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PREFACE

In late 1980 the United States Air Force Systems Command requested that the Air Force Studies Board examine issues of automation in combat aircraft for the 1990s and beyond. A steering committee was selected. BrigGen Robert A. Duffy (U.S. Air Force, retired), president of the Charles Stark Draper Laboratory, Inc., was named chairman. MajGen Richard G. Cross, Jr. (U.S. Air Force, retired), of the BDM Corporation, was appointed vice-chairman. Early meetings defined the task statement, narrowing the scope of the study to what was deemed manageable with the time and resources available. A statement of "terms of reference" (Appendix A) was developed to provide guidance to the committee as it proceeded. The terms of reference asked questions broader than those given in the statement of task, to encourage participants to think in the context of the operational Air Force and to identify the attributes of needed automated features. Briefing topics were selected and reviewed by the steering committee in meetings in Washington, D.C. and at Wright-Patterson Air Force Base. Experts were recruited; reports on many aspects of automation were selected for review. A month-long session was conducted at the Woods Hole Study Center of the National Academy of Sciences.

Briefings conducted at Woods Hole covered a variety of subjects related to automation. The participants also reviewed selected reports. Additional information was supplied by experienced engineering test pilots from the Air Force Systems Command, and combat pilots from the Tactical Air Command. The progress of modern technology for the automation of fighter aircraft, from the F-106 through the F/A-18, was examined, and representative aircraft were flown into nearby Otis Air Force Base for inspection by the study participants. Experienced technology development leaders from the Federal Aviation Administration (FAA), the National Aeronautics and Space Administration (NASA), the Navy, and the Air Force Systems Command were available throughout the month.

The committee organized a study group of three subcommittees to analyze specific problem areas and to formulate findings and recommendations. The Functions Subcommittee examined mission elements and queried design and development personnel and pilots on work loads and stress factors bearing on the suitability of automation for given tasks. The Human Factors Subcommittee examined the issues of pilot capabilities in the context of the functional regimes defined by the Functions Subcommittee. Similarly, the Technology Subcommittee assessed the ability of the development community to meet present and future technological needs. Members of the development test and operational communities were queried as a means of checking tentative findings and evaluating the current demands on pilots.

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STATEMENT OF TASK

The committee plans to conduct a summer study on automation in combat aircraft. As avionics and weapons systems have evolved, the information load and task load presented to the crew or pilot of a modern combat aircraft have continued to increase. The same electronics technology that has brought about this proliferation of tasks has also enabled the design of automated systems for performing some functions. Technology offers the potential or opportunity to automate many others. In the design of future aircraft and systems, informed decisions must be made about the allocation of functions as between the human pilot or crew and the automated gear. The study will address the kind of allocation needed to improve combat flight conditions, and will attempt to determine those functions that necessarily require the intervention of human judgment. To provide a basis for informed and effective design decisions, however, a research program must also address the fundamental problem of strengthening the designer's and user's confidence that automated functions will be performed reliably and effectively. This requires confidence in the reliability of hardware and software, and adequate experience, through simulation and with actual experience. The study will examine the issues and technology involved, and recommend a program of future research and development in this domain.

SUMMARY

This report is concerned with the automation of combat aircraft to support the mission of the United States Air Force. According to the statement of task decided upon by the Air Force and the National Research Council, this study addresses the issue in terms of manned systems. Given the limited time available for the study, the Committee on Automation of Combat Aircraft concentrated on single-seat fighters.

The term "automation" is subject to diverse interpretations. It has been used variously to describe the control of a single function by a simple on-off mechanism, as in the thermostatic control of building temperatures. It has been used to describe the concurrent display of data from various sources to a person for interpretation: an example is the cockpit displays of a modern fighter aircraft, which combine information, for instance, from a radar and an electro-optical sensor with computer-derived flight parameters. Automation has also been used to describe the control of complex processes, in which the automated system replaces some human monitoring, decisionmaking, and/or motor functions, as in automatic flight control.

In this study, the committee defined automation as those processes by which essential functions can be performed with partial, intermittent, or no intervention by the pilot. In this report, the term automation will describe any effort to move the cognitive processes of flying the aircraft and managing its weapons from the pilot or aircrew to a computer-dominated system.

Human Limitations in the Combat Environment

Technological advances in the past two decades have made possible the development of complex and more competent aircraft that can fly under more difficult conditions (such as close to the ground, at night, or underneath the weather), and at faster speeds. They can also perform more complex missions, such as simultaneously attacking multiple targets.

At the same time, and perhaps as a consequence of these technological advances, the environment in which aircraft must fly and fight has become more dangerous. Threats from the air and ground are faster moving and harder to detect. Not only are the aircraft vulnerable to enemy attack, but they can also be shot down accidentally by U.S. surface-to-air missiles.

The only element that has not changed significantly over the years is the human operator. The pilot is limited in his ability to assimilate and perform tasks. He may not be able to handle the increased workload involved in operating today's faster, more highly mechanized aircraft. Limitations in human capabilities are difficult to overcome, and as yet have not been completely described. The proper use of automation in aircraft could help to overcome these limitations.

In fact, both the military and commercial aviation communities have been using automation to various degrees over the years. Extensive automation has been used in manned vehicles such as the Space Shuttle. Air Force aircraft such as the F-106, F/FB-111, and others are also capable of semi-automated flight. Yet automation presents its own difficulties, in terms of cost, reliability, maintenance, and complexity of operation. To reduce cost and complexity, and because of technology limitations, the most recent Air Force aircraft (F-15, F-16, and A-10) have been designed with only selected automated features, to perform essential functions. These aircraft can be considered semi-automated at best.

Operating these high-performance aircraft (the F-15, F-16, and A-10) places great demands on the pilot. The increased workload that results from the complexity of the aircraft and the challenge of today's combat situation may lead to errors or mission failure.

This workload is especially evident in the cockpit. Recent advances in avionics and weapons technology have led to an exponential increase in the numbers of cockpit displays and controls since the 1920s. Through these displays, the pilot is given large quantities of information in rapid succession. He needs to be aware of the aircraft's internal and external situation, in addition to operating the fire-control system, selecting and firing munitions, and positioning a large number of switches. When the pilot focuses his attention on a particularly demanding function, such as locking onto an enemy target or following rugged, hilly terrain, he may lose track of others, even when provided with some automated functions (such as weight distribution, fuel-flow management, flight-attitude control, and threat warning).

In the past, when missions and aircraft were simpler, the pilot was able to assess the current situation and draw on past experience in executing his mission. If the trend toward complexity of aircraft and combat situations continues, the pilot will be increasingly unable to perform his mission without extensive aid.

By the 1990s, combat aircraft could be more fully automated to aid and support the pilot in performing his tasks and keeping track of the overall situation, thereby increasing the probability that the mission will succeed and the pilot and aircraft will survive.

If automation is truly to improve mission performance, aircraft designers must carefully consider where automation would best serve pilots' needs. They must examine not only the technology, but the human factors involved. This will require an understanding of how pilots process and assimilate information and how they think about their tasks, as well as an understanding of the performance characteristics of the controls and displays through which the pilot and the automated systems interact.

New Opportunities for Automation

The committee believes that new Air Force development and application of automated features based on computer technology can improve the operational effectiveness of combat aircraft. In addition, it will enhance the chances of survival for both the aircraft and the pilot. The reliability and capacities of computers are increasing. At the same time, size, weight, and cost per unit of computer power is decreasing enough to justify its extensive use to provide a comprehensive, integrated, up-to-the-minute model of the aircraft and its mission. Also, since software costs are dominating hardware costs, it makes economic sense to design systems with flexibility to accommodate new requirements and developments over the operational life of the aircraft.

Acceptance of Automation

Air Force personnel are generally receptive to further automation of combat aircraft. Although senior managers appreciate the potential of automation, they are not oversold on its merits. Because of their concern about increased cost and complexity of automated systems, and the possibility of low reliability, managers are conservative in making commitments to the increased use of automated systems.

The aircrews exhibit similar attitudes, with a strong "show me" tone. Pilots wish to retain the ability to select automated functions and to intervene in their operation. Aircrews want simplicity in execution as well as performance. They accept automation of functions that humans cannot perform adequately, functions that distract pilots from critical tasks, and functions or routines that are infrequently performed and can be done more reliably through automation.

Emphasis in the development of automated systems has been on data and information displays and on sensors--the "outer" ends of aircraft automation. The "inner" part of the problems--processing these inputs from diverse information sources to improve pilot awareness of the outside world and the status of his aircraft--is just beginning to receive needed attention.

Several current programs are developing technology that can help to identify the operational approach to and need for automation. These programs include the Advanced Fighter Technology Integrator/Advanced Maneuvering Attack Systems (AFTI-16/AMAS) program, the Low Altitude Navigation Targeting Infrared for Night (LANTIRN) program, and development of terrain following and terrain avoidance (TF/TA) technology. (See the Glossary for definitions of these programs.) The prototypes developed in these programs can contribute to understanding, and perhaps to satisfying, the operational community's immediate stated need for improved capabilities to fly low, at night, and during severe weather, using terrain for cover. The long-range goal is the ability to fly missions effectively in all types of weather, in the daytime and at night, devastating the enemy and surviving in hostile environments. To realize this goal, more complete forms of automation that do not detract from aircraft availability (because of "downtime" or problems with reliability) will be necessary.

Questions of Reliability

The availability of combat aircraft is a central concern. It depends on the reliability of the aircraft and their subsystems, and on the adequacy of maintenance and logistics. It is reasonably clear that reliability would be improved if these subsystems were subjected to follow-on cycles of modification after feasibility demonstration and testing.

The committee has not examined the problem of unreliability in enough depth to ascertain its actual causes, but inadequacies in testing, design margins, packaging, vibration isolation, and temperature control, along with excessive handling, appear to be sources of trouble. Developers of electronic systems for both commercial aircraft and strategic missiles have concentrated on these items in their programs to attain high reliability. We do know that environmental factors greatly influence the reliability of aircraft equipment, and that a tactical aircraft is exposed to far more hostile conditions than a commercial aircraft or a missile in a silo. These conditions include frequent power on-off cycles, short but intense sorties, and inexperienced maintenance crews.

Addressing some of these problems will help to improve aircraft reliability, especially if combined with designs that provide redundancy of components and fault isolation and detection. In addition, an overall systems architecture for the aircraft that allows the integration of various components and accommodates new developments will be of great benefit in developing reliable aircraft. Finally, pilots demand provisions to intervene in the case of subsystem failure.

The Need for Integrated Systems

Technology is available for developing suitable automation for combat aircraft of the 1990s, and to modify some existing aircraft and some now in production. To achieve this goal, the Air Force will have to define the requirements for automation, and recognize that the task requires an integrated systems approach, rather than a collection of piecemeal efforts. For such an integrated approach, a focal point for automation should be established. Flight trajectory and attitude control should be the focal point for all aircraft automation. This function--the maintenance of the correct flight trajectory and attitude, or orientation of the plan, over time--is the heart, mind, and nerves of the aircraft, to which all other functions are keyed. Therefore, it can form the core of a truly integrated system of automated features.

A flexible architecture for flight trajectory and attitude control is vital: logical partitioning and standard interfaces will be necessary to permit the later addition of sensors and weapons for more highly developed systems. This is a prudent way to accommodate change in a fleet of aircraft that will remain in use for a long time. Correct core design can lead to standardized software and hardware applicable to more than one airplane. A deliberate systems-oriented approach is essential to avoid a proliferation of incompatible functions, controls, and displays. A basic model should be developed for the architectural design. This model should include, at the least, the specifications of cockpit features, flight- and engine-control systems, and navigation elements.

A comprehensive, thorough, adequately supported testing and evaluation program must be a major element of any such development. The operational and engineering flight-test communities should be involved. If effective automated systems are to be available in the 1990s, now is the time to start.

A Note on Safety

This study group's discussions with military pilots lead it to conclude that flying high-performance aircraft is hazardous, and is likely to be more so in the future. During the course of this study, the group received information on certain safety-related technologies and systems that will affect future Air Force research and development (R&D). While these technologies and systems are not strictly within the scope of the study, they are of such importance that comments are appropriate.

Identification, Friend, Foe, or Neutral

A longstanding problem that still has no clear solution is the identification of friends, foes, and neutral forces, abbreviated IFFN. Reliable means of identifying friendly, as well as enemy, forces are vital. The combat arena of the future will be even faster moving than that of today and will be filled with intense activity. If identifications must be made visually by pilots, a significant tactical advantage of long-range detection sensors and long-range weapons will be lost. The development and use of reliable equipment for the identification of friendly, hostile, or neutral forces is crucial to increasing combat effectiveness and the chances of survival. One possible solution may involve the coupling of several sensors and systems to supply intelligence and positional information, as well as information on the situation external to the aircraft.

The problems of target assignment and acquisition go along with that of identification. Once identification is made, the next problem is the efficient use of the force to attack multiple targets. When there are multiple targets, it is helpful to have a system for exchanging information among individual aircraft to ensure that each plane attacks a different target. Such a target-assignment process would make more effective use of the fighting force and would also improve the pilots' general awareness of combat situations. Such a process is possible through the use of systems such as the multiple-access digital data link known as the Joint Tactical Information Distribution System (JTIDS). This and similar systems could aid in the identification process, and could have the ability to transmit large quantities of situational intelligence data.

Unmanned Vehicles

Although this study concentrated on manned aircraft, the use of fully automated unmanned vehicles (UVs) is worthy of comment. In some combat situations, such aircraft can be effective, and they reduce the loss of pilots. The technology is available to develop UVs that can perform automatically, without human intervention, such missions as defense suppression, reconnaissance, surveillance, and communications relay. Technology now under development for both manned and unmanned vehicles should allow the automatic performance of electronic warfare, damage assessment, and target assignment. The increasing power of small data processing machines has implications for the development of UVs, as do advances in sensors, structural materials, and propulsion technology. Given these developments, the prospects are increasingly good for including UVs as a part of a mixed force of combat aircraft. The principal obstacle to acceptance of unmanned aircraft is uncertainty about their costs.

Escape Systems

In some air-to-air and air-to-ground tactical maneuvers, departure from controlled flight does occur. When this happens, the aircraft may be at a speed and attitude that is at the edge of the safe ejection envelope. Even when ejection is possible, given the speed and attitude, the pilot has little time to recover the aircraft or to eject safely, if necessary.

Air Force and Navy statistics indicate that the survival rate of pilots who ejected from combat aircraft declined between 1976 and 1980. The survival rate in 1976 was 85 percent, in 1979 it was 70 percent, and in 1980 it was 72 percent.

In addition, during 1979 and 1980 there were as many ejections outside the escape envelope as there were in the previous three years. The fatality rate for Air Force pilots who ejected below an altitude of 500 feet was 57 percent during the past five years.

The Advanced Concept Ejection Seat II (ACES II) has improved the survival rate to some degree. The fatality rate is still unacceptably high, however, and solutions to this problem must be sought.

FINDINGS AND CONCLUSIONS*

1. The complexity of today's missions and high-performance aircraft has created workloads that at times impose intolerable demands on combat pilots.

2. Air Force development and application of automated features can improve operational effectiveness and enhance the chances for survival of pilots and combat aircraft.

3. The technology for automation of all routine tasks and of some others is now available. Full automation is costly and complex, however, and is not necessary in all manned combat aircraft.

4. The Air Force does not have an established position on the requirements for automation in aircraft.

5. There is currently no systematic, widely applied technology for allocating functions between automated systems and the pilot. Similarly, there is no criterion for balancing the costs of automating particular functions against the resulting improvements in combat performance.

6. Computer technology makes it possible to develop dynamic, integrated, and comprehensive automated systems for future combat aircraft. A systems approach, emphasizing the core function of flight trajectory and attitude control, is a logical and necessary starting point.

7. The aircrews' stated immediate need is for improved ability to fly low, at night, and during severe weather, using terrain for cover from enemy defenses. The critical and essential functions that could be automated to achieve this goal have not been completely identified, although current programs should illuminate this issue.

8. In such programs as AFTI-16 and LANTIRN, and in the development of technology for TF/TA, the Air Force research and development community is addressing important problems. These programs will develop technologies and an engineering perspective that are a valuable base on which to build. The approach remains piecemeal, however, and without clearly stated or widely understood objectives. A much-needed unifying focus is missing.

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*No priority ranking is intended in the ordering of these findings and conclusions.

9. There is a large gap between what is known in a laboratory setting of the basic characteristics of human psychomotor performance, and what is known about how pilots actually fly and react in modern combat aircraft. Much of the knowledge needed to design an automated aircraft that uses pilots' skills to the best advantage lies within that gap.

10. In the past, the unreliability of avionics systems has been a major contributor to the downtime or unavailability of combat aircraft. No effort to improve combat performance by further automation can succeed without adequate attention to the reliability and maintenance of the equipment.

11. Fighter aircraft under development or now entering the inventory are not automated to the extent that the pilot is wholly free to assess and monitor the combat situation and to plan his further strategy. No aircraft has provided him with effective, accessible aids for assessing alternative strategies.

12. Insufficient attention has been paid to past efforts at automation. A study of such efforts could help developers to repeat past successes and avoid past shortcomings.

13. Identification of unknown objects as friend, foe, or neutral (IFFN) is difficult today. IFFN will become much more important in the future because of improvements in weapons' ranges.

14. In tactical maneuvers in high-performance aircraft, pilots often fly at the edge of the safe ejection envelope. Current automatic ejection equipment is inadequate for such situations; the number of injuries and fatalities suffered by pilots who eject from combat aircraft is increasing.

RECOMMENDATIONS

1. There is a recognized need for automation. The primary goals should be to increase combat effectiveness to enhance survival of pilots and aircraft, and to decrease pilot work load.

2. There is evidence that such automation can be available in the 1990s. A firm decision can and should be made to automate specific critical functions and/or infrequently performed but essential functions that are currently performed manually.

3. A systems-oriented program aimed at improving and developing automation for the 1990s should be initiated now. The goal should be a core design that would form the basis of automated functions, building on flight trajectory and attitude control systems. Such a systems approach could prevent piecemeal automation that could be costly and would result in only partial solutions not adaptable to growth.

4. Four functional groups are promising candidates for automation: (1) flight trajectory and attitude control, (2) engine and power systems control, (3) weapons delivery and fire control, and (4) navigation and communications functions. Combinations of these functional families can be accomodated by the evolving technology.

5. The increasing number of displays used to present information to pilots, the amounts of information and instructions displayed, the limited cockpit area available for display, and the otherwise complex environment of the aircraft have created special problems. Complicated displays are difficult to read, and controls and functional mode selection are cumbersome and time-consuming. Consequently, necessary actions may sometimes be neglected. To reduce pilot workload and increase operational effectiveness, functions that divert attention from critical actions should be automated.

6. A method for allocating functions between automated systems and the pilot must be developed. A multidisciplinary team should examine potential hardware and software techology, as well as human performance, to lay the basis for clear decisions in this regard. The objective should be a practical method for quantifying the improvements in performance and survival that result from automating particular functions.

7. A separate and fundamental study should be initiated to shed light on (1) the mental model pilots create to aid in performing their combat tasks, (2) the performance characteristics of the controls and displays through which the pilot and automated

systems interact, and (3) human capabilities. This study should develop a multitask, experimental and analytic program to model pilot behavior. This program could be used as an aid in designing advanced automated systems, and in particular the cockpits of the future.

8. Automating or partially automating a higher class of appropriate cognitive functions, such as the ability to assess the combat situation, or to plan strategies and escape routes, should be a part of the Air Force's long-range program.

9. The rising trend in fatalities and serious injuries relating to aircraft escape systems indicates a need for improvements. Air Force activity in modifying escape systems (ACES II) may meet this need. The problem must be addressed, through either the ACES II program or a completely new approach.

10. Identification of objects for beyond visual range as friend, foe, or neutral (IFFN) cannot be automated with any confidence today. An automated system for such identification would permit important gains in combat effectiveness. A coordinated effort on this front is needed.

Chapter 1

FUNCTIONS SUBCOMMITTEE REPORT

INTRODUCTION

Advances in avionics and weapons systems have greatly added to the capability of combat aircraft. They are now able to perform more sophisticated missions, and operate under more difficult conditions, than their earlier counterparts. As a result, the cockpit has become increasingly complex, with various displays bringing vital information to the pilot. At this stage in development, the electronic systems designed to aid the pilot may actually be complicating his job; he is confronted with too much information to assimilate and act upon.

The same electronics technology that has brought about this proliferation of information (and associated tasks for the pilot) has also allowed the design of automated systems for performing some of these tasks. It is now possible to automate more of the functions a pilot must perform, thereby reducing his workload and optimizing the performance of the pilot and the aircraft.

In the design of future aircraft, an informed decision will have to be made on the proper allocation of tasks between the pilot and the automated systems. This study was commissioned to analyze ways of using automation to improve combat flight conditions, and specifically to address the question of which systems should be automated, and which require human intervention.

The study group formed three subcommittees: the Functions Subcommittee, the Human Factors Subcommittee, and the Technology Subcommittee. The Functions Subcommittee was asked to provide the other two subcommittees with a common context and terminology for their investigations. It concentrated on single-seat aircraft in air-to-air and air-to-ground missions, because of the Air Force commitment to these fighters.

An approach to automation cannot be developed solely on the basis of available technology; instead, it must consider the interactions of the pilot and the aircraft. Thus, the key questions are "Where would automation best serve the pilots' needs?" and "What is the state of the technology for automating these functions?"

The Functions Subcommittee identified the aircraft systems that come into play and the activities a pilot must perform during a successful combat mission. It then suggested several ways of ranking these systems and activities in terms of priority for consideration for automation. Its findings were used by the other two subcommittees in their examinations of human factors that must be considered in automation, and the technological opportunities and constraints for automation.

AUTOMATION TO ACHIEVE MISSION OBJECTIVES

The Functions Subcommittee approached the study with three basic assumptions. Automation will be feasible if all of the following conditions are met:

- Aircraft systems can be designed in suitable configurations that can be tied one to another.
- Aerospace technology exists to build such systems.
- Given automation, the pilot's job is neither trivial nor overly difficult.

The subcommittee defined automation as a process by which functions are performed with partial, intermittent, or no intervention from the pilot. It then identified the purpose of automation as achieving combat capabilities that are inherent in the existing man-machine system, but are as yet unrealized because of limitations in human capability or avionics technology. The logical functions to automate are those that will allow the reallocation of the pilot's attention from time-consuming or trivial tasks to those that require human judgment.

In any combat situation, there are three fundamental goals or mission objectives toward which the actions of the pilot and the entire friendly force are directed. Therefore, any attempt to improve combat flight performance, through either automation or human training, must be measured by how well the new strategy aids in meeting these objectives.

The three objectives are:

1. Avoiding personal catastrophe. The pilot strives to ensure his own safety, and that of other friendly forces. When this safety cannot be ensured, most missions will be aborted, except under extreme circumstances.

2. Maintaining and increasing the effectiveness of aircraft weapons systems. The pilot and wing commander strive for the "economical" use of the aircraft, its munitions, and other friendly systems against assigned threats and targets.

3. Succeed, or win, in the broad conflict. This is the primary concern of the theater commander, who strives to stabilize the conflict (i.e., prevent breakthroughs) and to converge on the enemy.

These three objectives form the basis of the following analysis: opportunities for automation are evaluated for their potential contribution to overall mission success.

To attain these mission objectives, a pilot must perform certain functions, given the aircraft systems available to him. From briefings and conversations with active-duty pilots and commanders, the subcommittee identified 16 systems the pilot uses and activities he performs in combat. These essential systems and activities serve as a guide to understanding where opportunities for automation might exist. The systems and activities are:

1. Malfunction Warning and Reconfiguration System (Malfcn Warn/Recon)
2. Navigation System (Nav)
3. Electrical Control System (Elec Cont)
4. Hydraulic Control System (Hyd Cont)
5. Taxi/Take-Off/Land (Taxi/TO/Land)
6. Autopilot System (Autopilot)
7. Target Sensing and Acquisition System (Targ Sens/Acq)
8. Flight Control System (Flight Cont)
9. Crew Escape System (Crew Escape)
10. Propulsion Control System (Propulsion)
11. External Data Input Systems (Ext Data)
12. Crew Station (Crew Sta)
13. Threat Warning and Countermeasures System (Threat Warn/CM)
14. Weapons Delivery/Fire Control System (Weps Del)
15. Identification: Friend, Foe, Neutral (IFFN)
16. Fuel Management (Fuel Mgmt).

Methodology

To address the question of which of these systems or activities to automate, it is necessary to examine how they work, both singly and in combination, to meet the mission objectives. Because these mission objectives are highly abstract, and can apply equally as well to tanks, for example, as to aircraft, the 16 aircraft systems and activities cannot be directly related to them. Instead, the subcommittee related the systems and activites to intermediate variables. These variables are six distinct phases in air-to-air and air-to-ground mission: prelaunch, launch, ingress, engage, recover, and turnaround. (There is some variability in the use of these terms, but they carry evident meaning for the missions discussed in this report.)

As the first step in this process, the subcommittee ranked each of the mission phases according to its importance in attaining the three objectives in air-to-air (Table 1-1) and air-to-ground (Table 1-2) missions. Weights were assigned on a scale of one to ten, with ten signifying that a phase is of critical importance in attaining that mission objective, and thus is of great concern to the pilot and commander. A rating of one signifies that the phase is of minor importance. For example, in air-to-air combat, the ingress phase is crucial to avoiding catastrophe (Table 1-1). These weights were summed in the last line of the tables, and the total weight was used in the rest of the analysis to represent the importance of each mission phase. (A note of caution is warranted with respect to Tables 1-1 and 1-2. These weights reflect the subjective judgment of a small sample of qualified individuals, and they should be regarded as impressionistic. A more precise analysis would require a wider sampling of expert opinion.)

Next the subcommittee asked pilots on active duty to rank each of the systems or activities according to how important it is in fulfilling each mission phase. Again, weights were assigned on a scale of one to ten. These rankings reflect both the pilots' assessment of how critical the system or activity is to the successful completion of the mission phase, and the degree of challenge or complexity involved in performing the task. A high number indicates that the system is extremely challenging and is of great concern to the pilot. Table 1-3 shows these rankings for air-to-air missions; Table 1-4 for air-to-ground missions. For example, Table 1-3 indicates that, in air-to-air missions, target sensing and acquisition is extremely important and challenging in the engage portion of the mission, but it is of minor importance, and is virtually unchallenging, in the prelaunch phase.

The ranking of each system or activity relative to the mission phases (Tables 1-3 and 1-4) is the point of departure for the following analysis. Because the mission phases are intermediate variables, representing the fundamental mission objectives, it is possible to determine how important each system or activity is to overall mission success. For this interpretation, the total weights in Tables 1-1 and 1-2, which indicate the importance of the mission phases, are used as multipliers for the respective weights assigned to the systems and activities in Tables 1-3 and 1-4. The results of this matrix multiplication are shown in Tables 1-5 and 1-6. As a specific example, for air-to-air missions, the total weight of the prelaunch phase is four (Table 1-1). That number is used to multiply the weight (two) assigned to the malfunction warning and reconfiguration systems in Table 1-3. Thus, in line 1 of Table 1-5, the weight for malfunction warning and reconfiguration is eight.

TABLE 1-1 The Importance of Mission Phases to Air-to-Air Mission Success*

Objectives Mission Phases	Avoid Catastrophe	Improve Efficiency	Succeed	Total Weight
Prelaunch	1	2	1	4
Launch	1	5	5	11
Ingress	10	9	10	29
Engage	10	10	10	30
Recover	10	6	5	21
Turnaround	1	1	1	3

---

*Weights are on a scale of 1 to 10; 10 indicates extreme importance, and 1 unimportance.

TABLE 1-2 The Importance of Mission Phases to Air-to-Ground Mission Success*

Objectives Mission Phases	Avoid Catastrophe	Improve Efficiency	Succeed	Total Weight
Prelaunch	8	8	10	26
Launch	6	6	5	17
Ingress	10	10	9	29
Engage	9	9	6	24
Recover	10	10	9	29
Turnaround	7	8	10	25

---

*Weights are on a scale of 1 to 10; 10 indicates extreme importance, and 1 unimportance.

TABLE 1-3 Importance of Systems and Activities to Success of Air-to-Air Mission Phases*

Systems and Activities / Mission Phases	Prelaunch	Launch	Ingress	Engage	Recover	Turn-around
1 Malfunction Warning/ Reconfiguration System	2	2	5	1	1	4
2 Navigation System	3	1	5	2	5	1
3 Electrical Control System	1	1	1	1	1	1
4 Hydraulic Control System	1	1	1	1	1	1
5 Taxi/Take-Off/Land	1	1	1	1	1	1
6 Autopilot System	1	1	1	1	1	1
7 Target Sensing and Acquisition System	2	3	8	10	5	2
8 Flight Control System	1	1	1	2	1	1
9 Crew Escape System	1	5	8	8	8	1
10 Propulsion Control System	3	3	3	10	3	1
11 External Data Input Systems	3	1	8	10	8	1
12 Crew Station	2	2	3	8	3	1
13 Threat Warning and Countermeasures System	1	1	8	10	8	1
14 Weapons Delivery/Fire Control System	1	1	1	9	1	1
15 Identification: Friend/Foe/ Neutral	1	1	10	10	10	1
16 Fuel Management	1	1	2	2	2	2

---

*Weights are assigned on a scale of 1 to 10; 10 indicates extreme importance and challenge, and 1 unimportance and lack of challenge.

TABLE 1-4 Importance of Systems and Activities to Success of Air-to-Ground Mission Phases*

Mission Phases Systems and Activities	Prelaunch	Launch	Ingress	Engage	Recover	Turn-around
1 Malfunction Warning/ Reconfiguration System	3	1	6	6	6	3
2 Navigation System	4	1	9	8	9	3
3 Electrical Control System	1	1	3	3	3	1
4 Hydraulic Control System	1	1	1	1	1	1
5 Taxi/Take-Off/Land	1	1	1	1	9	1
6 Autopilot System	1	1	2	2	2	1
7 Target Sensing and Acquisition System	3	1	9	10	9	3
8 Flight Control System	1	1	2	2	2	1
9 Crew Escape System	1	3	6	9	6	1
10 Propulsion Control System	1	2	2	2	2	1
11 External Data Input Systems	6	1	9	10	9	1
12 Crew Station	4	3	9	9	9	4
13 Threat Warning and Countermeasures System	2	2	10	10	10	2
14 Weapons Delivery/Fire Control System	3	1	8	10	3	3
15 Identification: Friend/Foe/ Neutral	1	1	6	6	6	1
16 Fuel Management	1	1	6	6	6	1

---

*Weights are assigned on a scale of 1 to 10; 10 indicates extreme importance and challenge, and 1 unimportance and lack of challenge.

TABLE 1-5 Importance of Systems and Activities to Overall Objectives in Air-to-Air Missions*

Rank Order by Sums	Mission Phases / Systems and Activities	Prelaunch	Launch	Ingress	Engage	Recover	Turn-around	Sums
10	1 Malfunction Warning/ Reconfiguration System	8	22	145	30	21	12	238
6	2 Navigation System	12	11	145	60	105	3	336
16	3 Electrical Control System	4	11	29	30	21	3	98
13	4 Hydraulic Control System	4	11	29	30	21	3	98
14	5 Taxi/Take-Off/Land	4	11	29	30	21	3	98
15	6 Autopilot System	4	11	29	30	21	3	98
5	7 Target Sensing and Acquisition System	8	33	232	300	105	6	684
12	8 Flight Control System	4	11	29	60	21	3	128
4	9 Crew Escape System	4	55	232	240	168	3	702
6	10 Propulsion Control System	12	33	87	300	63	3	498
2	11 External Data Input Systems	12	11	232	300	168	3	726
7	12 Crew Station	8	22	87	240	63	3	423
3	13 Threat Warning and Countermeasures System	4	11	232	300	168	3	718
9	14 Weapons Delivery/Fire Control System	4	11	29	240	21	3	308
1	15 Identification: Friend/Foe/ Neutral	4	11	290	300	210	3	818
11	16 Fuel Management	4	11	58	60	42	6	181
	TOTAL							6,152

---

*Weights are on a scale of 3 to 300; 300 indicates extreme importance, and 3 extreme unimportance.

TABLE 1-6 Importance of Systems and Activities to Overall Objectives in Air-to-Ground Missions

Rank Order by Sums	Mission Phases Systems and Activities	Prelaunch	Launch	Ingress	Engage	Recover	Turn—around	Sums*
8	1 Malfunction Warning/ Reconfiguration System	78	17	174	144	174	75	594 (386)
5	2 Navigation System	104	17	261	192	261	75	910 (592)
12	3 Electrical Control System	26	17	87	72	87	25	314 (204)
16	4 Hydraulic Control System	26	17	29	24	29	25	150 (98)
11	5 Taxi/Take-Off/Land	26	17	29	24	261	25	382 (248)
15	6 Autopilot System	26	17	58	48	58	25	232 (151)
4	7 Target Sensing and Acquisition System	78	17	261	240	261	75	666 (433)
14	8 Flight Control System	26	17	58	48	58	25	249 (162)
7	9 Crew Escape System	26	51	174	216	174	25	960 (624)
13	10 Propulsion Control System	26	34	58	48	58	25	993 (645)
2	11 External Data Input Systems	156	17	261	240	261	25	956 (621)
1	12 Crew Station	104	51	261	216	261	100	993 (645)
3	13 Threat Warning and Countermeasures System	52	34	290	240	290	50	956 (621)
6	14 Weapons Delivery/Fire Control System	78	17	232	240	87	75	729 (474)
9	15 Identification: Friend/Foe/ Neutral	26	17	174	144	174	25	560 (364)
10	16 Fuel Management	26	17	174	144	174	25	560 (364)
	TOTAL							9,419

---

*( ) values are scaled to Air-to-Air totals.

The total of the numbers in each horizontal column in Tables 1-5 and 1-6 can be used to rank each system or activity in terms of its importance to the overall mission. (Again, this ranking reflects a judgment of both how critical the system is to the mission, and how challenging it is to perform.) To derive a single number (instead of one for air-to-air missions and another for air-to-ground missions) to rank each system, the totals for each system in Tables 1-5 and 1-6 were added (after scaling down the values in Table 1-6 to give equal weight to both missions). The comparison of the two listings for air-to-air and air-to-ground missions correlates at the 90-percent level. The consensus of the two tables, equally weighted, is shown in Table 1-7.

To a first approximation, Table 1-7 suggests an order in which systems and activities could be considered for automation. A word of caution is necessary: some factors that influence whether a system should be automated may have been ignored by this methodology. There are undoubtedly anomalies in the rankings in Table 1-7, and further study is warranted.

Another consideration in determining the need for automation is the workload the pilot incurs when working with these systems in each mission phase. This consideration is illustrated by an interaction matrix showing the degree to which the pilot must use any two or more systems, or perform two or more activities, almost simultaneously (Table 1-8). Because the ingress, engage, and recover phases are the most work-intensive, the subcommittee constructed the matrix with these phases in mind.

Though the data in Table 1-8 generally agree with the earlier rankings of the importance and degree of challenge for each system (i.e., those systems considered to be challenging tend to involve a high number of interactions), there are some exceptions. Further study is warranted to understand why some systems are challenging and yet involve few interactions, and vice versa.

A PRIORITY FOR AUTOMATION

Although there are other concerns with respect to automating aircraft systems, it is possible to suggest where automation might be useful by examining in composite manner the two rankings: the importance of the systems and activities to the overall mission (Table 1-7); and the contributions of the systems or activities to pilot work load, as measured by the number of interactions required (Table 1-8). The data in these two tables were co-related. (The subcommittee hesitates to say "correlated.") The results are shown in Figure 1-1, where the subjective estimates of the importance of the systems and activities are displayed as functions of the systems interactions.

TABLE 1-7 Rank Order of the Importance of Systems and Activities to Mission Success, Averaged Over Air-to-Air and Air-to-Ground Missions

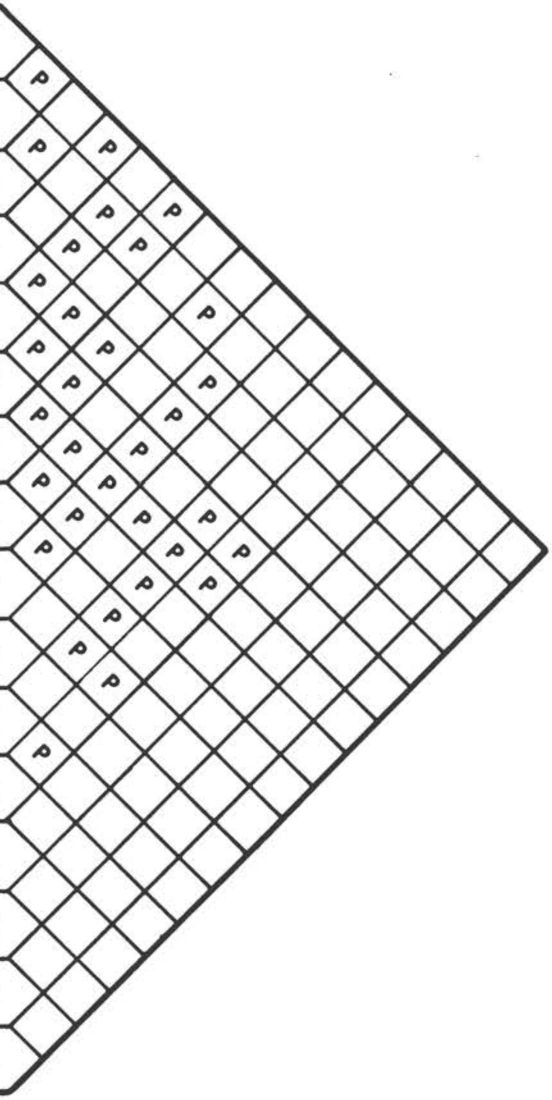
Rank Order	Total*	System and Activities
1	1350	External Data
2	1339	Threat Warning/Countermeasures
3	1290	Target Sensing/Acquisition
4	1182	IFFN
5	1135	Crew Escape
6	1068	Crew Station
7	927	Navigation
8	782	Weapons Delivery
9	660	Propulsion
10	624	Malfunction Warning/Reconfiguration
11	545	Fuel Management
12	346	Taxi/Takeoff/Land
13	302	Electrical Control
14	279	Flight Control
15	249	Autopilot
16	196	Hydraulic Control

---

*Sum of total weights from Tables 1-5 and 1-6.

TABLE 1-8 Interaction Matrix Showing Systems That Are Used Simultaneously**

Rank Order*	Means	No. of Interactions
15	Auto Pilot	(3)
12	Taxi/to/Land	(5)
7	Navigation	(3)
3	Target Sensors/ Acquisition	(5)
1	External Data	(8)
6	Crew Station	(10)
14	Flight Control	(6)
9	Propulsion Control	(5)
2	Threat Warning and Countermeasures	(8)
5	Crew Escape	(1)
8	Weapons Delivery/ Fuel Control	(6)
4	IFFN	(4)
10	Malfunction Warning/ Reconfiguration	(0)
13	Electrical Control	(0)
16	Hydraulic Control	(0)
11	Fuel Management	(0)



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*From Table 1-7.

**In the matrix, "P" emphasizes pilot interaction

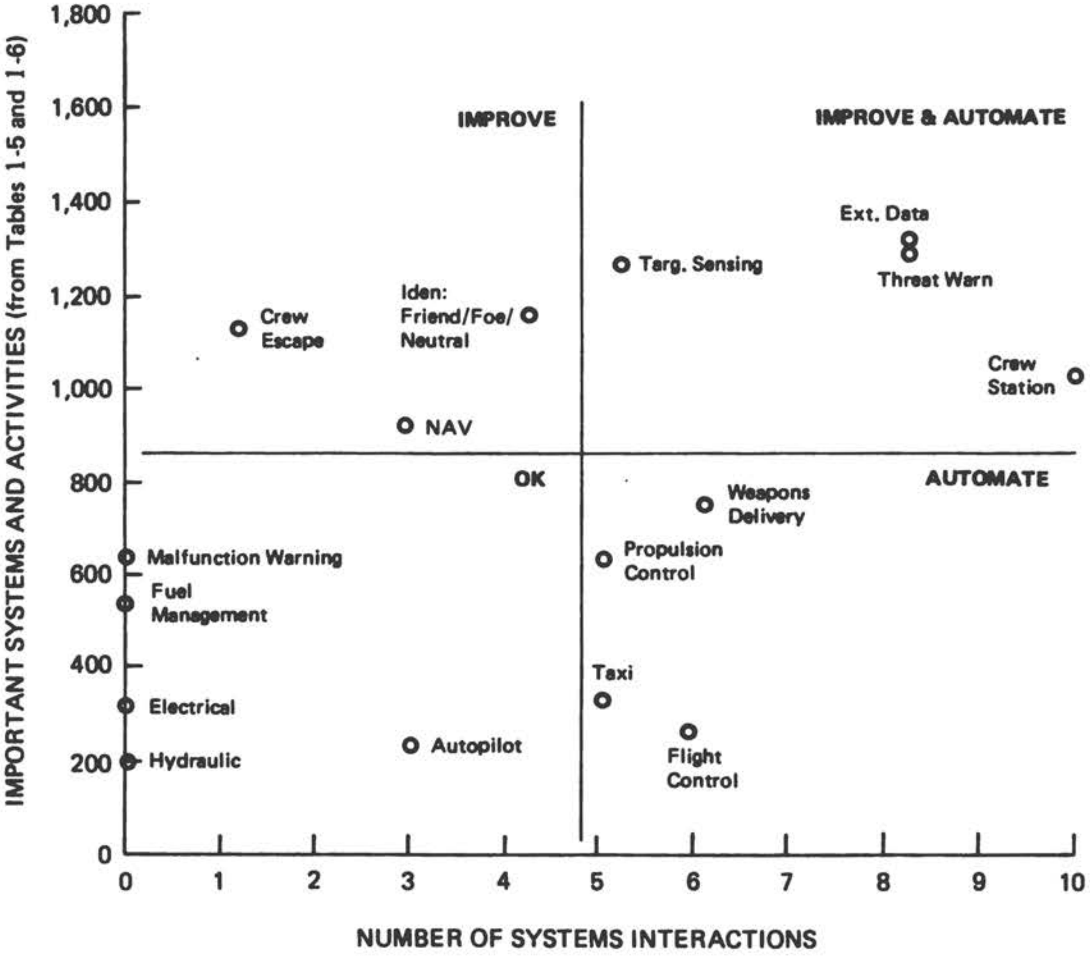


FIGURE 1-1 Estimates of system importance are shown as a function of the number of interactions (i.e., the degree to which a pilot must use two or more systems concurrently). This correlation allows systems to be grouped according to whether they need to be "improved," "improved and automated," or "automated," or are "OK" as they are.

In Figure 1-1, the data are divided into four quadrants, which group the systems and activities according to the degrees of challenge and numbers of interactions involved. High values on the ordinate indicate that pilots find these activities, given the state of the technology, difficult or risky to perform. Those systems and activities above the horizontal line (ordinate value of 800 and over) require attention to improve their design and performance; those below the line do not.

Because large sums on the abscissa suggest insufficient attention to pilot workload (since they signify large numbers of simultaneous interactions) the vertical line divides the systems into those that should be considered for automation to reduce workload (those with a value greater than 5 on the abscissa) and those that appear to impose a tolerable workload (those with a value less than 5).

On this basis, the quadrants in Figure 1-1 were labeled "Improve," "Improve and Automate," "Automate," and "OK."

The "improve" category (upper left quadrant) represents systems and activities that are challenging to use, and are thus of concern to the pilot, yet involve few interactions. At this time, these systems need to be improved to reduce their complexity from the pilots' standpoint. Once they are improved, then a decision should be made on whether to automate them.

The "improve and automate" category (upper right quadrant) represents systems and activities that are highly challenging to the pilot and involve high numbers of interactions. These systems must first be improved to reduce the pilots' concerns about them. When they are improved and perceived as less challenging they should be automated to reduce the number of interactions they involve.

The "automate" category (lower right quadrant) represents systems that have a high number of interactions but are not challenging or difficult for the pilot to perform. They are good candidates for automation at present.

The "OK" category (lower left quadrant) represents systems that are not challenging to the pilot and involve few interactions. They do not need attention.

The systems and activities that require improvement and/or automation are listed in alphabetical order in Table 1-9. (A rank order was not considered appropriate.) The systems and activities that are apparently mature enough, from the standpoint of design, for automation are listed in rank order in Table 1-10. It is the subcommittee's conclusion that the systems in Table 1-9 should be given attention before those in Table 1-10.

TABLE 1-9 Combat Aircraft Systems and Activities Requiring Attention to Design and/or Automation (in Alphabetical Order)

Systems and Activities
Crew Escape
Crew Station
External Data
IFFN
Navigation
Target Sensing/Acquisition
Threat Warning/Countermeasures

TABLE 1-10. Rank Order of Combat Aircraft Systems and Activities Mature Enough for Automation

Rank Order	Systems and Activities
1	Flight Control
2	Propulsion
3	Weapons Delivery/Fuel Control
4	Crew Station
5	Threat Warning/Countermeasures
6	External Data
7	Target Sensing/Acquisition

The data in Figure 1-1 can be used to describe further the potential for automation. For instance, these data can be used to examine groups of systems that are particularly important in combat missions. The subcommittee selected two groups: the target engagement group (target sensing, external data, crew station, and flight control), and the defense awareness group (navigation, external data, threat warning, and crew station).

Assuming a functional relationship between the importance of the systems (ordinate, y) and the number of interactions (abscissa, x) a linear regression of the data in Figure 1-1 was computed ($y \cong 400 + 100x$). This allowed an interpretation of the potential benefits of automating these two groups (target engagement and defense awareness), shown in Figures 1-2 and 1-3. The solid line linking the systems in the group plots the situation before automation, and the dotted line, that after automation. In each case, the number of interactions eliminated by automation is taken into account, and data points are replotted at an ordinate value less by 100 per interaction elimination. The subjective conclusion is that automation has greater potential for the target engagement group than for the defense awareness group.

This chapter has illustrated several methods of ranking systems for consideration for automation. The examples and conclusion included here are meant to describe an approach to the question; they are not, in and of themselves, intended to be a guide for the automation of combat aircraft.

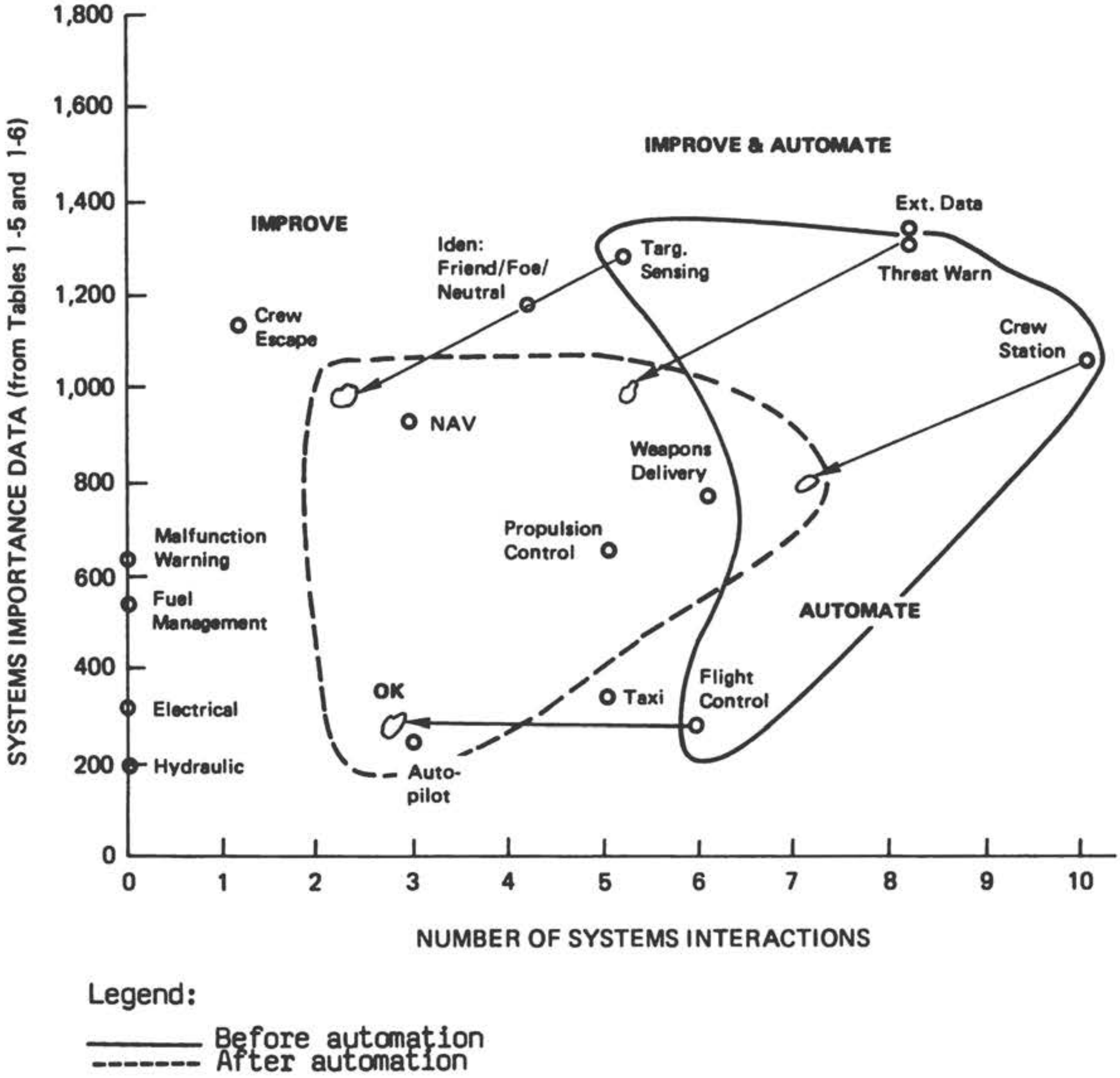
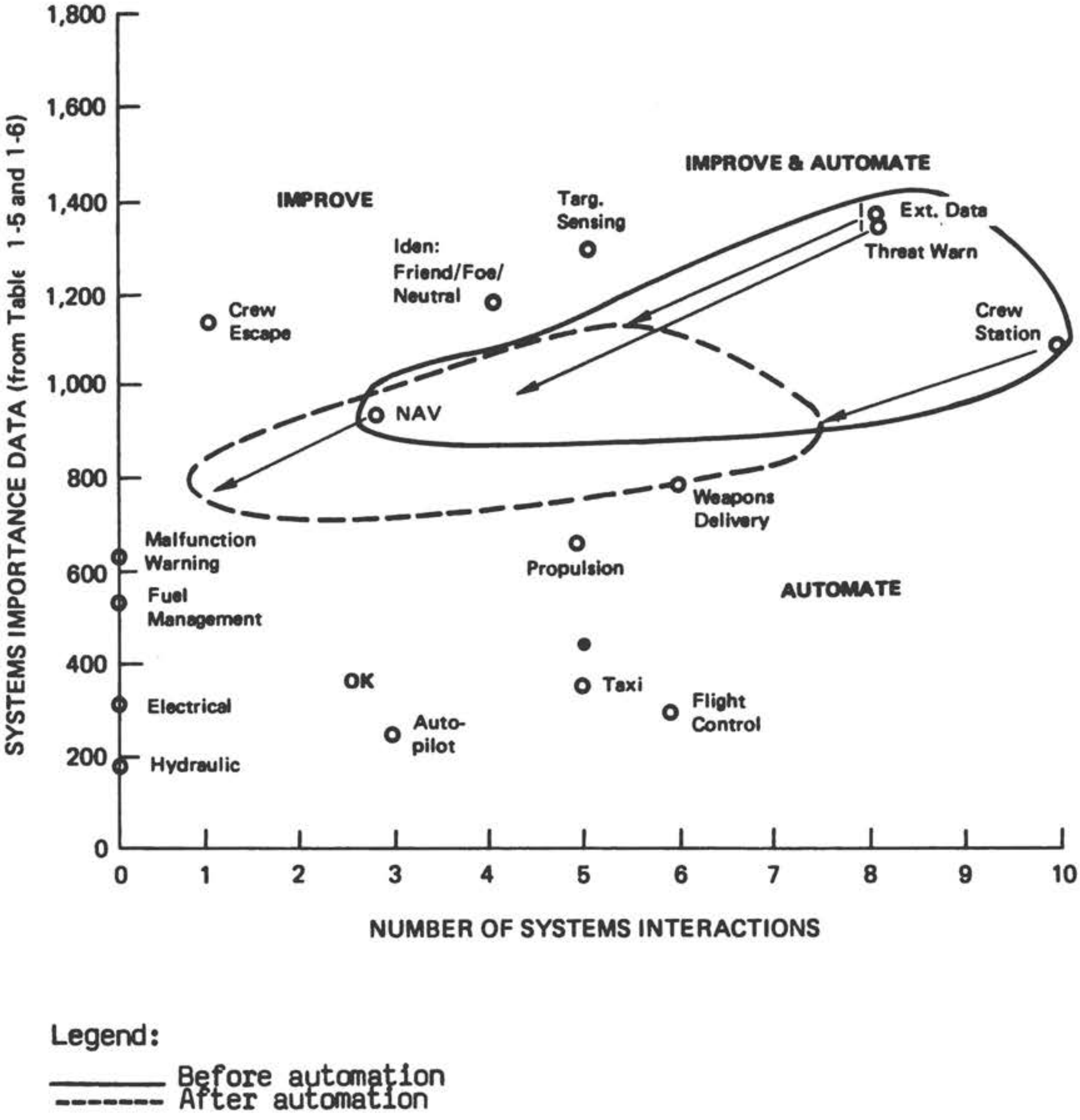


FIGURE 1-2 The effect of automation on reducing the difficulty and number of simultaneous interactions involved in the target engagement group (target sensing, external data, crew station, and flight control).



Legend:

——— Before automation

------- After automation

FIGURE 1-3. The effect of automation on reducing the difficulty and number of simultaneous interaction involved in the defense awareness group (navigation, external data, threat warning/countermeasures, and crew station).

Chapter 2

HUMAN FACTORS SUBCOMMITTEE REPORT

INTRODUCTION

The human operator is a crucial component of the combat aircraft system. Any attempt to automate combat aircraft--to allocate tasks between pilots and equipment--must be done in the context of human capabilities and limitations.

The subcommittee examined man as a systems component, discussing his abilities, such as perceptual skills, and limitations, such as a limited information-processing rate. Because of human limitations in the ability to process and assimilate information and to perform tasks, today's high-performance fighter aircraft may present an intolerable workload. If automation is to reduce pilot workload, and thus enhance performance, equipment must be matched to the pilot and his abilities.

In that context, the subcommittee examined the ways in which automation can be used to lessen pilot workload, as in reducing the number of concurrently performed tasks. Before recommending the types of automation that would assist the pilot, the subcommittee examined how pilots think about their tasks: how they process information and develop mental representations of these tasks. Human performance characteristics of the various controls and displays through which the pilot and the automated equipment interact should be the basis for the design of cockpit interfaces, and design is considered in that context.

Finally, guidelines are given for when and how to automate combat aircraft, as well as on how to avoid the pitfalls of automation. From these guidelines, the subcommittee then recommends research and activities necessary for the automation of combat aircraft in light of human factors considerations.

AUTOMATION AND PILOTS

The intelligent allocation of tasks between pilots and automated systems has long been recognized as a key problem in the development of aerospace technology (e.g., National Research Council, 1951). The committee's interpretation of automation as "those processes by which essential functions can be performed with partial, intermittent, or no intervention by flight crews" makes it clear that task allocation is not just a matter of dividing functions between pilots and equipment. Many functions will be best performed through the interaction of the pilot and the equipment. Nor, it should be clear, can tasks be allocated on the basis of a narrowly optimized consideration of whether men or machines can perform a given function "best," any more than an engineer would wire a plane with silver instead of copper conductors because it has a slightly lower resistance. As Fitts (1962) put it, "...a little reflection makes it clear that the central issue in choosing components for a complex system is usually not so much which component will do a better job, as which component will do an adequate job for less money, less weight, less power, or with a smaller probability of failure and less need for maintenance." In this chapter, we have therefore followed Fitts' (1962) approach of describing human capacities and limitations, rather than trying to list the ways in which man is superior to a machine and vice versa. (Examples of the latter are contained in National Research Council, 1951; Gagne, 1962; Woodson and Conover, 1964; and Woodson, 1981.)

Man as a System Component

Viewed as a component of a system, the human brings with him a certain number of capabilities and limitations. These includel(Table 2-1) "good perceptual" capabilities, a limited processing rate, a tendency towards certain types of error, flexible control, and specialized life-support requirements.

Humans are characterized by well-developed perceptual abilities (National Research Council, 1951; Cornsweet, 1970; Van and Warrick, 1972). The eye is so sensitive that it can detect the presence of as few as nine quanta of light, detect the flare of a match 15 miles away on a dark night, or the presence of a black wire one-sixteenth of an inch in diameter, viewed against the clear sky at a quarter mile. Of course these sensitivities occur only at certain frequencies in the spectrum. Perceptually, the human excels at such difficult tasks as recognizing faces, identifying objects, and comprehending continuous speech.

Humans are also characterized by a limited processing rate (Chapanis, Garner, and Morgan, 1949; Fitts and Posner, 1967; Harter, 1967; Welford, 1968; Newell and Simon, 1972; Ganz, 1975; Blumenthal, 1977; Ericksen and Shultz, 1978). Two events occurring closer together than about a tenth of a second will generally be perceived as a single event. The same time scale roughly holds for elementary cognitive processes (such as mental counting, or scanning a set of just-heard numbers for the presence of a given number) or elementary motor processes (such as tapping) with a range of 25-200 milliseconds/operation. An activity that requires integrated perception, decision, and motor action requires on the order of one-half second and results in the processing of something like 10 ⁓ 40 bits per second of information. A more complicated activity, in which some problem solving is involved, is likely to proceed along at more like

TABLE 2-1 A Few Characteristics of Man as a System Component

- Good perceptual abilities
    - Sensitive sound and light detectors
    - Good object recognition

- Limited processing rate
    - Limited input rate
    - Limited "thinking" rate
    - Limited motor-output rate
    - Largely single-channel operation

- Error prone
    - Limited precision
    - Capture errors
    - Sequence step omissions

- Flexible control
    - Can reprogram self
    - Adaptable
    - Poor monitor
    - Needs motivation

- Requires specialized life-support environment

---

5 seconds per step. A final limitation on processing rate is that the human is, with some minor exceptions, a serial processor of information. Attention to two or more activities requires rapid switching between the tasks.

Humans are prone to error in a number of ways (Van and Warrick, 1972; Norman, 1981). For one, there is a limit to the precision with which they can make judgments; they are able, for example, to distinguish among roughly seven colors or sounds when these appear alone. They are also susceptible to various types of execution errors, such as accidentally leaving a step out of a procedure (sequential errors) or mistakenly reverting to an old familiar procedure instead of an intended new one (capture errors).

Humans are characterized by flexible control (Mackworth, 1950; National Research Council, 1951; Newell, 1980). They can invent new procedures and adapt old ones to new circumstances. The other side of this flexibility is that they need to be motivated. They work best at tasks that provide activity and that are intrinsically interesting. Consequently, they tend to be poor monitors and watchkeepers.

Finally, humans require their own specialized life-support systems to function: maintenance of correct ranges of cabin pressure, temperature, humidity, ventilation, and oxygen. Performance is seriously affected by high acceleration, and humans require sophisticated emergency escape systems. Roughly speaking, the addition to the aircraft of another 150-pound man requires about 10,000 pounds of additional weight in support equipment.

These human capabilities have, of course, remained unchanged since the fighter aircraft of World War II were developed, but the tasks of the pilot have not. As a result of enhanced threats against combat aircraft, engineers have designed fighters to fly under more difficult operating conditions: close to the ground, at night, in bad weather, and at increasing speeds. Designers have used advances in electronics to make new types of offensive weapons, and they have designed aircraft that can respond to the threat of large enemy forces in certain areas by simultaneously attacking multiple targets.

All of these advances have caused a large increase in the number of tasks the pilot must perform, in the complexity of those tasks, and in the speed with which they must be done. This added complexity is reflected in the exponential increase in the number of both cockpit displays (Figure 2-1) and controls (Figure 2-2).

The result is a greater workload for the pilot. High workload induced by piecemeal automation may lead to errors, reduced accu-

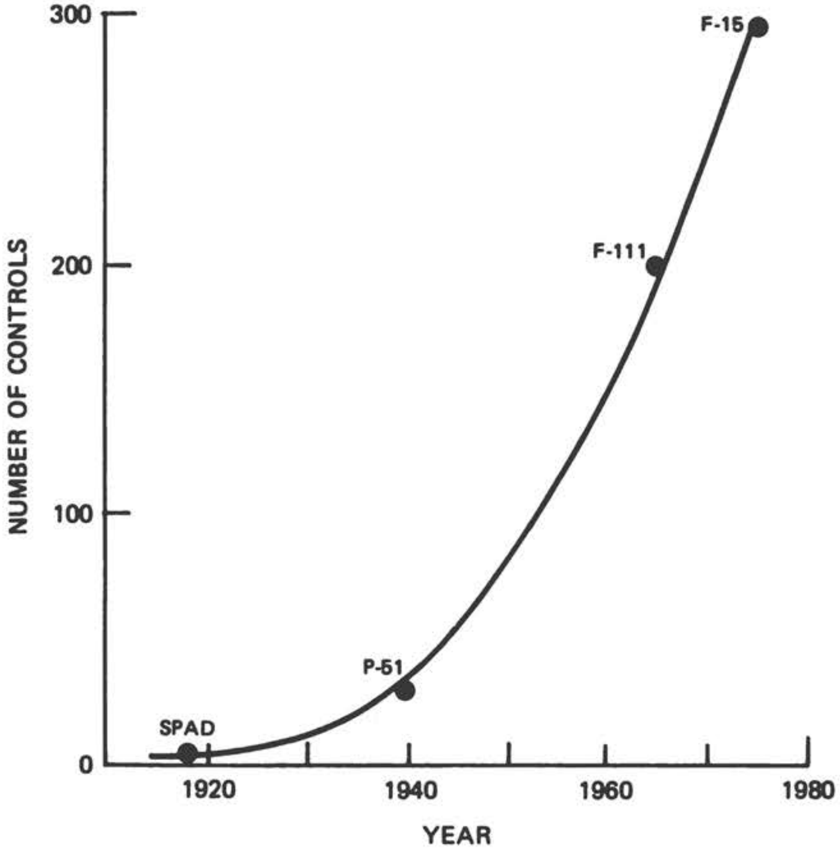


FIGURE 2-2 Number of cockpit controls per crew member in U.S. fighter aircraft, 1920 to 1980

racy, poor judgment, or nonuse of equipment. Automation offers possibilities for aiding the pilot. It provides the means to:

- Reduce excessive air crew workload
- Reduce errors
- Improve air crew performance
- Add new capabilities.

Of course automation is not the only means available for achieving these ends; alternatives such as revised procedures, improved training, or human engineering may be preferred choices in particular situations. Furthermore, realizing the potential of automation to enhance performance will depend on a careful analysis of a number of factors. Once sources of excessive workload are identified, automation can reduce that workload. But to reduce workload significantly, the design of an automated task and its cockpit displays and controls must be carefully matched to the pilot and his cognitive processing during combat. This, in turn, requires an understanding of pilots' mental representations (the formats in which they store information in their minds), the performance characteristics of the controls and displays through which the pilot and the automated systems interact, and human performance generally. Past human-engineering studies have provided considerable data on the perceptual and motor aspects of the interaction between humans and machine; successful human engineering of automation-enhanced manned cockpits will require increased attention to the cognitive (as opposed to the perceptual and motor) aspects.

Automation and Pilot Workload

There are several different, but related, sources of pilot workload for which some application of automation may be beneficial:

- Perceptual saturation
- Concurrently performed tasks
- Time-line compression
- Pilot bandwidth limitations
- Small-scale, routine operations.

Each of these poses its own problem for the pilot.

Perceptual Saturation

A number of critical events may occur at the same time, such as when several missiles simultaneously attack the aircraft. Since the human pilot is a serial processor and requires appreciable time for action, he may have great difficulties even keeping track of the threats.

Concurrently Performed Tasks

Pilots may have to operate several pieces of equipment concurrently. Figure 2-3 shows a time-line analysis of the activities in a current fighter, the AV-8B (for which data were available to the committee), during an air-to-ground (close air support) mission. The total time in the mission is 280 seconds, from loiter to bomb drop. The 16 systems and activities analyzed by the Functions Subcommittee are listed on the side. A shaded box is drawn if that system is used during a given 10-second interval. Up to six of the systems and activities listed in Figure 2-3 were operated within any 10-second period. This can be determined by drawing a vertical line anywhere in the figure. It will intersect six systems at most. Such shifting between tasks may cause errors because of the extra demands placed on pilots' memories.

Some systems of the aircraft interact with other systems more than with others. For the time-line used in Figure 2-3, Table 2-2 shows the number of times systems in the AV-8B fighter were used concurrently within the 10-second intervals. The systems that interact the most with other systems are threat warning and countermeasures, flight control, external data (largely communications), target sensing and acquisition, and weapons delivery.

Table 2-3 shows a similar analysis for an F-16 air-to-ground (close air support) mission. This figure reports the number of times the pilot is expected to shift his visual attention from one system to another. The results are similar; the systems that interact most with others are, by this analysis, flight control, threat warning and countermeasures, navigation, target sensing and acquisition, external data, and weapons delivery. Additional automation to reduce the number of concurrently performed tasks associated with these systems could help to reduce pilot workload.

Time-Line Compression

Because of the speeds at which encounters with the enemy occur, only limited time is available for judgment and action. For example, consider a head-on encounter between an F-15 and an enemy aircraft. For the F-15 pilot to fire a shot at the enemy from the maximum distance possible, he must perform the following tasks by the time the enemy is within range of his sidewinder missiles:

- Identify the other aircraft
- Communicate the presence of the enemy aircraft
- Hear the tone that indicates his missile is tracking

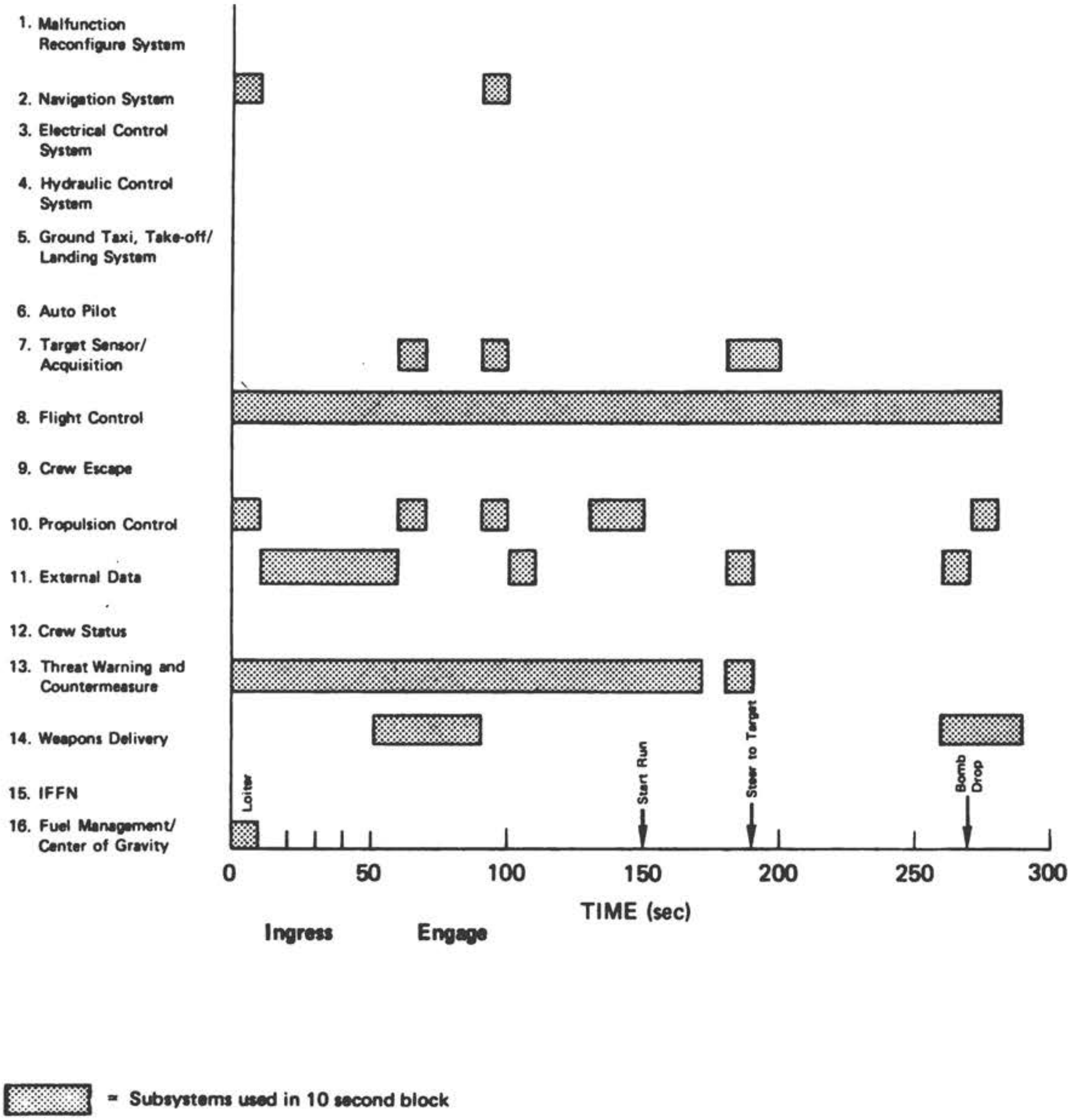


Figure 2-3 A time-line analysis of the activities of a current fighter, the AV-8B, during an air-to-ground mission

TABLE 2-2 Number of 10-second Intervals in Which Two Systems Were Used Concurrently*

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total Interactions
1	Malfunction/ Reconfigure																0
2	Navigation																⑨
3	Electrical Control																0
4	Hydraulic Control																0
5	Take-off/ Land																0
6	Auto Pilot																1
7	Threat Sensors/ Acquisition		1														⑭
8	Flight Control		2					4									㊼
9	Crew Escape																0
10	Propulsion Control		2					2	⑥								⑲
11	External Data		1					3	⑩		1						㉕
12	Crew Station																0
13	Threat Warn. and Countermeasures		2					3	⑱		⑤	⑧					㊶
14	Weapon Delivery							1	⑥		2	2		4			⑮
15	IFFN																0
16	Fuel		1						1					1			4

---

*Based on the 280-second air-to-ground mission described in Figure 2-3

NOTE: The larger numbers in the diagram have been circled to help them stand out.

TABLE 2-3 Number of Visual Attention Shifts Between Two Systems*

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
1	Malfunction/ Reconfigure																	0
2	Navigation								4			1		1	1		1	8
3	Electrical Control																	0
4	Hydraulic Control																	0
5	Take-off/ Land																	0
6	Auto Pilot																	0
7	Threat Sensors/ Acquisition								1					1				2
8	Flight Control										4	1		5	2		1	18
9	Crew Escape																	0
10	Propulsion Control											2		2	2		1	11
11	External Data													1				5
12	Crew Station																	0
13	Threat Warn. and Countermeasures																	10
14	Weapon Delivery																	5
15	IFFN																	0
16	Fuel																	3

---

*For an air-to-ground (close air support) mission in an F-16; ingress and engage phases only (Hanson, Jones, Macek, Peters, and Sanvig, 1979)

NOTE: The larger numbers in the diagram have been circled to help them stand out.

- Uncage his missile
- Ensure that the missile is tracking well by looking at his heads up display (HUD)
- Determine that the enemy is within the weapon's range
- Shoot the missile
- Plan his next move
- Wait 0.4 sec before the next missile comes off the rail
- Determine whether another shot is necessary.

At a closing rate of 2,000 feet per second, all this would have to happen within 2-3 seconds. The difficulty of performing these tasks in such a short period, given the performance times that characterize the human, suggests that missions would benefit from additional automation to eliminate some of these tasks or enable pilots to perform them faster.

Pilot Bandwidth Limitations

Humans are limited in the rate at which they can perform manual tasks. This characteristic is referred to here as pilot bandwidth limitations. Because the pilot needs on the order of one-half second to make a control adjustment, he is incapable of manually controlling aircraft that require much more than two corrections per second. Because the frequency of control adjustments required in the F-16 exceeds this human capability, the plane cannot be flown on a strictly manual basis. In such cases, automation is necessary to building a plane with certain performance characteristics. Other research (Roscoe, 1980) has shown that reducing the control order for flight control improves pilot performance.

Small-Scale Routine Operations

Operations that require numerous small steps can significantly increase pilot workload. Such tasks are time-consuming, they are prone to error because a step may be skipped, and they impose a memory load on pilots that may cause errors in the performance of other tasks. For example, to start operating the inertial navigation system (INS) prior to takeoff in an F-15, the pilot must:

1. Turn on the gyro compass mode
2. Type in the present position
3. After 3 minutes note a solid alignment light
4. After 9-14 minutes note a flashing alignment light
5. Turn the system to INS (operate state).

All the pilot wants to do is to turn the system on.

Matching Planes to Pilots

While, at one level, the pilot is flying the plane, firing its armaments, etc., at another level he is performing a set of abstract tasks, such as putting a cursor in a box on a cathode-ray tube (CRT) --instead of looking into the sight for the proper alignment for missile launch. This illustrates one advantage of displays based on automation: they allow greater freedom in substituting an equivalent easier task for a given more difficult one.

A second advantage is that if tasks are converted into a common digital medium, they can be integrated. An example is the coding of the surface-to-air missile threat into a flying task of avoiding an obstacle (as in the advanced electronic terrain mapping system [AETMS]). When a pilot is within range of surface-to-air missiles, the warning is displayed as a visual obstacle around which the pilot must fly. Automation in this case requires that pilots perform a single task, similar to avoiding a small cloud, rather than performing two completely separate tasks.

Automation can thus reduce the pilot's workload if it provides displays and controls that match the pilot's mental representations of his tasks--how he represents the real world in his memory. To the extent these do not match, pilots must perform additional mental operations to translate back and forth between displays or actions and their mental representations.

Increasing the ability to match automation to the pilot's representation would seem to rest on the further development of three areas of the technology base:

- An improved understanding of pilots' mental representations of their tasks
- Documentation of human performance characteristics for the generic components of cockpit designs
- Codification of the human performance science base.

Pilots' Mental Representations

Flying a combat aircraft is certainly an example of a high-level cognitive skill. As such, it is interesting to consider combat piloting in light of what has been learned about other cognitive skills, such as playing chess (Chase and Simon, 1973a, 1973b; Simon and Gilmartin, 1973; Charness, 1976). These studies show that chess skill has an important perceptual component. Chess masters consider fewer possible moves than do novices, for example. In fact, they usually plan a move in about 5 seconds. Unlike novices, masters can reproduce a chess board they have seen for only 5 seconds if the pieces are in a tactical arrangement. If the pieces are randomly placed, however, the masters have no advantage.

By looking at the way a chess master reproduces the play of the board, one can see that the chess master's mental image of the board consists of groupings of pieces, such as pawn chains, rather than the positions of individual pieces. He can remember tactical chess positions more easily than the novice because, as the result of this grouping, there are fewer things to remember. Studies of the cognitive skills used in Go, electronics, bridge, music, and physics yield similar results (Reitman, 1976; Sloboda, 1976; Engle and Bukstel, 1978; Egan and Schwartz, 1979; Larkin et al., 1980).

In light of the research on chess and other cognitive skills, one might expect that combat piloting, especially in the tactical air-to-air mission, would have a similarly demanding perceptual component and that in combat each tactical decision might require an average of 5 seconds (with a range of roughly 2-20 seconds). Furthermore, one might expect an experienced fighter pilot to develop mental representations for tactical patterns (i.e., to group these moves together in his mind) to enhance his ability to keep track of large amounts of information. Therefore, an understanding of the pilot's mental process, gained through an extension of the methods applied to other cognitive skill tasks, should be useful in designing cockpits. For example, discussions with air-to-air pilots served to emphasize the importance of what the pilots called "situational awareness." The fact that 75 percent of pilots "shot down" in the Red Flag training exercise never saw their attackers documents the problem.

A common characteristic of cognitive skill is the expert's ability to think in terms of larger scale units. Expert computer programmers, for example, may consider the effects of four or five assembly language instructions that do an integrated task as one of their building blocks, rather than in terms of what a single instruction may do. Similarly, pilots' representations of their tasks are likely to be in terms of "pop-ups," defensive "jinks," and other tactics, rather than in terms of the complicated control manipulations by which these maneuvers are effected. Automation that would make such maneuvers easy to perform (the simple button on the F-15 and F-16 that sets up all the displays and armaments for a dogfight), or provide pilots with information that would enable them to react faster, as in identifying approaching missiles so as to know the proper "jink" to use, would probably be worthwhile.

Human Performance Characteristics of Cockpit Components

Successful design of automated systems also depends on an understanding of how pilots respond to and use the individual components in cockpits. Although there are great numbers of automated devices aboard modern aircraft, only a modest number of techniques have been used to create the interfaces between these devices and the pilot.

Much research on human performance characteristics in aircraft cockpits has focused on the numerous dials and knobs that are used to convey information to the pilot, or are used by the pilot to perform his tasks. But as technology advances, these dials and knobs are being replaced by multipurpose cathode-ray tube displays, computer menus, and control sticks containing buttons. Theories and data relating human performance to these new methods will be essential in the design of future cockpits; much existing data on dials and knobs are no longer applicable. (See Ramsey and Atwood, 1979; Brown et al., 1980; Davis and Swezey, 1981, for the current state of the art in this area.)

As an example, one area in which research would be helpful is in methods for designating items on a display. Several methods are possible, such as the use of push-button menus, a system in which a button carries different sets of instructions according to which mode is selected; dedicated buttons, a system in which each button carries only one instruction; or cursors that are controlled from the throttle.

Each of these methods has its own performance characteristics. For example there are already theory and data about devices that move cursors on a cathode-ray tube (Card, English, and Burr, 1978), as well as research on the design alternatives. According to this theory, a person with an optimal device should be able to move a cursor and select a target in a time given by Fitts's Law (Welford, 1968):

$$\text{Movement time} = K + 0.1 \log_2 (D/S + 0.5) \text{ second,}$$

where D is the distance on the CRT between where the cursor starts and the target, S is the width of the target, and K is a constant, usually about 1 second. A spring-loaded isometric joystick with velocity proportional to the square of the force (like that on the F-16) will probably be slower, moving the cursor with a constant of proportionality of about twice the optimal rate:

$$\text{Movement time} = K + 0.2 \log_2 (D/S + 0.5) \text{ second.}$$

This cursor-moving device may make it more difficult to position the cursor on the target and may have higher positioning error than the optimal device. The tradeoff of speed for convenience of location may be necessary in the context of a certain cockpit. But designers must have models and performance profiles for the various cockpit components in order to understand the tradeoffs they are making.

Codification of the Science Base for Human Performance

Designing the controls and displays with which pilots operate airplanes rests largely on the following:

- A data base of past experience with controls and displays (now partly obsolete because of technological change)
- Time-line analysis tools, such as the McDonnell Aircraft Pilot Simulation Model and the workload analysis techniques of General Dynamics and others
- Simulation
- Flight testing.

At present, there are few practical models of human performance that can be used to design automated systems for pilot use. There are excellent models that describe human performance of manual control tasks, and these have been of assistance to cockpit designers in the past. There is a need for similar models to describe human performance with automated aircraft equipment.

Research in cognitive psychology is yielding some results on human performance that can be valuable in this area. If properly codified, these data might provide the science base to support the development of needed practical models. At present, the data are not in usable form; the sets are contradictory and need to be analyzed. Also, many studies are aimed at refining theory, rather than developing the approximation models needed in engineering design. Nevertheless, the results on chess and on moving cursors cited above are evidence that this emerging body of knowledge could be tapped to provide substantial insight into the design of future combat aircraft. A few models of the application of contemporary cognitive psychology to system design problems already exist (Pew *et al.*, 1977; Lane, Streib, and Leyland, 1980; Baron *et al.*, 1980; Card, Moran, and Newell, forthcoming). The Lane, Streib, and Leyland study has been used for time-line simulation in naval avionics. Baron's study has been used to research the behavior of air carrier crews in performing rapid sequences of tasks. Further work may yield analytical tools and practical handbooks that could significantly enhance designers' ability to engineer the controls and displays required for automated aircraft equipment.

AUTOMATION GUIDELINES

This section suggests guidelines on the types of functions that might be automated, how to automate them, and then warns against some pitfalls designers have encountered. The guidelines (summarized in Table 2-4) arise from the briefings given to the subcommittee, especially the TAC briefings (summarized at the end of this chapter), and from experience in the automation of commercial aircraft (Wiener and Curry, 1980). These guidelines are not complete, but are representative of the information that needs to be developed in more detail to enable the effective automation of combat aircraft. Consequently, these guidelines should not be considered

TABLE 2-4. Automation Guidelines For Combat Aircraft

- When to Automate
  - To reduce excessive workload.
    1. Consider automating to avoid perceptual saturation.
    2. Consider automating to reduce concurrent tasks.
    3. Consider automating tasks on compressed time-lines.
    4. Consider automating to avoid pilot bandwidth limitations.
    5. Consider automating to eliminate or consolidate small-scale operations.
  - To reduce errors
    6. Consider automating routine tasks.
    7. Consider automating memorization tasks.
    8. Consider automating sequential and timed tasks.
    9. Consider automating seldom-performed tasks.
    10. Consider automating monitoring tasks.
    11. Consider automating tasks pilots find boring and unmotivating.
  - To improve performance
    12. Consider automating precision tasks.
    13. Consider automating emergency-prevention devices.
    14. Consider automating complex mathematical or logical tasks.
  - To add new capability
    15. Consider automating to avoid the combination of low-altitude flight and any other task.
    16. Consider automating complex tasks that must be performed rapidly.
- How to Automate
  - Control tasks
    17. Design aircraft controls and displays to be compatible with pilots' mental representations of the tasks.
    18. Use automation to eliminate peak task demands.
    19. Provide optional capability for manual operation of the system.
    20. Allow for different pilot styles.
  - Monitoring tasks
    21. Keep false-alarm rate low.
    22. Provide operationally-relevant information.
    23. Allow for pilot query.
    24. Design alarms to indicate the extents of emergencies.
    25. Expose pilots to all alerts and to important combinations.
  - Planning and Tactical Maneuvers
    (Research needed)
- Pitfalls of Automation
    26. Beware of reliability and maintenance problems in complex systems.
    27. Beware of unnecessary use of automation.
    28. Beware of the lack of pilot acceptance.
    29. Beware of substitution of emergency backup systems for main systems.
    30. Beware of the loss of pilots' manual skills.
    31. Beware of increased training requirements.
    32. Beware of failure modes for complex systems.
    33. Beware of system inflexibility or unmodifiability.
    34. Beware of unknowns.

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specifications; they lack the necessary detail, and they may conflict with one another under some conditions. Finally, the subcommittee stresses that if automation is to be implemented successfully, good human-engineering practices must be followed in designing automated devices.

When to Automate

We have already identified four ways automation can aid the pilot:

- Reducing excessive workload
- Reducing errors
- Improving pilot performance
- Adding new capabilities.

These opportunities for automation are distinct, but not independent. An improvement that reduces workload during critical periods, for example, will probably also reduce error and improve pilot performance. It may enable pilots to perform tasks that were previously impracticable, thereby adding a new capability. The guidelines suggest areas in which automation may improve pilot performance and mission effectiveness. Determining whether there is a net improvement to be gained in a specific instance requires, of course, detailed study of the tradeoffs with other factors that might negate advantages (for example, added weight, reduced total system reliability, or cost).

Automating to Reduce Excessive Workload (Guidelines 1-5)

Guideline 1. Consider automating to avoid perceptual saturation.
Guideline 2. Consider automating to reduce concurrent tasks.
Guideline 3. Consider automating tasks on a compressed time-line.
Guideline 4. Consider automating to avoid pilot bandwidth limitations.
Guideline 5. Consider automating to eliminate or consolidate small-scale operations.

We have already discussed these previously. Examples of automation directed at these sources of workload are automatic target-acquisition and flight-control automation that reduce the pilot's control order.

Automating to Reduce Errors (Guidelines 6-11)

Guideline 6. Consider automating routine tasks.

The high frequencies with which many routine tasks occur make them candidates for errors (even if their error rates are low), and the well-defined nature of these tasks makes them easy targets for automation. By contributing to pilot workload, routine chores cause errors in other tasks. Examples of routine tasks that might be candidates for automation are fuel center-of-gravity management, flight planning, and data loading.

Guideline 7. Consider automating memorization tasks.

Designers can use automation to simplify tasks requiring both short- and long-term memory. Examples of memorization tasks are emergency responses and tasks involving detailed knowledge of the aircraft.

Guideline 8. Consider automating sequential and timed tasks.

A common error is to leave a step out of a sequence or to do one step twice (Norman, 1981). This may occur, for example, when changing the IFFN squawk or when sequencing fuel, selecting weapons, or arming weapons.

Guideline 9. Consider automating seldom-performed tasks.

Pilot performance of infrequent tasks may be lower than it is for the more frequent tasks. In such cases, automation can be used to place a "floor" under pilot performance. Examples include emergency responses and fault diagnosis.

Guideline 10. Consider automating monitoring tasks.

Monitoring is a task humans perform poorly. Moreover, this is a major source of workload in an advanced fighter, because of the large number of items that must be monitored. Therefore, it may be worthwhile to automate the monitoring of engine temperature, electronic countermeasures during engagement, and surface-to-air missiles.

Guideline 11. Consider automating tasks pilots find boring and unmotivating.

Pilots work best at active tasks that are intrinsically interesting (National Research Council, 1951). A certain kind of motivation and interest is required in a good fighter pilot. The pilots interviewed by the subcommittee appeared highly motivated by the operation of the aircraft itself and by their achievement in tactical maneuvers. Such intrinsic motivation is probably an important factor in the recruitment, retention, and performance of air crews and should be considered in the design of pilot tasks.

Automating to Improve Performance (Guidelines 12-14)

Guideline 12. Consider automating precision tasks.

The benefits of automating to obtain greater accuracy than pilots can achieve in important precision tasks, such as gun tracking, following and avoiding terrain, controlling engines, and landing when visibility is low, are obvious.

Guideline 13. Consider automating emergency-prevention devices.

The use of automation to help prevent departures from controlled flight, running out of fuel, or the like can not only reduce the incidence of these emergencies, but can also free the pilot to concentrate on his tactical tasks. Examples are angle-of-attack and g-force limiters, as in the F-16, and stall indicators, as in the F-111. Care needs to be taken, however, that aircraft performance is neither reduced nor made more predictable to an enemy.

Guideline 14. Consider automating complex mathematical or logical tasks.

Complex mathematical tasks are an area in which automation can greatly improve mission performance. Examples are simplifying computations of automatic ballistics and parameters, warning of the enemy weapon fragmentation envelope, automatic weapons release, continuously computed impact points (CCIP), and flight-path vectors on the heads up display (HUD).

Automating to Add Capabilities (Guidelines 15-16)

Guideline 15. Consider automating to avoid the combination of low-altitude flight and any other task.

Briefings and interviews with pilots emphasized that flying at very low altitudes and avoiding collision with the ground effectively prohibit pilots from engaging in other concurrent activities, such as responding to enemy threat warnings or taking care of malfunctioning systems.

Guideline 16. Consider automating complex tasks that must be performed rapidly.

Some tasks involve such sophisticated calculations and must be performed so rapidly that they virtually cannot be completed without automation. These tasks include electronic countermeasures and electronic counter-countermeasures.

How to Automate

There appear to be three dimensions along which automation can proceed (Figure 2-4): (1) automation of control tasks, (2) automation of monitoring tasks, and (3) automation of tactical and planning tasks. The subcommittee grouped the guidelines accordingly.

Automation of Control Tasks (Guidelines 17-20)

Guideline 17. Design aircraft controls and displays to be compatible with pilots' mental representations of the tasks.

A compatible system will reduce the number of mental operations the pilot requires to perform the task, leading to a reduction of the pilot's workload and probability of error.

Guideline 18. Use automation to reduce peak task demands.

Peaks in pilot workload can be reduced by automating tasks or parts of tasks. Pilot workload can also be reduced by shifting parts of tasks to more relaxed times in the missions.

Guideline 19. Provide optional capability for manual operation of the system.
Guideline 20. Allow for different pilot styles.

The environment in which the combat pilot works may be very unpredictable. The pilot should be allowed to overcome system inadequacies and failures. Since pilots are highly skilled, competitively selected, and highly trained, differences in pilot styles are probably not capricious but instead reflect methods individual pilots have discovered for improving performance. Pilots should, therefore, be allowed to operate automatic equipment according to their own preferences so long as system performance and safety remain within tolerable limits. Moreover, automation can be used advantageously when pilots are not as proficient as they should be.
The advice of these last two guidelines may be summarized as:

> "Use automation to put a floor but not a ceiling, on performance."

Automation of Monitoring Tasks (Guidelines 21-25)

Guideline 21. Keep the false-alarm rate low.

Monitoring systems with high false-alarm rates are often ignored or turned off. Unfortunately, it is difficult to define the maximum tolerable false alarm rate because it depends, among other things, on how critical the alarm is and on the phase of the mission.

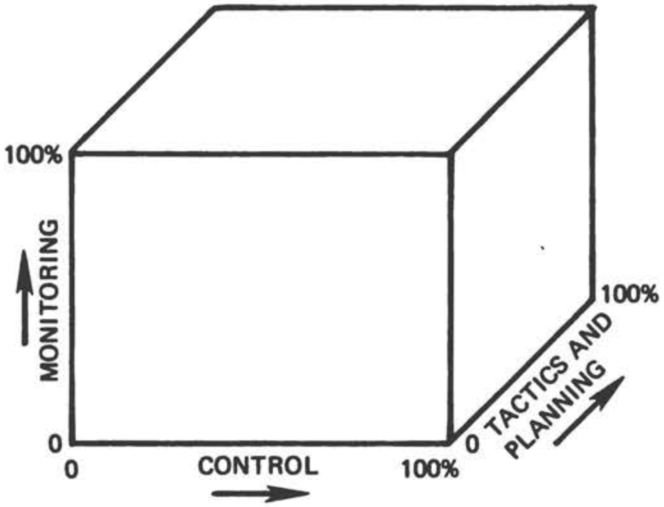

FIGURE 2-4. Automation can proceed along three dimensions: the automation of control tasks, the automation of monitoring tasks, and the automation of tactical and planning tasks.

Guideline 22. Provide operationally-relevant information.

This guideline is intended to reduce the pilots' mental operations and to increase their acceptance of automated systems. Pilots are most likely to accept monitoring systems that give them specific information about malfunctions; a display reading "low voltage" is less useful than one that says "generator off line," which is less useful than a display of capabilities lost or retained. Suggestions for remedial or compensatory action are also helpful. The danger in systems that provide diagnostic information and recommend remedial action is that they may be incorrect in unforeseen circumstances.

Guideline 23. Allow for pilot query.

Pilots may wish to query the system to verify an alarm (or lack of an alarm). Although this seems to be a useful mode of operation, actions critical to safety of flight should not rely on pilot action. The "stick pusher" system is one example of a critical action that has been automated.

Guideline 24. Design alarms to indicate the extents of emergencies.

An alarm that indicates the extent of an emergency enables pilots to allocate their attention time most effectively during crises. Current design philosophy is consistent with this guideline; alarms are classified as either warnings that require immediate action, cautions that require less immediate action, or advisories that require no action.

Guideline 25. Expose pilots to all alerts and to important combinations.

Multiple alerts arising from a single cause can be confusing when seen for the first time. Using a part- or whole-task simulator to expose the pilot to the alert system will reduce the errors caused by misunderstanding.

Automation of Planning and Tactical Maneuvers

Certain planning and tactical tasks must be completed, in advance, by either hours (as in mission planning), minutes (as in long-range engagement), or seconds (as in dogfighting). Because our experience in this area is more limited, guidelines for these tasks were not as easy to list as those for control and monitoring tasks. The subcommittee's discussions with pilots indicated, however, that two previous guidelines apply to planning and tactical tasks: guideline 17 (controls and displays should be compatible with pilots' mental representations of tasks) and guideline 20 (different pilot styles should be accommodated).

The task of planning a mission over a long period (hours) and subsequently loading data in bulk into flight computers can be automated. Pilots would like assistance in all phases of the mission: ingress, engagement, and egress. Factors to be considered during a mission include exposure to threats and the angle of the sun. These variables must be included in the program if automatic planning is to be of optimal use to the pilots.

Pilot performance of both planning and tactical maneuvers over a moderate period (minutes) could be assisted by decision aids. Similar aids have been developed to aid tactical officers during antisubmarine warfare in the deployment of sensors. It appears that pilots' preferences regarding types of weapons and offensive versus defensive positions can be incorporated into aids for ranking targets, making tactical maneuvers, and other decisions.

Automating tasks for short preparation periods (seconds) may be most worthwhile. For example, algorithms could be used to assist in maintaining "situational awareness" or aid in planning future moves.

The greatest impediment to implementing these short-term aids is the lack of tactical information in the plane's computer. The combination of information from sensors and the pilot's thoughts and observations will determine the utility of such aids. Simulation of sensors and aircraft that shows actual time elapsed would be extremely useful in dictating sensor designs and arrangements for these functions.

Pitfalls of Automation
(Guidelines 26-34)

Aircraft automation has been a learning process, involving exploration of opportunities offered by advancing technology and changing design concepts. Consequently, efforts to delegate or partially delegate flight tasks to machines have not always been immediately successful. In fact, some attempts have had adverse consequences. A study of pitfalls encountered in the past can refine current thinking about what and how to automate.

Guideline 26. Beware of reliability and maintenance problems in complex systems.

Because hardware and software systems have become increasingly complex, extra effort is necessary to achieving acceptable reliability and maintenance. Without this effort, errors and malfunctions seem to increase with the numbers of functions these systems perform. The adverse effects of system complexity on reliability and maintenance of aircraft should be borne in mind.

Guideline 27. Beware of unnecessary use of automation.

There are at least six alternatives to automation that can enhance the combat performance of pilots and aircraft: (1) improving human engineering in cockpit design, (2) improving procedures, (3) training pilots, (4) selecting pilots, (5) changing the compositions of crews, and (6) coping with stress and improving motivation. All six should be considered in pilot automation trade-off analyses.

Guideline 28. Beware of the lack of pilot acceptance.

Past experience has shown that unless pilots accept automation, they will not use it. Acceptance has not always followed the introduction of automation. If they judge an automated system as useless or unreliable, they will simply turn it off and find another way to perform necessary tasks. Designers should elicit pilots' opinions and suggestions at an early date.

Guideline 29. Beware of the substitution of emergency backup systems for main systems.

Automated systems designed for backup monitoring have been used as primary systems by commercial pilots. It is wise, therefore, to make sure that backup systems are at least as reliable as primary systems and are acceptable to pilots.

Guideline 30. Beware of the loss of pilots' manual skills.

An unanticipated consequence of the automation of commercial aircraft (human factors of flight-deck automation) was the overuse of automation by pilots and, as a result, a significant decline in their proficiency when flying manually (Boehm-Davis _et_ _al_., 1981). In some instances, pilots have had to be retrained.

Guideline 31. Beware of increased training requirements.

Although an attempt should be made to minimize the transition training required, in all cases training must be both feasible and adequate.

Guideline 32. Beware of failure modes for complex system.

Failure in some automated systems has been difficult to detect, and failure has emerged in unanticipated areas.

Guideline 33. Beware of system inflexibility or unmodifiability.

Unless care is taken, automated systems can critically limit user options instead of increasing them. That is, they can put a "ceiling" on performance. For example, hardware and software appropriate for an air-to-air mission may be designed so that it could not be converted to an air-to-ground mission either at base or in flight. The best of all worlds, of course, would be to strive for systems with versatility, flexibility, and possibilities for modification. These could be a means not only of building a sounder approach to future aircraft development, but also of better responding to unanticipated operational conditions.

Guideline 34. Beware of unknowns.

Unanticipated combinations of conditions may limit a system. To the extent possible systems should be designed with conscious effort to avoid surprises. Other precautionary measures include thorough and exhaustive systems analysis and design, a rigorous trial of the hardware and software in the most realistic simulator available--by the type of people who will use the equipment--and then flight and field testing to validate performance and production decisions. To date, there is no substitute for these tests and preconditions.

Summary

These guidelines for automating fighter aircraft are not complete, but represent the type of information that must be developed in more detail to ensure effective automation. Individual guidelines should be regarded with varying levels of confidence. Confidence could well be high for guidelines concerning routine, easily understood, and easily automated tasks. These include guidelines that would free pilots from a host of monitoring duties, memory and number-crunching exercises, and the constant attention to precise and sequential tasks. The committee is less certain, however, about guidelines for complex systems and tasks, particularly when automation is very difficult. Indeed, in many cases simple automation has remarkably reduced the stress and workload on pilots. So also have more complex systems such as those in the F-15 and F-16 aircraft, but not with consistent immediate success. Flexibility is necessary, to allow response to changes in air missions and technology in an effort to improve pilot and aircraft performance.

FINDINGS AND RECOMMENDATIONS

Finding. There is currently no systematic, widely applied technology for determining which tasks to automate and which to assign to pilots.

Recommendation. Develop the technology for function allocation.

Currently, the best we can do is to assign tasks on the basis of hunch and experience and then use extensive simulations to learn the results of our decisions. This process is slow and expensive, and it may miss opportunities for easily obtainable improvements simply because no one thought of them.

For many years, the Department of Defense management guide for human engineering in weapons systems (MIL-H-46855) has required system developers to assign tasks to men and machines at an early stage. For a number of reasons this guideline has not been followed. The Soviets appear to have a similar requirement (Myasnikov and Petrov, 1976, 1977). Any decision concerning automation should not only consider human factors, but should require a multidisciplinary team to examine potential hardware and software technology as well. Failure to emphasize this joint analysis has been one of the drawbacks of the Department of Defense guide and helps to explain why it is not followed.

The subcommittee found few reports or projects specifically discussing automation tradeoffs. Rather, emphasis has been placed on how automation should best be implemented through human engineering of displays and controls, as in the Digital Avionics Information System (DAIS) program. In a comprehensive review of human factors engineering in the Air Force (Parsons, Hendrick, Jones, Short, Snyder, and Williges, 1980), essentially no attention was given to the role this field has played or should play in decisions about automation. The human factors engineering study did, however, urge more involvement of human factors specialists in the conceptual phase of system development, where automation decisions are made. A 1980 report to the Air Force Systems Command on technology for human factors engineering included no technology that was directed specifically at automation tradeoffs (Williges and Topmiller, 1980). Technology has been developed for measuring pilot workload.

Finding. The effectiveness of automation depends on matching the designs of automated systems to pilots' representations of their combat tasks. This requires an understanding of how pilots think about their combat tasks, an understanding of the performance characteristics of the control and display components through which the pilots and the automated systems interact, and an understanding of human performance generally--all areas in which the science base is inadequate.

Recommendation. Develop models of pilot behavior, for example, specific models of workload and menu selection, as well as general models of how pilots process information and make decisions.

Recent studies in cognitive psychology appear promising but need to be codified into practical handbooks and models before they can be used by aircraft designers. One possibility would be to establish an intense experimental program over perhaps, a five-year interval.

Separate thrusts could be directed at understanding tactical pilot skill and the performance characteristics of cockpit interface techniques, and at the codification of the basic psychological literature in a form that would support engineering analysis. Simulation, followed by instrumented aircraft experiments, may be necessary to produce a useful product.

Finding. Tactical planning and decision aids may be close to technical feasibility.

Recommendation. Explore automation in tactical planning.

The introduction of communication digital avionics into the cockpit, the increasing power and numbers of computers on aircraft, and the availability of cathode-ray tube displays have gone a long way toward enabling the use of automatic or semi-automatic devices for tactical planning. In some tasks, such as taking electronic countermeasures, threat warning and other countermeasures, the short time available makes automated tactics especially attractive.

Finding. Guidelines can be helpful in deciding what and how to automate, but current advice needs to be expanded and improved.

Recommendation. Gather data on existing experience with automation and develop guidelines.

More effort should be devoted to studying past automation efforts so that successes can be repeated and shortcomings avoided. The Tactical Air Command (TAC) briefing held during this study, and summarized in the following section was a commendable and useful effort in this direction. Guidelines generated from such analyses of past experience need to be expanded and carefully scrutinized. Out of such an examination should eventually emerge an engineering technology.

USER EXPERIENCES WITH AUTOMATION

This section summarizes some of the Tactical Air Command's (TAC) experience in automating specific systems on combat aircraft.

Flight-Path Control

Based on its past experience, TAC emphasized the need to automate tasks and functions that require a level of precision that pilots cannot provide. Following and avoiding terrain and aiming weapons were examples of such tasks. The briefings also stressed the usefulness of automation in engine control, but coupled with pilot override. Automated fuel sequencing was also favored, but here too TAC recommended pilot override. Preloading navigation data in bulk on the ground, automatic sequencing of the data, and updating of the flight-control system's radar were regarded as helpful forms of automation. As examples of automation to assist the pilot, TAC noted the value of angle-of-attack and *g*-force limiters or "dampers," and an F-111 stall inhibitor. As examples of helpful automation involving integration, TAC pointed to combining inertial navigation and weapons delivery through the fire-control system.

Some automation received criticism. For example, the automated control of afterburning fan engines did not function properly. As an instance of undesirable effects of automation on the design of the crew station, the TAC cited the fly-by-wire development. In this system, electrical control replaces the combination of control by human and mechanical linkages, and pilots have been distressed by the loss of proprioceptive feedback and have expressed a need to introduce it artificially. One can question whether isometric proprioceptive feedback combined with visual feedback would actually have sufficed in these instances if pilots had not become accustomed to movement feedback. Thus, the criterion of "acceptability" for automation must include pilots' prior experiences with predecessor operations, though this criterion should not overwhelm others. User reactions should be matched against objective data when possible.

Target Sensing and Acquisition

The TAC briefings recommended the development of "multiple highly integrated sensors" to improve performance and reduce workload. If these sensors were available, pilots could derive composite information and would not have to switch their attention or displays from one sensor to another. The advantages are clear so long as the automatic process of integrating sensor inputs does not exclude critical data from one sensor because it was missing in another--that is, produce false negatives. Implementation might benefit from some kind of indicator reflecting the number of sensors that contributed to the detection of the target. This approach might help the pilot avoid false positives. Integration of radars and fire-control systems in the A-7, F-111, and F-16 was acclaimed. TAC welcomed the technology of passive sensors to augment radar in covert missions or areas where heavy countermeasures are confronted. TAC also welcomed digital doppler radar in the F-15 and F-16; it assists pilots by reducing the clutter with which they otherwise have had to cope in the F-104 and F-106 (with their analog radars), and thus simplifies one-man operation. LANTIRN, which is being developed to detect and track tactical targets at night and under the weather (condition that at present offers the enemy sanctuary) was hailed by TAC as reducing workload and improving job performance. Nonetheless, TAC expressed a need for all-weather systems for better performance against tactical targets. In its first briefing, TAC emphasized the need for efficient pilot interactions with sensor displays and controls (and for overrides); such human-engineering requirements might be present even in the absence of automation.

Threat Warning and Countermeasures

According to the briefings, the automation of threat warning and countermeasures is urgently needed. TAC also urged that threat warning and countermeasures be integrated. The A-10, F-16, and F-4 pods are not integrated, but the F-4G integrates Radar Warning Receiver (RWR) data with the flight control system. Although it is a critical area, threat warning and countermeasures did not receive detailed attention in the briefings, partly due to security restrictions. According to TAC, electronic warfare and countermeasures (EW&CM) involve a vast amount of data and a requirement for immediate actions. Research is needed to determine how these distinct operations should be arranged for pilot participation, what can be automated in each case, and how countermeasures systems can be made rapidly adaptable to the latest enemy threats.

Weapons Delivery

According to the second TAC briefing, automation has increased firepower. For air-to-ground combat, the F-16 and F-4G systems provide numerous visual and radar modes for fire control, including automatic ballistic and parameter computations, fragmentation envelope warning, and an automatic release option with pilot consent. For air-to-air combat, the F-15 and F-16 have advanced parameter/envelope computation, display of dynamic launch zones, simple "shoot cues," and selection of weapons preparation as well as heads up displays. The need for such computations was stressed in the first TAC briefing; this approach seems to be the proper way to automate weapon aiming to increase precision. To a considerable extent, the pilot remains in the loop, in air-to-air combat. For air-to-ground combat, TAC said that "automation of systems for low-altitude, night, or under-the-weather missions will improve effectiveness," and that an "adequate degree of automation allows aircrews to employ armament in increasingly adverse situations." Greater effectiveness has come, according to TAC, from the integration of tasks from different functional areas to a degree the pilot alone could not achieve, especially in navigation, target acquisition, and fire-control systems.

Support Systems

Automation seems eminently suitable for routine matters such as monitoring hydraulic and electrical systems, detecting malfunctions, and issuing warnings. The pilots' system for environmental protection should also be automatic, as should ejection upon pilot initiation.

Chapter 3

TECHNOLOGY SUBCOMMITTEE REPORT

INTRODUCTION

The technology for automating combat aircraft varies in maturity. Current developments aimed at automating flight trajectory and attitude control, threat warning, and weapons delivery are likely to succeed. On the other hand, technology for automating target identification remains elusive, although cooperative Identification Friend, Foe, or Neutral (IFFN) systems may be feasible.

Because of the difficulty encountered in target identification, it is suggested that automation be approached by aggregating in increments beginning with flight trajectory and attitude control, freeing the crew to handle more complicated tasks not yet automatable. Details are in the following text.

This section of the report discusses the technology required to permit automation in combat aircraft. Its intention is to illuminate what could be accomplished through automation, and what priority ranking is likely to produce better results. (See the Glossary for definitions of the programs and technologies discussed in this chapter.)

Mission Functions

The Functions Subcommittee identified 16 systems and activities in combat aircraft (see page 15). The Technology Subcommittee examined how those systems and activities interact to perform certain essential functions during a combat mission. The key functions identified for air-to-air and air-to-ground missions are:

- Flight trajectory and attitude control
- Threat warning and countermeasures
- Target sensing and acquisition
- Weapons delivery and fire control
- Crew escape.

(The subcommittee notes that all these functions are linked together in the crew station. Since the crew station is the focus of interaction between the pilot and the aircraft, it was considered by the Human Factors Subcommittee, and will not be discussed in this chapter.)

Table 3-1 shows how the systems and activities delineated by the Functions Subcommittee are related to these five mission functions. Because these systems and activities are used to perform the five mission functions, they can be considered subfunctions. Some of the systems and activities, such as malfunction warning and reconfiguration, are involved in all the functions. Others, such as target sensing and acquisition, are involved in only one function; i.e., the systems are identical to what the subcommittee calls functions. The four systems that are identical to functions are identified by circle at their intersections in Table 3-1.

In the discussion that follows, the functions are described in relation to the mission phases identified by the Functions Subcommittee: prelaunch, launch, ingress, engage, egress, recovery, and turnaround. (The Functions Subcommittee treated egress and recovery as one phase. In its more detailed discussion, the Technology Subcommittee found it logical to consider these as two distinct phases.) For the sake of uniformity, however, the two phases are reported as one.

The possibilities for automating each function are then discussed for each of the mission phases. (For example, see Table 3-2.) The present approach is described for that function, and an approach to automation is suggested. The technology needed for such automation, as well as current programs that address that technology, are then discussed. Following that, the subcommittee suggested where new research thrusts or added emphasis on existing programs would be beneficial in achieving the suggested approach to automation.

Finally, the subcommittee subjectively judged which research and development efforts would yield the greatest returns, and then established priorities for selecting functions for automation. Thus, in conjunction with the findings of the Functions and Human Factors Subcommittees, it is possible to suggest a rational approach to automation.

FLIGHT TRAJECTORY AND ATTITUDE CONTROL

All functions of a combat aircraft depend on maintaining the correct flight trajectory and attitude (the orientation of the aircraft in space) as a function of time. In examining flight trajectory and attitude control, the subcommittee found that the other mission functions (threat warning and countermeasures, target sensing and acquisition, and weapons delivery and fire control) are intimately tied to this function. Therefore, it is logical to consider flight trajectory and attitude control as the baseline, or "core function," in automating combat aircraft. Automated systems to serve other functions can then be linked with those that serve this core function in such a way as to form a single integrated system.

TABLE 3-1 The Relation of Aircraft Systems and Activities to Key Mission Functions

Functions \ Systems and Activities	Malfunction Warning/ Reconfiguration	Navigation	Electronic Control	Hydraulic Control	Taxi/To/Land	Autopilot	Target Sensing/ Acquisition	Flight Control	Crew Escape	Propulsion	External Data	Crew Station	Threat Warning/ Countermeasures	Weapons Delivery/ Fire Control	IFFN	Fuel Management
Flight trajectory and altitude control	X	X	X	X	X	X				X		X				X
Threat warning and countermeasures	X		X	X							X	X	Ⓧ		X	
Target sensing and acquisition	X		X	X			Ⓧ				X	X			X	
Weapons delivery and fire control	X		X	X								X		Ⓧ		
Crew escape	X		X	X					Ⓧ			X				

TABLE 3-2 Flight Trajectory and Attitude Control

	Prelaunch	Launch	Ingress	Engage	Egress and Recovery	Turnaround
Present Approach	• Manual Mission Prep • Keyboard Data Entry	• Manual Control • Essential parameters on HUD	• Pilot Flys Computed Steering CMD5 • Manual NAV Update • Manual Threat Avoidance	• Pilot Steering to Accomplish Attack • Manual Threat Avoidance	• Same as Ingress and Launch	• Repeat Prelaunch Functions • Replace Defective LRU's
Automation Approach	• Auto mission prep station • Pre Fly Mission • Cassette Data Entry	• No Change	• Precise 4D NAV Coupled to Flight/Engine Control • Auto TF/TA • Auto update of NAV and Threat Data • Auto Threat Avoidance	• Coupled Sensor/Flight/Engine Control • Auto Attack and Threat Avoidance • Task Tailored Control Laws	• Same as Ingress and Launch	• Reconfiguration/Fault Tolerant Systems • 100% Fault Isolation and Common Modules

Technology Needed for Automation Approach	• Data Base Terrain Threat Targets • Compact Mass Memory	• None	• Integrated Flight/Engine Control • Tightly Coupled TF/TA • Terrain and Threat Data Base • Compact Mass Memory • High Rate Data Network	• Coupled Fire/Flight/Engine Control	• Same as Ingress and Launch	• VHSIC • Distributed Functional Partitioning
Current Programs that Address Needed Technology	• DMA Data Base • CAMPS		• Interact (NASA) • LANTIRN • Blended TF/TA • GPS • JTIDS • PLSS • AETMS • TACTICAL Flight Management Program (AFFDL)	• F15 IFFC • AFTI-16 • IFFC • AMAS	• Same as Ingress and Launch	• DIGITAC III • Fault Tolerant Architectures (NASA) • Continually Reconfigurable FLT Control System
New Thrust or Further Emphasis Required	• DMA Data Base • Current Threat and Target Data Base • 100's Meg Bit Memory • Auto Mission Prep Station		• Compact Mass Memory • Threat Data Base • Blended TF/TA • Integrated Flight/Engine Control • High Speed Replacement for 1553	• Fire/Flight/Engine Control Coupling	• Same as Ingress and Launch	• Distributed Functional Modules

Because target sensing and acquisition, threat warning and countermeasures, and weapons delivery and fire control rely on flight trajectory and attitude control, they can be considered "operational mission functions," to distinguish them from the core function. These operational mission functions provide more precise trajectory control and extend the aircraft's ability to perform in different situations, and in different environments, such as flying at night or underneath the weather, or identifying targets that are beyond visual range.

(Crew escape is a vitally important mission function, and was selected for study by the subcommittee. The operational mission functions discussed above are used to achieve the mission goals. Crew escape is different; it comes into play when the flight trajectory and attitude control function has failed. For that reason, crew escape is not included in this analysis of the core function. It is discussed in full on page 91.)

Flight trajectory and attitude control is accomplished by the use of several systems and the performance of several activities identified by the Functions Subcommittee (see Table 3-1). These major subfunctions of flight trajectory and attitude control have been defined as follows:

- Flight control
- Propulsion control
- Navigation
- Fuel sequencing
- Warning and advisory systems.

"Flight control" retains its classical definition: control of aerodynamic surfaces to effect motion of the aircraft in space in response to pilot or sensory commands. In addition, the capacity to process steering commands from sensors and other instruments in order to follow a particular path in space is also considered part of flight control.

"Propulsion control" refers to the systems and techniques used to stabilize and control the thrust delivered by the engine in response to pilot and/or computer commands.

"Navigation" includes terrain following and terrain avoidance (TF/TA), as well as normal navigation modes. Thus it can logically be divided into vertical and horizontal navigation functions. These completely describe the three-dimensional points of a path in space. The addition of speed control to navigation, through the use of integrated thrust control, provides the capability of time-controlled navigation. In other words, if speed control is added to the navigation system, the system will then control the time at which the aircraft arrives at the target. This provides for four-dimensional navigation control (latitude, longitude, altitude, and time), and could lessen pilot workload during certain operations, such as the coordination of multiple-aircraft attacks. In addition, by controlling the attitude of the aircraft (roll, pitch, and yaw), a precise seven-dimensional system for navigation could be achieved; such a system would control latitude, longitude, altitude, time, roll, pitch, and yaw as well as rates for these quantities.

"Fuel sequencing and management" refers to the metering of fuel, and its transfer among the various storage locations in the aircraft. This ensures the proper flow of fuel to the engine at all times, and maintains the center-of-gravity range required for aircraft stability.

Each of the four subfunctions just described has been integrated or automated to some degree in present-day fighter aircraft. Technology is available for complete integration to form the composite function called flight trajectory and attitude control. As these subfunctions become more integrated and automated, then the final subfunction, "warning and advisory systems," becomes more critical. Such systems inform the pilot about the operation of all systems that contribute to flight trajectory and attitude control. These warning systems are expected to use both aural and visuals warnings to alert the pilot to situations that require his attention or action. The advisory function will probably be handled by a dynamic display of the aircraft's current situation and operational capability.

Table 3-2 outlines the present approach for flight trajectory and attitude control for each of the mission phases. It also shows the types of automation that could be applied to alleviate pilot workload and thus increase the effectiveness of combat aircraft.

Prelaunch Phase

The present approach to the prelaunch phase of the mission is basically manual, involving verbal briefings on target data, ingress and egress routes, threat locations, and weapon complements. Data are entered in the on-board aircraft systems via keyboards, with the attendant probability of human error. At present, no terrain information is available except that from contour maps and aerial surveillance photographs.

In an automated system, it would be most desirable to have a computer-assisted briefing system that would augment or supplant the verbal transmission of mission data. An important feature of this automation approach would be the availability of a cassette device that would allow automatic loading of all mission-required data into the appropriate aircraft components. The mission data required can be categorized as follows:

- Navigation data (terrain profiles, ingress and egress routes, and air-to-ground target locations)
- Threat locations and characteristics
- Target characteristics
- Weapons complements.

(This presupposes a TF/TA capability.) It would be necessary to update automatically this ground station data base with information from external sources (such as an airborne warning and control system [AWACS]), via a secure information transfer system.

If the data base were established in a ground-based mission preparation station, the next logical step would be to "prefly" missions. In the station, pilots could use simulations of representative on-board displays to familiarize themselves, in real time if desired, with critical parts of the mission. This would instill confidence in the pilots and would also increase their effectiveness.

Such automatic mission preparation stations must await advances in two areas of technology. The first is the creation of accurate data bases for navigation, threat locations, target characteristics, and weapons complements. The second is the development of the hardware and software for appropriate displays in real time. The ground stations' data bases for navigation and terrain profiles must cover wide areas to allow for versatile mission planning; this will require a mass memory more compact than those now available.

Several current programs (the Defense Mapping Agency's [DMA] terrain data program, the Computer Aided Mission Planning System [CAMPS], and the Advanced Electronic Terrain Mapping System [AETMS]) address, in part, the need for data bases. This added emphasis to produce a practical and reliable approach for an automatic mission preparation station for combat aircraft of the 1990s. In addition, development of a more compact mass memory to support the anticipated data storage requirements should be initiated.

Launch Phase

The launch phase of the mission includes take-off and climb to the altitude at which the ingress portion of the mission begins. At present, the launch phase is under manual control, with essential flight parameters displayed on the heads up display (HUD). There seems to be no compelling reason to automate this phase of the mission. There is, however, some merit in supplying the pilot with additional information on the HUD to aid in decisionmaking under unusual take-off conditions (such as an imminent threat, a damaged runway, or high gross weight). These conditions can be included in the system data base, so that the optimal take-off profile can be displayed continuously to the pilot. No new technology is required.

Ingress Phase

The ingress phase of the mission is defined as that portion of the flight profile that begins after launch and is terminated by arrival in the target area (in air-to-air or air-to-ground missions).

At present, ingress is controlled manually by the pilot, who is aided by computed steering commands displayed on the HUD, except in the F-111, which is capable of automatic terrain following. Navigation information (in the form of way point and target location data) is updated manually via keyboard entries in response to voice communications. Threat avoidance is pilot initiated in response to sensors or visual threat detection. No terrain data base is available on board: TF/TA is accomplished manually by visual control (except in the F-111), and this can be done only in clear weather and daylight. The F-111 can perform TF/TA automatically in response to steering information generated by on-board sensors. Time profiles for coordinated multiple-aircraft sorties are established by the pilot using on-board information.

In the automation approach, the core of the system should be precise four-dimensional navigation (latitude, longitude, altitude, and time), coupled to a full-authority flight- and thrust-control system (for a total of seven dimensions when aircraft attitude is added). The four-dimensional navigation system would include a capability for TF/TA and would use a terrain data base loaded during the prelaunch phase. The computed ingress route would use terrain masking while flying at low levels to penetrate and to avoid known fixed-point threats.

Enroute to the target positions, the navigation system would be updated automatically, using external data such as that, for instance, from the Global Positioning System (GPS). The capability for on-board updating, based on manual or automatic recognition of topographical or cultural features, would be retained to allow continued operation even if sources of external data are lost.

The flight-path control systems for TF/TA would use, in addition to the on-board data base, information generated by on-board sensors both to monitor the computed flight path and to determine the optimal flight path (this is called "blended" TF/TA).

The threat data base should be updated enroute to the target to account for semimobile or newly discovered threat sites. The information would be transmitted over a secure information transfer system and automatically incorporated in the data base. Whether the on-board computing facilities would alter the ingress route automatically to account for such threats has not been answered, but certainly their locations would be displayed automatically.

Flight-path control can be used for threat avoidance in two ways. Prior to lock-on and release of the weapon, terrain masking would be the primary method of avoiding fixed threats. For avoiding weapons in flight or countering a radar lock-on detected by on-board sensors, a preprogrammed maneuver, which would alter the flight path in an optimal fashion, is envisioned.

The technological advances required for automating flight-path control are primarily the generation of a data base for the TF/TA function and the development of compact mass memories (typically 500-1000 megabits) for storing the data. Access time for this memory would not be particularly critical; the main objective should be storage density. Emphasis must also be given to further development of integrated, full-authority electronic engine controls that permit the precise four-dimensional control required for tightly coupled terrain following and terrain avoidance.

Automation of the airplane as a whole requires high-speed data transfers between various systems and sensors to maintain stability and accuracy of the flight-path control. It is anticipated that this requirement will overload the present data network (MIL STD 1553), and that the development of a high-rate data network will therefore be required.

A number of current programs concentrate on automating flight-path control for the ingress phase of the mission. The Integrated Research Aircraft Control Technology (INTERACT) program, now in the proposal stage, addresses four-dimensional navigation in conjunction with the integration of engine, inlet, and flight controls. Other programs, such as the Global Positioning Systems (GPS), the Joint Tactical Information Distribution System (JTIDS), and blended TF/TA, address particular parts of the control problem. The only programs that treat the total integration of sensory and computing elements are the Tactical Flight Management Program and Pave Pillar. No known current programs address the development of high-density mass memories.

The need for a TF/TA capability in low-visibility situations, to allow aircraft to take advantage of terrain masking during ingress to the target, requires added emphasis on programs such as blended TF/TA and DMA data-base generation program. In addition, programs that address the four-dimensional navigation function in general, and in particular the integration of full-authority engine and flight controls for both the TF/TA environment and the complete mission, are necessary for successful automation of flight-path control. New efforts are needed in the areas of data-base generation, the development of compact mass memories, development and the synthesis of a high-data-rate successor to the current MIL STD 1553 network.

Engagement Phase

Flight-path control during engagement includes those functions not directly involved in weapon delivery, and those associated with the transition from ingress to engagement.

Present approaches involve pilot steering and maneuvering to a specified waypoint, or target acquisition and selection of the fire-control mode for weapon delivery. These specific modes are discussed in the section entitled "Weapons Delivery and Fire Control: Air-to-Air." Threat warning and target information updates are given orally by external sources or by audible or visible signals from on-board sources. Threat avoidance depends on manually initiated countermeasures and manual steering, except for specialized countermeasures.

Concepts are being developed for automating and integrating fire control and flight control. An extension of this concept to include propulsion control and related engine control is a needed next step. The coupling of fire control/flight control and propulsion control could significantly enhance the precision of flight-path control, eliminate the need for the pilot to manage thrust control, and incidentally increase engine life. For both the air-to-air and the air-to-ground attack modes, task-tailored control laws are needed. These are automated systems to tailor flight control to specific tasks (for example, to determine the optional route to the target in which the plane is least likely to be shot down). The coupling of fire- and flight-control with propulsion, in conjunction with such task-tailored control laws, would significantly enhance the accuracy of weapon delivery against multiple targets.

The F-15 Integrated Fire Flight Control (IFFC) and the Advanced Fighter Technology/Advanced Maneuvering Attack System (AFTI-16/AMAS) programs are aggressively pursuing the development and demonstration of an integrated system for fire and flight control for air-to-air and air-to-ground weapon delivery. They are employing task-tailored control laws to generate nonpredictable trajectories for weapon delivery, and thus reducing vulnerability to enemy fire during weapon delivery. The AFTI-16/AMAS program is extending the F-15 IFFC system to include a digital flight- and fire-control system; it will have a capability for a six-degree-of-freedom control, and will use advanced display concepts.

Several research programs now under way are aimed at developing coupling concepts for full-authority digital engine, inlet, nozzle, and flight control. These programs should give needed information for subsequent developments. As will be seen later, augmentation of the AFTI-16 IFFC/AMAS program to include integrated digital propulsion control would be desirable.

Egress and Recovery Phases

The egress and recovery phases of the mission extend from the termination of the engagement phase to the aircraft's landing on the runway. The flight-path control functions, in terms of corridor selection, threat avoidance, and precise navigation, are the same for the egress phase as for the ingress phase; their description need not be repeated here.

At present, recovery on landing is performed manually by the pilot, using ground-based navigation aids for steering commands. Further automation in this area is probably not justified.

Turnaround Phase

The turnaround phase of the mission is common to all functions and is addressed in the "Weapon Delivery and Fire Control: Air-to-Air" section.

Summary

The basic technology for automating flight trajectory and altitude control (sometimes called "flight-path control") is available today. To allow flight-path control throughout the mission envelope, added emphasis on various technologies associated with terrain following and terrain avoidance is necessary. The traditional separation of the propulsion and flight control functions cannot be continued if precise four-dimensional navigation is to be achieved. Control algorithms for the integration of these functions must be developed, and full-authority automatic control of engine parameters must be permitted.

Automatic fuel sequencing and management are highly desirable and are completely within the capacity of today's technology. However, if automation of this function is to be accepted by pilots, the system must be highly reliable, and a dynamic display of its status must be available for pilot monitoring.

Although the design of warning and advisory displays is highly dependent on the overall system architecture of the aircraft, the technology for an integrated warning system is available now. Data and analysis on human factors should be a prime consideration in the design, with emphasis on displaying warnings only when pilot intervention is required.

An automated system for flight-path control can form the core for the automation of the other mission functions, and for this reason should be addressed early. Care must be taken in the architectural design of this system, so that later advances in sensor and other technologies can be integrated efficiently into the core system.

The main development needs are (1) the generation of a reliable data base for terrain following and avoidance and for threat avoidance, (2) the development of a compact mass memory for data storage, and (3) the development of a high-speed replacement for the MIL STD 1553 data network.

The Tactical Flight Management Program and Pave Pillar are the only programs that address the system architecture and integration aspects of automation, and sufficient emphasis should be applied to these programs to allow timely application of their results.

THREAT WARNING AND COUNTERMEASURES

In keeping with the notion of building on the core of flight-path control, it can be postulated that the threat warning and countermeasures function imposes no special requirements in the prelaunch, launch, recovery, and turnaround phases, beyond those described in the discussion of flight trajectory and attitude control. The discussion here (see also Table 3-3) is limited therefore to ingress, engagement and egress.

Ingress and Engagement Phases

At present, ingress and engagement are aided by verbal updates on air and surface threats. Information on air threats is updated verbally from the Airborne Warning and Control System (AWACS) and Ground Control Intercept (GCI) systems. Information on ground threats is updated verbally from the EF-111 (the Air Force's F-111 aircraft equipped for electronic countermeasures) or the Big Look warning and surveillance program. The on-board radar provides a track-while-scan capability for both air and surface threats, and the pilot provides manual threat avoidance. Both automatic and manual countermeasures are used; for example, in the F-15 and F-16, the ALQ-131 electronic countermeasures pod operates automatically, but chaff and flares are deployed manually.

TABLE 3-3 Threat Warning and Countermeasures

	Prelaunch	Launch	Ingress-Engagement	Engress & Recovery	Turnaround
Present Approach	Refer to Flight Path Control • Prebrief S to A threats		• Verbal In-Flight Threat Info • EF-111 • On-board TWS • Manual Threat Avoidance • Auto and Manual CM	• Repeat of Ingress and Launch Functions –Plus– • Egress Procedures	• Refer to Weapon Delivery Air-to-Air Function
Automation Approach	Refer to Flight Path Control	Refer to Flight Path Control	• Threat Data Base • Real-time threat update • Auto response to new threat	• IFF with friendly troops	
Technology Needed for Automation Approach	Refer to Flight Path Control		• Stored Threat Data Base • Mass Memory • Data Link • Fire/Flight/TWS Integration	• New IFFN	
Current Program that Address Needed Technology	Refer to Flight Path Control		• PLSS • JTIDS • Purple Haze • ASPJ		
New Thrusts Required-or-Added Emphasis	Refer to Flight Path Control		• Continuous Threat Data Base • Mass Memory • PLSS • Data Link • Fire/Flight/TWS Integration	• New IFFN	

The automated approach would involve an on-board threat data base, updated in real time, along with sufficient sensors to permit automatic countermeasures or evasive maneuvers.

The technologies required to provide for automation include a threat data base stored in a mass memory, a data link, integrated fire control and flight control, and a track-while-scan capability. Little of this technology is being pursued.

Present or planned programs known to the study group include those working on the Precision Location Strike System (PLSS) data, the Joint Tactical Information Distribution System data link, the Purple Haze threat envelope display, and the Automatic Self Protection Jammer equipment.

Egress Phase

Requirements for egress are similar to those for ingress and engagement, except for a few important differences. First, U.S. combat aircraft risk being shot down by U.S. surface-to-air missile systems and anti-aircraft weapons, such as the shoulder-fired Stinger. The present approach is to fly an agreed upon set of altitude and check-point trajectories, while using the Mark XII Identification Friend or Foe system.

The automated approach would be to develop a new cooperative Identification Friend, Foe, or Neutral (IFFN) system based on emerging digital technology. IFFN has been difficult to accomplish electronically.

TARGET SENSING AND ACQUISITION

Target sensing and acquisition comes into play almost exclusively during the engagement phases of tactical missions. Therefore, other mission phases are not discussed here. Table 3-4 relates the mission phases with the present levels of automation and those postulated for future systems.

Engagement Phase

Currently, the target-acquisition phase of tactical air operations, both air-to-air and air-to-ground, involves high pilot workloads. In an environment that may include adverse weather, poor

TABLE 3-4 Target Sensing and Acquisition

	Prelaunch	Launch	Ingress	Engagement Air-to-Air	Engagement Air-to-Ground	Egress & Recovery	Turnaround
Present Approach				• Mostly Manual • Some Semi-Automatic	• Manual		
Automation Approach				• Automatic detection, acquisition, identification, and prioritization of targets	• Automatic detection, acquisition, identification and prioritization of targets		
Technology Needed for Automation Approach				• Beyond Visual Range I.D. • Multi-sensor correlation • External data correlation • Multi-target acquisition	• Automatic target detection, classification and identification • High resolution sensors		
Current Programs that Address Needed Technology				• JTIDS • IFFN Fusion • Jet engine modulation I.D. in F15	• ERIM Ultra-high resolution radar • Multiple Source Integration • JTIDS • Covert Strike • PAVE MOVER • LANTIRN • PLSS • Automatic SAR Target Classification • Correlated Sensor Data Display		
New Thrusts Required-or-Added Emphasis				• Beyond Visual Range I.D. • Multi-sensor correlation • Light weight helmet sight and display • IR Search & Track	• Auto target pattern recognizer • Multisensor correlation • High resolution sensors • Light weight helmet sight and display		

illumination, electronic countermeasures decoys, and battlefield confusion, the pilot must make difficult interpretations, which are thus susceptible to error.

Present systems, although they may employ digital processors and sophisticated displays, actually do little to aid the pilot in the interpretive task of target acquisition. Sensor data are presented with only minor (though important) processing. Even the "clean scope" display of modern pulse doppler radar leaves the pilot the task of selecting and interpreting the display. Some semi-automatic modes are available, chiefly in switchology or routine control functions. The Low Altitude Navigation Targeting Infrared for Night (LANTIRN) system, now under development, is intended to automate target detection, target classification, weapon assignment to targets, and weapon release. It will be the first operational employment of major automation in this realm.

To realize the potential inherent in the system represented by the pilot, aircraft, and sensors, much faster and more sophisticated data examination, processing, and correlation must be accomplished. Automating the tasks of target detection, acquisition, identification, and assignment would reduce the pilot's now saturated workload. At this time, the degree to which these functions can be automated is not clear. The pilot is a vital part of the system, but the appropriate level of his participation has yet to be defined. Digital processing, employed to aid the pilot in sensing, identifying, and acquiring targets, would improve the aircraft's combat effectiveness and provide the ability to operate in environments where they cannot function now.

Current programs are examining some aspects of the technology required to automate target sensing and acquisition. The Pave Mover system, for example, could contribute data on target location and guidance to tactical aircraft via its own data link or by the use of a secure information-transfer system such as the Joint Tactical Distribution System (JTIDS). JTIDS is an advanced communications system being developed to provide a secure antijamming network for two-way information transfer. Aircraft location is transmitted by the system to a targeting center, and target priorities are provided to the aircraft. JTIDS can also provide a common grid navigation system of sufficient accuracy for use in target acquisition, interface with the Tactical Air Navigation Systems (TACAN), and IFFN. Advisories and warnings from aircraft sensors, as well as priority sequencing for handling message traffic within the aircraft, are also being considered.

The LANTIRN program, begun in 1981, will examine some pertinent issues, including technology for advanced forward-looking infrared (FLIR) sensors, automatic target recognition, and multiple weapon launch. The extent of this effort is not known to this subcommittee, but our examination of hardware under development for near-term use indicates that additional analysis and experimentation, particularly in automatic target acquisition, will probably be required.

Related technologies are being developed in other programs. Covert Strike is working on automatic target recognition and bistatic radar problems. The Precision Locator Strike System (PLSS) program could perhaps supply new capabilities for threat data, as well as technology for target location and identification.

Technology in requirements for automated air-to-ground target sensing and acquisition include improved high-resolution sensors and data-processing techniques, and algorithms for high-confidence automatic target detection, classification, and identification. To assign target priorities and control weapon delivery, the data must be correlated with threat warning and external data. Promising new approaches are high-resolution synthetic aperture radar (SAR), millimeter-wave radar, CO_2 laser radar, bistatic radar, automatic target pattern recognition, and multisensor correlation.

Target sensing and acquisition in air-to-air engagements appears to require an automated system to gather and correlate data from multiple on-board sensors. The system should be able to accept data from external data links so it can be combined and correlated with sensor data. It should also be able to acquire, track, and display multiple targets and to implement a high-confidence noncooperative identification system suited for a beyond-visual-range multitarget environment. IFFN, infrared search-and-track sensors, multisensor correlation, and automatic target pattern recognition are some promising new approaches; others are discussed later in the section entitled "Current Programs and New Efforts."

Automatic target pattern and multisensor correlation are applicable to both air-to-air and air-to-ground combat. In an air-to-air mission, the combination of an infrared search-and-track sensor with radar could provide advantages in detecting and acquiring targets in an environment in which the enemy is employing countermeasures. Beyond-visual-range noncooperative target recognition (NCTR) for IFFN could also be aided by combinations of sensors and sensor modes such as: NCTR radar techniques; engine identification by jet engine modulation (JEM) sensing; electromagnetic emission recognition (passive NCTR); target shape recognition employing inverse synthetic aperture radar (ISAR) techniques; and multimode infrared search-and-track systems with automatic target signature recognition.

The automatic correlation of data from multiple sensors could enhance target acquisition and identification in both air-to-air and air-to-ground missions. The potential benefits include reducing target-acquisition time, increasing the confidence level of target detection and identification, increasing immunity to countermeasures, increasing acquisition range in adverse weather, minimizing performance loss in radar covert missions, and reducing pilot workload.

An example of potential multisensor correlation in air-to-ground applications would be the use of several alignable image-forming sensors with automatic target recognizers such as millimeter-wave radar, forward-looking infrared sensors (FLIR), and CO_2 laser radar. In addition, real-time data from threat warnings, prestored target and terrain data, and data from a secure information-transfer network could be correlated with the outputs of the image-forming sensors and processors to enhance the capability for target acquisition and identification.

WEAPON DELIVERY AND FIRE CONTROL: AIR-TO-AIR

Air-to-air missions have evolved from low-speed, one-on-one engagements with guns to projected engagements involving numerous forces using long-range, multitargeted missiles, launch-and-leave intermediate-range missiles, and short-range guns employed from highly maneuverable (quick-kill) airplanes. Without automation the operational complexity of such engagements will probably overtax the pilots' abilities to assess situations and select the appropriate offensive and defensive actions. For example, in a typical air-to-air situation (namely a defensive counter air mission) air superiority fighters will be faced with numerous targets and a surfeit of information. Issues having a direct effect on combat capability will include IFFN; the setting of target priorities and weapon assignments; weapon employment and launch envelope conditions; operations in a very intense electromagnetic environment; defense of high-value targets; command, control, and communications (C^3); and joint operations with the friendly surface-to-air defense systems. It is doubtful that even extensive information processing and improved displays could provide the pilot with the required data for decision and action; some level of automation would seem necessary for effective air-to-air operations.

Table 3-5 identifies the unique air-to-air functions for each mission phase. Technical considerations and possibilities for automation in each of these phases are addressed in the following discussion.

Prelaunch Phase

The prelaunch phase issues are fundamentally the same for all missions and are, therefore, discussed in total in the "Flight Trajectory and Attitude Control" section. Nevertheless, it should be

TABLE 3-5 Weapon Delivery (Air-Air)

	Prelaunch	Launch	Ingress	Engage	Egress & Recovery	Turnaround
Present Approach	• Manual Mission Prep • Keyboard data entry	• Verbal comm link for target update	• Verbal comm for target assignment • Refer to Flight Path Control Function	• Visual and radar detect, visual ID, auto launch zone computation, pilot null steering, manual weapon release	• Refer to Flight Path Control Ingress Function	• Repeat Prelaunch Functions • Replace defective LRU's
Automation Approach	• Auto Mission Prep Station • Pre fly mission • Cassette data entry	• Auto target update	• Real time display for targets designated by each attack plane • Refer to Flight Path Control Function	• BVR auto detect and ID • Auto threat prioritization, steering and weapon release		• Reconfiguration/ fault tolerant systems • 100% fault isolation and common modules
Technology Needed for Automation Approach	• DMA Data Base • Current threat and target data base • 100's Meg Bit Memory	• Data Link	• Data Link	• BVR ID • Priority Algorithms • IFFC • Integ Engine/Flt. Controls		• VHSIC • Distributed functional partitioning
Current Progress that Address Needed Technology	• DMA Data Base • CAMPS	• JTIDS	• JTIDS	• Multiple Source Integration • JTIDS • TAACS • MISVAL • AFTI-16 • F-15 IFFC • Interact (NASA)		• DIGITAC III • Fault Tolerant Architecture (NASA) • Continuously Reconfigurable Flt. Control System

New Thrusts Required-or-Added Emphasis	• Data Base
	  • Terrain
	  • Threat
	  • Targets
	• Compact Mass Memory
	• Auto Mission Prep Station
				• AA IFFN
				• Priority Algorithms
				• Integ Engine/Flt Controls
						• Distributed functional modules

realized that the data-base requirements vary considerably depending on the specific air-to-air mission. For example, in the defense of the continental United States (CONUS) there is no significant surface-to-air threat, so no threat data base is required. On the other hand, for offensive counter air missions (and particularly escort missions) the prelaunch data requirements equal or exceed those of the air-to-ground attack airplanes.

Launch and Ingress Phases

The launch phase is a subset of the ingress phase, since the only issue during launch is the receipt and treatment of updated threat and target information--also important during ingress.

Currently, verbal communications (via ground or airborne controllers [AWACS] or other attack airplanes) are the only means of receiving updated target data. For a single target or a target cluster, the pilot can enter the target coordinates into the fire-control system to obtain direction steering to intercept and/or to search the appropriate volume of sky with the fire-control radar to obtain lock-on and fire data. This verbal loop is highly susceptible to jamming and electromagnetic interference. It adds to the pilot workload, and cannot provide the pilot with visual information about the battle situation (which is particularly important in a multitarget situation). For these reasons, and the other benefits discussed in the following paragraphs a real-time, secure, jam-resistant data link would be highly desirable. The JTIDS data link appears able to meet this need.

Flight trajectory and attitude control is a critical issue in weapon delivery, particularly for offensive counter air missions. This includes automatic update of threats, automatic threat avoidance and countermeasures, and automatic terrain following and avoidance--all of which are discussed in detail in the sections entitled "Flight Trajectory and Attitude Control" and "Threat Warning and Countermeasures." In addition, some means of sorting targets and pairing them with aircraft must be done prior to engagement to ensure that each attack airplane engages a different target airplane. A real-time data link, through a secure information transfer system, can fill this need. The same data link can also be used to transmit to the rest of the force information on targets as designated by each attack airplane.

Engagement Phase

For weapon delivery and fire control during engagement, identification of airplanes as threats is fundamental. Although important for AIM-7 radar, this will take on added importance for the Advanced

Medium-Range Air-to-Air Missile (AMRAAM) program, due to multitargeting and longer missile launch ranges. While a secure information-transfer system can provide prior knowledge of airplane origins (and hence identification [ID]) in some scenarios, it is unlikely that such a system will be available or effective in all situations. Similarly, a corridor-firing doctrine may apply in some situations, but not universally. Classical IFF systems suffer from the uncertainties associated with hardware failures. Accordingly, techniques for positive identification of threats beyond visual range should be pursued.

Closely coupled to threat identification is the assignment of priorities to different threats; this is, in turn, also related to target assignment. When multiple targets are present, an automatic means of assigning priorities will be required. Even with the multilaunch capability of AMRAAM, the missiles are fired sequentially, which implies an ordering decision. On-board radars will have track-while-scan modes for multitarget tracking, but no method is now available for selecting a target for attack. In this highly dynamic situation, on-board systems with extensive stored data can automatically assign target priorities better than the pilot in most cases. In addition, the fire- and flight-control system (augmented by external data if available) can accomplish automatic flight-path steering and weapon release. This will require integrations such as those being developed in the F-15 Integrated Fire Flight Control (IFFC) program and in the AFTI-16 program. This integration is discussed more fully in the "Flight Trajectory and Attitude Control" section, earlier in this chapter.

Although a number of Air Force development efforts address the technologies needed to automate air-to-air engagements, additional effort is needed in identification of targets beyond visual range, in development of algorithms for determining and assigning target priorities, and in the automation of engine control for integrated fire and flight control (IFFC).

Turnaround

In air-to-air missions, the turnaround phase involves standard prelaunch phase functions, in addition to those actions necessary to restore the airplane to a full-mission capability. Typically, these additional actions would consist of removing and replacing failed electronic line-replaceable units (LRU). This repair activity could be significantly enhanced by (1) reconfigurable and/or fault-tolerant electronic designs that retain full-mission capability after component failure, (2) the use of common modules in electronic designs to reduce spare inventory requirements, and (3) achieving 100-percent fault isolation in electronic designs to minimize the need for intermediate shop equipment. The first improvement is applicable to all mission phases, since it permits mission completion even after failure.

These improvements can be achieved through the use of technology for very-high-speed integrated circuits (VHSIC). Avionics designers need to be aware of developments in the VHSIC field. A research program aimed at developing a reconfigurable and/or fault-tolerant system that uses common modules will also be important in improving the current process of restoring the aircraft to full-mission capability. Although several low-level programs are addressing parts of this problem, a more concerted effort should be mounted. Without such an effort, we can expect a significant inability to provide necessary equipment and to reduce logistic costs, as well as delays in mission completion and quick turnaround.

In the fully automated mode, built-in test equipment could check equipment just prior to recovery and provide indications via data link of line-replaceable units (LRUs) that require replacement.

WEAPON DELIVERY AND FIRE CONTROL: AIR-TO-GROUND

Air-to-ground weapon delivery has evolved from a relatively simple system in which the pilot could select a delivery maneuver from a straightforward display and then execute it through steering commands and the manual release of armaments. The advent of highly effective defenses has resulted in a large increase in pilot workload by decreasing the time available for target acquisition, classification, and identification. The amount of time available for making the decision to attack and for performing flight maneuvers to satisfy release conditions has also been reduced. Superimposed on these tasks is the need to choose from numerous controls those appropriate for weapon selection, arming, and release.

This section of the report describes the present approaches for weapon delivery in air-to-ground missons, and discusses the automation approach. It then discusses the technology needed for automation, the current programs that address this technology, and the development efforts needed to address the engagement phase of the mission. These are illustrated in Table 3-6. The "Flight Trajectory and Attitude Control" section of this chapter describes the prelaunch, launch, ingress, egress and recovery, and turnaround phases.

Engagement Phase

In the present approach for conventional munitions, the pilot detects the target visually, manually maneuvers the aircraft to acquire the target, engages the fire-control system, and manually

TABLE 3-6 Weapon Delivery (Air-Ground)

	Prelaunch	Launch	Ingress	Engagement	Egress & Recovery	Turnaround
Present Approach	• Manual Mission Prep • Keyboard data entry	• Verbal comm Link for target update	• Target assignment via verbal coordination • Refer to Flight Path Control Function	• Pilot visual Detect and Manual Steering (CCIP) • Pilot visual Detect and Auto Delivery (Dive Toss) • Pilot ID & Designate (Radar) with Manual Steering (Auto Rel) • Pilot visual ID & Designate (Laser, E.O.) • Manual Release • Pilot Visual ID (Guns) Manual Steering-Pipper	Refer to Flight Path Control Ingress Function	Refer to Weapon Delivery (Air to Air)

Automation Approach	• Auto Mission Prep Station • Pre fly mission • Cassette data entry	• Auto target update	• Real time display of target location • Refer to Flight Path Control Function	• Auto detect, ID & classification • IFFC/AMAS • Auto computed in flight weapon fusing • Voice function selection and execution

Technology Needed for Automation Approach	• Data Base
	  • Terrain
	  • Threat
	  • Targets
	• Compact Mass Memory
		• Data Link	• Data Link
			• Tactical flight management
				• Hi Res. Sensors, Auto pattern Recog
				• Auto-Correlation Technology
				• IFFC/AMAS
				• Auto Fire Control Fusing
				• Voice function selection (AFTI-16)

Current Programs that Address Needed Technology	• DMA Data Base • CAMPS	• JTIDS	• JTIDS • Tactical Flight Management	• LANTIRN • PAVE MOVER • Covert Strike • JTIDS • F-16 IFFC • AFTI-16 AMAS • SAIF
New Thrusts or Added Emphasis	• DMA Data Base • Current threat and target data base • 100's Meg Bit Memory • Auto Mission Prep Station			• Hi Resolution AIG Sensor • Pattern Recognition • Auto Correlation Technology • Distributed high data rate network • Advanced Aural (Voice) Recognition Technology

maneuvers in response to continuously computed impact point (CCIP) steering commands on the heads up display (HUD). Weapon release can be manual or automatic when the delivery solution has been achieved and release indicated. The dive-toss delivery mode is similar for target detection and fire-control engagement and maneuver. The weapon-release function is automated.

For radar-guided weapons, the pilot identifies and designates the target using the radar display and manually maneuvers to satisfy displayed launch commands; release of the weapon is automatic. For laser electro-optically guided weapons, the pilot visually identifies and designates the target, maneuvers manually to satisfy launch conditions, and manually releases the weapon. For guns, the pilot visually identifies the target, engages the fire-control system, and manually maneuvers the aircraft in response to steering commands on the HUD. Firing is manual.

Analysis of the present approach identifies three areas in which automation can be applied to reduce the number of simultaneous functions the pilot must perform:

- Automation of target detection, classification, and identification through the use of automatic pattern recognition and correlation techniques.
- Coupling or integration of the fire- and flight-control system. Steering commands, now displayed on the HUD, could be coupled with the flight-control system to provide more rapid flight-path convergence and stabilization for weapon release. An automatic release can also readily be incorporated.
- Blended terrain following and terrain avoidance information, available from the flight-path function, could appropriately be used to ensure automatically a minimum altitude for safe recovery.

The automation of target detection, classification, and identification necessitates the application of advances in the technologies of high-resolution sensors, pattern recognition, and autocorrelation. The specifics of these technologies are discussed in the section entitled "Current Programs and New Efforts."

Coupling or integration of the fire- and flight-control system necessitates the functional integration of the sensors, the fire-control computations, and the task-tailored flight-control computations. The object is to permit weapon line pointing while the aircraft is in a nonpredictable trajectory for weapon delivery.

Automatic computation for in-flight weapon fusing is considered feasible. Though present weapon fuse timing is adjustable, it is set during the prelaunch phase. Since this timing is adjustable, automatic computation and fusing as part of the fire control system would increase release opportunities for weapons, thereby removing the present constraint of having to achieve a precise altitude and velocity before release.

The programs outlined above are developing the critical individual technologies crucial to automation. They must be continued. In addition, continued and increased emphasis should be placed on the following aspects of target sensing and acquisition:

- High-resolution air-to-ground sensors
- Pattern recognition
- Autocorrelation techniques.

A new effort must be made to develop a distributed network for high-data-rate transmission. It should have a fault tolerance that satisfies the safety, performance, and reliability requirements of all users, as do those of the hydraulic and electrical distribution systems. This network would provide the core capability for on-board integration of mission functions.

CREW ESCAPE

Systems for crew escape are ranked high by pilots as an area that requires serious attention. A review of available data revealed that pilots of Air Force fighters who use current escape systems are injured or killed too often.

The present escape systems evolved from the first ejection seats, made in Germany and Sweden in the 1930s and early 1940s. The purpose of the ejection seat was to remove the pilot (in the seat) far enough from the aircraft to allow seat separation and safe parachute opening. The speeds of jet aircraft complicates the process.

The advent of highly maneuverable fighter aircraft capable of speeds greater than Mach 1 and roll rates greater than 300 degrees per second has underscored the need for a safe escape system. Much attention has been given to providing tolerable *g* loading and seat stabilization to avoid dangerous spin rates in a high-*g* field. However, considerably less effort has been directed at protection against variations in pressure during ejection; exposure to high dynamic pressures (*q*) during ejection can produce facial and flail injuries and can do damage to the lungs and abdominal organs. Protecting the pilot from injury will require intervention from the time of canopy release, because as the canopy opens it acts as an air scoop, directing ram pressures momentarily into the cockpit. The high ram pressure is followed by pressure oscillations that at some points go below the local ambient pressure.

The lower altitudes at which pilots now fly during tactical maneuvers further demands an improved escape system. In an air-to-air mission, the pilot typically spends much of his time below altitudes of 10,000 feet. In air-to-ground missions, the pilot maneuvers at low altitudes in terrain following and terrain avoidance. The high speeds at these low altitudes produce very high $\underline{q}$ and allow the pilot limited reaction time.

The day-to-day training missions for pilots on the Air Combat Maneuvering Ranges, Red Flag missions, and other types of air-to-air and air-to-ground engagements place the pilot and aircraft in attitudes in which departure from normal flight is dangerous. In these maneuvering attitudes there are also generally high $\underline{g}$ loads. When departures from normal flight do occur, the aircraft may already be at the edge of the escape envelope, where the pilot has little time available to recover to normal flight attitudes or make the decision to eject.

Statistics

Between 1976 and 1980, the survival rate for pilots who ejected from Air Force fighter aircraft declined from 85 percent to 72 percent. In addition, during 1979 and 1980 there were as many ejections outside the escape envelope--the speed and altitude at which ejection is safe--as there were in the previous three years. The Air Force's fatality rate for crew members ejecting below 500 feet has been 57 percent over the past five years. Between 500 and 1,000 feet, the fatality rate drops to and levels off at about 15 percent.

In addition to fatalities, various degrees of injuries have accompanied ejections. Many of those who manage to eject successfully receive major injuries; and only a few eject without injury. Most major injuries have been fractures of vertebrae, legs, ankles, feet, shoulders, and ribs. Although most of these injuries are not permanently disabling, they keep pilots off flight status for excessive amounts of time.

Current Programs

Crew escape is one of the most highly automated systems in today's fighter aircraft. After initiation by the pilot, the entire sequence, from canopy release to deployment of the pilot's parachute, is automatic. Automation should be continued, and the effort should be increased to develop new technologies that will increase the size of the ejection envelope and minimize injuries.

The Advanced Concept Ejection Seat II (ACES II) provides improved performance in several flight situations (such as low altitudes, high speeds, and adverse attitudes) and in unstable ejection trajectories. It also can improve multiseat sequencing and divergence performance and reduce injuries from parachute landing. Improvements planned for the ACES II seat include provisions for upper and lower extremity windblast restraints, a single-point harness-release system, continuous mode sequencing, improved stabilization in yaw, and logistics improvements. Aircraft with less effective ejection seats could be improved by being retrofitted with the ACES II. However, for high-performance fighters the option of using ejection capsules or other means of wind-blast protection should be considered seriously.

Conclusions

In the past, life-support equipment has been developed by redesigning or modifying existing hardware. This approach provides only limited solutions, and it precludes a systems approach to the problem of safe ejection.

Crew escape systems must be improved to save lives. In addition, training of fighter pilots, who are in short supply, requires a lengthy period and is estimated to cost $850,000.

CURRENT PROGRAMS AND NEW EFFORTS

Many technology development programs already under way in the Air Force and other laboratories bear directly on automation in tactical aircraft. Table 3-7 lists the applicable programs known to the subcommittee, and there are probably other government and industry programs. The programs cited in Table 3-7 have their own objectives, not all of which are related to automation.

Based on briefings and analyses, the subcommittee has compiled a list of new development efforts necessary to achieve the recommended level of automation for 1986--five years from the time of this study. Table 3-8 provides and overview of these recommended efforts.

Terrain, Threat, and Target Data Bases

Several programs, such as AETMS and CAMPS, depend on the DMA data base. To ensure prompt availability of the necessary information, priorities should be established to govern data compilation; geographic area and selected cultural features (e.g., churches and

TABLE 3-7 Composite-Current Programs

Program Title	Program Thrust	Critical Technology for Automation
DMA Terrain Data Base Compilation	Compile 3-D Terrain Data Base	Prioritized 3-D Data Base of Terrain and Selected Cultural Feature Data
CAMPS	Mission Data Preparation Unit	Preparation Unit for Cassette Load
JTIDS	Multi-Information Data Link	Data Update Link for Target and Threat ID and Location
IFFN Fusion	Sensor Integration Simulation for IFFN	Non-cooperative IFFN Techniques
COVERT MOVER	Bi-Static and Mono-Static Radar for Non-Emission Attack	High Resolution Sensor
PAVE MOVER	MTI/SAR Radar, Directs Attack Airplane	High Resolution Sensor
LANTIRN	Manual TF/TA, Night Target ID, Laser Designator, Hand-Off and Auto-Recognize	Auto Pattern Recognizer, Hand-Off
PLSS	Locate Emitting Threats	Continuous Threat Data
Tactical Flight Management	Integrate Technologies for Automated Airplane	What and How to Integrate Approaches
AFTI-16	IFFC, AMAS, Tailored Control Laws, Integration	Automated A-A and Automated A-G
F-15 IFFC	IFFC	Automated A-A and Automated A-G
SAIF	Weapon Fuzing for Unconstrained Attack	Automated In-Flight Fuzing
TAACS	Automate Information Processing Tasks	Automated Information Processing Tasks
MISVAL	Dynamic Launch Zone Computation	Activate Launch Zones for Automated A-A
INTERACT (NASA)	Integrated Flight Propulsion Control	Integrated Engine/Flight Control
Blended TF/TA	Blended Active and Stored Data for TF/TA	Auto TF/TA
GPS	Accurate Worldwide Grid Reference System	Navigation and Potential TF/TA Blending
AETMS	Stored 3-D Terrain Data Base, Real-Time Display	Storage, Retrieval and Display of 3-D Terrain Data
Purple Haze	Stored Data Base Threat Profiles	Stored Threat Profile Technology
ASPJ	TWS and Active ECM	TWS and Active ECM
UHR SAR	Flight Test of Advanced Radar	Ultra-High Resolution SAR
Automatic SAR Target Classification	Automatic SAR Target Classification	Automatic SAR Recognition
Correlated Sensor Data Display	Display of 4 Aligned Sensors	Multi-Sensor Correlation
PAVE PILLAR	Info Fusion, Architecture, Algorithms for Automation	Architecture, Algorithms Jointly Managing NAV, EW, Fire Control, Cockpit Data, Redundancy - Support System
Advanced Power Management	Optimal ECM Power Management	Algorithms, Situation Displays
HIMAR	Vehicle Trajectory/Attitude Control	Techniques for Thrust Vector and Management
Voice Function Selection	Provide Alternative Channel for Pilot to Aircraft Communication	Relieve Pilot Work Overload

TABLE 3-8 Composite-New Thrusts/Added Emphasis

Technology Need/Emphasis	Critical Aspect for Automation
Terrain Data Base	Blended Auto TF/TA, Sensor Correlation, Pilot Displays, etc.
Threat Data Base	Threat Avoidance, Combined Avoidance, Evasion, Electronic and Lethal Defense
Target Data Base	Enhance Target Auto ID and Acquisition (A-A & A-G)
Mission Data Preparation Unit	"Prefly" Mission and Auto Mission Load
Compact Mass Memory - 500 megabit	On-board Threat and Terrain Data Storage
Integrated Flight/Engine Control	Automated Aircraft Flight Trajectory, Attitude & Velocity Control
High Rate Data Network	Integrated Data Flow
Cooperative IFFN	Penetration Through Friendly Forces and A-A, A-G ID
Non-Cooperative IFFN	A-A, A-G ID
High Resolution Sensors	A-A and A-G ID and Recognition
Multi-Sensor Correlation	A-A and A-G ID and Recognition
Pattern Recognizers	Auto Target Recognition (A-A and A-G)
Target Priority Algorithms	Automated A-A Target Selection and Prioritization
Distributed Functional Modules	Availability, Mission Success, Quick-Turn
Light Weight Helmet Mounted Sight/Display	A-A and A-G Target Acquisition and Data Display
ALR 67/69 Update	Include Data Bus for Input to Data Base
Anti-Jam All WX TF/TA	All WX Penetration in Defended Areas
Aural (Speech) Recognition and Function Technology	Function Designation, Selection, and Execution
Tactical Flight Management Technology	Analytic Function Allocation and Automation Technology

schools) are important criteria. These efforts should be closely coordinated with the DMA. Efforts to compile threat and target data bases are also needed.

A compact mass memory is needed for storing all the data bases. This mass memory should be flight qualifiable (i.e., able to withstand flight conditions). The amount of storage needed is estimated to be of the order of 100-500 megabits. The information density used in current terrain data bases is about 2 kilobits per square nautical mile. In the future, even if terrain quantization techniques are improved, more cultural features will probably be added to the data base, resulting in the same density per square nautical mile (nm). One sortie or mission could use terrain data covering an area of 100 X 500 nm^2, for a mass memory requirement of 100 megabits. However, a squadron is likely to need to cover areas of 500 X 500 nm^2, which is the present U.S. Air Force design goal. Thus the objective for a compact flight-qualifiable mass memory could be of the order of 500 megabits.

Development of a ground-based unit to prepare data for mission planning should proceed. This unit could also be used by pilots to "prefly" missions.

Flight Trajectory and Attitude Control Weapon Delivery

Several programs relate to flight trajectory and attitude control: AFTI-16, F-15 IFFC, blended TF/TA, GPS, Highly Maneuverable Aircraft Technology (HIMAT), and others. Though this list is long, these programs do not address their tasks with an integrated approach. The subcommittee feels that further work is necessary to address automated flight trajectory and attitude control problems, including sensor inputs, threat and target data (real-time and prebriefed), automated flight-path and velocity control, time and space navigation, and automated attack sequences. This work would, of course, integrate many of the functions described in the sections entitled "Threat Warning and Countermeasures" and "Target Sensing and Acquisition."

Threat Warning and Countermeasures

On the basis of data available to it, the subcommittee concluded that little advanced work is being done on threat warning and countermeasures. This area is of great concern to operational pilots. Perhaps this issue is being addressed, but information was withheld from the subcommittee because of the unclassified status of this report. Nonetheless, the Automatic Self-Protection Jammer (ASPJ) and Advanced Power Management programs appear to offer little in the way of integrated, automated systems. Given the known shortcomings of current systems, automated tactical aircraft appear to need new systems with angular coverage approaching 360° in both azimuth and elevation, better directional accuracy, range data with azimuth and elevation, adequate frequency coverage for all threats, and the ability for smart signal spoofing for accurate threat isolation and rejection.

Target Sensing and Acquisition

In this area the highest potential payoffs for automation appear to be in cooperative IFFN, higher resolution sensors, and automatic target recognition. The Covert Strike and Pave Mover programs are working on technologies for bistatic and synthetic aperture radar (SAR), and LANTIRN is exploring new technology for forward-looking infrared sensor (FLIR) technology and automatic target recognition. Efforts to develop new techniques for focal plane array processing SAR suited to smaller aircraft, and additional automatic target recognition seem to be appropriate for automated aircraft. In addition, the use of a lightweight helmet-mounted sight/display for this application should be emphasized. Multisensor correlation studies should be expanded from the current programs to a level suited to a highly integrated automated system.

Cooperative IFFN

Automatic identification of other aircraft as friend, foe, or neutral can relieve the pilot of a difficult and tactically limiting task. If such identifications must be made visually by the pilot, a significant tactical advantage of long-range detection sensors and long-range weapons is lost.

Current cooperative IFFN equipment (Mark XII) will not be adequate for future automated systems, and very little R&D work is being performed on future systems.

Two significant problems have complicated IFFN, though both should yield to modern digital electronics. First, identification code security is likely to be compromised by wide distribution of the equipment; digitally authenticated signatures, perhaps by public key cryptography, is a promising area for investigation. Second, the size, weight, and power requirements of current equipment preclude application anywhere but on aircraft or ground vehicles. To ensure that they are not attacked by friendly forces, pilots would like to see every ground element on the friendly side equipped with a positive means of interrogating friendly aircraft. The Stinger, shoulder-fired rocket for ground-to-air combat, for instance, is just as deadly to U.S. aircraft as a Soviet surface-to-air missile (SAM). Again, digital systems may provide a solution.

Long-term solutions for IFFN could evolve from procedural techniques such as the use of flight corridors and altitudes, coupled with communications capabilities that supply external situational and intelligence data. However, the development and use of reliable new cooperative IFFN equipment is recommended. Such equipment would have a significant impact on air-to-air and air-to-ground warfare by greatly extending the range of identification beyond that at which visual recognition is possible. These long-term solutions--i.e., new equipment--must be preceded by adequate short-term solutions to give the pilot confidence in identifying other forces.

Noncooperative IFFN

Significant progress has been made on identifying engine types by detecting and classifying jet engine modulations (JEMS) of radar returns; tests have shown this to be effective when approaching a plane from the front or the rear.

Other promising techniques for noncooperative IFFN are passive noncooperative target recognition (PNCTR) and inverse synthetic operative radar (ISAR).

With PNCTR, a large proportion of threat aircraft could be identified by the radio-frequency parameters of their radar by using the on-board radar antenna in a passive listening mode.

Inverse SAR (ISAR), the shapes and sizes of tracked aircraft can be determined by using high-range resolution and stepped multifrequencies in the radar. This information could be useful for automatic identification.

Only a limited amount of work on these techniques has been performed to date. Noncooperative IFFN programs should receive significantly increased priorities.

High-Resolution Synthetic Aperture Radar. In numerous flight test programs, high-resolution SAR modes have been used by multimode radar systems for terrain mapping. These SAR systems can be used by pilots in detecting, recognizing, and identifying many classes of targets. An increase in the SAR resolution of tactical multimode radars coupled with accurate knowledge of target area location and accurate navigation systems accuracy could not only improve manual target acquisition, but could also make all-weather automatic target acquisition and identification more likely.

The goal of automatically recognizing tactical targets in adverse weather is a very challenging technical task, and improved SAR resolution is a prerequisite. Ultrahigh-resolution SAR has the best potential of all sensors for automatic detection, acquisition, and recognition of tactical targets in adverse weather. Although ultrahigh-resolution SAR maps can be made and used for manual target acquisition of tactical targets, many problems must be solved to make ultrahigh-resolution SAR practical in tactical aircraft.

Bistatic Radar. In a bistatic radar system, a plane flying over friendly terrain transmits a message to the strike aircraft above enemy terrain. The strike aircraft is equipped to receive and process that message passively. (When mapping in a passive mode, the receiver is quiet, because the illuminator is located in another aircraft, well behind the forward edge of battle.) The advantages of this approach include covert penetration, passive mapping of the target area, and passive acquisition of the target. The substantial technical challenges include coherent operation of the receiver and illuminator; high-resolution, distortion-free mapping; target tracking; and target classification. The Air Force Covert Strike program addresses some of these problems.

Millimeter-Wave Radar. Automation in tactical aircraft can benefit from the developing technology for millimeter-wave radar. The shorter wavelengths in this radar yield higher resolution for a given aperture size, and thus better data for a given aircraft nose size. The range of millimeter-wave radar may prove inadequate for search and acquisition, but its high-resolution target data will be a valuable input in automatic target pattern recognition.

Development is proceeding in at least three atmospheric windows--regions of the atmosphere where electromagnetic energy is not absorbed or scattered. Each has certain exploitable characteristics related to weather penetration, resolution, component availability, and other factors. Most applications to date have been in terminal missile guidance against tactical targets. It is believed, however, that millimeter-wave sensors under some conditions can achieve longer detection ranges and better weather and smoke penetration than forward-looking infrared (FLIR) sensors. It can also provide highly accurate aimpoint data, some unique signatures for target classification, and spectral data complementary to those from FLIR sensors and conventional radar for decoy discrimination and automatic target pattern recognition.

CO_2 Laser Radar. Perhaps the most promising new sensor technology for tactical aircraft is the laser radar. This device promises to provide a new type of target image, higher resolution, moving target indication, a very narrow beam, and few extraneous emissions. Although not useful in every weather condition, it does have good potential in some marginal weather conditions. It has enormous potential for automation in tactical aircraft because of the high-resolution images it can produce, because of its electronic beam agility, and because of its ability to provide guidance data for multiple targets and weapons on a single pass.

These laser radar problems are addressed in several Air Force programs, including the Multi-Function Infrared Coherent Optical Sensor (MICOS) program at the Air Force Wright Aeronautical Laboratories and the High-Velocity Missile (HVM) program at Eglin Air Force Base. Additional development work should probably be directed at making the laser equipment more rugged, reducing its size, improving its optical and frequency stability, dealing with pumps and gas-flow problems, developing coherent signal processing techniques, and improving gas laser components.

Finally, the CO_2 laser radar provides the means of simultaneously guiding multiple weapons to individual targets during a single attack pass. This function, when coupled with automatic target pattern recognition software, can provide a high level of automation in target acquisition and weapon delivery. When used with a high-speed weapon, such as Eglin's HVM, it should help to minimize the exposure of aircraft and aircrews to enemy fire while greatly increasing their available firepower.

Airborne Infrared Search and Track. The current trend in enemy threats has been toward small, fast interceptor missiles that have very small radar cross-sections. These missiles are poor radar targets, but better infrared targets. Consequently, there is a resurgence of interest in airborne infrared search-and-track (IRST) sensors to augment the airborne radars. IRST sensors also have other advantages:

- Immunity to radio-frequency jamming
- Covertness (passive)
- Fine resolution for raid assessment
- Immunity to radio-frequency decoying.

Although development of IRST systems stopped in the late 1960s, technology development applicable to these systems has continued. If these advances in signal processing, detectors, and cryogenics are incorporated into the IRST, the system becomes even more attractive.

Current trends in IRST are directed at applying these advances to achieve better clutter rejection, longer detection ranges, and improved reliability. In addition, multisensor correlation and display techniques are being developed. The Air Force is funding development of an IRST system for the F-15.

Future trends in IRST are expected to use focal-plane array technology to achieve even longer detection ranges, faster frame rates, and larger fields of view. Another future trend possibility is the use of wide spectral coverage (i.e., 8-12μ and 3-5μ), for further improved clutter rejection and target identification.

Automatic Target Pattern Recognition

Automated weapon delivery depends fundamentally and critically on automatic target recognition, except perhaps in a few simple cases. The pilot's participation is limited by the time available. The durations for a weapon-delivery pass are measured in seconds. When multiple targets per pass are considered (six to ten targets are mentioned in some current programs) the time available for search, interpretation, and manual decisionmaking is likely to be too short for reasonable human performance. In addition, the false alarm rate for targets will inevitably increase as the available time per task grows shorter and may well reach an unacceptable level before the human task limit is reached.

In theory at least, automatic target pattern recognition should be among the most fertile areas for automation. The principal utility of the digital computer in this realm derives from its ability to handle large amounts of data in short periods. It should thus be able to augment the pilot's abilities by processing sensor data using algorithms for target pattern recognition. The output of this algorithm would be a target data set requiring minimal pilot scrutiny and decision.

Research among government, academic, and industrial laboratories to date has demonstrated that defining algorithms is difficult and complicated. In some tactical scenarios, detection, recognition, classification, and identification may be required. When most or all of these are required, and at high statistical confidence levels, the mathematical definition and data-processing task is formidable. Some progress is being made, however, and workers in the field are generally optimistic. The problem is being approached from a rigorous mathematical standpoint, using shape, size, depth, contrast, edge matching, and other geometric techniques. More abstract mathematical transforms, using edge differentiation, negative space, and statistical processing, are also being used. Some of these lead to unfamiliar images that are more amenable to automatic decisionmaking, but still permit some pilot interpretation. Many heuristic techniques have also been defined; some appear in experiments, to produce good results. Due to the complexity of image mathematics, it may well be that future heuristic approaches will contribute to the definition of algorithms for target pattern recognition.

Assuming sensor data are available--and today's sensors could suffice for many applications--the development of algorithms for automatic target pattern recognition is a pivotal issue in automating tactical aircraft. It is difficult to conceive of an advanced automation system that does not relieve the pilot of this high-task-load mission phase. On the other hand, a mechanization that handled multiple targets at high confidence levels would quickly ensure the success and acceptance of an automated target sensing and acquisition system. Automatic target pattern recognition activities should be assigned a high priority in the overall automation scheme.

System Architecture

The new Pave Pillar program, and NASA's Integrated Research Aircraft Control Technology (INTERACT) program are addressing avionics design from a systems standpoint--an approach that considers the integration of various aircraft components. They also address the development of algorithms applicable to automation. Additional work needs to be performed on algorithms for establishing target priority, and on a network for high-rate data.

The Use of Aural Communication

Pilots' desires for improved crew stations have been interpreted to mean that the pilots need relief from their overload of tasks and information. One proposed method is to parallel the input and output of the pilots' eyes and hands by employing their ears and mouth, using tones, synthesized speech, and speech-recognition techniques. Research, however, has yet to show that a pilot's capacities for handling data is doubled by employing such a parallel channel. There is even some evidence that under overload conditions pilots generally "turn off their ears." Furthermore, speech-recognition techniques are not yet well enough developed to promise early use in the crew station as standard equipment. (The input technologies of tones and speech synthesis, however, appear to be adequate for use.)

AN APPROACH TO AUTOMATION

The previous section discussed the technology for automation. This section describes the ways this technology might be used.

Early avionics systems consisted of collections of distinct elements, partitioned so completely that different designs were used for different kinds of missions, or the elements were distributed among crew members. In current fighters, one design and one pilot can accomplish limited multiple missions. The current configuration has been achieved largely by automating single elements of the avionics systems. For example, the fire-control function integrates and automates several elements: navigation, target acquisition, processing, display, etc. Air-to-air gunnery is a typical example of present-day automation. In the latest fighters (F-15, F-16, F/A-18) the pilot's selection of a single air-to-air gun switch results in automatic radar search and track, automatic computation of launch zones, and automatic display of essential flight/gunnery parameters. However, there is no automation among elements. In firing air-to-air guns, the pilot controls the airplane manually to meet the firing envelope displayed by the automated systems.

The pilot, then, serves as the automation "core," processing in his brain all the data flowing in through his eyes, ears, hands, and body, as illustrated in Figure 3-1. By throwing switches, maneuvering the aircraft, or releasing weapons, the pilot then takes whatever actions are needed to meet the conditions indicated.

The practice of automating only within elements probably resulted from (1) improvements made to correct specific workload bottlenecks reported by aircrews, (2) logical extensions of existing designs to accommodate new sensors and weapons, (3) automation concepts and designs funneled into elements along the lines of established development organizations, and (4) limitations of technology transfer within the Air Force and between it and its contractors.

It is clear that automation among elements--as opposed to the past practice of automation within elements--will be necessary for the improved design of combat aircraft. The first issue is how to integrate the automated elements.

There are two contrasting ways to proceed. The "top-down" approach begins by tackling the difficult problems first--by attempting to automate those elements for which such systems have not yet been developed. After these elements were automated, an architecture could be designed to link together the various automated components of the aircraft. Since some of that technology (for example, technology to automate target sensing) remains elusive, the final, integrated approach cannot yet be implemented. Another approach to automation would provide a more immediate payoff.

The subcommittee recommends the "bottom-up" approach to automation. It starts with those elements that can be successfully automated, and then integrates them into a core function. As technology

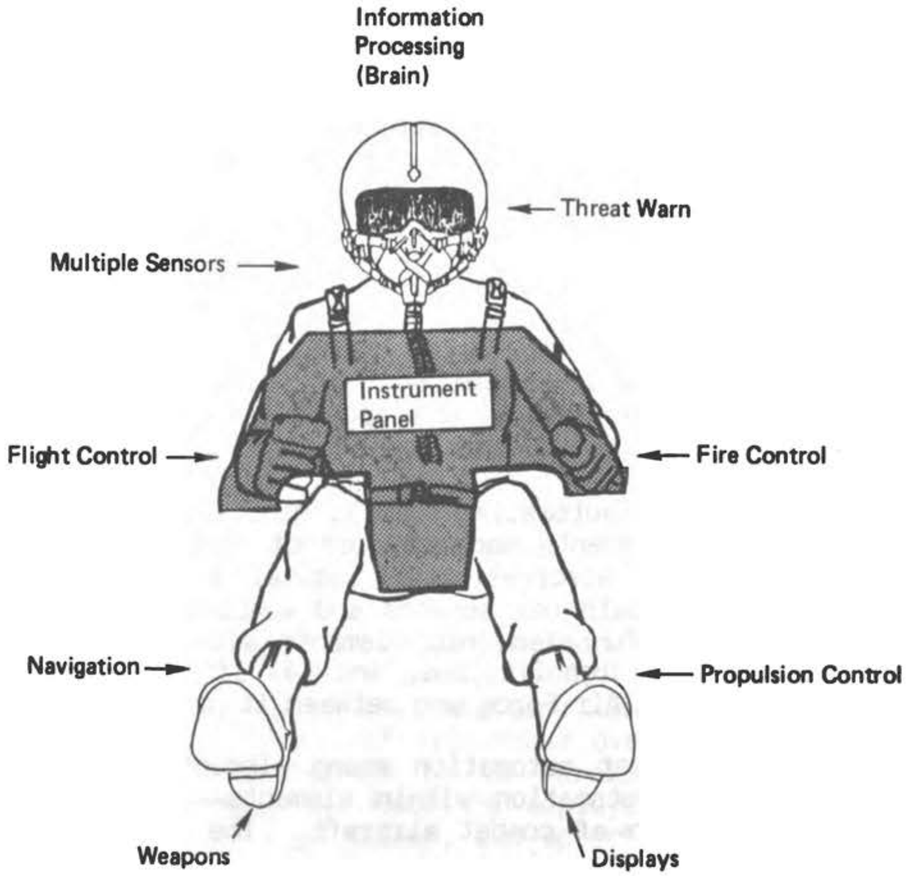

FIGURE 3-1. The pilot is the automation "core," processing all the data from aircraft elements. The result is a high workload and a limit on performance.

develops to automate additional elements, they can be added to the core function. Technology exists to implement this approach now, building on the core function of flight trajectory and attitude control.

Flight Trajectory and Attitude Control

All functions of a combat aircraft depend on the central function of flight trajectory and attitude control--the maintenance of the correct flight trajectory and orientation, or attitude, of the aircraft. As described earlier, this core function includes the subfunctions of flight control, fire control, navigation, and propulsion. When propulsion is added to the navigation function, it provides the capability for four-dimensional navigation (latitude, longitude, altitude, and time). When attitude control (control of roll, pitch, and yaw) is integrated into this system, then precise seven-dimensional navigation can be achieved.

On the basis of this analysis, the subcommittee suggests a systems approach to automation that treats flight trajectory and attitude control as the foundation for all aircraft automation. Figure 3-2 illustrates how this approach differs from current programs on combat aircraft automation. The current automation approach in Figure 3-2 (left) shows two current programs--essentially "top-down" approaches. The LANTIRN program links together weapons delivery, sensors (target sensing and acquisition), fire control, and navigation. Yet at this stage, technology does not exist for automating the function of target sensing and acquisition--a significant stumbling block to the implementation of this program.

The IFFC program links together fire control, flight control, and navigation--but leaves out the important function of propulsion.

The recommended core automation approach (the "bottom-up" approach) of Figure 3-2, right, links together fire control, flight control, navigation, and propulsion. At this stage, the crew integrates the other functions of threat warning and countermeasures, target sensing and acquisition, and weapons delivery. When the technology is available to automate these operational mission functions, they can be integrated into the core function.

If implemented properly, this rational approach to automation should result in standardized interfaces, processing, and hardware. Figure 3-3 shows this logical progression. Eventually, all functions would be automated and integrated. Free from the tasks involved in flying the aircraft, the pilot would have sufficient time to manage and monitor the situation and to make important decisions.

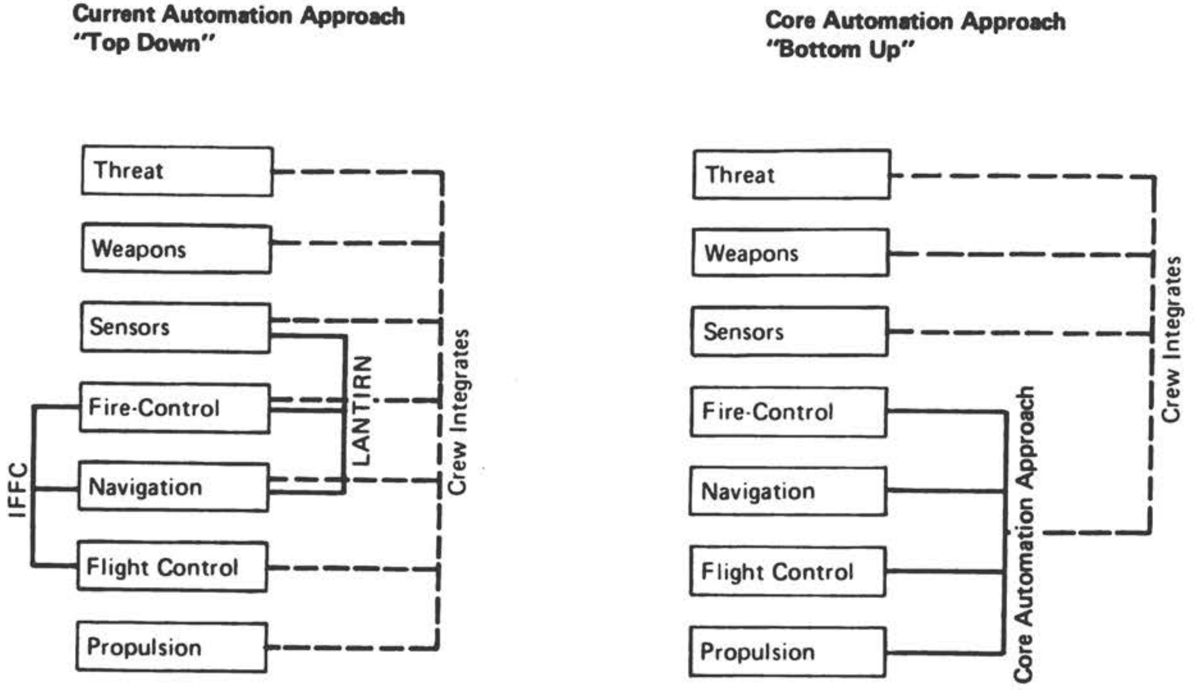

FIGURE 3-2 In the current automation approach (left), the LANTIRN programs link together weapons delivery, target sensing and acquisition, fire control, and navigation. The IFFC program links together fire control, navigation, and flight control. In both programs, the crew integrates all of the functions. In the recommended core automation approach (right), fire control, navigation, flight control, and propulsion are integrated to form a composite function called flight trajectory and attitude control. The crew integrates this core function with the other mission functions.

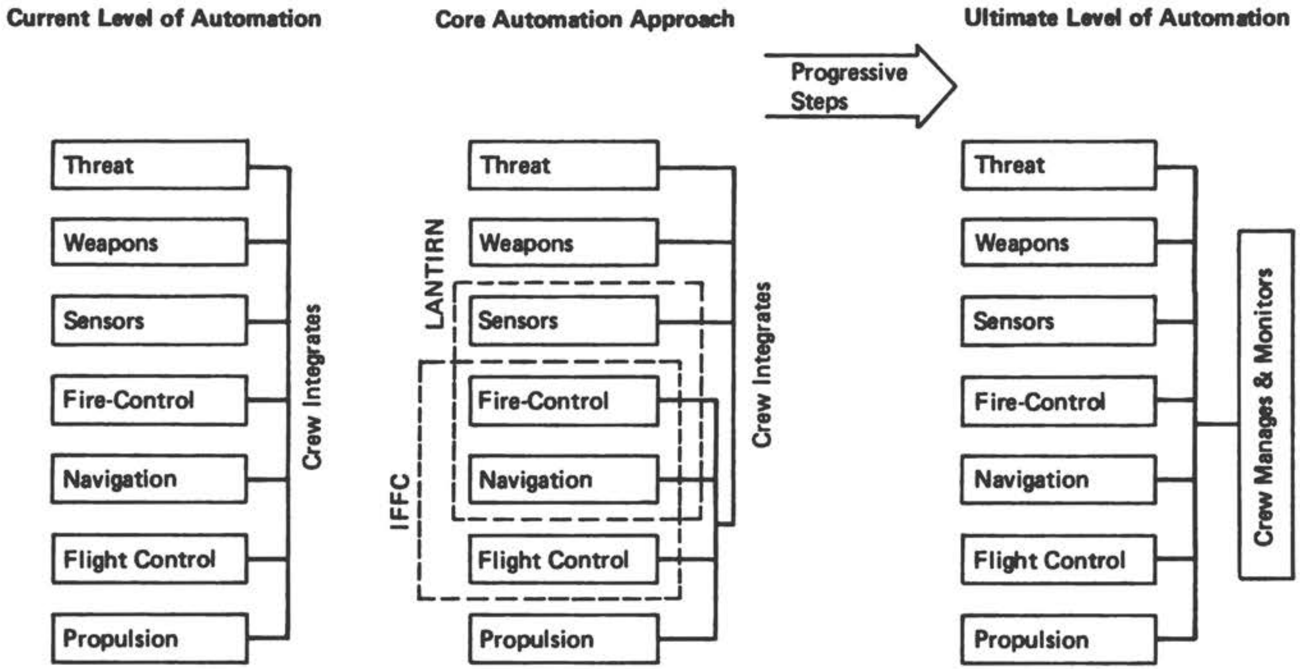

FIGURE 3-3 In the current level of automation (left), the crew integrates all mission functions. In the recommended core automation approach (middle), the crew integrates the composite function of flight trajectory and attitude control with the other mission functions. In the ultimate level of automation (right), all the functions are integrated, and the crew manages and monitors the system.

Conversely, if automation does not progress as a logical extension of flight trajectory and attitude control, or if this function is not handled properly, then the result will be a proliferation of unintegrated systems and activities.

This raises the second question concerning the recommended approach: how to automate the flight trajectory and attitude control function.

Core Function Implementation

Successful automation of the flight trajectory and attitude control function will require a flexible architecture (not a collection of distinct systems and activities) with logical partitioning and standard interfaces. Such an architecture could accommodate current and future operational mission functions (target sensing and acquisition, threat warning and countermeasures, weapons delivery, etc.) in a process of continual growth and integration. This core function would control surfaces, engines, crews, weapons, and sensors.

The capabilities of this core function could be distributed among many processors or concentrated in a few suitably redundant processors. Its processing could be implemented in hardware or software as appropriate. Its data could flow through a single bus, multiple parallel buses, or a hierarachy of buses.

Reliability and availability will be critical to the design, as each element of this function will be vital to mission completion and flight safety. If it is not reliable and available, the system will be ignored and circumvented by crews. Manual operation of a system designed for automation will prove less successful than the piecemeal automated systems of today. Redundancy employing parallel identical equipment is a possibility, but it is better to provide redundancy by building in the capacity for reconfiguration. The latter possibility also exists for common reconfigurable modules.

This discussion identifies the third issue of automation: What program is needed to automate the core function of flight trajectory and attitude control? This is covered in the following recommendations.

RECOMMENDATIONS

Core Program

The current F-15 IFFC program addresses part of flight trajectory and attitude control by coupling the functions of flight and fire control. The AFTI-16/AMAS program extends this application by coupling a digital flight- and fire-control system and by implementing task-tailored control laws.

Neither program couples propulsion control with fire and flight control. The coupling of these subfunctions could provide early information to assess automation techniques. Because of its digital flight control and advanced cockpit, the AFTI-16 is the likely airplane for this propulsion coupling. However, even though the F-15 IFFC and the AFTI-16 will provide integration and redundancy techniques and flight trajectory algorithms, they do not address the issue of core architecture for future automated systems. Accordingly, it is recommended that the Air Force initiate an effort to develop the overall core architecture for flight trajectory and attitude control, establish appropriate standards, and produce a prototype for flight test and evaluation as a total system.

Reliability, system availability, and maintenance must be explicitly and thoroughly addressed in the program to develop the automated core system. Such things as automatic reconfiguration, fault tolerance throughout the system, and state-of-health reporting are of prime importance.

Research and Development

Although we have emphasized the core and building-block approach to aircraft automation, it is evident from the discussions and recommendations of new efforts that a capability for target identification will greatly extend the fighting ability of combat aircraft. Accordingly, we recommend a new program on cooperative IFFN and increased emphasis on noncooperative IFFN research.

A NOTE ON REMOTELY PILOTED VEHICLES

Ultimately, the completely automated combat aircraft would be a remotely piloted vehicle (RPV). What are the characteristics and appropriate missions of the unmanned RPV? RPVs are relatively inexpensive compared to piloted vehicles, and they are simpler, smaller, and lower in observable signatures. Their missions are less complicated, more dangerous in wartime, and lower in international repercussions in peacetime. Good examples are the U.S. Army's Aquila artillery target spotter, cruise missiles for deep penetration bombing, and the U.S. Air Force's Firebee for reconnaissance. In order to accomplish the mission, all functions (e.g., flight control, throttle control, fuel sequencing, navigation) are completely automated for all segments of the mission (launch, ingress, engagement, egress and recovery). It is interesting to note that the three missions above were first flown with manned aircraft and later converted to RPVs. One can speculate that as missions, functions, and technology are better understood, more missions could be accomplished by RPVs.

APPENDIX A

TERMS OF REFERENCE

This study is concerned with automation both of and in combat aircraft to support the Air Force's mission. The term "automation" has of diverse interpretation. It is used variously to describe the control of a single quantity by a very simple on-off mechanism (as in thermostatic control of temperature). It is used to describe the concurrent display of data from several sources to a person for interpretation. An example is the displays of a modern fighter aircraft, which combine information from, say, a radar, an electro-optical sensor, and computer-derived flight parameters. Automation has also been used to describe the control of complex processes in which the automated system replaces some human intellectual capabilities.

Automation of human decision processes is the subject of this report. Past automation efforts have served to augment human strength (as with servo-actuated remote manipulators) or to provide automatically processed information about the environment (as in a radar or electro-optical tracker). In this report, the term "automation" will describe any effort to move the cognitive content of flying an aircraft and managing its weapons from the aircrew to an automated system. The level of automation can be measured by the system's ability to exhibit cognitive behavior. Table A-1 describes a scale that spans the spectrum from complete human control to complete automated control.

There may be a provision for crew override of the automated processes, and there may be supervisory arrangements for the crew. Hence the automated system may be largely invisible or it may, in effect support the man. In the latter situation, it may still be transparent to crew actions. In the context of the study, "aircraft" means a fighter airplane performing any of the usual tactical missions. The boundary of the study is the combat aircraft itself, which includes sensors that bring salient features about the external world into the aircraft environment. Included in this context is the aircraft-end of all communication and data exchange to and from external sources, e.g., JTIDS data links. Maintenance and training aspects of automated systems are germane, as are the interface provisions between the human and the machine. Issues and questions such as the following are of concern to the study.

What capabilities are needed? For what missions? Why does the Air Force wish to automate? Is it to reduce the crew work load? Is it to provide opportunities for smaller crews? Is it to enhance aircraft performance in combat? Is it to provide more efficient peacetime performance? How are the maintenance and training affected? What are the automation opportunities for each of these?

TABLE A-1. Levels of Automation

100% Human Control	1. Human considers decision alternatives, makes and implements a decision.
	2. System suggests set of decision alternatives, human may ignore them in making and implementing decision.
	3. System offers restricted set of decision alternatives, human decides on one of these and implements it.
	4. System offers restricted set of decision alternatives, and suggests one, human may accept or reject, but decides on one and implements it.
	5. System offers restricted set of decision alternatives and suggests one which it, the system, will implement if human approves.
	6. System makes decision and necessarily informs human in time to stop its implementation.
	7. System makes and implements decision, necessarily tells human after the fact what it did.
	8. System makes and implements decision, tells human after the fact what it did only if human asks.
	9. System makes and implements decision, tells human after the fact what it did only if it, the system, thinks he should be told.
100% Automated Control	10. System makes and implements decision if it thinks it should, tells human after the fact if it thinks he should be told.

Source: Sheridan (1979).

What posture should the Air Force take on automation? What is its point of view? Should it change? Should the aircraft with its automated systems be regarded as an extension of the aircrew, or should the crew be seen as the "operational manager" of a weapons system in action? In this context, the latter view characterizes new generations of commercial transports.

What in mission insights about "the machine" does the crew need if the automated systems are his extensions? If he is the operational manager of a weapon system?

What minimum level of automation should the Air Force insist on in all new aircraft or in upgraded aircraft (e.g., coordinated flight control as on the F-15, fuel management, center-of-gravity management, enroute flight control)?

How much is enough? What is the depth to which automation should proceed? Should it be confined to constraining vehicle maneuverability (e.g., within acceleration limits as with the F-16)? What should be its role in flight control? Should it be allowed to perform at mission level (e.g., in weaponry targeting and control, in combat maneuvering)? Should it even go so far as to completely control some missions from start to stop?

What is the appropriate R&D program to further and support Air Force interests in aircraft automation? Does it address projected hardware and software pertinent to aircraft automation for the time of its development? What studies are needed to identify capabilities of man and his limitations in an information rich environment? What studies are needed in computer systems for such applications? What new sensors might be needed to support highly automated situations? What system organization and architecture questions must be answered? What system-level studies are needed to examine the desirability and thrust of automated efforts?

To summarize another way, the Air Force must understand what aircraft automation is all about; it must understand why automation should be undertaken; it must have a point of view on the matter. Drawing on its own knowledge and insights, the Air Force wishes to develop a cohesive and consistent posture on automation rather than depend on happenstance ideas that come along as part of weapon system development programs.

As a point of context, it is noted that a man can make mistakes or blunders, the effect of which is to make short-term decisions inimical to long-term performance. Presumably the automated system must accommodate such aberrations; but is it possible to do so in a wholly unconstrained circumstance? If not, what are the minimum constraints that are essential to impose? It is further noted that an interesting attribute of man is that he can conduct unplanned, ad hoc, short-term experiments to assist his understanding of what may have taken place in the outside environment or in his automated situation. He can be, so to speak, a "cut-and-try artist" in seeking a response to a changing unanticipated situation. To what extent can or should automation replace or serve such a capability?

It has been suggested that appropriate jobs for automation include rapidly changing situations, repetitive tasks, situations in which excessive strength is needed, long-duration tasks in which fatigue, boredom, anxiety, or acceleration forces, diminish pilot capability, and situations in which complexity of assessment is too high. Correspondingly, it is suggested that appropriate jobs for man include judgment of situational changes, needed adaptations that have not been foreseen, improvised responses, and, importantly, the addition of reliability and adaptability. If the matter is structured conceptually in this way, are we unknowingly blocking insights for significantly different and perhaps more powerful approaches?

However and wherever automation is to be fitted into combat aircraft of the future, there are important collateral issues that must be attended. Among them are:

A high level of organizational acceptance as well as individual personal acceptance of the automated features. Otherwise, such systems may be unable to perform to maximum degree because aircrews or organizations will ignore or circumvent them.

As part of the acceptance aspect, systems must exhibit high reliability and high availability. The system that "isn't there" because of malfunctions will be seen as undesirable.

Systems must be highly maintainable. Automation is expected to produce more combat effectiveness (among other payoffs), and therefore ready and prompt maintenance features will be essential for quick turnaround of such sortie capability.

State-of-health reporting to the crew must be done appropriately. An automated system is likely to be highly redundant, and it may be essential for the crew to know at all times how much of the redundancy is still operational. One aspect of this matter is that of fault detection and isolation, which may be reported to the crew directly, or conceivably, indirectly in terms of loss of capability. Another aspect is fault diagnosis and isolation to facilitate appropriate maintenance response by the ground crew.

From the overall Air Force point of view, there are other significant collateral issues of importance:

There is much evidence that a major weapon system will stay in the inventory a lot longer than in the past--typically, fifteen to twenty-five years for current systems. Because both the threat and the available technology change significantly over such a period, systems typically undergo several cycles of major modification. Almost certainly, such modifications are virtually impossible to predict during initial systems design, and it becomes relevent to ask of an automated system: what effect might automation have on the next version of a system? Might the entire automated system have to be totally discarded with a fresh start? How can such systems be designed or modularized to minimize the consequences of change? Might necessary changes be accommodated through software or by substitution of "new invention" hardware at the box level? Can we preserve the overall automated system architecture from generation to generation? Is standardization an issue? Why?

Automation--certainly in the classical sense--implies preplanning of actions. To what extent can future technology provide adaptability to unforeseen, unplanned circumstances? Alternatively, how does one define the limits for automation in order to avoid unnecessarily constraining Air Force utilization of weapon systems?

A troublesome, technically motivated observation causes us to note that automation implies extensive combination or use of information from a variety of sources to accomplish one or several end tasks. As with most situations in which exploitation of information is a central and salient feature, successful automation of combat aircraft may well transcend historical jurisdiction or organizational boundaries. The classical parochial and dissected view of an aircraft is not likely to survive. In the information sense, it can no longer be looked on as a propulsion system with its controls, thrusting an airframe with its controls, carrying some sensors with their controls, delivering weapons by an avionics system with its controls and displays, all integrated and managed by a crew. The interplay among all systems will be so tight and the exchange of information so intensive that for many automated applications, only a system-level aircraft view will be appropriate.

In our report we should comment on how germane the established Air Force program is to the issues above. Are there evident gaps? Should additional program elements be described to the Systems Command in order to enhance USAF options for future aircraft acquisition? Is the currently approved program too rich in some areas? Too lean? Is the thrust of the Air Force R&D properly pointed and focused technically? Are there system-level issues not being addressed?

We are not in an advocacy role. We are responsible for an objective evaluation of the state of the art and the opportunities it offers. After a critical examination, it is our responsibility to report on the status and adequacy of programs to enhance the options available to the Air Force. Finally, some advice could be offered if we feel the thrust of the Air Force is misaligned.

APPENDIX B

AGENDA, SUMMER STUDY ON AUTOMATION IN COMBAT AIRCRAFT

Carriage House
NAS Summer Study Center
Woods Hole, Mass.
July 6-31, 1981

Monday, July 6, 1981

0800	Registration	
0900	Review of Organizational Plans for the Summer Study	Mr. R. Duffy, AFSB
1100	Advanced Tactical Fighter Program USAF Future Fighter Aircraft Plans	LtCol Stewart Cranston, RDQT
1200	LUNCH	
1300	Fighter Aircrew Technology Program Unconstrained Tactical Attack Program	Mr. W. Gene James, AFWAL/FIG
1400	Advanced System Architecture	Mr. Frank Scarpino, AFWAL/AAA
1500	Adjourn	

Tuesday, July 7, 1981

0800	Function Allocation for Man Machine Interface	LtCol Johnny Brisby, AFAMRL/HED
0900	Crew Workload Study Program	LtCol Robert O'Donnell, AFAMRL/HEG
1000	TAC Design Evaluation Program	Dr. Kenneth Boff, AFAMRL/HEA
1100	Discussion	
1200	Lunch	
1300	Integrated Fire/Flight Control Simulation	Mr. James Hunter, AFWAL/FIGX

July 7, Continued

1400	Fire Fly III/Integrated Fire-Flight Control	Lt Henry Ziemba, AFWAL/AART
1500	Continuation of Discussions	
1600	Adjourn	

Wednesday, July 8, 1981

0800	Soviet Combat Aircraft Automation	Mr. Clyde Autio, FTD/SDNS
0900	Summary - A Literature Survey Results of Variable Aircraft Tests on Control Augmentation and Display Augmentation	Mr. Morris Ostgaard, AFWAL/FIG
1000	Discussion	
1200	Lunch	
1300	Advanced Fighter Technology Integration	Mr. James Ramage, AFWAL/FII
1400	Automation and Flight Control -- the Sensors	Mr. Charles Abrams, Navy NADC
1500	Discussion	
1600	Adjourn	

Thursday, July 9, 1981

0800	Technical Advances in Control Display	Mr. Morris Ostgaard, AFWAL/FIG
0900	RPV's	Mr. Starr Colby, Lockheed Aircraft Co.
1000	Impact of Simulation Studies on Automation	Mr. Richard Geiselhart, ASD/ENECH
1100	Discussion	

July 9, Continued

1200	Lunch	
1300	Roundtable Discussion	LtCol David Milam, Maj Harry Heimple, AFFTC, Edwards AFB
1600	Adjourn	

Friday, July 10, 1981

0800	What Human Factors Can and Cannot Do	Dr. Robert Hennessy, NAS-NRC
0900	Smart Anti-Vehicular Airborne Munition (SAVAM)	Mr. Don Shuster, Sandia Laboratories
1000	NASA Automation	Dr. Renwick Curry, NASA/Ames
1200	Lunch	
1300	What the Civilian (FAA) World Sees in Automation	Mr. Neal Blake, FAA
1400	Design of Intelligent Systems	Dr. Julie Hopson, Navy NADC
1500	Air Force Cockpit Needs of the Future	Mr. Ron Vokits, ASD/AXT
1600	Adjourn	

Monday, July 13, 1981

0800	PAVE MOVER	Capt Martin Biancalana, RADC
0900	Synthetic Aperture Radar Techniques in Airborne Radar Covert Strike	Mr. Paul Johnson, AFWAL/AA
1000	Low-Altitude Navigation Targeting Infrared for Night (LANTIRN)	Mr. Richard Wallis, SPO/ASD

1100	Discussion	
1200	Lunch	
1300	Air-to-Air Fire Control for Multiple Target Attack	Capt David Chaffin, AFWAL/AART
1400	Automation in Electro-Optical Sensor Avionics	Dr. Harold Rose, AFWAL/AA
1500	Summarization of Avionics Lab Presentations	Dr. William Eppers, AFWAL/AA
1530	Wideband Data Processing for Aircraft Processing	Mr. William E. Wolf, RADC
1615	TAC Comments on Automation in Aircraft	LtCol Mark Foxwell, IWS Maj David Yates, Nellis AFB Col Walter S. Radeker, Eglin AFB
1740	Adjourn	

Tuesday, July 14, 1981

0800	Continuation of Briefing - TAC Comments on Automation in Aircraft	LtCol Mark Foxwell, IWS
1200	Lunch	

July 14, Continued

1300	Discussions	Maj David Yates, Nellis AFB
1700	Adjourn	

Wednesday, July 15, 1981

0800	Avionics Acquisition and Support	Mr. Hy Shulman, Mr. J.R. Gebman, Rand Corporation
1000	Cockpit Design - F-18 Advanced Crew Systems	Mr. E.C. Adam, McDonnell-Douglas

July 15, Continued

1200	Lunch	
1300	Discussion on the F-18 Tour of Otis AFB	LtCol Peter Field, USMC
1800	Adjourn	

Thursday, July 16, 1981

0800	Identification Technology Synthetic Aperture Radar for Weapon Delivery	Mr. M.E. Radant, Hughes Aircraft
1200	Lunch	
1300-1600	Daily meetings of the three study subcommittees	

Friday, July 17, 1981

0800	Navigation, Terrain Following, Threat Avoidance Using the DMA Terrain Data Base	Mr. William Weber, Hughes Aircraft
1200	Lunch	
1300-1600	Daily meetings of the three study subcommittees	

Monday, July 20, 1981

0800-1200	Speech Recognition	Mr. M. Kabrisky, AFIT/ENG Mr. E. Werkowitz, AFWAL/FIGR
1200	Lunch	
1300-1600	Daily meetings of the three study subcommittees	
1600-1700	Daily meetings of the subcommittee chairmen, technical directors, the study chairman and study vice chairman	

Tuesday, July 21, 1981

0800-1000	Daily meetings of the three study subcommittees	
1000-1100	JTIDS	Col Norman Wells, ESD, Hanscom AFB
1200	Lunch	
1300-1600	Daily meetings of the three study subcommittees	
1600-1700	Daily meetings of the subcommittee chairmen, technical directors, the study chairman, and the study vice chairman	

Wednesday, July 22, 1981

0800-1600	Daily meetings of the three study subcommittees
1600-1700	Daily meetings of the subcommittee chairmen, technical directors, the study chairman, and the study vice chairman

Thursday, July 23, 1981

0800-1200	Tactical Air Operations - 1990's	Mr. Conrad Martinez, Jr., AFWAL/FIMB
1200	Lunch	
1300-1600	Daily meetings of the three study subcommittees	
1600-1700	Daily meetings of the subcommittee chairmen, technical directors, the study chairman, and the study vice chairman	

Friday, July 24 - Thursday, July 30, 1981

0800-1600	Daily meetings of the three study subcommittees	
1600-1700	Daily meetings of the subcommittee chairmen, technical directors, the study chairman, and the study vice chairman	

Friday, July 31, 1981

0900-1200	Outbriefing	Mr. R. Duffy, AFSB

APPENDIX C

GLOSSARY

ACES II (Advanced Concept Ejection Seat II): Advanced seat, used in the F-15 and F-16 with improved low-altitude, high-speed, adverse-attitude unstable-trajectory safe ejection envelope.

AETMS (Advanced Electronic Terrain Mapping System): Air Force Wright Aeronautical Laboratories research and development program to develop algorithms for displaying, in real time, terrain contours and features, using digital mapping data.

AFTI-16/AMAS (Advanced Fighter Technology Integrator/Advanced Maneuvering Attack System): Flight Dynamics Laboratory Flight Test program to demonstrate the capabilities of integrating into an F-16 the actual control, digital flight director fire control, electronic display, and helmet mounted display.

AFWAL (Air Force Wright Aeronautical Laboratories): A designated Air Force Laboratory combining programs in the Propulsion, Materials, Flight Dynamics, and Avionics under a single management to achieve improved technology development and integration.

AIM-7: Air Force designation for a production continuous wave (CW) radar-guided homing air-to-air missile.

ALQ-131: Designation of electronic countermeasures pod and equipment used on F-15 and F-16 aircraft.

AMRAAM: Advanced Medium-Range Air-to-Air Missile.

ASPJ (Automatic Self Protection Jammer): Development program to automate jamming capability.

AWACS: Airborne Early Warning and Control System

Big Look: Nickname for several ongoing early warning and surveillance programs.

Blended TF/TA: Terminology used to describe a Flight Dynamics Test Development program attempting to integrate digital land mass, navigation radar, and infrared technology to provide a near pursuit terrain following/terrain avoidance capability.

C^2: Command and control.

C^3: Command, control, and communication.

CAMPS (Computer Aided Mission Planning System): Ongoing development program to computerize and mechanize the planning and prelaunch loading of mission planes.

CCIP: Continuously Computed Impact Point.

Covert Strike: Wright Aeronautical Laboratories development program using bistatic or monostatic radar for nonemission attack.

DAIS: Digital Avionics Information System.

DMA: Defense Mapping Agency.

ECM: Electronic Countermeasures.

EF-111: Air Force electronic-countermeasures equipped F-111 aircraft.

F-15: "Eagle" air superiority fighter.

F-16: "Fighting Falcon" air combat fighter.

F/A-18: "Hornet" Navy air combat fighter.

FAA - Federal Aviation Administration

FLIR - Forward-looking infrared.

g Tolerance: Ability to adapt to gravity load beyond normal force.

GCI (Ground Control Intercept): Terminology used for ground radar operations in directing aircraft to a target or point in space.

GPS (Global Positioning Systems): A satellite network that provides a worldwide grid positioning and velocity reference system. Frequently referred to as NAVSTAR.

HUD (Heads Up Display): A windscreen-mounted transparent device on which information such as vehicle altitude, attitude, velocity, and target commands are projected.

HIMAT (Highly Maneuverable Aircraft Technology): NASA Flight Research program examining benefits of high accelerations using remotely piloted vehicle technology.

HVM (Hyper-Velocity Missile): An Air Force Armament Laboratory missile development program.

IFFC (Integrated Fire Flight Control): Joint Flight Dynamics and Avionics Laboratories demonstration program of functionally integrating flight control and fire-control technology to achieve maneuvering weapon delivery for air-to-air to air-to-ground missions. Flight testing is underway, using an F-15 aircraft.

IFFN: Identification Friend, Foe, or Neutral.

INS: Inertial Navigation System.

IR: Infrared.

ISAR (Inverse Synthetic Aperture Radar): Rome Air Development Center program to develop techniques for determining the sizes and shapes of tracked aircraft using high-range resolution and stepped multifrequency radar technology. See <u>SAR</u>.

INTERACT (Integrated Research Aircraft Control Technology): NASA research program to demonstrate an interactive propulsion and flight control system design process and architectural implementation.

IRST (Infrared Search and Track): Avionics R&D Program on advanced infrared systems for high-altitude, long-range air-to-air operations, including integration with long-range pulse doppler radars.

JEM (Jet Engine Modulation): A program of continuing research and development to determine signature characteristics of jet engines.

JTIDS (Joint Tactical Information Distribution System): An advanced communications system being developed to provide a secure antijammer network for two-way transfer of information including navigation data.

LANTIRN (Low Altitude Navigation Targeting Infrared for Night): A system development program for a pod-mounted navigation and terrain following radar, infrared target detection classification system, and fire control.

LRU: Line Replaceable Unit.

MICOS (Multifunctional Infrared Coherent Optical Sensor): Air Force Wright Aeronautical Laboratories research and development program on advanced electro-optical sensors.

MIL STD 1553: Military standard designation for 1-megahertz serial databus used in aircraft.

NASA: National Aeronautics and Space Administration.

NCTR: Noncooperative target recognition. (See PNCTR.)

Pave Pillar: Air Force Wright Aeronautical Laboratories program for developing advanced avionics architectures, integration technology, and automation algorithms.

Pave Mover: Program developing target strike director capability employing synthetic aperture radar to detect and identify moving targets.

PLSS (Precision Locater Strike System): Airborne or mobile equipment that detects and locates sources of radio frequency emissions and guides weapons to targets.

PNCTR (Passive Noncooperative Target Recognition): Technology employing the on-board radar antenna in a passive listening mode to determine the radio frequency parameters of threats.

R&D: Research and development.

RED FLAG: Training exercises held at Nellis Air Force Base, Nevada.

RPV: Remotely piloted vehicle.

SAIF (Standard Avionics Integrated Fuse): Armament Division program to develop automatic in-flight weapon fusing.

SAM: Surface-to-air missile.

SAR: Synthetic aperture radar.

TAACS (Tactical-Air-to-Air Coupling System): Air Force Wright Aeronautical Laboratories program to automate information processing.

TAC: Tactical Air Command.

TACAN (Tactical Aid to Navigation system): An operational ground-based position transmitter employed in the tactical environment to position aircraft and identify target locations.

Tactical Flight Management Program: Flight Dynamics Laboratory research and development program dealing with trajectory automation algorithms, analytic methodologies for functional integration, and core automation architectural concepts.

TF/TA: Terrain following/terrain avoidance technology and programs.

TISEO: Target Identification System Electro-Optical.

UVs: Unmanned vehicles.

VHSIC: Very high speed integrated circuits.

APPENDIX D

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