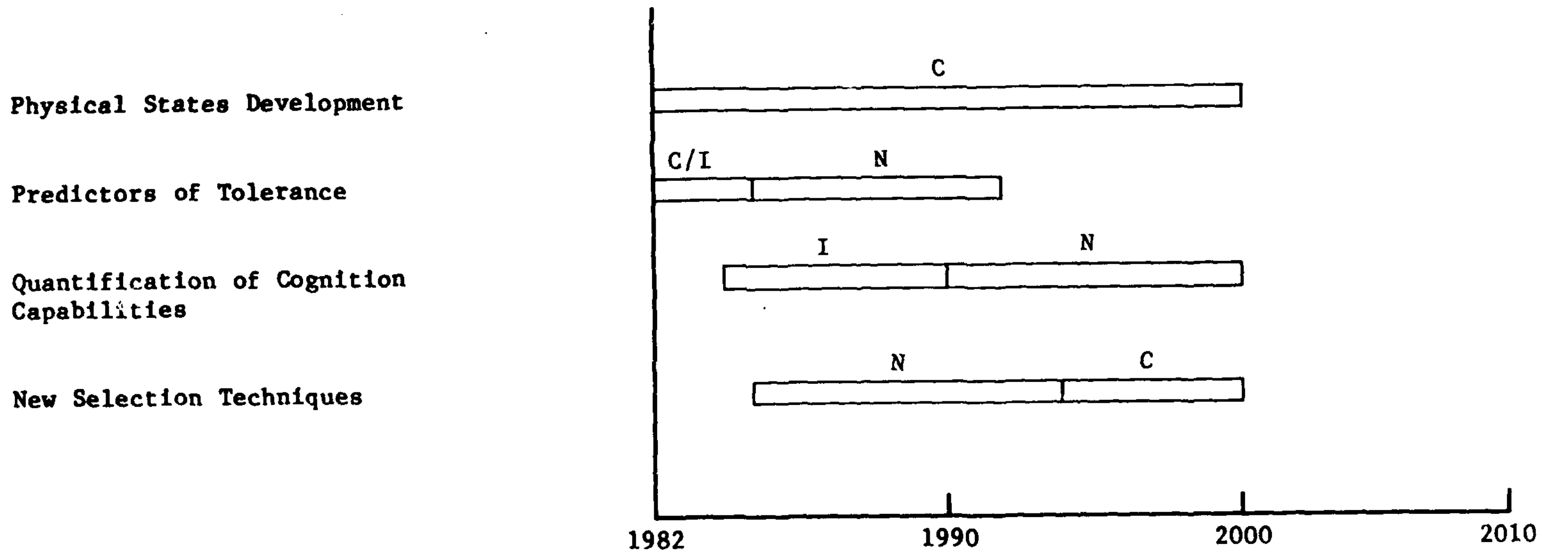
1. Physical Performance

a. Introduction

New crew selection methods for the high performance, high technology aircraft of the 21st century are necessary if the desired performance expectations are to be achieved. The trends that these selection methods may follow in the future are included in Fig. 10. This is especially true for in-combat situations where additional stresses are encountered. Fundamental to establishing crew selection criteria is the determination of the physical and mental characteristics required of specific crew members. Some baseline requirements will derive from aircraft operational features design specifications. Biomedical monitoring of crew members during flight, covering of the intensity range of physical and mental stresses (e.g., sensory-motor performance and decision-making capability vs workload, G forces, vibration, noise, hypo-hyperthermia, hypoxia and emotional stresses), is necessary to the collection of data to establish realistic crew selection criteria. These data must be collected during simulated and actual operational conditions.

b. Objectives

This research topic is primarily focused on the objective evaluation of the physical performance of the crew. The main objectives are as follows:



C = Continuation of ongoing research
I = Considerably increased effort
N = Major new initiative

FIGURE 10. CREW SELECTION - FUTURE TRENDS

(1) Develop instrumentation to monitor the various physiological variables to be evaluated (during both flight simulation and actual operation of the aircraft).

(2) Develop instrumentation to accurately simulate the physical requirements of crew members under a variety of mission-related conditions.

(3) Develop protocols to evaluate maximal strength, work, power and endurance capabilities for given specific tasks, and the effects of fatigue.

(4) Establish criteria and standards for various crew positions.

(5) Determine the validity and reliability of these physical evaluation protocols.

c. Approach

The development of the physical criteria and standards for crew selection requires the delineation of the performance characteristics of specific aircraft. It would also be important to assess the physical intensity, duration and frequency of required missions. Screening of large numbers of potential crew members will require the development of instrumentation to accurately measure the physical requirements of the crew member(s) under a variety of mission-related conditions. This instrumentation can incorporate strain-gauges and position sensors for use as ergometers to determine maximal strength, work, power and endurance. The effects of fatigue on the operating capability of the crew member(s) can also be determined.

d. Facilities

New and more advanced physiological monitoring techniques and instrumentation are necessary to the development of selection criteria. During flight, data related to muscular strength, work, power and endurance as required for various mission related tasks must be obtained. Both aerobic and anaerobic metabolic energy costs must be determined. Dynamic (movement) and static (isometric, e.g., handgrip and body stabilization) tasks are to be evaluated. The effects of fatigue on performance will also need to be examined. These evaluations will require specially instrumented aircraft incorporating advanced data recording and/or radiotelemetry techniques.

It will also be necessary to develop flight simulation facilities in a laboratory setting. During simulated flight conditions it is desirable to obtain data related to maximal muscular strength, work, power and endurance for given physical tasks. The relative stress (percentage of maximal capability) placed upon the crew member(s) during actual flight conditions can be assessed. High reserve capacity is a desirable objective. Before, during and following flight simulation, complete monitoring of physiological responses (as indicated above) is necessary to determine organ system abnormalities, reserve and recovery time. Complete computerization of these data would be desirable.

e. Applications

The ability of the Air Force to utilize the maximal capability of the aircraft in the year 2000 will, to a large extent, depend upon the crew selection. If proper criteria are established and methods developed which enable accurate prediction of a crew's performance under a variety of actual flight conditions, mission accomplishment will be more likely.

2. Predictors for Physiological Deterioration and Recovery Rate in Response to Transmeridian Flight

a. Introduction

Performance and physiological functions show deterioration after rapid travel by air across time zones - the syndrome known as jet-lag. The exact mechanisms underlying jet-lag are not fully understood and efforts should be directed to defining the pathophysiological mechanisms involved and developing methods to better facilitate adaptation to a new time zone.

It has been shown that disturbance of circadian rhythmic internal phase relationships in animals, particularly over long time periods, can result in pathological manifestations. In humans, circadian desynchronization in shift workers is often manifested by various psychosomatic complaints, including fatigue, sleep disturbances and gastrointestinal problems. Transmeridian flight, which induces phase shifts between the circadian rhythms of the body and the timing of external environmental synchronizers, often results in non-specific fatigue, insomnia and sleep disturbances, gastrointestinal complaints, headaches, disorientation and irritability. Significant deterioration in simple (reaction time) and complex (flight simulator) performance has been demonstrated following eastbound transmeridian flights. Significant performance decrements occur at certain specific times of day following westbound flights.

Individual differences have been found in the extent of deterioration in performance and well-being and in the duration of readaptation following time zone crossings. As a result of this variability, efforts have been made to identify environmental, psychological and physiological costs of various flight schedules. Correlations have been found between duration of readaptation and direction of flight, strength of environmental cues, rhythm stability, amplitude and phase angle, and personality factors (extraversion/intraversion, neuroticism). Greater deterioration of performance, along with increased internal dissociation between internal circadian rhythmic oscillators, has been demonstrated following phase advances (eastbound flight) than in phase delays (westbound flight). Therefore, eastbound flights, or shiftwork schedules involving phase advances of the circadian system, are more likely to be predictive of impaired performance than other schedules. Internal circadian dissociation is associated with substantial sleep deprivation and disruption. The resulting performance impairment is most likely due to disruption of the normal progression of sleep stages than sleep deprivation itself. Several models, based upon either circadian oscillatory mechanisms or workload factors (e.g., duty hours, times of departure and arrival, layovers, etc.), have been generated in the attempt to predict the physiological cost and readaptation time in response to transmeridian flight or experimentally induced rhythmic desynchronization.

b. Objectives

The general objective of this research is to identify individual parameters of the circadian system (e.g., rhythm amplitude, phase angle, period, wave form or stability) as measured during control conditions (12L:12D) - (12 hours light - 12 hours dark). In addition, constant conditions of light which predict the rate of readaptation following phase shifts in the environmental light-dark cycle can identify individual parameters of the circadian system. These predict patterns of circadian rhythm dissociation and recovery which have implications for substantial deterioration in performance and well-being.

c. Approach

(1) Applied Research

(a) To establish the extent of the inter-individual adaptive capacity.

(b) To develop travel and rest schedules for time zone crossing which promote rapid adaptation of sleep-wake cycles and performance rhythms to the new time zone.

(c) To develop educational programs to assist individuals to best adapt their sleep patterns to a new time zone.

(2) Basic Research

(a) To define the mechanisms of circadian phase-resetting in man.

(b) To define those environmental parameters that influence the rate of resynchronization.

(c) To establish the neurophysiological mechanisms involved in entrainment in animal models.

(d) To develop and evaluate mathematical models of the human circadian timing system which can be used to predict the rate of adaptation after shifts across time zones.

d. Facilities

The study of the process of resynchronization after shifts in environmental time cues requires laboratories in which external time cues can be strictly controlled and in which artificial time cues can be provided. These should be coupled with polysomnographic and neuroendocrine facilities.

e. Applications

There is great practical importance in the potential of establishing physiological criteria, based upon specific individual parameters of an individual's circadian rhythmic system, that can be used to predict the duration of readaptation of the circadian system following transmeridian flight. This is particularly true with respect to predicting impairment in performance and well-being in a specific individual following specific types of time zone or shiftwork changes as a function of the dynamics of the circadian system. This research has important implications in terms of identifying personnel who are particularly susceptible to certain types of time zone changes by measuring certain physiological variables in the normal working environment. Conversely, this research also has important implications with respect to altering mission schedules for specific individuals, based upon characteristics of their circadian system, to minimize deleterious changes in performance and well-being resulting from time zone or shift work changes.

Future Air Force missions will involve transmeridian flight and alterations in work/rest schedules which have implications for impaired performance due to circadian disruption. It will first be necessary to study the relationship between the various patterns of circadian desynchronization and readaptation in response to a variety of altered light-dark photoperiod regimens in controlled animal experiments in order to evaluate utility of the predictive factors.

The above is necessary since a number of extraneous variables are present in human studies (e.g., social interaction, psychological stressors, duty schedule fatigue, variable diets) which can obscure the relationship between the predictive factors, observed performance changes and readaptation duration. It will be necessary to conduct human studies to evaluate possible interactions between the various stressors encountered in mission situations and the effects of transmeridian flight and shift work upon the circadian system and to further evaluate the utility of predictive factors in the operational environment.

3. Morning and Evening (Owl-Lark) Differences in Sleep and Performance

a. Introduction

For morning people ("larks"), vigilance and critical performance are better in the morning, worse in the afternoon, and worst at night. Evening people ("owls") have the opposite problem, reaching their best late in the day. Loss of sleep aggravates the effect to the extent that one may not be able to overcome the performance degradation of working at the wrong time of day. There are pronounced 24 hour cycles of metabolism and heat loss which clearly separate the larks from the owls, and which correlate nicely with circadian variability in vigilance and simple performance tests. Questionnaires have been developed to distinguish these types but they need refinement and criteria must be established for whether an individual's "owlness" or "larkness" exceeds the limits acceptable for group behavior and operational demands.

b. Objectives

(1) To design improved tests to establish owl and lark characteristics of personnel.

(2) To correlate owl-lark scores with performance and adaptability to mission constraints.

c. Approach

There is a need to refine the questionnaires for defining owl and lark characteristics and to conduct a detailed set of studies to establish the physiological and psychomotor differences between owls and larks at different circadian phases. There has been little effort to correlate such behavior with the most effective way to schedule such individuals in high performance requiring tasks; furthermore, it is possible that individuals with extreme lark or extreme owl scores may have significant sleep-wake problems which might make them unacceptable for selection as pilots.

d. Facilities

These studies require metabolic and endocrine research facilities and special equipped laboratories where environmental variables can be controlled so that they will not mask circadian phase variables under study.

e. Applications

For critical short term missions, it may be appropriate to schedule groups of owls or larks at the peak of their performance. In other situations where maintained performance around the clock is required, it may be better to have the individuals with early morning alertness monitoring high vigilance morning tasks, whereas the owl, or evening person, should monitor late night tasks.

4. Cognitive and Personality Variables

a. Introduction

Each potential aircrewman selectee manifests individualistic and idiosyncratic cognitive and personality characteristics which interact in differing patterns, manifested behaviorally, under different circumstances or situations. Since the complexity and differing demand characteristics of future aircrew missions certainly comprise such different situations and requirements, relevant selection criteria need to be established to optimize crew performance and mission accomplishment. While there undoubtedly will (and should) continue to be basic entrance-level selection criteria (educational, social history, physiologic, psychologic, etc.), these will hardly be sufficient to assure optimal placement, trainability, etc. Rather, continued selection criteria should be addressed toward the integration of mission characteristics/requirements with the best aircrewman to accomplish the objectives of a particular type of mission. Thus, particular cognitive and personality characteristics will need to be assessed in relation to mission demands to determine the optimal combination which would then serve as the basis for selection of the best "type" of aircrewman for training and assignment to a particular mission type.

b. Objective

To develop and refine assessment methodologies and instruments which will validly and reliably differentiate a spectrum of capabilities and styles in terms of cognition and personality functioning and trainability in specific skills.

c. Approach

Assessment of cognitive functioning should transcend traditional methodologies (intelligence-testing, contingent reaction times, "pathology-oriented" tests, etc). Rather, newer approaches which assess efficiency of information processing, cognitive style, effective early decision-making (with minimal information), and rapid problem-solving need to be implemented. Many of these are available in the research domains. Others will need to be developed, improved or refined.

Subtle personality characteristics, such as evidence of immaturity, problems in impulse control, acting out, poor social judgment, areas of intrapsychic or interpersonal conflict, questionable psychologic adjustment, etc., should be assessed, necessarily by more than a perfunctory psychologic history. In addition, new and more subtle and sophisticated psychometric instruments will need to be developed - tests addressed to delineate levels of functioning in the psychologically healthy (non-pathologic) subject.

Current trends in experimental neuropsychologies indicate that new and developing neuropsychometries and more sophisticated assessment methodologies will be available to evaluate excellent and highly gifted neuropsychologic functioning. These include lateralization of functioning, processes which delineate the selection of the most pertinent in a profusion of data, effects of insufficient problem-solving, etc. Adoption of these types of neuropsychologic assessments could significantly advance the identification of cognitive variables which could serve as part of aircrew selection criteria.

The above-described new psychometric and psychologic assessment methodologies should provide definite advancements in determining selection criteria. However, they would be most effective when complemented by comprehensive methods of quantifying performance and optimal functioning. Such methods, as closely and as realistically as possible, should measure performance outcomes in simulations of actual missions. This approach would utilize a fully simulated mission with on-line monitoring of performance levels, decisions made, etc., and concomitant psychophysiologic monitoring (and perhaps videotaping). Deviations from preprogrammed optimal performance levels would be measured. Different scenarios should be available. These should include such variable parameters as periods of boredom (no-go waiting), information overload, time-limited decision points, instrument/system/information failure, unavoidable (programmed-in) frustration, real consequences for failure or poor performance, etc. Results of such integrated simulations of various mission types would be correlated with the other selection criteria (some of which were described above) to help determine the optimal characteristics of the best integration of cognitive/personality "type" or style and mission effectiveness. This same methodology also could be used to assess enhancement potential or trainability on various parameters. Something less than the ideal fully computer-controlled simulation just described would be to begin to approximate this ideal level of sophistication by providing similar tasks in a psychophysiology laboratory where definitive, if less comprehensive, correlations should be derivable.

The proposed combination of new cognitive, neuropsychologic and personality assessment instruments and methodologies additionally should provide a rich data base, especially when coupled with mission simulations, psychophysiologic monitoring and other relevant considerations (fatigue, circadian and sleep cycle disruptions, workload, crew interactions, pilot-ground-based operator "shared" responsibility, etc.). This data base should provide information which could subserve the even more complex (and unreliable with current evaluation procedures) task of assessing such important characteristics as level of maturity, maintenance of performance, competency and evaluative judgment under a variety of conditions such as workload, stress and crisis.

It should be recognized that the complex interaction between cognitive and personality variables is likely to change over time. Such changes are the normal consequence of progression through the phases of adult psychological development (only partially and incidentally correlated with age). Thus, the initially determined optimal aircrewman-mission-type matching cannot be expected to be immutably fixed. Rather, the need for continued aircrew evaluation and reassignment should be recognized as given.

In terms of maintenance of performance levels, when considering high demands, long duration, etc., the objective assessment of fatigue and performance decrement will be crucial (subjective evaluations being notoriously unreliable). The operational level application of on-line psychophysiologic and test task performance monitoring should provide a basis to resolve this problem. Accustoming the aircrewman to such continued monitoring and training him/her to use it would seem to be essential. The comprehensive selection assessment procedures (psychometric, psychophysiologic, performance) via integrated laboratory and simulator techniques should greatly facilitate the training of and acceptance by the future aircrewman of such on-line monitoring.

The development of the techniques by which to select the optimal aircrewman characteristics for integration with a particular type of mission necessarily will require prior or concomitant determination of the attributes and requirements of each particular mission. This will include type of airframe or platform, threat, integral tasks, best location in the system for human decision making, etc. It is only by assessing specific contexts that appropriate selection criteria for the optimal aircrewman-mission matching can be determined.

In conjunction with establishing and implementing selection criteria, investigation of the potential for enhancement, improvement, change, etc., of the various abilities and learned skills, also should be possible. Diverse methods of behavioral manipulations would be utilized. As an example, simulator motion sickness could be "treated" by biofeedback-mediated self-regulation training techniques.

d. <u>Facilities</u>

At the outset, fully integrated computerized psychophysiology/performance laboratories will be necessary. Ultimately, an integrated psychophysiology/performance/complex simulator computerized system should be implemented in order to, as accurately as possible, model a probable mission. Generous support for development of psychometrics, of course, will be implemented.

e. Applications

Implementation of these recommendations should greatly enhance the objective of establishing significant aircrew selection criteria for future high-demand and very specialized missions and for optimal enhancement of various abilities and learned skills.

5. Identification and Evaluation of Possible New Techniques for Selecting Fliers

a. Introduction

Current USAF techniques for selection of fliers are derived from traditional psychological tests, psychomotor performance tests, physical standards arising from conventional examination techniques, and a semi-structured interview to determine motivation, all applied to a self-selected (volunteer) population. Graduation from college is used as a performance standard.

This process yields a pool of flight-training selectees, of whom some 20 percent will not complete flight training. Thus, flight training itself is a selection process, albeit lengthy and rather expensive. (USAF has about $15,000 invested in a student pilot who washes out at the point of first solo flight.) The trend toward fewer and more complex aircraft requires more selectivity in identifying applicants with superior flying potential.

b. Approach

In the past, innate flying skill ("good hands") has been demonstrated only by performance; there were no accurate predictors. At best, flight surgeons or instructor-pilots would notice that a given individual had "good reflexes," was a "natural athlete," or "just looked like a pilot." A totally new approach to this problem would be in the use of advanced techniques to identify those elements of neural organization and function which account for "good hands." If, for example, flying skill relates to a particular ability to perceive and process information about space, time and velocity, this may be reflected in specific and measurable neurophysiologic parameters.

There are several new techniques which can be usefully investigated:

(1) Brain Electrical Activity Mapping (BEAM) - This approach uses computer software to condense and summarize the spatiotemporal data gathered by conventional electroencephalographic electrodes while the brain is "at rest," or after specific sensory inputs. Brain activity is displayed on a colored cathode ray tube as sequential images of topographic electrical activity taken milliseconds apart, showing area, direction and intensity of activity. This technology shows promise of predicting dyslexia in pre-school children; there is no theoretical reason why it may not also show the neural organization correlated with innate flying skill in pre-flight applicants.

(2) Position Emission Transaxial Tomography (PETT) - This very expensive technique uses radionuclide-labelled glucose to give information

about differential brain metabolic patterns. It displays data in a fashion similar to the BEAM.

(3) Event-Related (Cortical Evoked) Response - This technique underlies BEAM and PETT, using repetitive stimuli (usually auditory or visual) to produce responses which are extracted from random brain electrical signals by computer averaging techniques. USAFSAM currently is supporting research to determine if a specific 300-millisecond (P-300) wave pattern can be linked with superior flying ability.

(4) Biofeedback techniques give an individual precise digital or analog data on physiologic processes which are otherwise perceived vaguely, if at all. It may be possible to apply biofeedback methods to newer diagnositc techniques such as BEAM, to enhance desirable patterns of function.

(5) It may be fruitful to evaluate the so-called "sixth sense," with which some individuals detect or react to the presence of the enemy earlier than others. During World War II, the US Navy identified men who could see slightly farther into the ultraviolet spectrum than most, and considered using them and UV signal lights for securing ship-to-ship communication. It may be possible to identify and take advantage of other extended sensory and intuition capabilities.

A research model could be established for the investigation of these and other innovative selection techniques, so that they may be evaluated in standard ways. There would need to be a central agency responsible for identifying useful technical advances that might apply, and for monitoring their evaluation.

c. Facilities

These would depend on the particular technology being evaluated. BEAM is reasonably cheap and portable; PETT is expensive and requires access to a cyclotron. Some new technologies may be best evaluated at USAF facilities, others in research or university settings. A central group should be designated as a monitor for such research.

d. Applications

Such techniques, if fruitful, may be used for general flier selection, or to differentiate fliers into specific career tracks. If desirable characteristics may be enhanced, this enhancement may be used in the initial training environment, or in maintaining proficiency.

The ability to detect specific innate skills may also lead to specific means of presenting data that will take advantage of the skills which are detectable, thus influencing future designs of systems.

6. Assessment of Motivation to Fly

a. Introduction

The present USAF evaluation of motivation to fly is a semistructured interview: the "Adaptability Rating for Military Aeronautics"

(ARMA). AFR 160-43 directs that the ARMA be administered by a flight surgeon as part of the initial flying physical examination, and that the interview last about 30 minutes. In practice, this system is almost useless. Flight surgeons rarely have 30 minutes to devote to this interview. Their skills as interviewers vary tremendously. There is no feedback to them from the Air Training Command concerning whether or not they are selecting "winners." T.e process itself has been studied only briefly, in the late 1930's and early 1940's, with poorly designed study models which did not validate the system.

In short, motivation in flying applicants is measured only in that they volunteer, and are free from grossly psychopathological processes. Further, the genesis of motivation in successful fliers has been studied only at the most superficial level. Why is this important to understand? Flawed or low motivation leads to early departure from a flying career, either to look for greener pastures, or because of development of a conscious or unconscious fear of flying.

b. Approach

Conduct an in-depth, psychodynamically oriented evaluation of small, representative groups of fliers picked at various career points. For example:

(1) Successful and unsuccessful student pilots.

(2) Highly-rated Fighter-Attack-Reconnaisance (FAR) and Tanker-Transport-Bomber (TTB) pilots at the six-year career point:

(a) Who are staying in the Air Force,
(b) Who are leaving the Air Force for other flying jobs, and/or
(c) Who are leaving the Air Force for non-flying jobs.

(3) Fliers who develop a disqualifying fear of flying.

These evaluations should be aimed at defining psychogenetic features of motivation in successful and unsuccessful fliers, with an eye toward eliciting developmental or historic markers useful to less-skilled evaluators. Once identified, these markers should be used as predictors of success in a double-blind framework for purposes of validation.

c. Facilities

No special facilities are required.

d. Applications

(1) More precise definition of predictors and identifiers of a healthy motivation to fly.

(2) More effective use of flight surgeons in the selection process.

(3) Possible encouragement of certain types of young people to seek careers in aviation.

7. Cognitive Selection Factors

a. Introduction

Increasing technological capability is not only exceeding physiological limits but cognitive processes as well. Present and projected workload problems demand increased cognitive skills such as rapid information processing and judgments. Logical, serial thinking that may be highly satisfactory for leisurely tasks can become a handicap under high workload conditions in operational environments.

Historically, Western civilizations have emphasized and cultivated thought processes that can be taught and measured, i.e., logical, deductive, serial processes. However, Eastern civilizations have tended to emphasize and cultivate thought processes that are quite different, i.e., global, intuitive, parallel processes. In terms of hypothesized laterality, these two general thought processes, logical and global, may be likened to left brain-right brain functions. Although both cognitive processes are in use to some degree at any one time, the increased workload and more judgmental, less mechanical nature of pilot skills needed to perform future missions, call for an examination of how to optimize those cognitive processes. That optimization will require research about what cognition is, how present cognitive skills are measured, and possible enhancement techniques, all in terms of Air Force mission requirements.

b. Objectives

To determine, measure and enhance optimum cognitive styles needed to perform particular aircrew tasks.

c. Approach

(1) Identify different cognitive processes.

(2) Determine the measurement techniques of different cognitive styles and relate those capabilities to performance.

(3) Relate those cognitive processes and measures to mission requirements.

(4) Determine the degree to which cognitive processes can be enhanced by practice, training and/or psychopharmacological techniques.

d. Facilities

Create laboratories devoted to research into cognitive processes, such as for the understanding, classification, measurement training and enhancement of different cognitive processes.

e. Applications

Different cognitive styles, laterality differences and thinking processes among individuals have the potential to optimize the selection and enhancement of aircrew performance and will provide a timely symbiotic relationship between man and machine.

8. Sensory Selection

a. Introduction

Sensory capabilities clearly limit the role man can play in increasingly complex technological systems. A full understanding and measurement of sensory limits and capabilities is needed to create meaningful aircrew standards. Many physiological standards used to select Air Force personnel have not related well to mission performance. This lack of relationship is primarily due to a lack of contextual consistency from sensory stimulus and sensor/display system through the air crew's data processing system and relates to performance.

Present vision standards relate almost entirely to visual acuity, a measure of the optical quality of the eye. Good optical quality is important; unfortunately, there has been little performance relationship between visual acuity and visual target acquisition under most viewing conditions. This lack of relationship has resulted in a general reluctance to accept present vision standards. However, increasing scientific evidence shows that measurements of the next stage of visual system - the retina-brain system - can closely relate to the capabilities of the pilot to see a target under conditions not directly related to optical quality. A relationship between those kinds of new visual tests and performance can be used to help create more meaningful visual standards. Interestingly enough, research using those new visual techniques has also suggested certain enhancement techniques. A similar research approach is needed for other known sensory modalities, viz., hearing and tactile (especially important with the increased emphasis on pressure-type aircraft controls).

b. Objective

To create performance-based sensory standards and enhancement techniques.

c. Approach

(1) Determine known sensory limits and capabilities within performance related quantitative framework.

(2) Relate sensory limits and capabilities to mission requirements and technological limits and capabilities.

(3) Create performance-based standards using (1) and (2).

(4) Determine effects of (3) on manning problems and other related problems.

(5) Determine enhancement techniques.

(6) Investigate creative strategy competencies.

d. Facilities

Interdisciplinary laboratories are needed that are capable of combining diverse scientific research areas with Air Force realities such as mission and manning requirements. We need to move away from highly specialized, single-level research groups toward broad based multi-level groups capable of providing parsimonious basic and applied research solutions.

e. Applications

Performance-based sensory standards will help clearly define the optimum role man can play in high technological environments. This information is needed for a viable multiple track selection process. For example, there has been a strong desire to create a dual track pilot selection process in which visual acuity will play a major role. Since increasing evidence shows limitations of present standards based on acuity, emerging visual tests may provide a more meaningful tool for pilot selection. Further, since this new research can be intrinsically coupled to visual target acquisition models, data relevant to visual capability may be provided to the stategic military planner to help better quantify operator performance. Equally important are safety considerations. Flying and driving demand visual tests that relate to proper and safe use of those vehicles. This approach may be helpful for other sensory systems, such as hearing. In summary, the creation of sensory standards based on operator capability and performance may provide a positive impact on selection, training, utilization and survivability of our important human resources.

9. Motivation - Total Career

a. Introduction

To possess the skills to do a job will not ensure the effective application of that skill throughout a career. In addition to measuring and evaluating skills to perform a mission role, it will be necessary to evaluate motivation to perform.

b. Objective

Develop objective measures to determine appropriate motivation for skill application. This can include the analysis of ambition.

c. Approach

Individuals of equal skill may differ considerably in successful application of those skills. "Desire" or motivation is one key element in this differential application of skills. By evaluating (biochemically and psychologically) individuals of equal skills but of differing accomplishments, some objective measures of motivation should be determined. From these measures, a test for field application should be developed to be used in the selection process.

d. Facilities

(1) Neuropsychology laboratories
(2) Chemical laboratories

e. Application

Improved selection techniques with increased return on investment from training costs.

10. Selection Strategies

a. Introduction

At present, there is insufficient knowledge of the ideal physical/psychological profile demographies of the population from which potential aircrew are selected. This deficiency makes it impossible to assess the potential impact of contemplated changes in selection standards. For example, if a change in visual standards is contemplated, there is insufficient data to adequately predict the impact on the size of the selection pool of candidates. This problem will become increasingly complex as the required skills and selection discriminants become more sophisticated. As an illustration, one may have a mission that could best be accomplished by a candidate with an "Atari score" of X, but there are only one hundred candidates in the pool with that score that meet all other criteria. If you need one thousand aircrew members for that mission role, you must be prepared to adjust the required "Atari score" or change other criteria to provide a larger pool of suitable candidates.

b. Objective

Develop accurate projections of prevalence of required mission skills, and physical and psychological characteristics in the potential aircrew candidate population.

c. Approach

Take required mission skills tests and medical standards measures and apply them to a sample population to determine prevalence figures for individual selection criteria.

d. Facilities

(1) Physical examination centers
(2) Behavioral assessment laboratories
(3) Clinical laboratories

e. Application

USAF medical standards decision makers can assess impacts of standards changes and establish alternate selection strategies where required.

11. Weighting of Standards

a. Introduction

As flying selection standards become more complex and measure more parameters, the pool of potential flying trainees becomes smaller. This pool may, in time, become so small as to be unduly limiting.

b. Objective

Keep the pool of potential flying trainees as large as possible.

c. Approach

(1) Periodically review selection standards, liberalizing them whenever possible.

(2) Weigh some or all standards, or assign individuals into a continuous rather than in a pa -fail basis (i.e., 90th percentile vision, 75th percentile cardiovascular fitness, etc.).

(3) Allow an overall weighed score for total suitability for flying training.

d. Facilities

No special facilities are required.

e. Application

A larger pool of flying trainees, weighed for specific Air Force missions.

12. Maturity - Quality - Impulse Control

a. Introduction

Maturity has been defined as the delay of instantaneous present gratification in the service of longer-term goals. It includes impulse control. This has long been a problem in pilot selection.

b. Objectives

The USAF desires aggressive, energetic, action-oriented, courageous fliers who are at the same time amenable to strict flight discipline and to rules of engagement. These qualities should endure for an entire flying career. This is the traditional pilot.

Other characteristics are also desired. For a weapons-system operator, for instance, one would choose a logical, cool, data-processing, computer-minded person who does not get caught up in the excitement of the moment.

For some crew positions, such as commander of a multi-crewed aircraft, or ground mission director, leadership characteristics such as charisma, the ability to inspire confidence, and the assumption of the role of invulnerable protector in combat are desired.

c. Approach

As new weapons systems are conceived and developed, the personality characteristics desired in various crew stations must be identified, tested and coordinated. It may be that the maturing process, with its change from impulsive action to introspection, from inexperienced enthusiasm to experienced caution, from denial of danger or exhilaration in it to recognition of danger and less willingness to chance death, will suggest a logical progression from one type of crew position to another. Thus, personality development research into cognitive, affective and behavioral aspects of development could be integrated into career progression, through several roles. The approach should be through the disciplines of behavioral psychology and of sociology.

d. Facilities

Role study will probably require either "hands-on" *in vivo* evaluation of flying crew in their aircraft, or *in vitro* assessment in simulators.

e. Applications

(1) Aircrew selection

(2) Career management and progression (perhaps by allowing greater self-selection)

13. Multiple Track

a. Introduction

Since mission roles will become more and more complex and more and more diverse, the universally assignable aircrew member will no longer be possible. While there will be a minimum set of standards required for military service, special selection standards will be required for each major aircrew mission role such as tanker, transport, bomber, fighter, RPV controller, weapon systems operator, etc. Selection standards and training will be closely coupled to mission demands. While there will be a shift in emphasis on the type of mission roles required (from physical/mechanical to information assimilation, integration, decision making and execution) a wide range of mission roles (including the traditional aircrew roles presently used) will still be needed in the 2000 time frame.

b. Objective

The development of accurate selection standards for each specific mission role.

c. Approach

First identify skill/skill areas, physical and psychological characteristics required for successful completion of each existing projected mission role. Then develop techniques for evaluating (quantifying) the required skill areas and physical, psychological characteristics. Using measurements of successful performers for existing mission roles and estimations for projected mission roles, establish selection standards for each specific mission role. Traditional medical standards may have to be relaxed to provide adequate numbers of suitable candidates for highly specialized, complex mission roles. This means it will be important to decide what selection parameters are not essential for successful job completion.

d. Facilities

(1) Neurosciences labs
(2) Aircraft
(3) Access to operational mission crew members
(4) Simulators
(5) Centrifuge
(6) Physical exam centers
(7) Traveling teams/labs for field assessment of job requirements

e. Application

(1) Better match - man to mission
(2) Reduced training costs
(3) Increased chances for mission success

14. "X" Factor

a. Introduction

By the year 2000, further requirements in identifying the qualities that make "good" crew members will have occurred. The "right stuff" is a phrase used currently, but little understood.

b. Objective

Identify the now-unknown personality and other elements comprising the individual qualities underlying a successful performer for a specific mission.

c. Approach

Psychophysiologic, psychometric, motivational and other studies will be directed to identifying the hitherto unknown factors in the "right stuff" equation. Certain studies of outstanding performers will be conducted.

d. Facilities

Psychophysiologic, biomedical, psychometric laboratories.

e. Application

Optimal crew selection for Air Force missions.

C. Crew Enhancement

1. Optimal Physical Fitness

a. Introduction

The development and maintenance of optimal physical fitness of members is necessary for the achievement of optimal capability of the aircraft weapons systems of the year 2000. Fitness development and maintenance are quite specific to the tasks that are required of the crew members. Therefore, ground training will require exercise equipment which simulates the exact task (with respect to limb positions and muscular activity) to be performed in operating the aircraft under a variety of mission oriented circumstances. To achieve improved fitness levels, the principle of "overload" should be followed. This relates to progressively increasing the intensity and/or lessening the time of performing a given exercise task beyond that which is normally required under actual operating conditions. This improves physiological reserve of crew members, makes any given task relatively less stressful and delays the onset of fatigue. Thus, more fit individuals can sustain higher levels of exercise for longer periods of time because:

(1) Their skeletal muscles are better adapted to perform at higher rates of aerobic and/or anaerobic energy expenditure.

(2) Their cardiovascular, respiratory and other organ systems have greater functional capacities to support higher rates of energy metabolism.

The more fit person will also recover from a given exercise task faster. Because of the advantages of a fit crew, much research will be necessary to enable optimal crew physical fitness development and maintenance considering the enormous stresses which may be encountered in flying the aircraft of the future.

b. Objectives

To improve and maintain high levels of fitness for aircraft crew members, the main objectives are as follows:

(1) To evaluate the intensity, duration and frequency of specific physical tasks that are required for aircraft operation during various missions. (These data were also required for "Crew Selection: Physical Performance Evaluation," section V.B.1.)

(2) To develop flight simulators which enable the above specific tasks to be performed on the ground. These simulators should enable quantification of muscular strength, work and power for each task. They should also permit the setting of the desired intensity at which the crew member(s) will exercise. (This instrumentation was also required for section V.B.1.)

(3) Establish specific exercise programs using the above simulators to improve the performance of given tasks. This may involve both continuous and interval types of exercise programs. The exercise variable mode, intensity, duration and frequency will need to be studied for optimal results.

(4) Establish criteria for the maintenance of given fitness levels. This will require the determination of the frequency and intensity of exercise necessary to prevent detraining.

c. Approach

Data concerning the physical requirements of the crew during aircraft operation would be obtained as described in Section V.B.1. The specialized flight simulators described could also be used for physical exercise training for specific tasks. These ergometer-type devices can provide measurable and controllable exercise loads. Physiological responses (metabolic, muscular, cardiovascular, pulmonary, etc.), should be monitored to determine current levels of fitness, and the effectiveness of various exercise protocols for improving and maintaining fitness. Of course, these same instrumentation and procedures can be used to evaluate the effects of drugs and other methods on exercise capabilities.

In summary, much of the same instrumentation protocols described Section V.B.1 can be used for the improvement of fitness and maintenance of higher fitness levels. Major research efforts are needed to determine the most effective exercise protocols to use, as well as the best combinations of exercise mode, intensity, duration and frequency. Studying other factors such as nutrition, lifestyle and recreational activities are also be important.

d. Facilities

Since specificity of exercise is important for optimal training for a given task, flight simulators could be adapted for exercise training regimes. Physiological monitoring instrumentation is also necessary for periodic evaluation of exercise capacity and organ system status.

e. Application

Considering the time and expense required for crew selection and training, the development of techniques to improve their fitness and to maintain higher levels of fitness are extremely important. Not only will crew members be eligible for flight status for more years, they will be capable of greater flight performance and have a higher level of readiness.

2. Instrumentation for Fatigue Monitoring

a. Introduction

Fatigue monitoring systems need to be developed for selecting appropriate crew members of advanced aircraft weapon systems, and for assessing the performance capability of crew members during missions. Such instrumentation that monitors the onset and degree of fatigue can be useful in the evaluation of an individual's performance capability, and to signal the appropriate time to terminate a mission or to change personnel. It is conceivable that fatigue detecting devices can utilize EKG, EEG, EMG, blood chemistry, and/or biomedical indicators or nervous system functions as input signals. Much research is needed to evaluate individual and collective changes in psycho-physiological function with the onset and progression of fatigue. Subsequently, appropriate criteria and standards for mission-related fatigue could be established and signaled.

b. Objectives

To develop a crew member fatigue monitoring system, the following objectives apply:

(1) To establish criteria for the onset and degree of fatigue by way of changes in physiological variables during specific tasks.

(2) To develop instrumentation that would integrate the above changes in physiological variables and provide an index of fatigue.

(3) To establish fatigue norms for specific mission-related tasks.

(4) To establish the validity and reliability of fatigue norms.

c. Approach

To establish an accurate fatigue monitoring system, criteria for fatigue need to be determined. This will require specialized instrumentation to monitor various physiological variables for correlation with the onset and progression of fatigue during specific tasks. The degree of fatigue which correlates with malperformance of the tasks also needs to be determined. Following this, fatigue monitoring instrumentation which receives input signals from several physiological systems needs to be developed. Such instrumentation could be set to pre-determined fatigue levels to inform the crew member(s) when the fatigue level is potentially detrimental to the mission. This would permit appropriate modification of the mission or a change in personnel.

d. Facilities

This project would require special laboratory facilities which are equipped with flight simulation instrumentation. Physiological monitoring instrumentation would also be required to detect signs of fatigue. Facilities are also required for designing and constructing the fatigue monitoring instrumentation.

e. Application

Considering the importance of optimal crew member performance during missions, it is desirable to monitor fatigue status. In this way, realistic expectations can be derived with respect to physical performance capability. With the onset of fatigue, appropriate action can be taken to best achieve the desired outcome of the mission.

3. Duty Time - Rest Time Scheduling Procedures

a. Introduction

In continuous 24 hrs/day, year-round operations (such as air traffic control, C^3I, support services) personnel must be scheduled to provide continuous services. Most shift work schedules currently in use by both military and civilian facilities do not take into account even the most basic scientific knowledge about sleep-wake cycle physiology and the limits of human circadian entrainment. Further work needs to be done on both the basic theory of scheduling and its practical application.

b. Objectives

(1) To establish the phase response characteristics and range of entrainment of the human sleep-wake cycle.

(2) To study the mechanisms determining the rate of adjustment to work-rest schedules in animal models (preferably with nocturnal sleep and diurnal wakefulness).

(3) To develop mathematical models of the control of the human sleep-wake cycle that can predict the limits of schedule tolerance.

(4) To design duty-rest schedules which least disrupt the sleep-wake cycle and minimize deteriorations in alertness and performance.

(5) To conduct field trials of duty-rest schedules to evaluate their effects on performance, productivity and their health consequences.

(6) To develop educational programs to assist personnel to best adjust to rotating duty schedules.

c. Approach

A program of both basic and applied research is required. Some fundamental information is already available on the range of entrainment of human sleep-wake cycles and this can be used to designed duty-rest schedules which least disrupt the sleep-wake cycle and minimize deterioration in alertness and performance. The application of existing knowledge of the human sleep-wake cycle is at a very primative level, and is nonexistent in the field of duty-rest time scheduling. The United States lags behind certain European nations and the Soviet Union in paying attention to circadian factors and scheduling. This gap in scheduling competence needs to be closed.

While there is currently an opportunity to apply information about the circadian system to current rest-duty schedules, there is an even greater need for basic research to define the oscillator characteristics of the circadian pacemakers that time sleep and wakefulness and that influence the ability of sleep-wake cycles and physiological and psychological functions so as to readjust to changes in shift. In particular, a phase response curve for the human circadian system needs to be defined, the arrangement regulation of the human sleep-wake cycle needs to be characterized adequately, and mathematical models need to be constructed using coupled oscillator features that can predict the limits of schedule tolerance. Basic research also needs to be conducted using animal models to investigate the factors that determine the rate of adjustment to work-rest schedules. In order to provide a reasonable analogy to man, these studies should be conducted on animals that are awake during the day and sleep at night.

d. Facilities

In order to undertake the necessary field studies of rest and duty time schedules and to evaluate them, improvements need to be made in portable monitoring equipment that can continuously and automatically record activity and body temperature measurements. Technology in this area is in its infancy and needs support from a strong development program.

Secondly, the determination of human phase response and entrainment capabilities requires laboratories in which external time cues can be strictly controlled and in which artificial time cues can be provided. These facilities should have strong polysomnographic and neuroendrocrine capabilities.

e. Applications

The military must function continuously 24 hours a day, with efficiency and smooth performance in many key aspects of the system. There are significant costs incurred by inappropriately designed duty-rest time schedules which reduce the performance and productivity and increase the probability of errors through fatigue on the part of personnel. It is important to pay attention to the application of current knowledge on shift work scheduling, but also to basic research which will enhance shift work scheduling in the year 2000.

4. Long Term Health Consequences of Rotating Rest and Duty Time Schedule

a. Introduction

Animal studies indicate that 5-20 percent reductions in longevity occur in animals subjected to frequently changing (e.g., once a week) day-night schedules. Studies of industrial rotating shift workers suggest there are certain significant medical consequences of shift work. Little data, however, has yet been obtained from either humans or animal models, and the health consequences (both short and long term) of military schedules have only been minimally evaluated.

b. Objectives

(1) To establish a compendium of rest and duty time schedules currently in use by U.S. and NATO armed forces, and establish procedures to classify them and monitor their costs and benefits.

(2) To establish animal models clinically exposed to the schedules currently experienced by military personnel and study the specific health consequences.

c. Approach

The long term consequences of rotating rest and duty time schedules are poorly understood but there is now sufficient information to give credence to concerns about effects on morbidity and mortality. In the first place, there is very little information on the schedules that actually are in existence, many of them being chosen at the local base level. It is important to classify these schedules and to systematically monitor their costs and benefits. This information, in the long term, should feed back to the design of better schedules which minimize adverse consequences on health.

It is also important to establish an animal research program which can investigate the medical consequences of long term exposure to the rest and duty time schedules that are currently used. The aim is to understand the pathophysiological mechanisms that might be involved in reductions of longevity.

d. Facilities

Animal research facilities are required that can control environmental time cues and can apply light/dark and other time cue schedules to animals isolated from other knowledge of time. These facilities should be equipped with pathological and physiological monitoring support.

e. Applications

Information gathered in these research programs can be used to reduce the morbidity and mortality associated with rotating rest and duty schedules. This direction of research has a real possibility of enabling crews to perform without deterioration over extended careers, a key consideration given to the expense of training such personnel as air traffic controllers and others on rotating schedules. Furthermore, information from the classification and monitoring of rest and duty time schedules can provide useful feedback to the design of such schedules.

5. Circadian Control of Sleep, Performance and Neuroendocrine Functions

a. Introduction

Alertness, vigilance and psychomotor performance, as well as sleepiness and the ability to sleep, each show circadian (approximately 24 hour) cyclical variations which markedly influence the ability of an individual to function in round-the-clock operations. The amplitude of circadian rhythms in some performance variables is enhanced in extended duty periods by sleep deprivation and fatigue. Recent research strongly indicates that it will be profitable to mount an intensive research program (both basic and applied) to characterize the structure and function of the circadian timing system and develop strategies to enhance performance during round-the-clock operations.

b. Objectives

(1) To determine the influence of circadian phase (as opposed to local clock time) on relevant performance, alertness and vigilance variables.

(2) To characterize in humans the structure and function of the multioscillator circadian timing system which controls sleep-wake cycles, neuroendocrine, thermoregulatory and psychomotor performance rhythms.

(3) To study the neurophysiology of circadian pacemakers in animal models (which preferably have diurnal activity and nocturnal sleep habits comparable to man).

c. Approach

The circadian timing system is one of the most poorly characterized physiological systems. This is because the neural pacemakers which time circadian rhythms have only begun to be identified in the last decade and the neural and endocrine mechanisms of communication of circadian timing information and the consequences of disruption of circadian temporal order are just now beginning to be investigated.

The Air Force should institute a major basic research program to characterize in humans and in relevant animal models (diurnal activity and nocturnal sleep), the structure and function of the circadian system. This research will impact on many applied areas, including the role of sleep and strategies for sleeping on extended duty, in situations concerned with mood and effective state, the response to extreme environments and former regulation, and the strategies for shift work scheduling in extended duration missions. It will also provide information that is relevant to crew selection issues. It may be possible, for example, to select those individuals who will best adapt to duty periods of different times of day and night.

d. Facilities

Human facilities are required in which there are strict environmental time cues, and well-equipped polysomnographic and neuroendrocrine facilities should be present. The animal studies need to be conducted in laboratories specially designed to isolate animals from time cues and to study them through chronic implantation techniques for extended durations.

e. Applications

The applications of this basic research program are diverse. It will impact on many areas of applied research and on operations where there are requirements for extended duration missions or for transfer of individuals across time zones.

6. Circadian System Control Over Mood and Affective State

a. Introduction

Several lines of evidence point to the importance of circadian oscillator relationships in the control of mood. Phase advances of the sleep-wake cycle appear to be associated with mood elevation and certain phase delaying schedules have depressant effects. The shifts in the sleep-wake cycle that occur with the reduced day lengths of winter appear to cause internal phase angle shifts of the circadian system which have a depressant effect. Certain mood altering drugs cause appropriate shifts in the circadian system. The applications to date have been largely with manic-depressive patients but the circadian control of mood changes requires a more detailed follow up and the mechanisms should be explored for they may influence the performance of a pilot in highly demanding situations.

b. Objectives

(1) To characterize and measure variations in affective state induced by phase shifts of the circadian system, as in transmeridian travel.

(2) To establish the circadian mechanisms underlying the control of mood in human and animal experiments.

(3) To study in animal models the effects of psychotropic drugs which phase-reset the circadian system and influence mood.

(4) To develop strategies to enhance mood in operational situations.

c. Approach

A strong basic research program is required to investigate the role of circadian relationships in the determination of mood and effective state. At the moment, there is only a working hypothesis, which offers wide ranging implications but needs to be thoroughly evaluated in both in animal and human experiments. This research effort needs strong support and mathematical modeling to understand the nature of phase relationships as well as different environmental situations and increased support to understand the more fundamental neurophysiology and neuropharmacology of circadian pacemakers.

d. Facilities

This research program requires facilities for conducting neurophysiological and neuropharmacological experiments in animals in laboratories equipped to control environmental time cues and to measure sleep and other physiological and pharmacological variables.

7. The Timing of Recovery Sleep During Extended Duty

a. Introduction

Many missions require extended periods of wakefulness and allow only a short period for recovery sleep before beginning another extended duty period. There is little information available on the best time to schedule recovery sleep. The duration of wakefulness prior to going to bed is not a good prediction of sleep duration or quality. Recent work, however, suggests that sleep duration and organization may be predicted quite precisely using circadian oscillator phase theory. It may be possible to use the core body temperature rhythm, an output of one of the two major pacemakers in the human circadian system, to predict sleep duration and structure and make decisions about optimal timing of recovery sleep.

b. Objectives

(1) To investigate the relationship between sleep and the phase of the body temperature rhythm.

(2) To investigate the mechanisms mediating arousal at the rising phase of the body temperature rhythm.

(3) To investigate the neurophysiology of circadian oscillators and determine their properties in animal models.

(4) To develop strategies to optimally schedule recovery sleep after extended duty periods.

(5) To develop techniques for ambulatory monitoring of fatigue, alertness and body temperatures for use in field situations so that decisions can be made.

c. Approach

The main focus in sleep research up to the present has been a study of the brain stem mechanisms which are involved in the generation of sleep and sleep stages. However, the timing of sleep has not been thoroughly studied and some revolutionary findings have now made it quite clear that sleep duration and organization is not a function of how long a person has been awake beforehand, but instead is a function of the phase relationship between two main pacemakers of the circadian timing system. These studies indicate that sleep duration and organization is highly predictable depending on circadian phase of the deep oscillator which is reflected by the core body temperature rhythm. These considerations make it essential that an effort is mounted towards understanding the basic neurophysiology and neuropharmacology of circadian pacemakers. Mathematical modeling should also be undertaken to understand the dynamic relationships and the consequent influence on timing of sleep and sleep structure.

Besides basic animal studies, there is a need to investigate directly the timing of sleep at different phases of the circadian system and to generate strategies for timing recovery sleep in extended mission durations.

These efforts will have to be supported by techniques for ambulatory monitoring which can be used to judge circadian phase and correlate alertness performance and sleep-wake variables with it.

d. Facilities

There is a need to develop ambulatory monitoring capabilities so that experiments can be conducted on individuals in natural environments over extended duty periods. In addition, there is need for basic research and well-equipped laboratories with temporal isolation facilities for both humans and animal models.

e. Applications

The need for extended periods of wakefulness with little time for sleep is a common feature of military missions, and yet incredibly little is known about the most effective stategies for scheduling the time of sleep. This research program is of high priority because of its immediate application and it should also have to provide, as a long term goal, a basic theory to support future strategies in extended duty missions.

8. Internal Desynchronization and Decreased Performance - The Influence of Circadian Rhythm Variation, Disruption and Operational Stressors Upon Performance Efficiency (Vigilance and Attention)

a. Introduction

Extensive work has been conducted on the effects of various operational stressors upon task performance levels in both operational and laboratory settings. However, relatively little attention has been directed to the measurement of circadian variation in various operational tasks and the possible differential effects of stressors upon performance at different phases of the circadian cycle. Circadian variation occurs in a variety of performance tasks, including grip strength, psychomotor and tracking tasks, and vigilance, reaction time and cognitive tasks. Immediate information processing and psychomotor task rhythms are roughly in phase with the core temperature circadian rhythm, but the rhythms in high memory load information tasks are out of phase with body temperature. Therefore, circadian influences on performance levels at a given time of day are task dependent.

Disruption of the circadian system by shiftwork or transmeridian flight may result in performance impairment, particularly if the circadian system is phase advanced (e.g., eastbound flight or progressively earlier duty schedules). Circadian system disruption and the subsequent performance decrements are highly variable among individuals, which probably reflects differences in the underlying circadian oscillatory systems. Higher cognitive function (e.g., decision-making) tasks are more adversely affected by transmeridian flight than are psychomotor tasks. This finding may be related to recent evidence indicating that circadian rhythms in high speed and low speed memory processing tasks may be coupled to different circadian oscillators and therefore may dissociate from each other following phase shifts.

A number of operational stressors (e.g., noise, humidity, temperature extremes, barometric pressure changes, social interaction) have been found to have a negative impact on performance efficiency. It is likely that there is circadian variation in the impact of these stressors upon performance although this has not been investigated. Very little work has been conducted on the effects of combinations of operational stressors on performance. Available evidence indicates that the effects of combinations of stressors on performance are additive and task dependent. It is likely that the sleep disturbance and impairment in performance and well-being following transmeridian flight or shiftwork may be augmented in individuals subjected to these other operational stressors. Differences observed in performance and circadian system response to phase shifts induced by transmeridian flight or ground based alterations in work/rest schedules may reflect the influences of operational stressors interacting with the effects of transmeridian flight. It has been difficult to evaluate observed performance decrements in response to circadian disruption or other stressors in terms of physiological mechanisms since few studies have employed simultaneous measurements of both physiological and performance parameters.

b. Objectives

(1) To determine the influence of circadian variation on a variety of performance tasks related to operational goals (aeronautical environments).

(2) To evaluate the effect of circadian system disruption induced by transmeridian flight or shiftwork on a variety of operationally related performance tasks.

(3) To determine the effects of operational stressors upon circadian variation in performance tasks and also in combination with circadian disruption induced by transmeridian flight or shiftwork.

(4) To develop performance tests for use in experimental conditions that can be used effectively to evaluate performance in operational tasks.

c. Approach

Age samples of male and female Air Force pilots will be used to establish actual performance standards used in simulated mission operations. These simulator-developed tasks will be used to predict performance changes in operational situations. Further, work will be conducted on the development of performance tests to evaluate cognitive functions such as decision-making and reasoning in the extended duty period, e.g., long duration flight.

d. Facilities

This research will require a human research isolation facility for the study of circadian influences upon performance in combination with phase shifts of the circadian cycle and/or other operational stressors. A performance laboratory will be necessary for the development and testing of appropriate performance tasks.

e. Applications

Future Air Force missions will undoubtedly involve exposure of personnel to a variety of operational stressors, including circadian disruption induced by transmeridian flight or shiftwork. With the increasing development of technology and information processing, it is expected that the future Air Force personnel will have to perform tasks with an increasingly higher cognitive load and increasing quantities of information to assimilate, and will have to perform these tasks at all phases during the circadian performance cycle. Therefore, it is of importance to the Air Force to provide answers to the following questions by conducting the appropriate studies:

(1) What is the effect of circadian variation on a variety of operationally related performance tasks, particularly the higher cognitive tasks?

(2) What is the effect of circadian system disruption by shiftwork or transmeridian flight upon operationally related performance tasks, particularly the higher cognitive tasks?

(3) What is the extent of circadian variation in performance decrement resulting from the effects of different operational stressors?

(4) What is the impact of circadian disruption upon performance efficiency which is already adversely affected by operational stressors? Does the combination of operational stressors have serious consequences for the capacity to carry out operational performance tasks at different times of day, particularly the higher cognitive tasks?

(5) Is it possible to develop countermeasures in terms of optimal work/rest scheduling to correspond to the task dependent differences in circadian performance efficiency and circadian task sensitivity to operational stressors?

(6) What kinds of easily administered reliable performance tests can be developed which provide realistic evaluation of operational performance changes for different kinds of tasks? Can these tests be utilized to simulate the effects of operational stressors under various mission conditions upon task performance?

(7) What are the physiological processes and mechanisms which underlie the observed performance changes?

9. <u>Evaluation of Multiple Zeitgebers in the Rate of Readaptation to Transmeridian Flight and/or Shift Work</u>

a. <u>Introduction</u>

There has been considerable effort over the past 15 years to determine the effects of various zeitgebers (e.g., photoperiod shifts, social, temperature and altitude) on physiological functions. It has long been inferred, and supported by some experimental evidence, that performance decrements follow light cycle alterations. Photoperiod shifts (i.e., shift work, transmeridian flight) have been reported to cause fatigue, insomnia and sleep disturbances, gastrointestinal disorders, anorexia, psychological abnormalities and nervousness. There is a need to study psychomotor deficits or memory impairments as related to physiologic impairment in response to various zeitgebers and combination of zietgebers.

b. <u>Objectives</u>

(1) To describe the influence of various environment synchronizers (zeitgebers) on physiological control mechanisms in humans.

(2) To determine the deleterious effects of circardian system disruption upon sleep, well-being and performance related to disturbances in physiological control systems.

(3) Establish the time course in physiological regulatory capacity following alterations in zeitgebers (e.g., light-dark ratios, phase advances, phase delays, social and diet).

c. Approach

Experiments to evaluate zeitgeber strength and multiple zeitgebers on physiologic and performance rhythms in controlled environments will be conducted on humans. The relative importance of these various environmental factors on maintaining circadian rhythm stability and their influence on the rate of resynchrony of circadian rhythms will be established. The importance of the significant zeitgeber, strength of the zeitgeber and combinations of zeitgebers in the aeronautical environment will be evaluated.

d. Facilities

Environmentally controlled isolation facilities for the study of circadian influences upon pilot performance, in combination with phase shifts of the circadian cycle and/or other operational stressors, will be needed. A flight simulator will be necessary for the development and testing of appropriate performance tests with and without various zeitgebers.

e. Application

There is a need for research into the effects of various zeitgebers (known and unknown), combinations of zeitgebers and zeitgeber strength on circadian rhythm disruption to sensitive homeostatic regulatory systems in humans in the aeronautical environment.

10. Ambulatory Monitoring in the Aeronautical Environment

a. Introduction

Inadequacies in bioinstrumentation have impeded collection of information in such areas as muscle fatigue, metabolic rates, blood hormone levels, blood pressure and activity levels of the pilot in the aeronautical environment. Therefore, there are no detailed evaluations of muscular activity, motor coordination or changes of stress hormones of the individual pilot in flight. Although indirect evidence suggests that brief, heavy workloads can be met adequately, the findings are equally suggestive of impaired capability in a prolonged effort, both during and after flight.

b. Objectives

(1) Develop a light weight personal physiological recording system. This system must have a high degree of accuracy, rapid sample rate, and data storage, analysis and reduction capacities.

(2) There is a requirement for detailed analysis of the cyclic aspect of sleep and wakefulness, heart rate, body temperature, central nervous activity, endocrine activity and plasma electrolytes (e.g., Na^+, K^+, Ca^{++}).

(3) The equipment should be easily applied and maintained by an unskilled person under adverse conditions.

(4) The system should indicate a system malfunction to the pilot.

c. Approach

Evaluate the state of the art as to availability of physiological monotoring equipment. Initiate a design program to miniaturize the sensors and electronic circuits. A hormone sensor should take priority in the evaluation of the systems. Finally, the overall equipment should be tested in the cockpit environment.

d. Facilities

Engineering research and development laboratories will be utilized, along with environmentally controlled simulators for testing the equipment before it is field tested.

e. Application

There is a need to evaluate line pilot physiological systems in response to phase shifts of the circadian system in combination with operational stressors to evaluate physiological adaptability and effects upon performance efficiency.

11. Countermeasures for the Amelioration of Impairment in Performance in Response to Transmeridian Flight

a. Introduction

A number of treatments have been tested or suggested to alleviate the deleterious effects associated with transmeridian flight or to hasten the readaptation process. These treatments include exercise, preadaptation by altering sleep/wake cycles, drug administration, altered meal timing and constituents, relaxation techniques, electrosleep therapy, biofeedback, autogenic training and even acupuncture. Recent efforts in the research for effective chronotherapeutic treatment of transmeridian jet-lag or shiftwork-induced circadian disruption have largely concentrated on the administration of drugs or manipulation of meal timing and constituents.

Controlled or restricted access to food (feed-fast cycles) in animals can be made to oppose or augment the effects of a lighting regimen and therefore may act as rhythm synchronizers. Certain food constituents (for example, carbohydrates) may also have rhythm synchronizer characteristics. The diurnal alteration of food constituents (high carbohydrate breakfast, high protein dinner), which appears to facilitate circadian rhythm readaptation to phase shifts in rats and humans, is thought to be directly related to the increased synthesis of brain serotonin and noradrenaline, respectively.

A chronobiotic drug is one which specifically affects some aspect of biological time structure. Drugs such as alcohol and caffeine are commonly used by aircrew to facilitate sleep or reduce symptoms of fatigue and increase alertness. Chronobiotic drugs influence the duration of readaptation following phase shifts or transmeridian flights by (a) acting as a synchronizer which forces desynchronized rhythm components into phase, or (b) intensifying the effects of other synchronizers, reflected in the lengthening or shortening of the natural circadian period length. Drugs which influence the circadian system by type (a) action induce a circadian phase response cure in which the observed circadian rhythms exhibit a phase advance or delay, depending upon the phase of the rhythm at which the drug is administered. These drugs include ACTH, theophylline, pentobarbital, L-Dopa, parachlorophenylalanine, carbachol, librium and estradiol. The period altering (b) drugs have the potential to influence readaptation by altering circadian period length in the direction of phase shift and include deuterium, lithium, amphetamine and the tricyclic antidepressives. Recent work has demonstrated that chronobiotic drugs (theophylline), in combination with optimal timing of food-fast cycles or meal constituents, can facilitate readaptation following phase shifts in rats and can reduce fatigue and sleep disturbances in humans following transmeridian flights. However, the relative influences of drugs, feed-fast cycles and altered meal constituents upon adaptation to time zone changes in humans have not been evaluated in controlled experiments. Many of the drugs utilized as experimental chronobiotics have toxic or long-lasting side effects and would be inappropriate for operational use. Therefore, more work is needed to identify drug and food constituents which would be effective in promoting circadian rhythm stability and readaptation following transmeridian flight or shiftwork and which would not interfere with operational tasks.

b. Objectives

(1) Indentify and develop chronobiotics to a stage where their probable efficacy and safety for human use could be evaluated in flight duty crews following transmeridian flight or shiftwork schedules.

(2) Evaluate combinations of chronobiotics as to their effectiveness in re-establishing circadian rhythm phase relationships.

c. Approach

The experimental approach involves the testing of a variety of prospective chronobiotic drugs with respect to pharmacokinetics, routes and timing of administration. The effects of these, with respect to inducing appropriate phase shifts in the circadian system, would be assessed. The maintenance of internal rhythmic stability would be comonitored. These drugs will be studied in combination with the administration of specific food constituents or feed-fast cycles to determine if a multiple zeitgeber approach can be used to further facilitate adaptation to transmeridian flight or shiftwork schedules.

d. Facilities

Environmentally controlled chambers for conducting human and animal drug research. Research scientists with experience and expertise in a variety of chronobiotic drug research to carry out the work.

e. Applications

There is great practical significance to the Air Force in the development and testing of safe over-the-counter administration procedures for chronobiotic drugs and/or feed-fast meal constituent combinations whose side effects do not significantly impair mission operational performance. These can be employed to reduce fatigue, sleep disturbances and potential performance decrements resulting from circadian rhythm disruption induced by shiftwork or transmeridian flights.

12. Control of Attentional States

a. Introduction

Data management, decision-making, and design of data display all require a secure knowledge of the limits of information registry in various working modes (relaxed; "automatic" routine job, focused, with peripheral scan or sampling; maximal organizational effort at high information rate; multimodal; integration; and so on). Existing research efforts are exploring relatively low level problems, whereas magnitude is a critical issue. Control of attention in a negative sense (e.g., meditational skills) is still in an anecdotal stage, but might be useful in fatigue prevention via recovery during rest stages.

b. Objectives

To define the normal range of focused and nonfocused capacity to store data in short and long term memory. To study fluctuations of this capacity due to fatigue and/or physiologically disrupting states (such as transmeridianal, diurnal phase-shifting and/or neuropharmacological impairment of central synaptic function).

c. Approach

Multimodal, attentional research, as well as intramodal tracking via interactive (i.e.. operator adjustable display) simulator settings, appears most promising. A large literature base already exists on which to build specific projects.

d. Facilities

Laboratory instrumentation for stimulus presentation and recording of operator response. Simulator environments to be made available for such research.

e. Applications

Owing to the expected problems in massive data management demanded by integrated weapons systems, optimal data display will require a secure knowledge of the limits (high and low) of normal, focused/unfocused/ conscious/unconscious ability to track and store information. Because human operators (crew) differ widely in attentional behavior, the range of difference is important to consider in display design. Compensations for individual differences should be part of display features.

13. Control of Affect States

a. Introduction

Because we can recognize mood changes subjectively (but not reliably so), objectively (especially after training), and through current psychopharmacological research, we have a rudimentary knowledge of the central neurotransmitter profiles that reflect/cause such states. Moods select repertories of behavior and control both in attentional and cognitive brain operations. Intragroup communication of affect typically overrides individual member's mood states, i.e., group conformity is the rule, not the exception. Therefore, its management is critical to multi-member crew operation.

b. Objective

To learn methods of controlling affect states (e.g., depression/anxiety); monitoring their presence and degree; developing indices that permit exact psychopharmacological management of these intermediate duration brain states; and defining the nonverbal (empathic) communication of these states.

c. Approach

Multiple physiological indices of well-identified examples of mood states in normals needs development. In addition, control of mood state via neuropharmacological manipulation need further study, including aspects of psychoenzymology. Work can be accomplished with higher primates using controlled, repeatable mood evocations.

Nonverbal communication skills depend on a sure knowledge of basal ganglia functions which integrate posture, emotional expression and other coordinate tasks of posture, including task performance in the presence of kinemotor and kinesthetic perturbation.

d. Facilities

Primate neuropharmacological research center.

e. Applications

Mood control is vital for capacity to carry out mission, solo or in group. Communication in group produces mood synchrony. Behavioral and pharmacological control ensures maximal efficiency of personnel in long, stressful, unforgiving performance environments.

14. Signature Card for Parameter Settings of Control Displays

a. Introduction

The most troublesome area for practical use of computational aids is the user interface. This is especially critical for man-machine integration in aeronautical systems, where data intake rate and decision consequences are likely to be maximally stressed. Because people vary widely in genetic and acquired skill profiles, system displays are designed for a nominal average crew member. Both crew selection and training narrow the variance in operator skills. Nonetheless, by definition of the concept of the average, the human/machine match will be suboptimal to some degree.

b. Objective

To "fine tune" the display and control interface of integrated weapons/control systems so that it matches optimally to operator cognitive style.

c. Approach

Design flight simulators such that some degree of parametric control of display rates, image size and function sampling distribution is present. When adjusted to be optimal for a given operator, an insert card is punched out to set the optimal parameters. Insertion of the card into an onboard control system sets the preferred parameter profile. Study of parametric choices can yield data for the developmental direction of new system displays.

d. Facilities

(1) Simulator
(2) Field simulators of more restricted scope for parametric settings

e. Application

Optimal control design for onboard display/control systems.

15. Recovery Time Requirements from Missions and Recreational Activities

a. Introduction

To enable optimal readiness for flight missions, it is important to evaluate the time requirements for complete recovery from physical and mental activity. For instance, how much time should be allowed between missions, and how much time should be allowed following various forms of recreation (such as sports activities) or training before a mission can be performed at optimal efficiency. Therefore, research is needed to evaluate recovery time from various activities to set standards for mission readiness.

b. Objectives

(1) To develop instrumentation to evaluate the resting physiological status of individuals.

(2) To evaluate the recovery of individuals following stressful physical activities, i.e., training and recreational activities.

c. Approach

Instrumentation for monitoring and criteria for establishing the recovery from exercise bouts are needed. This would involve the construction of portable instrumentation that could be worn by individuals which would monitor various physiological variables that are related to recovery, e.g., metabolic rate and cardiorespiratory responses. This instrumentation could then be used to evaluate the recovery time from various missions, and from various training and recreational activities.

d. Facilities

Laboratory facilities for designing and testing the specialized instrumentation required for recovery monitoring.

e. Applications

Considering the importance of crew readiness, establishing standards for recovery from missions and other forms of physical and mental exercise is necessary. The *specialized monitoring* instrumentation could be used as an indicator of crew readiness for various missions to insure optimal performance.

16. Adaptation to the Environment

a. Introduction

Heat, cold, hypoxia, G forces and similar factors have been of aeromedical concern since the beginning of flight. Each advance in aeronautics has been accompanied by continuing research in the new stresses involved. The next generation of high-performance aircraft may well involve the imposition of high-onset Gs in the X and Y axes.

b. Approach

Aircraft designers and mission planners must maintain liaison with aeromedical laboratories. The research approaches used to determine physiologic burdens and support systems in the past have been effective and should be continued. There must be continuing feedback from the aeromedical laboratories to the designers about the parameters that limit human performance, so that we do not design aircraft that cannot be flown to their full performance. For example, if rapid-onset Gs in the X, Y, or multiple axes are contemplated, the human limitations and possible means of overcoming them should be thoroughly explored before such design parameters become "*set in* concrete."

c. Facilities

These will be determined on a case-by-case basis. It is likely that facilities already in existence will form the basis for any new research parameters explored.

17. Maintenance of Pre-Mission Readiness/Anticipation Excitement

a. Introduction

Some of the missions predicted by proposed weapons systems involve possible long-term stand-by in alert status, perhaps even in an isolated environment, e.g., VTOL aircraft deployed to a "tennis court" with upgrading of defensive posture to a cockpit alert, awaiting orders to launch or to stand down. This poses questions concerning the reasonable/maximum duration of such posture before psychophysiologic changes occur which will degrade chances for mission completion.

b. Objectives

(1) To maintain a given flier in the alert posture as long as possible.

(2) To determine when his/her potential for mission completion has begun to degrade.

(3) To determine what can be done to enhance the duration of alert.

(4) To determine what on-off schedule allows the maximum number of hours on alert per group of aircrew.

c. Approach

Basically, this will require a psychophysiologic approach.

(1) Degree of sympathetic arousal on alert.

(2) Trend of this arousal (does it increase or decrease with time, and with what sort of curves).

(3) Launching missions (real or simulated) and various points on these curves, and determining degrees of effectiveness of these missions.

(4) Enhancement of number of hours available for alert.

(a) Scheduling (see circadian research in section V.C)

(b) External enhancement

- Drugs
- Diet
- Recreation (reading, cockpit games)

(c) Internal enhancement

- Relaxation technique - autogenic training, deep muscle relaxation, autohypnosis, acupuncture, pressure, biofeedback, mental imaging, meditation.

- Alerting techniques - autohypnosis, mental imaging, biofeedback.

d. Facilities

(1) Aircraft

(2) Simulators

(3) Physiologic and perhaps biochemical monitoring

e. Application

(1) Operational requirements imposed in aircrew - desirable and maximal.

(2) Possible *in vivo* monitoring systems built into such aircraft.

Note: This approach may also be used for the use of these modalities in long-duration missions, both solo and multi-crew.

18. Physiologic Innate Needs - Long Duration Flight

a. Introduction

There is a considerable body of knowledge about long-duration (24 hours or more) space flight, but USAF missions have exceeded 24 hours only in a few instances. Routine combat or combat support missions of two to seven days will introduce some new problems.

b. Objectives

(1) To determine which, if any, physiologic factors will limit long-duration aircraft missions.

(2) To determine what can be done to remove or lessen these limitations.

c. Approach

(1) Review of literature.

(2) Physiological monitoring of aircrew on simulated long-duration missions.

(3) Physiological monitoring of aircrew on *actual* long duration missions; subjective and objective assessment of physiological changes which relate to mission limitation. Such changes may be subtle: digestive disturbances from dietary limitations, decreased cognitive or interpersonal skills from a change in the quality of sleep, chronic mild dehydration from low humidity, or lack of aerobic exercise in those accustomed to it, for example. These will need to be correlated with any degradation in peak mission effectiveness.

d. Facilities

(1) Aircraft capable of long-duration flight.

(2) Simulators.

(3) Capability for physiologic, biochemical, performance and behavioral monitoring in both environments.

(4) Onboard delivery systems to inflight aircraft (mail, medication and other items).

e. Applications

(1) Mission profiles

(2) Aircraft design

19. Enhancement of Morale During Combat

a. Introduction

The incidence of combat fatigue increases when morale is poor. Such combat fatigue may manifest itself in aircrew as acute stress reactions, psychophysiological disorders, fear of flying or other phenomena. These conditions may represent a major loss of available aircrew during prolonged combat.

To enhance morale in aircrew, an instrument is needed to measure this very abstract entity. Much of the present data comes from conventional military experience, and is not necessarily directly transferable. A number of indirect measures of declining morale have been used in the past, such as increased substance abuse, increased non-effectiveness rates, increased incidence of disorders preventable by personal discipline, e.g., sunburn, immersion foot, malaria, dysentery, venereal diseases, increased Article 15 actions, and others. These may not be as applicable to aircrew as they are to other military members; the indicators may be more subtle.

b. Objectives

(1) To determine measurement of aircrew morale.

(2) To develop means of enhancing aircrew morale before and during combat.

c. Approach

Research in this area may well be sociologic and descriptive in nature, rather than being "wet bench." Several avenues may be useful to consider.

(1) How may confidence be built in each aircrew member, not only in his regard for personal abilities and the unit aircraft, but also in the unit and in individual personal contribution to the total combat mission?

(2) Can aircrew be effectively trained to perform properly while they are afraid? Fear causes cognitive, physiologic and behavioral changes. There is some evidence that familiarity with the first two may be used to lessen the third; i.e., "you may feel afraid and know that you are afraid without shame, but we expect and insist that you do your duty anyway. You may not act afraid." Knowing in advance that fear causes palpitations, dry mouth, tremors, gastrointestinal sensations, urinary frequency and so on serves to lessen the impact of these occurrences.

This training (aside from familiarity briefings) is inhibited by ethical considerations. A flier cannot be placed in real fear for his life in simulated combat. There may be some similarity to intense fear of failure, and there may be some realistic but ethical means to induce a real performance anxiety as a simulated combat stress. For instance, a flier who is afraid of wash out due to poor performance in simulated combat may serve as a model for a flier who fears death is likely when flying combat missions.

(3) There are other factors involved in morale that are under more direct organizational control:

(a) Communication with family. This may be enhanced by regular mail delivery or (especially with long-duration missions) by telephone or video patches. There may be negative morale impacts from such communications; this also should be evaluated.

(b) The best possible amenities should be provided, e.g., food, bathing, lodging and recreation. Again, such considerations must be included in long-duration flights.

(c) Strong unit identity is necessary for good morale. This may include a re-examination of policies concerning relatively brief association with a given outfit. It is well to give indoctrination in the history and past achievements of that outfit, and to foster a feeling of continuity with those accomplishments, a "passing on of the baton." This may also mean a carefully considered policy of unit rotation into and out of action in prolonged combat. Rotation of individuals weakens unit integrity.

d. Application

The application of those principles that are found pertinent to specific Air Force missions is probably more in the field of personnel management and leadership than in biotechnology. There must be communication between all disciplines involved.

20. Cognitive Skill Training

a. Introduction

In higher interactions with the world, the pilot operates with his own automatic control systems as well as those of the aircraft. In effect, the aircraft and its systems become a large prosthetic device. The mutual (interactive) molding of the most effective device implies augmenting, both cognitive skills and machine skills. This involves the concept of optimal placement of locus of control (active/passive) and malleability of control loops to changing environmental requirements.

Personnel selection of the flying crew has in the past and present rewarded crew members who could exert rapid, complex, often nonconscious ACTIVE control of vehicle or weapons systems. On many future aircraft, most executive options will be removed. In effect, "active" learning of passive/adaptive complex decision-making skills will then be required. Irrespective of personnel selection efficiency, the problem will remain; even "naturally" accomodative personality types will need to augment their skills in specific directions. Training experiences will be necessary that include conscious modeling of the inevitable, passive-control experience. Prediction/error and mismatch of subjective (mental) models to external realities produces confusion, anxiety or consternation, depending upon the degree of threat to one's viability.

b. Objective

Development of maximally adaptive cognitive skills for data systems characterized by great complexity, high processing rates and passive (follower/adaptor) role with regard to decision-making, at many levels of automatic controls.

c. Approach

The approach involves simulator construction with rewards for recovery from mismatch states, plus training for systematic context shifts so as to reach an acceptable degree of match. Design of recovery algorithms of a "manual override" type to deal with large-scale system failure. Exercising of failure states.

d. Facilities

Simulation laboratories with representative data displays - probably part of the flight physiology training program.

e. Applications

With crew so removed from potential control of complicated systems, failure of any kind can easily, or even instantly, escalate to catastropic failure. It is vital to alter bistable function/failure - to some sort of graded degree of control - to be exerted by crew so that they can salvage maximally from the failure state. Otherwise, the probability of error being significant, losses of aircraft and battle stations due to human confusion may be unacceptably high.

21. Psychoenzymology

a. Introduction

Evidence accumulates that drug abuse occurs due to special effects of substances, mediated through enzymatic processes and, ultimately, central neurotransmitter pathways that are not shared universally by all people. High pressure liquid chromatographic methods coupled with immuno-radioliganding of enzymes can elucidate specific genetic markers. Through their expression as enzymatic proteins, operating in the brain to make neurotransmitters that, in turn, create the "drug high" and tension states (for which drug ingestion is sought as a reducer), the genetic loci of vulnerable people can be identified.

Overwhelming affect states impair function severely. Use of specific ligands can control the rate limiting enzyme, and thus provide control of mood organizing neurotransmitters.

b. Objective

To discover genetic markers of vulnerability to drug abuse (alcohol and other substances). To use specific ligands as agents for control of rate-limiting enzymes important in central neurotransmitter production.

c. Approach

Genetic study of high density families vulnerable to drug abuse (several generations of first-degree relatives who all show the vulnerability, comparing these with resistant subjects).

d. Facilities

Epidemiologists, medical record accessing systems and neurochemistry laboratories.

e. Applications

(1) Owing to the severe degradation in performance subsequent to substance abuses, major human-error-caused mishaps occur. The information may prevent: needless loss of life, loss of equipment and increased vulnerability of integrated defense systems due to failures in personnel performance. Detection of "at-risk" individuals permits self-protection and special training to avoid abuse.

(2) Considerable variation in central neural transmitter kinetics occurs from individual to individual. Locating gene markers for, e.g., "hyper" or "hypo" responders permits alerting them to use specific pharmocological compensatory agents so as to constrain neural transmitters to optimal production/degradation/re-uptake rates. This means that personnel who would not ordinarily qualify for high stress performance could be supported pharmacologically as needed.

22. Recreational-Social

a. Introduction

Mission skills will require continual reinforcement and upgrading. Many of the longer mission roles will require "diversionary/recreational activities." Ideally, some of the "recreational activities" would also be useful in upgrading/reinforcing mission skills.

b. Objectives

The development of inter- and intramission entertainment, recreation, and social activities that enhance combat skills.

c. Approach

Using known skills, physical and psychological characteristics required for mission accomplishment, develop "games" activities (physical, cerebral, cerebellar, interactive, analytical, attack, etc.) that enhance desired combat skills. Measure desired outcome in terms of subjective "entertainment" experienced by crew members and the potential objective improvement in combat skills.

d. Facilities

(1) Neurosciences labs

(2) "Games Arcade"
(3) Behavioral psychology lab

e. Applications

(1) Improved morale leading to increased effectiveness
(2) Possible reduction in "upgrade training costs"

23. Enhancement of Human Reliability in the Operation of Large Complex Systems (C^3I)

a. Introduction

The human operator is less than perfectly reliable, but the "less" is more qualitative than quantitative, and operator reliability research is basically in its infancy. Very recently, concern for reliable operations of nuclear power generating systems has resulted in provocative progress, with a substantial possibility of applications for USAF centers for "Command, Control, Communications and Intelligence (C^3I).

b. Objectives

(1) To analyze human reliability into its components, attach quantitative error probabilities to each component and develop a time history for each of the probabilities; identify the most valuable measures.

(2) To develop a human reliability model to serve as a tool for further studies as C^3I systems change.

(3) To extract from the above those components (dimensions) which can be enhanced through special training.

c. Approach

Conduct laboratory studies in a unique, highly flexible simulation facility using current C^3I operators or "just likes" as subjects; validate findings in C^3I facilities, ground-based and airborne; develop, validate and implement training techniques.

d. Facilities

Unique simulation laboratory with broad-band measurement capabilities and a strong interdisciplinary staff.

e. Applications

(1) Improved operator reliability in C^3I systems
(2) Enhanced C^3I training programs

24. Effects of Aging on Information-Processing/Decision-Making Effectiveness

a. Introduction

C^3I centers vary in size, scope of responsibility, breadth of functions and level of command. Staff rank and experience increases as each of these increase. Within a single center there are also variations in experience, skills and rank. There is an approximate relationship between age and experience/skills/rank. There are no data on whether the processes of information-processing/decision-making change with age, or whether the processes vary in effectiveness.

b. Objective

(1) To quantify the process changes and effectiveness of information-processing/decision-making with experience/skills/rank/age.

(2) To develop training techniques to enhance performance in the younger operators if the older are better, or in the older operators if deficiencies have developed.

c. Approach

Conduct laboratory studies in a psuedo-C^3I simulation facility (the same facility as that used for Human Reliability studies) using current fully qualified C^3I operators in the appropriate breadths for experience/skills/rank/age; validate findings in real C^3I facilities; develop, validate, implement training techniques.

d. Facilities

Unique simulation laboratory with broad-band measurement capabilities and a strong interdisciplinary staff.

e. Applications

(1) Improved/homogeneous C^3I staff

(2) Staffing guidelines for best mix of experience/skills/rank/age

(3) Minimizing center performance compromise due to age

25. Functional Age Changes

a. Introduction

In the year 2000, the cognitively oriented crew member will have received an estimated 3 million dollars in training. Early "outs," "throwaway" pilots, and similar concepts will become prohibitively expensive. Retention of greater numbers of older pilots who have the appropriate functional capabilities will become necessary. The experience and judgment of the older crew member are assets to be retained when possible.

b. Objective

To develop a series of functional assessments for specific crew functions and for individual crew health status that permit continued duties irrespective of chronological age.

c. Approach

Individual functional capabilities concerning the key operational performance requirements are undertaken. These are quantified and matched with acceptable performance criteria. Disease states are screened, especially those that impair performance.

d. Facilities

Psychophysiological, biomedical and simulator laboratories.

e. Application

Crew performance enhancement through retention of highly trained and experienced individuals.

26. Data Management

a. Introduction

Users of technical equipment are usually ignorant of design principles that underlie its correct operation. The exploration of best format of explaining operating principles for given subject material has seen little basic research with the exception of studies published by MRC Applied Psychology Unit - Cambridge, England. The problem is universal, but particularly acute when assigning processing best done by machines and that best done by flight crew.

b. Objective

To discover the optimal forms of data presentation for rapid and secure comprehension.

c. Approach

Multisensory data formatting with degree of comprehension as an output variable.

d. Facilities

Experimental psychology laboratories.

e. Application

Given the magnitude of expected data role presentation, projected as exceeding current human capacity, special skills are absolutely necessary if full use of system power is to be achieved.

VI. CHEMICAL AND BIOLOGICAL DEFENSE

VI. CHEMICAL AND BIOLOGICAL DEFENSE

A. Introduction

This chapter deals with a large number of substances that can be categorized into four types: chemical agents, toxins produced by biological agents, biological agents and environmental pollutants. Because of the perceived threat of chemical warfare, chemical agents will be discussed in greatest depth.

Over the past several years the AF has become increasingly aware of the seriousness of the threat of chemical and biological warfare (CBW), and the potential importance of environmental toxins, especially during long-duration missions. There is also a growing recognition of the impact of such threats on every aspect of AF (missions) and the difficulty in providing defense against such dangers. Presently, the readiness of the AF to mount a credible defense to these threats is marginal.

Large amounts of weapons in the Warsaw Pact arsenal are devoted to chemical agents (especially organophosphates, cyanide, and blister agents). There are reports of use of mycotoxins and other agents in Afghanistan and elsewhere; an unexplained epidemic of anthrax in Sverdlousk, USSR; and voluminous USSR publications on various biological toxins. These reports underline the potential threat.

The following agents seem to be the greatest threats to AF operations:

(1) Pre 2000 - Organophosphates, especially persistent agents; vesicant agents; conventional BW agents: (a) Toxins - botulism, enterotoxin, mycotoxins, etc.; (b) anthrax, tularemia, Venezuelan Equine Encephalitis, etc.; mixed agents; synergistically acting agent mixtures.

(2) 2000-2020 - The above agents will remain threats; genetically engineered organisms.

Development of future agents is difficult to predict. Genetic engineering technology will permit production of known toxins and microorganisms which are not useful currently in offensive warfare because of the low yields obtained and/or stability problems. Genetic engineering will also permit the development of novel organisms with altered characteristics. The most dangerous threats are agents which defeat existing and planned protection systems - masks, filters, protective clothing, immunity, antibiotics and detection systems. These threats occur in all environments in which pilots and critical AF personnel must operate: fixed enclaves (with collective protection features) such as airbases; aircraft; unprotected environments - movement between enclaves and aircraft; and at decentralized (e.g., VSTOL) sites. The CW/BW threat to the crew operating and servicing VSTOL aircraft is very similar to the threat the ground forces will be exposed to.

In addition to CW/BW agents, performance degradation of pilots could occur from pollutant buildup in enclosed systems. These pollutants might originate from aircraft and would interact with other stresses. This threat is enhanced in long-term missions. In open flying systems, outside air pollutants may enter the aircraft through the air intake. At higher altitudes such pollutants (e.g., ozone) could become concentrated with air compression.

While more specific recommendations will be included in the text to follow, six general recommendations are presented here:

(1) There is an important need to incorporate CW/BW defense requirements into the conceptual and engineering design of all AF systems.

(2) The intelligence community should assign personnel to gather, analyze and disseminate relevant CW/BW information. Their attention should not be confined only to major potential adversaries. CW agents are easily produced and inexpensive and thus readily available to any country, no matter how undeveloped, and to terrorists.

(3) Integration and systemization with CW/BW matters within the AF should be promoted with a high level focal point at Air Staff level.

(4) Improved communication and collaboration with the Army is essential. Although the Army is the "lead agency" in CW/BW matters, the AF has special and urgent needs that require its significant commitment to research and development in this field.

(5) Joint planning and cooperation with our military allies on CW/BW matters should be given greater emphasis.

(6) The importance of protecting facilities and personnel involved in C^3I functions that are so critical and potentially vulnerable is strongly emphasized.

The value of ongoing research in such areas as biomedicine, the physical sciences and chemical defense cannot be overemphasized. A plan of action for such research is presented in Figure 11, and its components are detailed in the discussion that follows.

B. Biomedical Research Area

1. Introduction

This area includes those research topics that relate to the human response to exposure to agents and to prophylaxis and treatment.

Although considerable research has been conducted on the effects of potentially lethal, acute doses of agents, the effects of low dose subacute doses of agents on behavior and mental performance are poorly understood. Preliminary data in small animals show decrements in behavioral performance without changes in physical performance at low levels of agent exposure. This decrement is of great significance to the AF in evaluating the ability of pilots to operate in combat. Research to elucidate more precisely these decrements in behavioral performance in small animals, and ultimately in subhuman primates, is required to predict the threat to pilot performance and to establish models to determine if drugs proposed to counteract the lethal or physically incapacitating effects of agents are effective against the mental

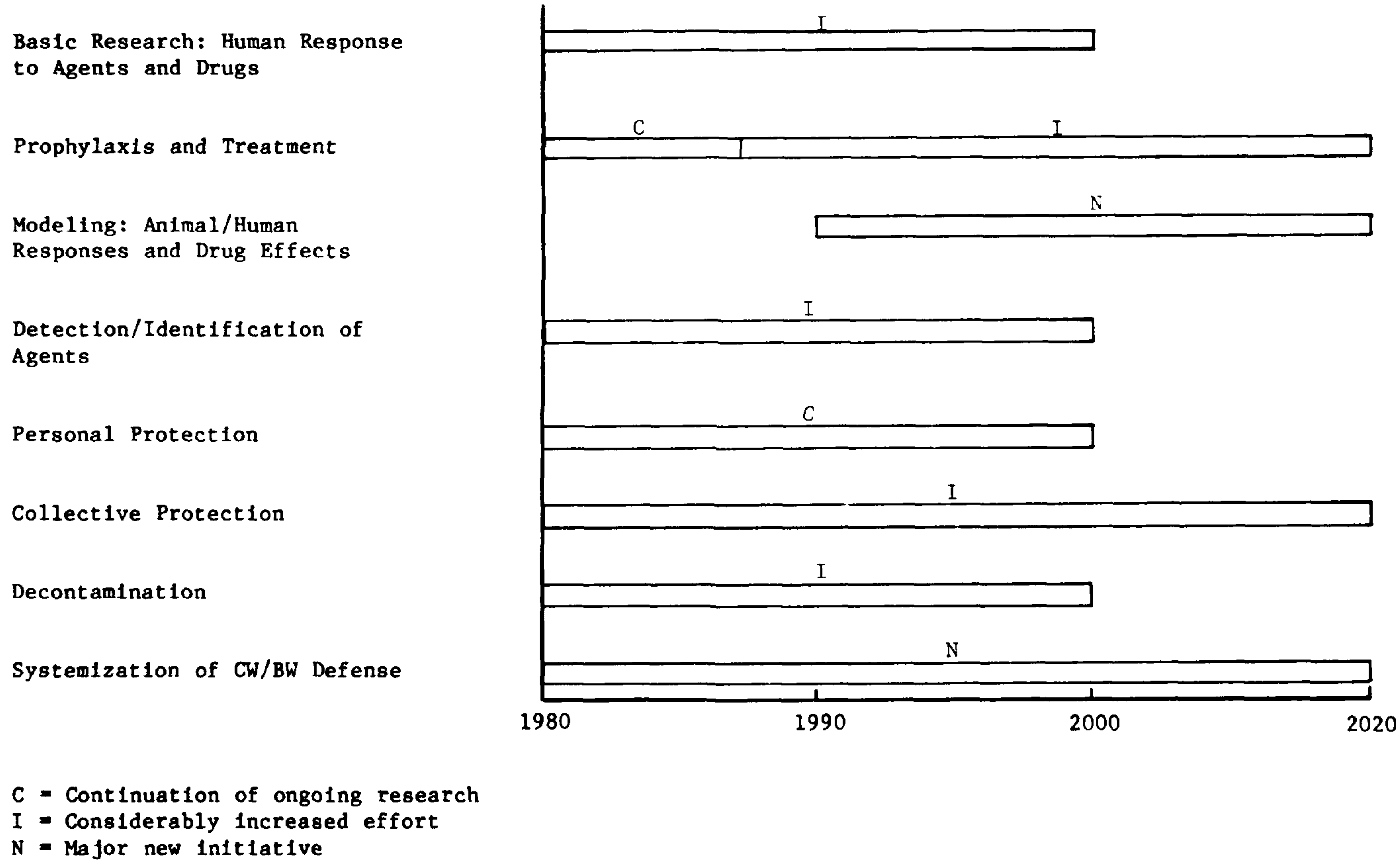


FIGURE 11. RESEARCH PLAN: CW/BW DEFENSE

incapacitation found with low dose agents. Basic biochemical pharmacological data is minimal and without a major research effort in this area, modeling will be severely restricted.

Classically, toxicologists have assumed a direct correspondence between the dose or atmospheric concentration of a chemical and the concentration-time product for the chemical at the target organ. This assumption ignores the impact saturable pathways involved with metabolism, transport and excretion of the toxicant, and metaboites can have on kinetic behavior. Pharmacokinetic theory provides the framework to describe mathematically the dose of the parent chemical or reactive metabolite at the site of action in vivo.

Prophylaxis and therapy of CBW agents and toxins should be viewed as the last line of defense after individual and collective protective measures and decontamination. The reasons for the tertiary importance of drugs are the specificity of their effectiveness against single classes of agents (requiring a multiplicity of drugs for total CBW protection) and the effect of drug side effects on military performance. Research is required to increase the general effectiveness of drug prophylaxis and therapy and to reduce drug-induced decrements on military performance, but is unlikely to yield quick dividends.

Three levels of protection are potentially achievable by drug therapy or prophylaxis: protection against lethal effects of agents, protection against physical incapacitation and protection against central nervous system (CNS) incapacitation.

Current or projected drug regimens protect against several LD50's (doses that will kill 50 percent of the experimental animals) of organophosphate nerve agents, but offer little protection against physical or CNS incapacitation induced by these agents. There are no effective drug regimens protecting against lethality or physical incapacitation of vesicant agents. Current drug development efforts focus on achieving protection against lethality or physical incapacitation and do not directly address protection against CNS incapacitation. Although the Air Force, like its sister services, must be interested in preventing agent-induced lethality and physical incapacitation, it has a special requirement to protect against mental decrements which obviate mission performance. The Air Force should, therefore, pursue a novel strategy of drug development - one which emphasizes protection against central nervous system aspects of agent poisoning. A major obstacle to this approach is the dilemma that drugs that enter the CNS to protect against agent effects are themselves more than likely to cause CNS side effects.

2. Subarea 1: Human Response

a. Objectives

The objectives are to quantitate human physiologial and behavioral responses to chemical agents and to develop validated physiological models. These models will be used to extrapolate from limited data bases with test animals to predict human response to agents. Extrapolation will be conducted by computer simulation based on variations in physiological parameters between different mammalian species and basic biochemcial data.

b. Research Approach

The ultimate product of research will be the linking of physiological and behavioral metrics into one model which will allow accurate prediction of human performance under the influence of various chemical agents and toxins.

Mathematical simulations of chemical reaction processes are well established and the necessary computer-based simulation packages are available from a number of sources. Simulation of physiological systems is still in its infancy. Physiological models use composite anatomical compartments, such as liver, lung, brain, etc., each with physiologically meaningful, independently measured properties.

In the near term, emphasis should be directed toward developing the basic biochemical and pharmacological information, especially for organophosphate toxins, but for other potential agents as well. Data on performance degradation due to agents is critical for predictions of mission accomplishment under varying threats, design of protective equipment and specifications for detection and monitoring instrumentation. Models must be developed which will provide the framework to design the necessary experimental protocols for elucidating mechanisms. Basic physiochemical parameters, such as distribution, binding and partition coefficients, must be determined for both systemic and nerve toxins and the metabolic and transport pathways. In vivo inhalation and percutaneous kinetic data must be generated under well-defined simple and complex exposures to validate simulations using simplified models and modifications made to define the physiological components and constants. Behavior metrics which quantitate the performance decrement resulting from known exposures to chemical agents will require standardization to allow comparison with physiological changes. Major emphasis should be given to identifying species variations and extrapolation from animals to man based on variations in physiological parameters. Research to investigate the influence of low level chronic or repeated exposures on visual capacity, respiratory function and the central nervous and cardiovascular systems needs to receive high priority. Major research efforts should also be dedicated to the design of nontoxic simulants that can be used to train personnel in chemical defense tasks and to verify the effectiveness of protective equipment. These simulants must provide a quantitative measure of exposure by duplicating the chemical and physical parameters of the real agent. The use of physiological models will greatly aid in the design of these simulants.

With the development of verified models to predict human performance from lower mammal testing, increased emphasis should be directed toward the interaction of chemical agents and fatigue and the influence of physical stresses (heat, vibration, etc.) and other chemical stresses (e.g., antiradation drugs and treatment).

In situ detectors for biological indicators of intoxication should be explored for implantation in humans to provide information for assessing pilot performance capability. This type of device could also control the release of drugs to either counteract the agent or enhance the performance capacity of the pilot long enough to accomplish the mission.

3. Subarea 2: Prophylaxis and Treatment

a. Objective

To develop drugs which prevent death, disability and CNS incapacitation induced by chemical agents without themselves inducing decrements in pilot performance.

b. Research Approach

Expanded basic research into the CNS effects of agents, both direct and indirect, is needed to form the basis for novel, revolutionary approaches to prevention and therapy. We are currently paying the price for the limited basic research in this area undertaken in the past decade. High priority should be given to the development of animal models which predict qualitatively and quantitatively CNS decrements induced by both agents and potential prophylactic and treatment drugs. Likewise, development of animal models to test efficacy of drugs in preventing CNS incapacitation is urgently needed.

In the longer term, the subject of vaccines against selected agents should be reexplored. While this approach has been dismissed previously as fruitless, the committee believes that recent advances in immunology make this a feasible approach.

We recommend the initiation of a novel approach to drug development that seeks to achieve protection against agent-induced CNS incapacitation at the possible expense of protection against lethality. Such a drug would potentially protect or prolong the capability of a pilot to be operationally effective at low doses of the agent. Effectiveness of such a drug regimen would be dependent upon highly effective systems for protection of pilots against chemical agents. Possible drug development approaches include: (a) a pro-drug that enters the CNS but is not activated except in the presence of an agent; (b) a drug that only enters the CNS after agent-induced changes occur in the blood brain barrier (research is also required on agent effects on the blood barrier); and (c) a combinations of drugs which act synergistically to protect against an agent at doses lower than that which individually cause drug-induced CNS incapacitation.

C. Physical Sciences Research Area

This section deals with those research topics that relate to the physical sciences and engineering: detection and identification of agent, protection, and decontamination.

1. Introduction

There are a number of promising technologies in chemistry, electronics, physics and related fields, which, if exploited, can improve the capability of the military services to detect and identify chemical warfare agents and toxins, and environmental pollutants (see Fig. 12). Some of these opportunities represent new fundamental approaches, some could be available by exploiting the technology developed for environmental and industrial hygiene purposes, and some represent technologies under development for other purposes

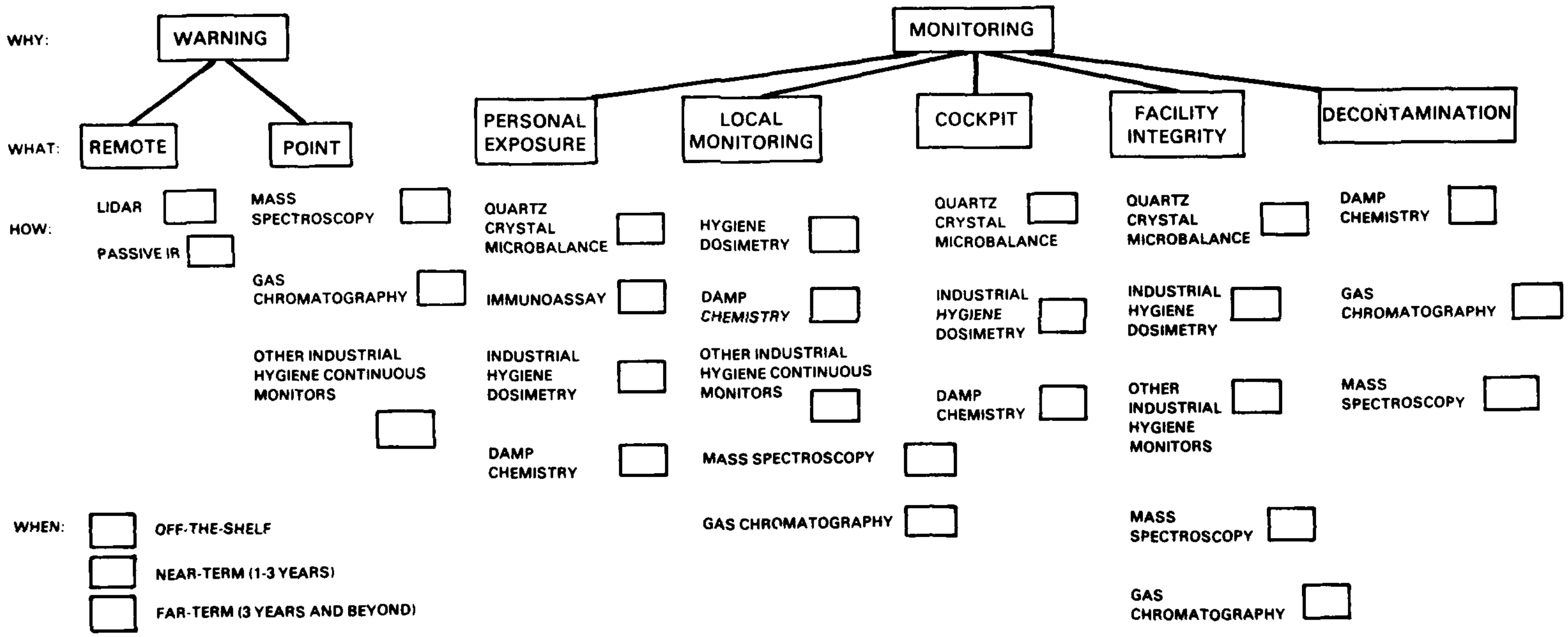


FIGURE 12. CHEMICAL WARFARE AGENT DETECTION AND IDENTIFICATION OF TECHNICAL OPPORTUNITIES

within the military community which could be used for agent detection and identification. Figure 3 depicts the general functions of an air base chemical defense system. Much of the material in this section has been taken or adapted from a recent USAF-Scientific Advisory Board report which contains an extensive assessment of potential developments in this field.[1] A discussion of several of the most promising of these technologies follows.

The most effective method of ensuring that personnel can continue to operate in a CW environment is to provide protective systems which isolate them from the hazard. Conventionally, such protection is considered under two major headings - personal (individual) protection, and collective protection. Historically, individual protection was developed first and it is the only form of protection provided for a large proportion of the ground forces. In this situation, it is assumed that the individual can move away from the toxic environment when he needs to shed his protective ensemble in order to obtain rest and relief. In situations where the individual cannot move out of the toxic environment, clean areas (collective protection), which are maintained free of toxic agents, are provided. As the limitations imposed by the individual protective ensembles became apparent, the concept of collective protection was applied to vehicles such as tanks, i.e., a clean environment was created within the vehicle by sealing it and ventilating it with filtered air.

In the near term, while the Air Force continues to use the airframes already in or about to be introduced into the inventory, protection against CW agents will continue to be provided by individual protective ensembles and collective protection. The levels of protection afforded by the ensembles now under development for Air Force aircrew (employing positively ventilated respirators, charcoal impregnated clothing and butyl or neoprene gloves) will be adequate for certain kinds and durations of agent exposure, but the impairment of performance which they and the associated ground operating procedures will impose are unacceptable. In many situations, the levels of protection afforded by current ensembles for ground personnel may be inadequate and these ensembles certainly impose considerable limitations upon the ability of the wearer to perform certain tasks (e.g., runway repair and weapon loading). It is assumed that within the next 5-10 years, effective, semi-hardened (i.e., hardened against conventional weapons) collective protection will be provided for all personnel including command and control groups.

In the longer term, it is likely that a clean environment can be created within the crew compartment of the aircraft, permitting the aircrew to fly without encumbering protective gear. To be effective, this approach must be combined with procedures which ensure that liquid or solid toxic materials will not be carried into the crew compartment either on the ground or in flight. Such an approach is almost certainly essential where the duration of a single sortie exceeds 10-16 hours.

Decontamination of personnel, equipment and facilities is a complex and difficult task. While some toxic agents, such as cyanides and arsenic compounds, dissipate rapidly, others, such as the nerve agents and mycotoxins, are more persistent. The persistence of these agents can be further enhanced by mixing with certain carriers or by encapsulation. To be useful, decontaminents must be efficient, inexpensive, nontoxic and noncorrosive to the materials used in aircraft and other critical aerospace equipment and electronics.

Decontamination of personnel presents special problems. Decontamination and removal of protective clothing must be accomplished without contamination of the skin, inhalation of agent, or compromising a clean collective protection facility. Decontamination of skin requires chemicals which either deactivate or remove the agent without damage or serious irritation to the skin, eyes or mucous membranes.

The large use of aluminum, plastics and other easily corroded materials by the Air Force puts severe constraints on developing chemical decontaminants for aerospace equipment. Oxidizing agents useable for Army equipment consisting mainly of steel are not applicable to aircraft. In light of these constraints, the necessity for decontamination of certain equipment should be carefully addressed to determine if the hazards of leaving it undecontaminated or using less rigorous cleaning materials are sufficient to warrant the costs of developing new decontaminating chemicals.

The capability to deactivate large areas to allow unprotected access does not exist at this time. This is especially critical for runways if Rapid Runway Repair teams are to repair damaged runways in the times required without the additional restrictions of wearing chemical agent protective clothing.

2. Subarea 1: Detection and Identification of Agents

a. Objectives

The objectives are to promote research in selected scientific fields that are likely to "pay-off" with major advances in capability in the longer term, to assure broad capability that will permit adapting to a wide variety of agents, and to design capability for several purposes in detection and identification of agents.

b. Research Approach

For the near term requirement, the following five technologies that are presently under development or are prime candidates for adaptation for CW defense should be promoted: passive remote infrared sensing, gas chromotography and mass spectroscopy, quartz microbalance, industrial hygiene dosimetry and continuous monitoring, and damp and wet chemistry utilizing multilayer film elements and "spray on" detectors.

To meet longer term requirements several technologies may be applicable and worth exploration: lidar, infrared fibers and sources, miniature gas chromatograph (Etched Silicon Wafer), flame photometry detector, organometallic reactions, immunological approaches, and biosensors.

Research with long term payoff: a study should be conducted of the remarkably sensitive and discriminating olfactory (small) mechanisms that might be used to develop a means to distinguish individual chemical or toxic agents.[2] Aeronautical or space-based surveillance platforms should be used to attempt to identify specific signatures of missiles during pre-launch and launch phases to distinguish chemical and/or bacterial weapons on warheads.

3. Subarea 2: Protection

a. Objectives

The objectives are to improve individual protective ensembles; to provide permanent, hardened collective protection facilities; to develop and implement the concept of a "clean cockpit"; and to assure that aircraft designers plan for CW/BW protection throughout the design and development phases of new aircraft.

b. Research Approach

(1) Personal protection - Basic research into the chemistry and synthesis of new materials to be used in the manufacture of individual protective garments is needed. Semi-permeable and nonpermeable materials should be considered and special attention paid to hand protection. Materials research should place importance on low cost as a means of providing disposable outer garments. The capability for water and nutrient intake and body-waste disposal is required for individual protective equipment. The final goal of such research is to provide ensembles which impose no penalties on the performance of the user. Other concepts for individual protection, such as spray on/peel off protective skins, self-decontaminating and self-repairing skins, should be explored. For the distant future, more exotic varieties of individual protection such as energy fields may be considered. Current technical solutions to personal thermal conditioning present severe limitations. Research is needed to identify and apply alternative technologies for cooling which are more efficient in providing greater conditioning with lower energy consumption. Tradeoff studies should be conducted to evaluate the employment of liquid conditioned garments as a means of providing adequate cooling for the aviator. New visor materials are required that do not impair vision or visual fields, while providing CW protection and conforming to the head. Such materials must also provide protection against other aviation hazards, e.g., bird strike and high-speed escape. Current batteries are large and heavy and impose limitations for the provision of blown, filtered air supplies and personal thermal conditioning. New approaches to the portable supply of electrical power should be explored. Air cleaning ("filtering") for particulates and BW and CW agents is an area of great concern. Research is needed to identify novel approaches to permit lower resistance to flow with smaller bulk and weight in the near- and mid-term. New concepts for residual capacity indicators, if appropriate to the "filtering" method, are required.

(2) Collective protection - Current methods of ventilating collective protection facilities use very large flows of filtered air, which require large filters and have high power consumption. The advantages of recirculating air within the toxic-free area and alternative methods of ventilating contamination control areas should be explored. Residual filter capacity indicators are needed to avoid unnecessary, costly replacement of these large filters. Adequate supplies of drinking and washing water will require new approaches to the separation and removal of a broad spectrum of potential agents from large volumes of water. Personnel working away from main operating bases require collective protection. In the far term, novel approaches other than conventional structures, such as air curtains or other destructive/protective barriers should be considered. Current methods of

assessing the effectiveness of the protection provided by collective facilities and of the procedures used by individuals to process from contaminated to toxic-free areas are unsatisfactory. Research is urgently required to devise improved techniques. This would include basic research leading to the development of nontoxic simulants for use in the exploratory development of processing procedures, as well as research leading to new analytical methods and tools to determine dosage sustained by the individual.

4. Subarea 3: Decontamination

a. Objectives

The objectives are to decrese dermal absorption, inahalation or ingestion of the CW agents by personnel to negligible levels (these levels will vary for different agents and are presently not well defined); to develop methods that can cover large surface areas; and to devise chemicals that are generally effective and not only specific for certain classes of chemicals.

b. Decontamination of Personnel

Methods are needed to determine whether decontamination of skin surfaces is sufficient and whether the use of emulsifiers or other agents might improve decontamination effects. It cannot be emphasized enough that many presently used and proposed methods of decontamination are hazardous to personnel using them.

c. Decontamination of Equipment

Methods are urgently needed for the decontamination of highly sophisticated equipment. For electronic equipment, only surfaces can be decontaminated by present methods. The use of chemicals in the gaseous phase, or methods of degassing such equipment under low pressure or by increasing rapid volitilization of the offending agent and trapping it should be explored.

d. Decontamination of Buildings, etc.

The use of UV light, microwaves, or other energies should be developed for large surface area decontamination. For chemicals resistant to degradation by such energies, thermal degradation methods should be explored; these should not cause volitilization of chemicals or toxic combustion products. The focus should be on covering large areas at one time. Sealers and other covering material should be developed for chemical contamination that has permeated walls or penetrated soils. Treatment of drinking water by UV light to alleviate chemical contamination should be explored. Decontamination of dispersed toxic clouds might be accomplished by UV light or by producing air turbulence. Eventually, detection devices for chemical pollutants should be developed which could simultaneously decontaminate the area. Microwaves and UV light might find application here. A promising approach is the development of "new" bacteria, antibodies and other receptors which could destroy offending agents by binding or digesting them. Future research in this area may result in the development of technology applicable to special decontamination problems.

D. Systems Approach to Chemical Defense

1. Introduction

Integration of the multitude of variables inherent in the planning of chemical defense strategies and assessing the ability of the USAF to conduct its mission in a chemical agent environment require an overall systems approach. Current efforts to model the impact of a changing threat or defense capability are, at best, rudimentary. This seriously hampers the assessment of deficiencies, research and funding promoting cost tradeoffs and comparison of operational alternatives.

2. Objectives

To develop the operations research capability to model the various components addressed in this section in human response to various agents under varying exposure scenarios, alternative personal and collective protection methods, methods for decontamination, and various detection and monitoring schemes.

3. Research Approach

Paramount to this research effort is the design of the research associated with the individual component so it is usable in a large scale modeling effort. This will require extensive cooperation of the various AF (and Army) organizations involved with R&D for toxicology, protection, decontamination, prophylaxis and detection. Achieving this focusing of research will require high level attention and management.

Basic technology for handling simulation and modeling in real time is currently available; however, a significant AF effort must be implemented to use this technology to allow planners to compile predictions and tactical commanders to assess threat data that is critical to the realistic prediction of capability. A concerted effort must be made to have up-to-date information.

4. Facilities

For the great majority of the research proposed in this chapter, no new facilities will be required. Existing facilities within the military agencies or available at university and/or industrial research centers will be sufficient.

E. References

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2. Dravnieks, A. Olfactory Information Processing and Mechanisms. Chapter 4-4. In, Principles and Practice of Bionics. Editors: VonGierke, H.E., Keidel, W.D., and Oestreicher, H.L., Agard Conference Proceedings No. 44. London Technical Press, 1970.

VII. SIMULATION

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A. Introduction

Flight simulators have been used as tools for enhancing crew performance for at least 60 years. The first interactive simulator dates from 1929. Visual systems for simulator have a shorter history, starting with a very simple one in 1949, to any time of day or night, variable weather, wide Field of View (FOV), computer generated image (CGI) systems in the 1970's. Motion platforms have evolved, over the same temporal period as the host simulators, to the current complexity-performance level of six degrees of freedom, smooth turnarounds and lags approaching 100 ms.

From a research point of view, these simulator system developments are thought provoking and discouraging. They are discouraging in that each of these three developments were initiated and evolved to a high degree of complexity and cost without the benefit of systematic behavioral research on the benefits of their characteristics in flight training applications.

The scientific and operational communities therefore have not verified benefit-performance continuums upon which to base recommendations for modification, discontinuation or acceleration of concepts or developments.

In 1982, military flight simulators are accepted equipment for: (1) development and maintenance of skills for operational flight crews, (2) engineering design and development, and (3) research supports. Their future use will increase and broaden, driven by the need to maintain a high level of combat proficiency and, at the same time, conserve fuel and equipment.

Research is required to improve simulator design and performance retrofit older simulators, but most importantly to improve cost and training effectiveness. These latter goals will not necessarily be reached by adherence to the concept that all improvements must accrue from increased realism and complexity of equipment.

The future will see increased demands imposed by the operational environment, which will stress human abilities to the utmost. It follows that development of simulators to train aircrews to perform these highly demanding tasks will be a serious challenge, one unlikely to be met only by technological development in simulation. What is necessary is to develop a base of basic sensory, perceptual and behavioral data so that innovative, effective and efficient training methods and equipment can be developed on a sound basis as opposed to the cut, try and hope method used today. A timetable for continued and future research efforts is presented in Fig. 13.

The areas in which research is needed are:

(1) Basic data on spatial orientation and visual perception.

(2) Simulation as a <u>tool</u> for system design.

(3) Operator performance enhancement through simulator research.

Simulation and Flight Training

Basic Research on the Interactions Among Spatial Orientation, Perception & Perceptual Motor Learning

Gaze Stability

Analytical Design Requirements for Flight Simulation

Human Operator Performance

Performance Measurement

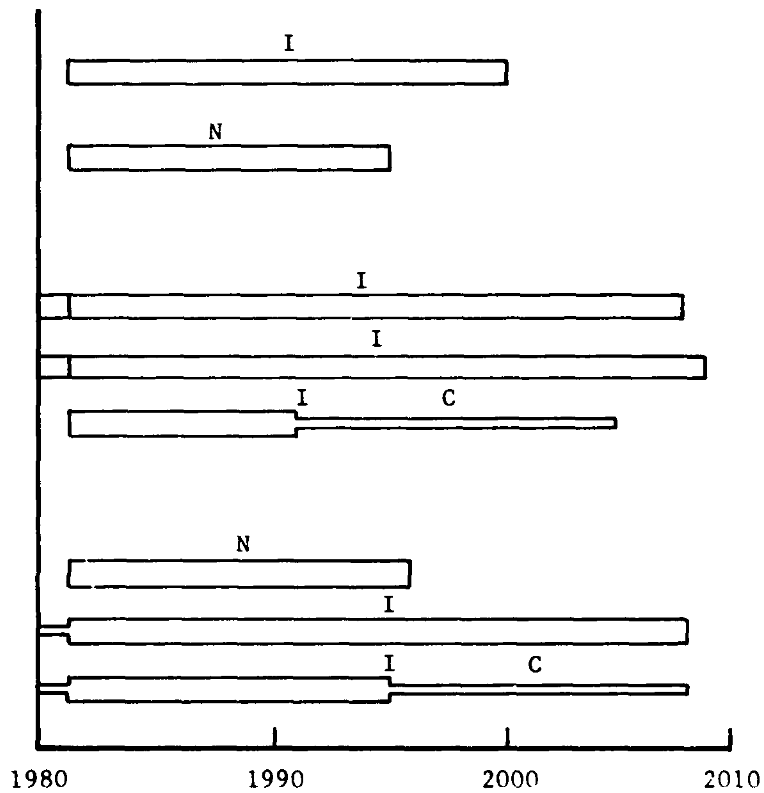
Ground Based Simulation Validation

Visual Scene Augmentation in Flight Training Simulators

Augmentation

Simulator Training Process Analysis

Foveal Image Detection in Simulator Visual Displays



C = Continuation of ongoing research
I = Considerably increased effort
N = Major new initiative

FIGURE 13. SIMULATION

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(3) Operator performance enhancement through simulator research.

B. Simulation and Flight Training

1. Introduction

The design of simulators requires an understanding of how the human operator responds to visual and bodily motion cues, how this information is used in spatial orientation, and the nature of perceptual motor learning. Unfortunately, the majority of studies in the visual motion perception literature were designed to determine the reaction of static observers to the movement of small stimuli. Vehicle guidance involves movement of the observer as well as the external world; large as well as small portions of the visual field; and the participation of vision, the vestibular sense, and somatosensory systems in the perception of object, as well as self-motion and spatial orientation.

Of particular relevance to simulator design and training are the interactions among the visual, vestibular and somatosensory systems. These sense modalities complement and support each other in the interest of veridical perception. The faster reacting vestibular system provides the initial information about body motion. Visual information provides information about sustained body motion. During deceleration, the false vestibular signal is "corrected" by the visual system. Although vision acting alone is adequate to provide information about the motion of small environmental objects, orientation in space and perception of self or vehicle motion involves the interaction of visual and vestibular inputs.

2. Basic Research on the Interactions Among Spatial Orientation, Perception and Perceptual Motor Learning

a. Objectives

An inherent limitation of ground based simulators is that it is not possible to fully simulate the vestibular stimulus. However, simulation of body/vehicle motion may be mediated by vision alone if large areas of the visual field are stimulated. Incorporation of motion cues, either with a moving base or by large visual field stimulation, is expensive, so information regarding the mechanisms supporting the appreciation of self-motion is of prime importance in simulator design. Unfortunately, our knowledge of these mechanisms, particularly in the peripheral visual field, is limited and basic data regarding the function of peripheral vision and its role in spatial orientation and perceived motion is lacking.

b. Approach

A characteristic of the interaction among the sensory systems subserving spatial orientation is plasticity. This adaptibility permits the organism to adjust to body growth, rearranged inputs (spectacles, vehicle motion, altered gravitational fields, etc.), and normal changes in sensory and motor mechanisms. Normally, these changes are gradual and the adaptation process is unnoticed. If, however, the pattern of inputs is suddenly altered, an intersensory "mismatch" occurs which may lead to spatial disorientation and/or motion sickness. In the context of simulation, the fact that the pattern of vestibular-visual interaction is to some extent necessarily different in actual flight from that in the simulator is a matter of concern.

The consequences of simulator induced alterations in multimodal interactions among sensory systems is poorly understood. The possibility that one may, through training, learn to quickly adjust to different patterns of stimulation is suggested by a number of studies and should be explored in the simulator context. At present, our knowledge of intersensory plasticity is limited and basic information would be most helpful in the design of simulators and their use in perceptual-motor training.

The sensory and motor systems involved in spatial orientation also subserve the prime function of the visual system-fixational or gaze stability. In the absence of such stability, visual simulation is not only useless but may contribute to spatial disorientation. Unfortunately, the existing literature on visual perception is concerned almost exclusively with the abilities of static observers. We do know, however, that the correlation between visual acuity for a static and a moving observer is zero. Thus, the extrapolation of individual data on resolution capacity, depth perception and motion sensitivity to a moving or vibrating vehicle demands some knowledge of gaze stability mechanisms. We also know that such mechanisms are easily degraded by stress, vibration, lack of sleep, hypoxia, drugs and even the normal ageing process. Therefore, knowledge of the efficiency of gaze stability mechanisms would be helpful in pilot selection, vehicle design and prediction of performance decrement.

Experiments are required to further define the interaction of visual, vestibular and somesthetic (tactile, proprioceptive) cues on human perception of spatial orientation. The influence of the pilot's active role in vehicle control and consequent ability to anticipate its motion must be better understood in the orientation perception context. Although there has been a great deal of research on vision, vestibular function and visual/vestibular interaction in the last decade, much of it has had a physiological and clinical focus. Increased emphasis is needed on behavior and perception. Research to date on visually induced self-motion has utilized relatively simple displays consisting of moving stripes or randomized dot arrays. In order for data from experiments on motion cue interaction to be usefully applied in predicting human responses in flight simulators, research is needed to better define the motion cue information content present in more realistic, "out the window" visual scenes encountered in simulation applications. Experiments are needed to define the influence of these natural cues, as well as the artificial orientation cues available from cockpit displays on orientation perception in pilots. Increased research emphasis should be placed on defining the role of somesthetic cues in orientation perception, as it seems likely that improved "inside the cockpit" motion cueing systems will be necessary to adequately simulate high G and low altitude flight. Interpretation of motion cues is undoubtedly very dependent on experience and context. The effects of experience, context and adaptation must be taken into account in the design of experiments on orientation perception, and also reflected in analytical models for the orientation perception process.

To facilitate further research on orientation perception, an effort should be made to develop and validate improved methods for measurement of spatial orientation, including both perceptual measures (magnitude estimation) and performance based methods (closed-loop manual control describing function analysis).

3. Empirical Measurement to Establish "How Much Motion is Enough"

a. Objective

To establish for the design of practical flight simulators what quality and quantity of motion cueing is "enough."

b. Approach

As described earlier, it is believed that it may eventually be possible to answer this question, given a particular specification of the training or research mission of a simulator, using analytical models for spatial orientation perception. However, in the near term, for those simulation applications of particular concern to the USAF where motion cueing may be critical, e.g., nap-of-the-earth, VTOL, CCV, this question should be considered on an experimental basis. Alternative schemes for motion washout should be evaluated, including the utility of "full gain" external disturbance cueing and "reduced gain" active maneuver cueing. Tradeoffs between motion base excursion and inside the cockpit, somesthetic cueing should be also evaluated.

C. Analytical Design Requirements for Flight Simulation

1. Introduction

Currently, simulation requirements are obtained through a combination of experiments and known equipment capabilities and limitations. For the complex demands of the 2000's, this approach is inefficient and costly. By that time period, a systematic method can, and must, be developed based on human operator performance models and mission requirements.

2. Human Operator Performance

a. Objectives

Human operator perception, control and decision theories, combined with quantitative descriptions of the specific tasks, will be combined to establish fidelity requirements for simulating visual and motion systems.

b. Approach

The establishment of fidelity requirements involves gathering of appropriate data and development of specific analytic methods. These methods include:

(1) Extensions and application of existing pilot/crew manual control theories.

(2) Application of human decision theory.

(3) Application and extension of time line analysis and discrete task analysis.

Also, performance and other measures (see Chapter IV) will be developed to evaluate the effectiveness of the "theoretical" simulation requirement, as well as actual known hardware limitations.

To validate the developed theoretical methods, and to obtain experimental data for other basic simulation research (e.g., basic motion cue and visual cue studies), a high fidelity ground-based simulator is required. This system must have adequate data collection capability. Every effort should be made to use existing facilities of this type. However, if early studies indicate the need, in-flight simulators should be considered along with the possible development of an entirely new research simulator facility for national use.

The resulting analytical design tools and procedures, coupled with greatly simplified but valid models of human operator visual and motion sensing, will be applicable to a wide range of AF flight crew simulation developments from part-task devices to relatively sophisticated advanced system simulations. The underlying theory should save funds by replacing the alternative trial-and-error methods used today to develop simulator requirements.

3. Human Performance Measurement for Simulator Evaluation

a. Introduction

Using current measures of performance, it is difficult to infer or evaluate the performance stategy that the pilot employs in the simulated flight task. This is particularly true for tasks involving an interactive adversary, such as in air combat. Because the relationship between the performance metrics and performance objectives of the pilot (or trainer) is not clear, current measures have numerous shortcomings:

(1) They only give limited guidance concerning simulator design characteristics necessary to produce the desired performance.

(2) They do not clearly suggest how training might be modified to improve its effectivenesss.

(3) Use of the measures in simulator validation is difficult.

Furthermore, in the highly cognitive task environment anticipated for future USAF missions, an understanding of the pilot's cognitive processes and strategy will be crucial.

b. Objectives

(1) To develop metrics that quantify those aspects of man-machine performance that the pilot is (or should be) observing and controlling to achieve specified objectives.

(2) To develop a model-based methodology for suggesting optional performance strategies and metrics for future USAF missions.

c. Approach

The development of these metrics first requires postulation of a quantitative theory or model of human performance for the specified flight tasks. Second, one must derive from the theory measures which logically tap the desired aspects of performance. Finally, the sensitivity and validity of candidate metrics must be evaluated in simulated and actual flight to determine their utility.

The initial stages of such a program would not require special facilities. They would, however, require an interdisciplinary team of personnel skilled in performance measurement and modeling. Currently available models of human monitoring, orientation perception, manual control and decision-making are sufficiently developed to pursue development of a metrics program for tasks such as close-in air-to-air combat.

The metric evaluation phase of the program would require flight simulation facilities with state-of-the-art visual displays and performance capabilities.

The theories and metrics developed in the proposed program would have the following applications:

(1) They would permit comparison of the task performance strategies in simulated and actual flight for validation purposes.

(2) They would suggest simulator or aircraft design changes to produce better compatibility with the task performance requirements.

(3) They would constitute an operational definition of required piloting skills and suggest improved training techniques.

In addition, such a model-based approach will allow more lead time in the design and development of simulation for new USAF missions by helping to define pilot performance objectives, and by suggesting optimal performance strategies to achieve the objectives.

4. Ground-Based Simulator Validation

a. Introduction

As noted in both the Engineering Core Group summary, i.e, "future simulation process and equipment may be as essential to success as the mission equipment itself," and the Biotechnology Core Group summary, "we don't know how to validate simulations," much remains to be done in the general areas of simulation fidelity, validation and the effective use of simulators for both engineering design and crew training.

Demanding future mission environments, including low-altitude, in-weather and night attack, pose completely new problems for the crew. The necessary means for accomplishing such missions are selective automation, effective man-machine interface (displays, controllers, etc.), and thorough rehersals of the final operation. The first two means present a bewildering array of system candidates that can probably only be evaluated with some form of simulation. The need for rehersals usually dictates gound-based simulation for cost and safety reasons.

One would think modern simulation facilities are suitable for these purposes. In fact, they are not. Developed mainly on a "fascination with reality basis," current simulations employ the state-of-the-art equipment to reproduce the best real world environment that is available, with little or no regard for the question "is it sufficient?" Thus, as simulation becomes an even more important aspect of advanced systems development and employment, simulation validation/calibration will be an absolute necessity.

Often, basic simulation dynamics are not quantitatively validated; instead a few pilot comments are solicited and then the simulator is pressed into use for training or engineering purposes.

b. Objectives

To provide the basic experimental data to validate ground-based simulators and simulation techniques for future complex man-machine system designs and training.

c. Approach

Every major airframe manufacturer has a ground-based simulation facility in use on a daily basis. Coupled with USAF, Navy and NASA facilities, there is no shortage of equipment, or for that matter, opportunities to collect data. What is lacking, however, is a national program to define the required validation data and experiments and the means to reduce the results into a reliable source of "can and cannot do" information for ground-based simulators. To fill this need a systematic program is required which should include in-flight simulation and collection of flight data for validation purposes.

In the near term, the need for simulation validation is most urgent in the tactical area of night/all weather ground attack. The answers are needed now. In the longer term, the need will shift to prolonged space and/or stategic missions. In all cases, both the engineering (simulator as a design tool) and training uses (aircrews, controllers, commanders) of simulators will benefit from the effort. The scope is large, the pay-off is great and the need is imperative.

D. Visual Scene Augmentation in Flight Training Simulators

1. Introduction

Flight training simulators naively have been regarded as aircraft substitutes. Consequently, simulators have been designed to be like aircraft, instructional methods used on simulators parallel those used in aircraft and increasing realism has been accepted as the principal means for improving the training effectiveness of simulators. A more enlightened and less restrictive view of flight training simulators is to regard them as devices to support and facilitate the learning of skills. From this viewpoint, a broad range of innovative possibilities is apparent for the design and use of simulators to achieve the training goals of increasing proficiency and reducing training time.

Following from the simulator as an aircraft substitute concept, developments in visual simulation for training have been focused on increasing the image quality, field of view and detail of CGI. While a high degree of realism undoubtedly will be forthcoming through CGI engineering advances, exploiting CGI technology to augment visual displays offers a far greater opportunity for enhancing training effectiveness.

Visual augmentation is defined as any addition, deletion, or manipulation of a displayed scene to facilitate the acquisition of perceptual, cognitive and motor skills. Features can be added to the scene that have no natural world counterpart or representations of natural features can be deleted, highlighted, exaggerated and in other ways enhanced.

Augmentation is applied routinely in real-world settings and cockpit instrumentation. For example, visual landing aids at an airfield provide sources of information to a pilot which are more easily or accurately interpreted than natural cues. Conventional cockpit instruments are designed to permit the rapid acquisition of information with greater resolution than is possible by viewing a natural scene. Future cockpit displays are likely to make extensive use of techniques akin to augmentation. Major Jack Thorpe of DARPA, commenting on cockpit applications of Computer Generated Imagery (CGI), said in a recent interview, "Perhaps the most exciting application involves the generation of wholly synthetic scenes that have been stylized to provide critical information very effectively." The article continues, "Or rather than a wholly synthetic scene, the displays might project some enhanced, exaggerated or modified view of the real world that makes it easier for a fighter pilot, for example, to function more effectively." (Aviation Week & Space Technology, December 14, 1981.)

Clearly, these observations are as germane to simulator training as they are to actual flight operations. The ultimate intent of augmenting visual information in flight training simulators is to facilitate and enhance the learning skills and/or the ability to use natural sources of information. It has often been said that the purpose of a training simulator is to support skill learning and not to duplicate the real world. Development of augmentation techniques of training, which deliberately depart from realism, appears to be one of the best means for increasing training simulator effectiveness. Use of CGI in both current and future flight training simulators offers essentially unlimited flexibility for the development and application of augmentation techniques.

2. Augumentation

a. Objective

The research objective is to discover principles for the application of visual augmentation to increase the effectiveness of flight training simulators. Augmentation is foreseen as a means to increase training effectiveness by improving skill proficiency and reducing training time.

b. Approach

The research challenge is to determine what kinds of augmentation are most useful and the strategies necessary to use augmentation most effectively. Also, deliberate departures from visual scene realism which go well beyond augmentation as defined here should be explored.

(1) Kinds of augmentation - Basic research is necessary to investigate the interpretability of alternative forms of augmentation and their relative values for increasing the rate of learning and accuracy of natural cue discrimination and flight control skill acquisition. Based on analyses of the sources of natural cues in the visual scene, work should be performed to discover how enhancing those sources which are postulated to be important affects learning. Similarly, sources considered to be irrelevant or which mask relevant cue sources should be deleted to determine effects on learning.

(2) Strategies of use of augmentation - Fundamental questions about the efficacy of strategies of use of augmentation will require research to answer. These questions include: should augmentation provide feedback about error or correct performance; what tolerance bands for the presence or absence of augmented feedback are most effective; should augmented information be present continuously, withdrawn by fixed schedule, or withdrawn on a schedule adaptive to trainee performance?

(3) Departures from realism beyond augmentation - Augmenting a scene which is representational of the natural world is not the only possibility for increasing training effectiveness by deliberately departing from realism. Alternative displays which provide all essential information for flight skill learning but are not conventional scenes should be investigated for training potential. For example, providing an outside view of the aircraft rather than a cockpit view may be more useful for teaching complex maneuvers by facilitating the learning of cognitive schema for a maneuver. Consider that most flight manuals portray maneuver patterns from an overview position. Viewing a maneuver execution from an outside view may be more helpful than the cockpit view for initial stages of learning.

Basic research on augmentation can probably be supported using any flight simulator equipped with a CGI visual system. Certainly many basic research issues can be investigated with relatively inexpensive simulators such as those available at many universities and Air Force laboratories. Exploratory research and advanced development work may require the use of a more sophisticated simulator, such as the Advanced Simulator for Pilot Training (ASPT).

Visual augmentation is probably useful for training all visually guided flight tasks. The most important applications foreseen are for training low-level flight/ground attack in a high-threat environment, Basic Flight Maneuvering (BFM) and Air Combat Maneuvering (ACM). In low-level flight/ground attack, for example, augmentation could be used to: portray a "highway in the sky" threading across the terrain at the desired altitude; change the color or in some way highlight terrain features that encroach on the flight path if the present heading and altitude are maintained; and represent the ground-threat weapons envelope which the pilot must avoid. In

BFM and ACM, augmentation could be used to: portray a corridor for a maneuver which adjusts dynamically depending on pilot skill level or past deviations from the desired profile; depict future paths and maneuvers of threat aircraft; and display own and threat weapons envelopes.

The projected use of CGI for both training and cockpit displays, as noted above, implies that research on augmentation for training is likely to have implications for future operational problems related to cockpit display of information. Solutions to problems such as methods for portraying navigation routes, weapons and envelopes; prediction of future position of own and threat aircraft; and integration of information for rapid acquisition will substantially enhance both training and operational effectiveness.

3. Simulator Training Process Analysis

a. Introduction

Flight training simulators are typically designed to permit previously trained pilots to perform tasks as they should be performed in the aircraft. They are seldom designed for the conduct of the training needed by personnel who are unable to perform such tasks. A reason for this situation is that existing training requirements analysis guidance addresses the end product of training, i.e., operational performance goals, rather than the process of training itself. Thus, simulators are designed in response to definitions of criterion performance. Mechanisms for the development of criterion performance tend to be ignored, particularly where such mechanisms might distract from the fidelity of criterion performance.

While specification of criterion performance cannot be ignored in simulator design, attention to it alone is insufficient. Attention also must be given to the instructional processes through which criterion performance is to be trained. These processes must include provisions for guidance and feedback during training, the development of discriminations and their generalization, and the use of mediational processes. Training requirements analyses are incomplete until such training processes considerations have been addressed.

The need to analyze instructional processes in preparation for the design of simulators and training programs has been largely ignored by training technologists. Procedures are needed for the conduct of such analyses. Tc date, however, only procedures for analyses of operational tasks have been formulated, e.g., job/task analyses procedures as described in Instructional Systems Development (ISD) manuals and handbooks.

b. Objective

The objective of the proposed research will be to develop procedures and guides for the conduct of training process analyses. The products of such analyses will specify mechanisms for development of the skills involved in criterion performance.

c. Approach

The approach to the proposed research would be analytic and developmental. It is anticipated that several iterations would be required, with trial applications of proposed procedures and guides, and revisions made based upon experience during such applications.

The procedures to be developed would be applicable to all future Air Force simulators and simulator training program development efforts.

4. Simulator Training Technology Transfer

a. Introduction

Effective training through simulation is not necessarily dependent upon the availability of simulators that are high fidelity, i.e., exact replicas of the aircraft they simulate, nor is it necessary that training in a simulator employ the same instructional practices and procedures that are employed for training conducted in aircraft. The "fidelity" model of simulator design and utilization can even lead to excessive procurement cost inefficiencies in training that should be avoided. Instead of depending upon such a model to assure training effectiveness, training simulator designers and training program developers should design their systems to exploit the capacity of humans to employ mediational processes during learning and to develop robust skills. Further, simulators should be designed specifically to help trainees learn to make and generalize discriminations. Such exploitation could result in devices that differ in many respects from the vehicles simulated but that can be used more efficiently in the training of the operators of these vehicles.

Exploitation of these human learning capabilities requires special knowledge and skills on the part of design personnel. However, simulators and simulator training programs in the Air Force are typically designed by personnel who, for the most part, are not knowledgable with respect to the human learning process and behavioral technology underlying efficient instructional processes. Usually they are pilots and their expertise is primarily in flying and conducting instruction in aircraft. Because of the organizational and management structure of the Air Force, the influence of such personnel upon future simulator and training program design is likely to continue undiminished. In order for the design efforts of Air Force pilots to be effective, the existing knowledge and skills related to simulator design and utilization technology must be made available to them in a form that will not require extensive study.

One mechanism that can be most useful in making this technology available to Air Force personnel is the use of carefully developed demonstration programs. In fact, demonstrations of simulator design for training and of effective and efficient training through simulation, e.g., provisions for teaching and discrimination for providing guidance, for augmenting feedback, and for assuring response generalization, may be the most effective way to transfer the relevant learning process and behavioral technology to those who have opportunities to use it.

b. Objective

The objective of the research would be to conduct exemplar training simulator design and utilization projects, and supporting tutorial documentation, to serve as models for Air Force personnel who are responsible for these efforts operationally.

c. Approach

In order to develop exemplar simulators and simulator training programs, a four-part approach must be followed:

(1) Simulator design and utilization projects must be selected that cover a wide range of training objectives, levels of skills to be developed and levels of device complexity.

(2) Personnel who are acknowledged to be expert in relevant educational and behavioral science areas, and who are experienced in the design of training simulators and simulator training programs, must be selected to develop the exemplar designs.

(3) The simulator and simulator training program designs must be developed and implemented.

(4) Tutorial documentation must be prepared to address the various design features involved, the underlying instructional, learning process and/or behavior control principles, and the rational for their application.

The applicability of the exemplar program to Air Force simulator design and utilization projects would be limited only by the generality of the training objectives, level of skills and device complexities encompassed in the programs. Advances in the human learning data base or in the nature of simulator training applications would have to be addressed through modification to the exemplar simulator and training program and/or to the accompanying tutorials.

5. Foveal Image Detection in Simulator Visual Displays

a. Introduction

Currently available and projected out-of-the-window visual displays are a major limiting factor in the use of flight simulators to train mission tasks that involve interaction with visual targets and threats as well as the visual environment. The "foveal visual system's" capacity to discriminate very small stimuli and near threshold patterns cannot be practiced in simulators, because the visual information upon which such discriminations must be based cannot be presented. For example, engagement must be initiated at long range and based upon visually derived target information that subtends visual angles as small as 30 arc seconds, but resolution of simulator visual displays presently under development are no better than 2-4 arc minutes. Low speed, low altitude (nap-of-the-earth) air vehicle maneuvering is another example of a visual task for which current visual displays are inadequate. Such maneuvering is dependent upon visual determinations of vertical and horizontal separation from natural and cultural objects, but present displays lack the image detail, perspective cues and/or sharp focus in horizontal and vertical dimensions necessary to such performance.

b. Objective

The objective of the research would be to increase the information content and resolution of flight simulator visual displays to approximate more nearly the resolving power of the foveal visual system.

c. Approach

Parallel research and development efforts involving multiple approaches should be undertaken, since none is currently acknowledged as having full potential for solution of the problem presented.

Facilities should be available that will permit exploration of new technologies which can present very small objects at various contrasts and spatial frequencies, rapid angular velocities without temporal anomalies, and forms without dynamically irregular boundaries and with variable ranges of density and frequency of details.

Significantly increased simulator visual display information content and resolution would be applicable to the training of all tactical tasks involving visual target acquisition and engagement, and mission activities such as rescue and resupply that must take place within the nap-of-the-earth flight regime and/or involve vertical lift vehicles.

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VIII. RADIATION ENVIRONMENTS

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A. Introduction

Electromagnetic and particulate radiation pose major threats to national survival. Nuclear weapons, high-energy lasers and future high-powered pulsed Radio Frequency Radiation (RFR) systems all represent potential anti-personnel devices.

Future strategic weapons systems, AWACs and National Command Authority aircraft will probably be required to operate in intense radiation (fallout) fields for long periods of time (days to weeks). Such radiation presents both internal/external (inhalation-ingestion) hazards. More than 60 percent of the United States may be covered with radioactive debris within 48 hours, depending on the numbers, yields and dispersion of nuclear weapons.

High and medium energy lasers now add the a dimension of crew vulnerability, coupled with electro-optic vulnerabilities, that clearly suggests the need for protective devices and materials.

Pulsed RFR leads to the concept of directed energy, similar to charged particle beams and high-energy laser devices, and clearly suggests a variety of anti-personnel concerns.

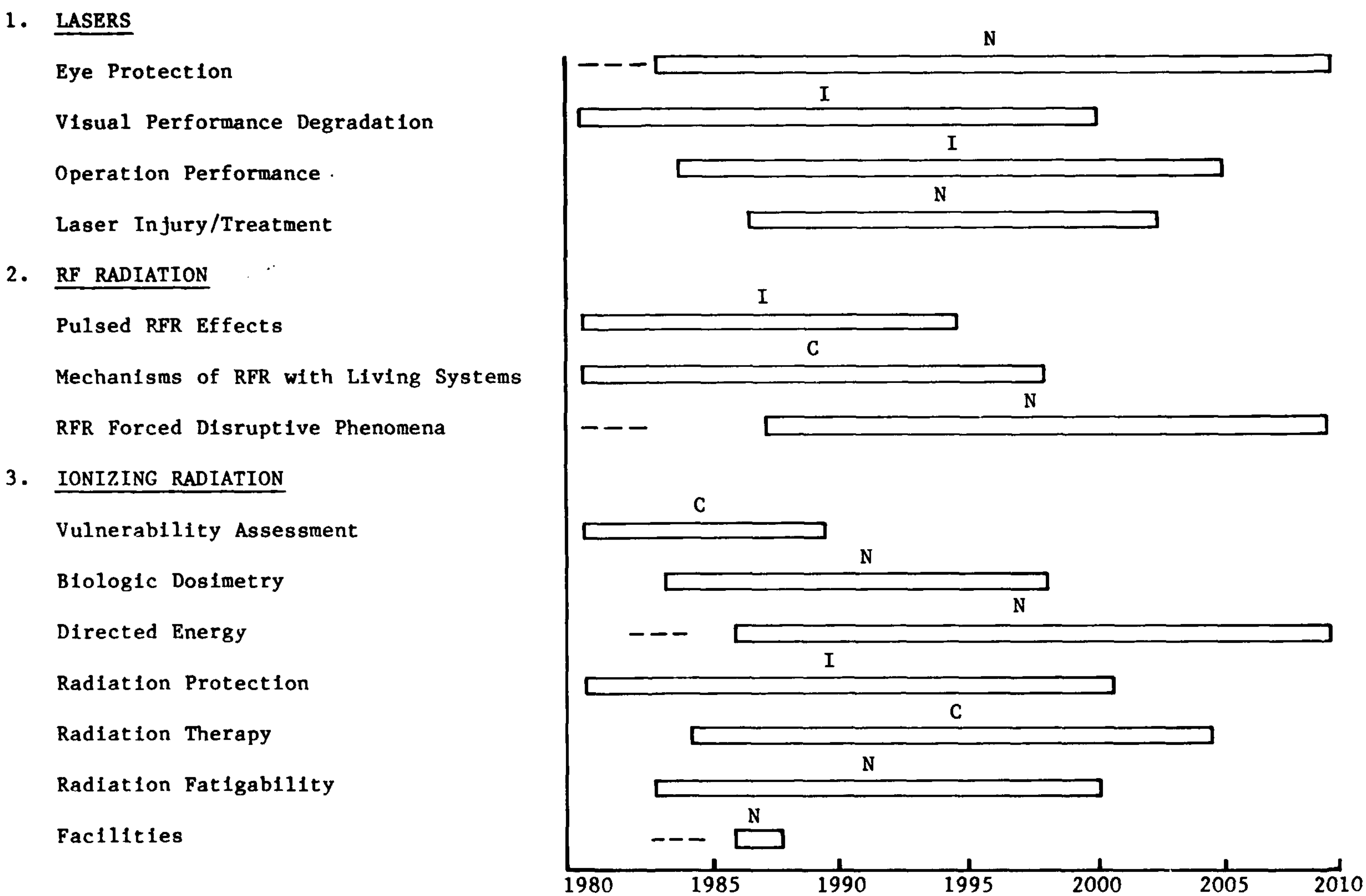
The following breakouts identify several research endeavors for near- and far-term that can influence employment of aeronautical systems and the kinds of crews and equipment required for military air operations in the period 1990-2020. A timetable for such research is charted in Fig. 14. By the same token, these endeavors are not limited to endoatmospheric operations, they apply just as well to exoatmospheric operations.

B. Lasers

1. Introduction

The use of lasers in military operations is a fact, and continued developments and increased uses by the military are reasonable assumptions. Existing target designators and range finders, employing specific wavelengths in the visible and near-visible spectrum, are capable of producing significant ocular injury. The basic technology is currently available for the development of wavelength agile and ultrashort pulse lasers with sufficient energy per pulse to pose a significant threat to vision, both in tactical and strategic operations. The eye is the most susceptible biological target in these scenarios. Visual effects caused by exposure to laser radation can range from essentially none through temporary flash blindness to immediate and permanent loss of vision. In addition, the susceptibility of external sensors (FLIR, TV), canopies and windscreens to high-energy laser radiation has been demonstrated, and provides another threat to vision outside the canopy.

The most obvious strategy to counter these threats is the development of eye protection and hardened canopies/windscreens and sensors. In the event solutions are inadequate, reducing the exposed canopy area or completely enclosing the cockpit will require consideration. The effects of ocular exposure, including injury, on operator performance, need to be studied and



C = Continuation of ongoing research
I = Considerably increased effort
N = Major new initiative
- - - = Feasibility

FIGURE 14. RADIATION ENVIRONMENTS

quantified to establish vulnerability and to identify needs for treatment of ocular injury.

2. Eye Protection

a. Objective

To conduct research in the design, development, evaluation and integration processes for laser eye protective devices and/or new windscreen materials and techniques.

b. Approach

The development of laser eye protection materials is of critical importance. Advances in laser technology are far outstripping advances that are being made in hardening materials. The ideal eye protective material/device is one that would provide protection against any wavelength and pulse width while still allowing transmission of sufficient light to permit the crew to perform critical visual tasks. Some form of improved filter is needed, the technology for which does not now exist. Basic research in this area should be expanded to provide such a device.

Progress is being made in the development of narrowband, absorbing and reflective filter materials. These filters, when available in several years, can be adapted for use as an interim measure until more versatile filters are developed. It is essential to determine the protective qualities of these materials and the quality of vision they allow.

Development of a protective material is only the first step in developing adequate laser eye protection; once a material is developed, it must be incorporated into an eye protective device. This device must then be tested for suitability and aircrew/ground crew acceptability.

To overcome any visibility problems associated with the new protective materials, consideration must be given to making cockpit lighting and displays complementary to the protective devices.

If new materials are not suitable or adequate for integration into ocular protective devices or aircraft windscreens/canopies, then alternative means must be developed to provide visual information to the aircrew from the external environment, while at the same time providing ocular protection. The impact of this technology on total mission performance would have to be evaluated.

3. Visual Performance Impairment

a. Objective

(1) Assess visual performance impairment following exposure to laser radiation.

(2) Examine and characterize potential ocular stress produced by injury from new laser systems.

b. Approach

Characterize visual system performance in terms of contrast discrimination, spatial frequency response, color discrimination, optical transfer functions, etc., through psychophysical and electrophysiological techniques as a basis for determining performance loss following laser exposure.

Develop and improve methods of assessing visual system performance, both baseline and under stress, in terms of the parameters used to characterize system capability. Specifically, examine visually evoked potentials as a means of characterizing visual system performance and cognitive functions for use when optical stress precludes the use of cooperative subjects. In this connection, a better understanding of the variability of the Visual Evoked Response (VER), along with techniques to reduce variability or remove it from the signals, would shorten data gathering periods and enhance the application of VER as an assessment technique.

Behavioral studies should also be incorporated into the battery of assessment techniques used to study the degradation of visual performance. Such studies should be consistent in examining tracking, detection, recognition and other tasks requiring cognitive and motor responses to visual stimuli.

4. Operator Performance

a. Objective

Assess aircrew performance using electro-optical sensors and devices that have been irradiated with lasers, and examine alternate means of providing visual contact with the environment external to the cockpit.

b. Approach

The quantification of laser effects on operator performance will require high fidelity man-in-the-loop simulation studies, as future aeronautical missions will be highly dependent on the use of avionics (FLIR, TV and other sensors) for success, while still requiring the performance of visual tasks through windscreens and canopies. These systems are susceptible to laser irradiation from potential threats, and operators will still be required to perform their missions in this environment. This scenario does not necessarily involve the direct exposure of the eye to irradiation; the man is still a key element and his interpretation of the avionics displays and visual performance through the windscreen will be critical. Therefore, the measurement of operator performance in high fidelity simulations of these scenarios is essential.

Such an approach requires a strong interaction with the engineering community which must define the physical effects of the avionics and windscreens. These effects would then be incorporated into man-in-the-loop simulations. Controlled experiments can then define the significance of laser exposures on mission accomplishment. These results would establish "hardening" requirements for system designers to reduce vulnerability. Once this baseline is established, other experiments would explore operator techniques and strategies to enhance the performance of the total manned system in the laser environment.

5. Laser Injury/Treatment

a. Objective

Assess medical implications of laser exposure, ranging from treatment of severe injury to the use of laser radiation to enhance healing.

b. Approach

At the present time, there is a good understanding of the susceptibility of the human eye to many of the presently available laser wavelengths and pulse widths. Development of new laser technology must be monitored closely so that as lasers operating at new wavelengths and pulse widths are developed, the necessary biological injury studies can be performed and vulnerability levels estimated. Future studies would have to be performed if revolutionary advances in laser technology, e.g., the X-ray laser, introduce unanticipated bio-effects. The studies should include severe skin burns as well as eye injuries.

If laser exposure cannot be avoided, then given the estimate that there will be increased occurrence of more severe laser injury, it will be necessary to establish casualty treatment procedures. Training needs to be conducted in the handling and treatment of these casualties.

Furthermore, research opportunities exist for the exploration of the usefulness of laser radiation in the treatment of wounds.

C. Radiofrequency (RFR) Radiation

1. Introduction

Biotechnology requirements in the next three decades must consider significant advances in electronic (electromagnetic radiation) warfare, since both offensive and defensive systems will add significant radiation stress to humans in a wide range of military operations. We can expect increases in available on-board power; development of sophisticated methodologies for detecting, tracking, identifying and attacking; and ultimately the development of systems to inflict intense pulses of electromagnetic energy on an adversary.

As the technological race continues, knowledge of mechanisms of action of RFR with living systems and the assessment of pulsed RFR effects will demonstrate the vulnerability of humans to complex pulsed electromagnetic radiation fields in combination with other stresses.

2. Assessment and Development of Pulsed Radiofrequency Radiation Effects

a. Objectives

(1) Develop techniques to deposit radiofrequency radiation (RFR) at selected organ sites.

(2) Develop mathematical models and physical measurement capabilities (microdosimetry) to track the real-time RFR energy distribution within organ sites as a function of physiological responses such as diffusion and blood flow.

(3) Establish thresholds and other response rates for selected biological effects as a function of RFR wave parameters (shape, width, repetition rate, resource groups and intensity).

(4) Develop laboratory tools to simulate likely real-time RFR encounters in Air Force operations (from VLF to millimeter wave frequencies).

b. Approach

Advances in the understanding of the fundamental interactions of pulsed RFR fields with living systems are necessary in order to proceed with studies of the effects of pulsed RF radiation. Depending on the organ site, physiological function or biological effect of interest, appropriate frequencies will be studied for this specific effect. Parametric studies will then be applied to establish specific pulsed profiles for the predominant biological effects observed. From selected parametric studies, mathematical models will be developed and validated for use in the development of more advanced systems, countermeasures and specific military scenarios.

In all of these endeavors, efforts will be devoted to prudent physical and physiological extrapolation from the research on laboratory animals to humans in operational environments.

3. Mechanisms of Radiofrequency Radiation with Living Systems

a. Objectives

(1) Advance the understanding of RFR interactions at the molecular, cellular and tissue levels of biosystems.

(2) Develop methodologies to extrapolate from measured RFR effects in animals to expected effects in humans.

(3) Learn how RFR interacts with biological systems to cause performance changes.

b. Approach

The study of fundamental mechanisms of RFR interaction involves effects on chemical reaction dynamics, macromolecular confirmation, membrane responses, diffusion coefficients, molecular resonances, microscopic thermal gradients and acoustic phenomena, and will require extremely complex biochemical/biophysical measurements. Success will depend on advances in spectroscopy (absorption, Brillouin, Raman), nuclear magnetic resonance (off-resonant irradiation studies), and photon correlation methodologies. These methods will enable one to measure RFR forced motion in molecules and RFR driven perturbations in macromolecules and membranes. Additionally, photon correlation and spectroscopic techniques will be especially useful in tracking chemical reaction pathways. Initial work should be in relatively simple *in vitro* systems. Progression to living systems will be contingent on advances in microdosimetry and high resolution physiological monitoring.

4. RFR Forced Disruptive Phenomena

a. Objectives

(1) Define the ability of RFR to interrupt, degrade or direct human central nervous system functioning.

(2) Define the ability of RFR to interrupt or degrade physiological functions such as cardiac output and respiration.

(3) Define the ability of RFR to interact with chemical and other physical agents, and to assess their combined impact on humans.

b. Approach

Currently available data allow the projection that specially generated radiofrequency radiation (RFR) fields may pose powerful and revolutionary antipersonnel military threats. Electroshock therapy indicates the ability of induced electric current to completely interrupt mental functioning for short periods of time, to obtain cognition for longer periods and to restructure emotional responses over prolonged intervals. Experience with electroshock therapy, RFR experiments and the increasing understanding of the brain as an electrically mediated organ suggest the serious probability that impressed electromagnetic fields can be disruptive of purposeful behavior and may be capable of directing and/or interrogating such behavior. Further, the passage of approximately 100 milliampere through the myocardium can lead to cardiac standstill and death, again pointing to a speed-of-light weapons effect.

Experiments should be designed using the data accummulated on cell and tissue effects derived from basic mechanisms studies and using waveform parameters defined by pulsed and other modulation research studies. The behavioral experiments should include: psychological observation and testing, electroencephalographic analyses and *in situ* electrode recording work. While initial attention should be toward degradation of human performance through thermal loading and electromagnetic field effects, subsequent work should address the possibilities of directing *and* interrogating mental functioning, using externally applied fields within the possibility of a revolutionary capability to defend against hostile actions, and to collect intelligence data prior to conflict onset.

A rapidly scanning RFR system could provide an effective stun or kill capability over a large area. System effectiveness will be a function of waveform, field intensity, pulse widths, repetition frequency and carrier frequency. The system can be developed using tissue and whole animal experimental studies, coupled with mechanisms and waveform effects research.

Microresonance and receptor site mechanisms research will suggest specific frequencies which may interfere with or enhance drug or chemical agent effects. Confirmatory experiments in animals will be necessary. Using relatively low level RFR, it may be possible to sensitize large military groups to extremely dispersed amounts of biological or chemical agents to which the unirratiated population would be immune.

D. Ionizing Radiation (Weapons)

1. Introduction

In the base escape, deployment and reconstitution of strategic forces, as well as in the excercise of long term loiter aircraft such as NEACP-AWAC's, etc, exposures to delayed (decaying dose rate) radiation will occur. While it is generally accepted that both fractionation and protraction of dose yield a less severe effect than a single acute exposure (of the same magnitude), "sure safe" to "sure kill" dose limits have been requested by the Air Force for loiter scenarios. These "penalty"/vulnerability tables, comprising dose vs performance degradation with time into the mission, will also assist in re-establishing hardening criteria for both man and the aircraft. Conversely, tactical aircrew degradation will come from acute exposures associated with other stressors such as fatigue, chemical agents and G forces. In order that aircraft may operate from unmanned airstrips and on old bases, radiation dose rate meters (ground to air) become mandatory. For personnel, biologic dosimeters will be of greatest usefulness. Radiation protection and therapy may on the one hand augment mission completion capabilities, and on the other hand assure a reconstitution restrike posture.

2. Vulnerability Assessments of Military Significance for Man in the System

a. Objectives

(1) Define those dose rates, i.e., 50 r/hr, 100 r/hr, etc., that will yield 24-, 48- and 72-hour accumulated rad doses that are compatible with "sure safe" and "probable mission completion" dose schedules. (These dose constraints must accommodate multiple launches with limited downtime, i.e., 1-4 days for the strategic and/or assessment aircraft). - 1985

(2) Establish, if feasible, levels of vulnerability/dose against complexity of duties, i.e., Battle Staff Commander vs other. - 1990

(3) Determine aircrew radiation sensitive/nonsensitive responders. - 2000

b. Approach

The use of (a) subjective estimations or scaling methods based upon previous animal research, human accident reviews, and radiation therapy observations; (b) operator-psychological response models (simulations); and (c) biochemical biophysical models of radiation injury (or other similar stressors). These modelings should be used to evaluate critical time and mission tasks such as aerial refueling with respect to time on boom, number of pounds of fuel transferred, or number of breakaways as assets in decisions of go-no-go, alternative targets, or return to alternate base.

Ideally, simulations may be developed to validate such models. If so, attempts should be made to degrade the simulator in parallel with crew degradation to reflect on additivity or synergism of effects.

These dose/performance matrices, when properly scaled, can be used in tactical scenarios in assessing the number of potential sorties, length of sortie and time between sorties. Animal data and radiotherapy experiences help define a spectrum of ionizing radiation sensitivity which may correlate well with biochemical and/or cellular systems. Statistical evaluation of these data, along with "incapacitation" mechanisms research, may enable development of crew selection (radiation) criteria or protective (radiation) procedures.

3. Biologic Dosimetry

The only sure thing a military member carries is himself, thus the biological dosimeter may eliminate one of the most uncertain steps in dosimetry, the relation of dose received by the dosimeter to dose received by the aircrewman. Placement, shielding and dose distribution will always be significant problems, but the elimination of several magnitudes of doubt can be achieved by using the body itself as a dosimeter. A final consideration is the evolving SAC requirement for on-line real time dosimetry (dose rate and total dose) in the aircraft (long-term loiter), and external to the platform during ground operations at remote areas.

a. Objectives

(1) Identify biochemical parameters that will provide an early, accurate indication of the degree of radiation injury sustained.

(2) Develop clinical tests giving absorbed radiation doses based on those biochemical parameters and suitable for use in field medical facilities.

(3) Develop a method for use by medical personnel in the field which quickly identifies supralethally irradiated personnel to the triage team.

b. Approach

In time, biological dosimetry for national emergencies may evolve out of blood studies, waste product studies, hair, fingenails, expired breath and/or other chemical rearrangements. At present, some of these dosimetry methods are in the stage of developing usable dose-response curves, however, conversion to functional dosimetry has not yet begun.

(1) Blood studies - The biological significance of changed serum concentrations may prove to be an invaluable marker of radiation damage. At the present time changes in magnesium, copper, zinc and iron levels are the most notable.

(2) Waste product studies - Waste product studies are an adjunct to blood studies. Possible biologic markers in urine are the histamine released by mast cells post-irradiation and various polymines (spermine, spermidine, putrescine). Experimental evidence has also shown that histamine and prostaglandins are released into the urine of irradiated rats and such a release may be dose-dependent. Therefore, the possibility of their use as indicators of radiation injury is of great importance and should be investigated.

(3) Hair, fingernails (chemically treated) and/or respiratory products may be subtle indicators that could yield both biologic surface and depth doses.

In addition to the above, comprehensive development of new techniques is needed for measuring biochemical indicators of radiation injury in physiologic fluids, respired gases, waste products, fingernails, etc. There should be systematic analyses of selected serum and urinary constituents for use as biological dosimeters that have the greatest promise. A simplification or modification process could be applied to biochemical assay techniques of those constituents having the best dose-response characteristics. Automation and miniaturization of any developed assay technique for possible in flight or airfield assessment is of extreme priority. Oral administration of a benign substance that reacts/decomposes/rearranges quantitatively with low levels of radiation would be ideal.

4. Directed Energy

a. Objectives

(1) Understand the electromagnetic pulse phenomenon and its potential soft kill (vulnerability) on people.

(2) Define vulnerability envelopes of pulsed particulate radiation on human operators.

(3) Thorough understanding of mechanisms of action on the human - define concepts for countermeasures.

b. Approach

The human operator (aircrew) indeed appears to be vulnerable to energy deposition well below system hard kill energy requirements. Systematic studies of short duration pulses, i.e., nanoseconds, repetitively pulsed will be used to define threshold values and later vulnerability envelopes for such endpoints as retinal vessel leakage, corneal curvature, retrograde amnesia, convulsions, stupor-like-state and/or collapse.

Progressive understanding of these phenomena, the causation, degree of impairment and level of recovery may suggest both physical and biologic countermeasures for aircrew safety.

5. Radiation Protection

a. Objectives

(1) Develop chemical agents or physical means to increase radiation tolerance of man.

(2) Develop chelating agents to reduce absorption of fission products from inhalation and/or ingestion.

b. Approach

Continue development of drugs and evaluate sub-toxic combinations of radioprotectants to maximize radiation protection and the sequelae of radiation exposure. Integrate these evaluations with the relatively non-toxic vitamins and elemental diets. Reduce toxicity of chelating agents and make them self administering. Develop garments or cockpit and seat configurations that can optimally shield the bone marrow or, as an alternate inflight solution, hermetically seal life support crew compartments so as to be impermeable to gases, particulates and other radiations.

6. Radiation Therapy

a. Objective

Bone marrow reconstitution - Develop simple theraputic methods to enhance post irradiation survival by non-contemporary means, i.e., endogenous stem cell manipulation; exogenous stem cell replacement; or universal stem cell.

b. Approach

Development of recombinant DNA, monoclonal antibody (hybridoma), eluriation and fluorescence activated cell sorter technology to harvest stem cells. Develop the capability to store and clone universal donor stem cells. Alternately, significantly diminish the stem cell antigenic potency or provide blockage of its antigenic capability with monoclonal antibodies. Continue to develop the capability to regulate the immune response.

7. Radiation Fatigability

a. Objectives

(1) Define mechanism of radiation induced fatigability.

(2) Test the hypothesis that such physiologic decrement is related to cellular damage expressed by the residual stem cell levels.

b. Approach

The research would be designed to produce dose/response data for mathematical modeling of the effect of dose protraction and fractionation upon total dose effectiveness for decrements in both hemic stem cell populations and various levels of physical and mental performance. Biochemical metabolic serum and urine assays would also be devised to be carried out in parallel to provide additional assay systems describing loss of physical well being.

8. Facilities

A multipurpose Directed Energy Laboratory is proposed to include, within the structure, high energy lasers, an electron charged particle accelerator and a high powered millimeter wave generator. There are threat analyses which clearly suggest that high powered, repetitively pulsed electromagnetic beams (laser, e^-, RF), can produce human vulnerabilities, such as flashblindness, prolonged loss in visual acuity, damage to skin, a possible retrograde amnesia, retinal vessel leakage, a "stupor like" convulsive state, as well as changes in corneal curvature. Because of the isolation of the facility, small animal facilities for different species are required. Two of the laboratories would be devoted specifically to test and evaluation of various materials and/or devices promising for countermeasures. Computational capabilities must be 1985 state-of-the-art and all analytical (biochemical-biophysical) equipment must be of equal update.

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APPENDIX A

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APPENDIX A

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APPENDIX B

BIOTECHNOLOGY AREAS OF EMPHASIS FOR POTENTIAL 1990-2020 MANNED AIRCRAFT MISSIONS

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BIOTECHNOLOGY AREAS OF EMPHASIS FOR POTENTIAL 1990-2020 MANNED AIRCRAFT MISSIONS

1. Extraordinarily complex automated people/information systems with human roles biased toward monitoring, supervising and decision making.

   Key Issues:

   How to achieve a symbiotic relationship with automation.

   How to make combat decisions on the basis of symbolically presented battle situations.

   Quantitative understanding of the evolution, propagation and reduction of critical error(s) in people/machine systems.

   Proper methods to alert crew to complex system degradation.

   Determining training and simulation needs for successful operation of degraded systems.

2. High intensity, long-duration, unforgiving missions.

   Key Issues:

   Nature of operator performance degradation (e.g., reduced capacity due to divided attention, complex operations, fatigue, etc.).

   Definition of "impaired operator" capabilities to assist system designers to provide back-up modes.

3. Extended biodynamic environment for enhanced performance (e.g., six degree-of-freedom control modes, high G maneuvering, tailored control modes, restraint systems, thermal loading). Accommodation to unexpected maneuvers due to automatic or 3rd party control of aircraft.

   Key Issues:

   Desirable tailored control modes, associated restraint systems, manipulators, etc.

   Escape systems, suits.

   Low profile/observable vehicle display, controls, manipulators, etc. (supine, prone, Mini MX VTOL - standing).

   High G maneuvering, low-level prolonged vibration.

   Compensation/cancellation of biodynamic feedthrough on controlled displays.

4. Simulation for system concept design, development formulation and training.

   Key Issues:

   Simulation validity, fidelity (especially of degrading environment), tailoring for critical issues of performance training, etc. Need to validate simulators before actual hardware is available and during design development.

5. Major technological advances in display media, computation and "manipulative" interfaces (e.g., explore voice actuation, evoked response).

   Key Issues:

   Improvement of existing functions.

   "Invention" of new uses of human capabilities for information transfer, presentation and response to massive new information quantity and rates to achieve command or combat decisions.

6. Refinements in crew selection - quantify decision-making capabilities, motivation, maturity, team player competency - find remaining decision capacity under degrading environments.

7. Physical and chemical enhancement as well as impairment of crew - sustained alertness, before and between missions, conditioning, circadian disruption, training sleep skills, biofeedback, avoidance of degrading substances (e.g., drugs, coffee, smoking, etc.).

8. Chemical biological attack initiatives (including all toxic agents) - detection, protection, models for chemical effects, including scaling from animal experiments.

9. Ionizing radiation - long duration loiter, residual and acute radiation, neutron weapons. Radiation hazard must also take account of on-board environment.

10. Laser threats - pulsed, high and medium energy, effects on vision re-radiation/flash blindness, optical devices.

11. Other electromagnetic-microwave from own aircraft or from attacker; manipulators, etc.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report discusses the basic biotechnology research problems that require solution by the year 2000 to ensure optimum performance of manned Air Force aeronautical systems. The projected aeronautical systems for strategic, tactical and support systems are discussed, with emphasis placed on the roles of increased automation and information processing, as well as the increased physical stress of higher performance aircraft, extended mission durations and new weapon threats. Six generic areas of biotechnology are considered, along with the

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) research needed to address the needs of the year 2000 aircrew. First discussed is the human-machine symbiosis needed in systems that will become extraordinarily complex. This is followed by the related needs in developing improved human-machine information interfaces that avoid overloading the human operator or pilot. Many missions of the future will be unforgiving and of high intensity. The problems and research needed to deal with the increased stress and to protect and enhance aircrews' performance during these missions are discussed in detail. The report discusses how simulators can be advanced to provide not only better training for aircrews, but also how they can be used in the development of new systems for optimizing the human-information-machine relationship. The increasing complexity of aeronautical systems discussed early in the report is complemented by a chapter on crew selection and enhancement. More care and better techniques are needed for selecting candidates for each aircrew position and for enhancing their capabilities in order to maximize their potential for successfully accomplishing their missions. The report is completed by chapters on the problems and research issues facing aircrews who must operate in chemical and biological warfare environments and in radiation environments.

The breadth of topics covered in this study required that the report be published in two volumes. Volume 1 is a very brief summary of the research issues and the proposed research plan. Volume 2 provides, for the interested reader, a more detailed discussion on the background and proposed solutions of each of the research issues.