

COPY 1 *2*

DOT/FAA/CT-82/73

FEDERAL AVIATION ADMINISTRATION

AUG 18 1982

TECHNICAL CENTER LIBRARY
ATLANTIC CITY, N.J.

EVALUATING THE USE OF ELECTRONIC FLIGHT INSTRUMENT SYSTEMS IN GENERAL AVIATION AIRCRAFT

J. B. Shelnutt

Prepared by
Seville Research Corporation
400 Plaza Building
Pensacola, Florida 32505-5196

June 1982

Final Report

This document is available to the U.S. public
through the National Technical Information
Service, Springfield, Virginia 22161.



U.S. Department of Transportation
Federal Aviation Administration
Technical Center
Atlantic City Airport, N.J. 08405

1. Report No. DOT/FAA/CT-82/73 DOT/FAA/EM-82-14		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Evaluating the Use of Electronic Flight Instrument Systems in General Aviation Aircraft				5. Report Date June 1982	
				6. Performing Organization Code	
				8. Performing Organization Report No. TR 82-01	
7. Author(s) J. B. Shelnett, J. M. Childs, W. W. Prophet, J. P. Smith, and B. Strauch				10. Work Unit No. (TRAIS)	
9. Performing Organization Name and Address Seville Research Corporation* 400 Plaza Building Pensacola, Florida 32505-5196				11. Contract or Grant No. DOT-FA-79NA-6040	
				13. Type of Report and Period Covered Final Report	
12. Sponsoring Agency Name and Address Federal Aviation Administration Technical Center Atlantic City Airport, New Jersey 08405				14. Sponsoring Agency Code	
15. Supplementary Notes Embry-Riddle Aeronautical University *Under Subcontract to: Regional Airport Daytona Beach, Florida 32014					
16. Abstract Several avionics manufacturers have announced plans to produce electronic flight instrument systems (EFIS) for general aviation aircraft. In recognition of the need for information concerning the impact of these new systems on pilot performance, the FAA has initiated a two-phased research program devoted to planning and conducting exploratory evaluations that will assess the ability of general aviation pilots to operate EFIS-equipped aircraft. The results of the first phase of this project are presented in this report. The objectives of this phase were to determine the specific goals of the exploratory evaluations and to develop general guidance--i.e., a conceptual approach--for their conduct. The conceptual approach is described in terms of (1) the information needed from the planned evaluations, (2) the general design of the overall study, (3) requirements for the performance measurement systems that would be employed to collect data and for the analysis of that data, (4) requirements for test facilities and equipment, and (5) procedures for selecting and training evaluation subjects. While the conceptual approach that was developed is specific to the planned research, it is discussed and described in general terms to increase its utility as general guidance for planning evaluations of pilot performance.					
17. Key Words Electronic Flight Instrument Systems General Aviation Pilot Performance Performance Measurement Test and Evaluation			18. Distribution Statement Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161		
19. Security Classif. (of this report) UNCLASSIFIED		20. Security Classif. (of this page) UNCLASSIFIED		21. No. of Pages 236	22. Price

EXECUTIVE SUMMARY

Several avionics manufacturers are developing electronic flight instrument systems (EFIS) for use in corporate and other general aviation aircraft. The advanced cathode ray tube and digital microprocessor technology employed in such systems has provided these manufacturers with an unprecedented opportunity to develop new display formats. Impetus for new formats is derived from the desire to address certain shortcomings in the design of conventional flight instruments that are associated with a variety of pilot performance problems. Additional impetus for new display formats is derived from the need to aid the pilot in the performance of new flight control and navigation functions arising from new requirements that are being placed on general aviation operations--e.g., the need to compute and execute fuel-efficient horizontal and vertical flight profiles. In short, the EFIS afford an excellent opportunity to reduce or restructure information processing demands placed on pilots, and, in turn, enhance their performance.

However, optimism over the potential of the new displays to enhance pilot performance should be tempered with concern that the introduction of the EFIS, like that of any innovation, may create new, unforeseen pilot performance problems. Such problems may arise from the failure of designers of the EFIS to consider the diverse capabilities of the wide range of pilots who will use these systems or, conversely, from the failure of the pilots to be properly prepared to meet demands associated with use of the new equipment.

OBJECTIVES OF THE PRESENT STUDY.

Unfortunately, it is difficult to predict the exact impact that the first generation EFIS will have on the performance of general aviation pilots. In recognition of the need for information to support such predictions, the FAA Technical Center and the FAA's Office of Systems Engineering Management have initiated a two-phased research project. The project is devoted to planning and conducting a series of exploratory evaluations in which the performance of pilots flying EFIS-equipped aircraft will be compared with that of pilots flying aircraft equipped with conventional flight instruments. The first phase of the project, which is the subject of this report, had two major objectives. These were to determine how the exploratory evaluations should be designed and to develop general guidance--i.e., a conceptual approach--for the conduct of the evaluations. A secondary objective of this phase was to discuss the general issues involved in the design of the planned exploratory evaluations in such fashion that guidance was provided to aid in the planning of similar evaluations for other purposes--e.g., comparing alternative formats of advanced displays, testing EFIS-equipped aircraft to determine their airworthiness, and assessing the effectiveness of instruction designed to teach pilots how to use the EFIS.

APPROACH.

This report presents the conceptual approach developed for the exploratory evaluations. To aid in developing and structuring the conceptual approach, a

general model of the activities involved in planning evaluations of pilot performance was described. These activities were grouped into five main phases.

These five phases, in turn, served as topics for Chapters II through VI of this report. These phases (and chapter titles) are as follows:

II. ANALYSIS OF INFORMATION NEEDS

III. DETERMINATION OF THE GENERAL DESIGN OF THE EVALUATION

IV. DETERMINATION OF REQUIREMENTS FOR PERFORMANCE MEASUREMENT
AND DATA ANALYSIS

V. DETERMINATION OF REQUIREMENTS FOR TEST FACILITIES AND
EQUIPMENT

VI. DEVELOPMENT OF PROCEDURES FOR SELECTING AND TRAINING
EVALUATION SUBJECTS

The conclusions that were drawn as a result of these various activities constitute the conceptual approach that was developed for the planned exploratory evaluations. Such conclusions and recommendations are presented in the last section of each chapter. They also are summarized below to facilitate their review.

ANALYSIS OF INFORMATION NEEDS.

The first generation EFIS represent the advent of a new generation of cockpit displays, controls, and associated systems that will alter the fundamental role of the pilot in general aviation aircraft. While some similarity exists among conventional flight instruments and first generation EFIS displays, there are differences in display content and format that will change the nature of a wide variety of task demands that are placed on the pilot.

Due to the lack of programmatic general aviation research comparable in extent with the studies performed by the military and air transport aircraft manufacturers on electronic flight displays, it is difficult to predict the impact that these changes will have on pilot performance. It is the lack of this information that provides impetus for the proposed exploratory evaluations. Such research is needed to aid in the determination of the beneficial effects, relative to the enhancement of pilot performance, that may accrue from the use of the EFIS in general aviation aircraft. Information concerning these benefits would be vitally important in promoting acceptance of the EFIS and building pilot confidence in them.

The exploratory evaluations also are needed to aid in the identification of pilot performance problems that may arise when the first generation EFIS are used in actual general aviation flight operations. This information would fulfill a variety of needs associated with the development of EFIS operating procedures, the design of training for the pilots who use the EFIS, and the development of recommendations for the design of future generations of the EFIS.

To be of maximum utility, the exploratory evaluations should (1) compare the performance of pilots flying aircraft (or aircraft simulators) equipped with first generation EFIS with the performance of pilots flying conventionally equipped aircraft, (2) employ general aviation pilots whose skills represent the range of capabilities that may be found in pilots who will fly EFIS-equipped aircraft, (3) assess the performance of these pilots in flight situations that reflect the full range of situations that they realistically may encounter in actual flight operations (with emphasis placed on those situations in which the pilots are more likely to have problems), and (4) assess the impact on pilot performance of the use of automated flight control systems, particularly when these systems are used with the EFIS.

DETERMINATION OF THE GENERAL DESIGN OF THE EVALUATION.

The exploratory evaluations should employ both maneuver-oriented and operations-oriented proficiency checks as techniques for evaluating pilot performance. Maneuver-oriented check procedures, which currently are used for most pilot proficiency checks, provide the most efficient method of exploring the ability of the pilots to operate their aircraft in a wide variety of flight situations. Operations-oriented check procedures, on the other hand, are not widely used at present--especially in research. These procedures are derived from techniques developed by the air carriers for Line Oriented Flight Training (LOFT). They afford the opportunity to evaluate certain higher order pilot skills that can be assessed best by observing the ability of the pilot to respond to critical events in situations that simulate requirements that would be imposed by actual flight operations.

With respect to the overall design of the planned evaluations, a completely randomized, multifactor design should be employed. In such a design, a different group of pilots would be used for each experimental treatment. For example, it is recommended in the present report that pilot performance be assessed with respect to whether the aircraft that is being flown is equipped with (1) EFIS or conventional flight instruments, and (2) one of three types of flight control systems--i.e., a manual system, a simple one- or two-axis autopilot, or a sophisticated automated flight control system. In this case, it is recommended that six groups of pilots be used, one for each combination of flight instrument system and flight control system (e.g., EFIS with the manual system, EFIS with the simple autopilot, EFIS with the sophisticated automated flight control system, and so on). The randomized, multifactor design is recommended to assure that the pilots who serve as subjects do not become "test-wise" through repeated exposure to the same test situations--as would be the case if the same pilots were used repeatedly for all experimental treatments.

DETERMINATION OF REQUIREMENTS FOR PERFORMANCE MEASUREMENT AND DATA ANALYSIS.

Objective procedures should be used to structure administration of the maneuver-oriented and operations-oriented proficiency checks conducted during the exploratory evaluations. Most flight checks that are conducted in operational situations tend to be nonstandardized and subjectively scored. Requirements for data in the exploratory evaluation, however, necessitate the use of formally defined, objective procedures.

With respect to maneuver-oriented checks, these procedures should, at a minimum, specify (1) criteria for selecting the sample of maneuvers to be evaluated, (2) a method for segmenting each of the maneuvers into smaller units that facilitate observation and recording of performance data, (3) the system performance variables that need to be measured and when they should be sampled, (4) the desired values and tolerance limits for each performance variable at the point when it is to be measured, and (5) methods for scoring performance that reflect both the frequency and criticality of errors made by the pilot. Such procedures are described in detail in Chapter IV, and examples of their application are provided in that chapter and in Appendices E and F.

With respect to operations-oriented checks, procedures for their development should specify (1) how to construct a scenario that is realistic, includes flight conditions that require the skills that are of interest, and is sufficiently flexible to permit the pilot to respond to critical events without artificial constraints on his actions; (2) the nature of system and pilot performance variables that are to be measured; (3) desired values and tolerance limits for each performance variable over the full range of points at which measurement of that variable is relevant and feasible; and (4) methods for scoring performance that reflect both the frequency and criticality of errors made by the pilot. Such procedures are described in Chapter IV and examples of their applications are provided in that chapter and in Appendix G.

DETERMINATION OF REQUIREMENTS FOR TEST FACILITIES AND EQUIPMENT.

The preferred test vehicle for the planned evaluations is a high fidelity simulator with advanced motion and visual systems (i.e., a simulator that meets Phase III requirements for training simulators as specified in FAR Part 121.407). In comparison with an aircraft, such a device affords several advantages with respect to the use of potentially dangerous test situations in which pilot performance problems are more likely to occur; the control of test conditions; and the observation, measurement, and assessment of pilot performance. Further, simulation provides certain cost advantages that can reduce the amount of funding required for the planned research.

Lower fidelity simulators, such as those owned by the FAA Technical Center and NASA's Langley Research Center, also could be employed in the planned evaluations. While these devices could not be used to assess as wide a range of flight situations as would be possible with a higher fidelity device, they provide an efficient means for screening a large number of flight situations for potential pilot performance problems.

Similarly, an aircraft also could be used as a test vehicle, but the range of flight situations that could be assessed would be limited by the need to ensure the safety of the test--especially since "typical" general aviation pilots would be used rather than test pilots. Use of an aircraft, however, does afford several advantages--e.g., increased realism of some test situations and the likelihood of greater acceptance of evaluation results by the general aviation community. Further, the availability of production EFIS will enable a research aircraft to be configured for much less cost than previously possible with specialized, experimental flight displays.

DEVELOPMENT OF PROCEDURES FOR SELECTING AND TRAINING EVALUATION SUBJECTS.

As previously stated, the planned evaluations should employ as subjects pilots with skill levels that best represent the capabilities of pilots who normally will fly EFIS-equipped aircraft. Since the recommended evaluation design--a randomized, multifactor design--does not allow for distinctions to be made in pilot skill level, the subjects should be selected so that they have capabilities that are approximately alike. If only one "category" of pilot is used, then professional pilots who regularly fly corporate aircraft should be employed as subjects. If additional research resources are available, however, then the design of the evaluations should be modified to allow for a wider range of pilots to be employed as subjects.

The training that the subjects receive should be representative of the instruction that most general aviation pilots actually will receive when they purchase EFIS-equipped aircraft. For example, if a specific production EFIS is used (or simulated) in the evaluations, the commercially-produced training that is available to pilots who buy aircraft equipped with that system should be used to prepare the subjects for their proficiency checks. If training is specifically developed for the evaluation, then the training program should be documented and disseminated as an aid to personnel in the general aviation community who are faced with developing instruction to teach pilots to use EFIS. Similarly, the progress and problems experienced by the subjects during training should be measured, assessed, and documented. Such information also would be of value to training personnel in the general aviation community.

PREFACE

The substantial growth of general aviation in recent years has made this segment of civil aviation a valuable part of American society and its economy. For such growth to continue, however, general aviation must meet the severe challenges posed by an accident rate that is one of the highest among major forms of transportation. Since an overwhelming majority of general aviation accidents have been attributed to errors made by the pilot, the most promising approach to improving safety is through the study of factors that influence the performance of pilots and use of the resulting knowledge to devise actions that will reduce the probability of such errors in future flight operations.

In recognition of the need for this approach, the Office of Systems Engineering Management of the Federal Aviation Administration (FAA) and the FAA Technical Center have initiated a program of research that is focused on the general aviation pilot. The Embry-Riddle Aeronautical University (E-RAU) and the Seville Research Corporation are performing the research jointly under Contract No. DOT-FA79NA-6040. Seville's activities are conducted under subcontract to E-RAU, the prime contractor.

The research program is divided into several projects. The first such project identified major performance problems of general aviation pilots, and also the research needed to support the development of actions that would address these problems. The results of this work were described in an FAA report, Human Factor Problems in General Aviation (FAA-CT-80-194). Other projects in this program were designed to address high priority research needs identified during this first report.

The research described in this report was conducted as part of one such project. The major goals of the project were to (1) develop general guidance for planning exploratory evaluations of pilot performance in general aviation aircraft (or simulators) equipped with electronic flight instrument systems; and (2) conduct a series of such evaluations to aid in identifying potential benefits as well as possible pilot performance problems that may be associated with the use of these new display systems.

The project was divided into two phases. This report was written at the end of the first phase of the project. Work during this phase included determination of requirements for the exploratory evaluations and development of a conceptual approach for performing them. The exploratory evaluations will be conducted in the second phase. Knowledge gained from the evaluation will be used to refine the general guidance for planning such evaluations, and to develop a data base concerning the ability of pilots to operate general aviation aircraft equipped with electronic flight instrument systems.

This report is the second of two reports that were produced during the first phase. The first report described the results of initial analyses conducted during the early part of this phase. This report, titled General Aviation Pilot Tasks and Information Needs, is included in Appendix D of the present report.

E-RAU was responsible for the preparation of the first report and the conduct of the analyses described therein. The Seville Research Corporation had the responsibility for the remaining analyses and the second report. Dr. Jerome I. Berlin, former Director of E-RAU's Research Center, was Program Manager for the contract under which this research was conducted. He was assisted by Mr. E. Peter Denlea. Dr. Wallace W. Prophet served as Program Manager for Seville, and Dr. Jack B. Shelnutt was Seville's Project Director. Dr. Jerry M. Childs, Dr. James P. Smith, and Dr. William V. Hagin of Seville, and Dr. Barry Strauch and Mr. Carl Monk of E-RAU provided technical assistance for this report. Ms. Faye Sanders coordinated the literature review conducted as part of the effort. Ms. Carrie Morris served as technical editor. The Contracting Officer's Technical Representative was Mr. Douglas P. Harvey. He was assisted by Mr. Robert J. Ontiveros.

TABLE OF CONTENTS

	<u>Page</u>
I. INTRODUCTION	1
Background	1
Approach	6
II. ANALYSIS OF INFORMATION NEEDS	11
Determination of Potential Benefits	12
Identification of Potential Pilot Performance Problems	18
Sources of Information Concerning EFIS Displays	26
Information Needs in Evaluation Design	40
Conclusions	44
III. DETERMINATION OF THE GENERAL DESIGN OF THE EVALUATION	49
Design of Proficiency Checks	49
Design of the Evaluation	55
Conclusions	56
IV. DETERMINATION OF REQUIREMENTS FOR PERFORMANCE MEASUREMENT AND DATA ANALYSIS	58
Development of Maneuver-Oriented Proficiency Checks	58
Development of Operations-Oriented Proficiency Checks	79
Conclusions	91
V. DETERMINATION OF REQUIREMENTS FOR TEST FACILITIES AND EQUIPMENT	93
Use of Simulators as Test Vehicles	93
Use of Aircraft as Test Vehicles	104
Conclusions	106
VI. DEVELOPMENT OF PROCEDURES FOR SELECTING AND TRAINING EVALUATION SUBJECTS	108
Selection of Subjects	108
Development of Training for the Subjects	109
Conclusions	111
REFERENCES	113

TABLE OF CONTENTS (Continued)

APPENDICES

- A. Description of Electronic Flight Instrument Systems that Will Be Installed on General Aviation Aircraft
- B. List of Organizations Contacted
- C. A Bibliography of Empirical Studies of Electronic Flight Instrument Systems
- D. General Aviation Pilot Tasks and Information Needs
- E. List of Candidate Maneuvers and Adverse Conditions for their Performance
- F. Examples of Recording Forms for the Maneuver-Oriented Proficiency Checks
- G. Description of a Scenario for an Operations-Oriented Proficiency Check

LIST OF ILLUSTRATIONS

	<u>Page</u>
Figure 1.--Examples of Factors that Influence the Performance of General Aviation Pilots	2
Figure 2.--Activities Involved in Planning Evaluations of Pilot Performance	8
Figure 3.--Major Steps and Component Activities Involved in Planning Maneuver-Oriented Evaluations	59
Figure 4.--ILS Approach Maneuver Segments	65
Figure 5.--Example of a Completed Pilot Performance Description Record (PPDR)	73
Figure 6.--Major Steps and Component Activities Involved in Planning Operations-Oriented Evaluations	80
Figure 7.--Example of One Segment of the Scoring Form for Scenario Performance Evaluation	86

TABLE OF CONTENTS (Continued)

LIST OF TABLES

	<u>Page</u>
Table 1.--Examples of Sources of Display Standards and Other Design Guidance	33
Table 2.--Design of the Proposed Exploratory Evaluation	56
Table 3.--List of Candidate Maneuvers to be Performed Under Favorable Conditions	62
Table 4.--Examples of Performance Variables that Have Been Measured in Past Research	67
Table 5.--Flight Variables, Desired Values, and Tolerance Levels for a VOR Approach Segment	70
Table 6.--Examples of Test Conditions that Will Increase the Difficulty of Task Demands	83
Table 7.--Error Frequencies by Category in the Smith (1979) Study	90

I. INTRODUCTION

A. BACKGROUND.

General aviation has grown substantially in recent years, and, as a result, it now fulfills a variety of important roles in American society. Such growth is projected to continue in the future as both the need for general aviation's services and its capabilities to provide them continue to expand. Full realization of this projected growth, and of associated economic and social benefits, is constrained, however, by an accident rate that is one of the highest among major forms of transportation.

In addition to the obvious unacceptability of the loss of lives and personal injuries, the costs of such accidents are escalating rapidly, reflecting the increased cost of aircraft as well as general societal trends such as increased accident litigation. Moreover, perception by the public of general aviation safety will have a significant impact on the extent to which people will accept, support, and use its services. Clearly, then, improvements in general aviation safety should be sought to reduce the human and economic toll associated with the high accident rate, and also to aid in assuring the continued growth and prosperity of this vital segment of American society and its economy.

PILOT PERFORMANCE PROBLEMS IN GENERAL AVIATION. Analyses of general aviation accidents have revealed that the vast majority of such mishaps--over 80 percent--can be attributed to errors made by the pilot (Shelnutt, Childs, Prophet, and Spears, 1980). Simply attributing such accidents to "pilot error," however, does not serve to reduce the probability that similar accidents will occur in the future. Recognizing the need to address the pilot error problem, several recent studies of general aviation safety have concluded that the most promising approach to improving safety is through the analysis of factors affecting the performance of general aviation pilots, and use of the resulting knowledge to devise and implement actions to enhance their performance (e.g., Connor and Hamilton, 1979; General Accounting Office, 1980; McCourt and Hewin, 1979; Shelnutt et al., 1980).

A number of factors influence the performance of general aviation pilots.¹ As depicted in Figure 1 (adapted from Shelnutt et al., 1980), many of these factors affect the nature of task demands placed on the pilot. For example, the design of cockpit displays and controls--i.e., the so-called pilot-aircraft interface--influences the nature of information processing tasks as well as a wide variety of other demands placed on the pilot as he maneuvers the aircraft. Task demands are also influenced by factors associated with (1) other aspects of

¹The approach to the analysis of pilot performance problems that is described in the following paragraphs is taken from an FAA report, titled Human Factors Problems in General Aviation (FAA-CT-80-194) (Shelnutt et al., 1980). The approach is briefly reviewed here because this view of pilot performance problems and how they should be addressed is crucial to much of the discussion that follows. Further, substantial confusion exists within the aviation community concerning "human factors," and the nature of research on factors influencing pilot performance (General Accounting Office, 1980). As such, the reader is referred to the above report for additional discussion.

AIRCRAFT

- COCKPIT CONTROLS AND DISPLAYS
- AIRCRAFT HANDLING CHARACTERISTICS
- VISIBILITY FROM THE COCKPIT
- COCKPIT ENVIRONMENT

AIRPORTS

- RUNWAYS
- APPROACH AIDS

AERONAUTICAL INFORMATION SYSTEMS

- INFORMATION CONCERNING OPERATION OF THE AIRCRAFT
- INFORMATION CONCERNING USE OF NATIONAL AIRSPACE SYSTEM
- COMMUNICATIONS WITH AIR TRAFFIC SERVICE FACILITIES

These factors interact to create the task demands placed on the pilot.

If yes, then the pilot probably will not make any significant errors.

Does the pilot have the capability to meet task demands?

These factors interact to influence pilot capability.

If no, then pilot performance problems are likely to occur.

PILOT CERTIFICATION AND RATING STRUCTURE

- ENTRY LEVEL REQUIREMENTS
- TASK SUBSETS FOR CERTIFICATES AND RATINGS

TRAINING AND PROFICIENCY ASSESSMENT FOR CERTIFICATES AND RATINGS

- TRAINING REQUIREMENTS
- TRAINING METHODOLOGIES
- DESIGN OF TRAINING DEVICES
- CERTIFICATED FLIGHT INSTRUCTORS
- PROFICIENCY TESTS

CONTINUATION TRAINING AND RECURRENT PROFICIENCY ASSESSMENT

- CONTINUATION TRAINING
- RECURRENT ASSESSMENTS OF PILOT PROFICIENCY

FIGURE 1.--EXAMPLES OF FACTORS THAT INFLUENCE THE PERFORMANCE OF GENERAL AVIATION PILOTS
(ADAPTED FROM SHELNUTT, CHILDS, PROPHET, AND SPEARS, 1980).

the design of the aircraft (e.g., handling qualities), (2) the design of airports (e.g., characteristics of the runway that influence the difficulty of landing and takeoff tasks), and (3) the specification of aeronautical information systems (e.g., aircraft operating procedures, instrument flight procedures, and air traffic control communications procedures).

Thus, the total demand placed on the pilot at any point in time is determined by the interaction of a large set of factors. In parallel, the capability of the pilot to meet these demands is influenced by another large set of factors (which are also depicted in Figure 1). For example, whether someone is legally permitted to perform a given flight task, or even permitted to fly, is determined by requirements specified in the FAA airman certification and rating structure. Further, the training a pilot receives, both in preparation for a certificate or rating and in the maintenance of proficiency, has an extensive influence on his capabilities to meet task demands.

When the pilot does not have the capability to meet task demands that may arise during a given flight, he may likely make an error. Such errors and other pilot performance problems can, therefore, be conceptualized as arising from mismatches between the level of demand imposed by pilot tasks and the ability (and motivation) of the pilot to perform these tasks (Zeller, 1978). Extending these approaches, it becomes clear that the way to reduce these problems is to identify and modify (1) the factors that influence task demands that exceed pilot capabilities, and/or (2) those factors that influence the capability of the pilot to perform the tasks in question. Thus, modifications of such factors can be viewed as potential avenues for reducing the frequency of pilot errors, and, in turn, the frequency of aircraft accidents.

ELECTRONIC FLIGHT INSTRUMENT SYSTEMS: THE POTENTIAL SOLUTION TO MANY CURRENT PROBLEMS AND THE POSSIBLE SOURCE OF NEW PROBLEMS. The design of the pilot's primary flight instruments--one of the major factors influencing task demands placed on the pilot--has received considerable recent attention in the general aviation community due to the nearing introduction of electronic flight instrument systems (EFIS) for general aviation aircraft. Several avionics manufacturers have announced plans to produce EFIS for corporate and other large general aviation aircraft, with some firms predicting they will start deliveries as early as 1982 (Scott, 1981).¹ Some of the manufacturers also are planning to start in the next five years to produce less expensive versions of these systems for smaller aircraft, such as light twin-engine and even high performance single-engine aircraft.

The attention that EFIS are receiving is due, in part, to the use of digital computer and cathode ray tube (CRT) display technology in these systems. Such technology represents a substantial departure from the mechanical, electro-mechanical, and electronic technology used in most existing flight instruments. This advance in technology will probably result in major changes in the design of new cockpit equipment for general aviation aircraft, the construction of such equipment, and, in time, the maintenance of such equipment. Given the sizable potential avionics retrofit market in general aviation, the new technology will

¹Appendix A contains a description of the different versions of EFIS that will be produced for general aviation aircraft.

also probably have a considerable impact on the refurbishing of many existing aircraft (Quinby, 1980).¹

More importantly, however, the technology employed in the EFIS has provided avionics manufacturers with an unprecedented opportunity to develop new flight displays. The new CRTs and the microprocessors that drive them provide avionics designers with a blank screen that can be filled with an almost unlimited variety of display formats. Thus, general aviation is preparing with considerable speed to enter a new era in cockpit technology. This era will be characterized by substantial changes in the type and amount of information presented to the pilot, the form in which it is displayed, the manner by which it is accessed, and the way in which it is used.

Impetus for such change, aside from the obvious economic motivation, is derived from a desire to use advanced technology to develop new flight displays that will enhance pilot performance. Such enhancement may be achieved, in part, through the development of improved displays that do not suffer from many of the design shortcomings associated with existing electromechanical flight instruments. Such shortcomings, as will be discussed in Chapter II, are related to a number of pilot performance problems. Furthermore, displays will also be developed that will enable the pilot to perform functions arising from new requirements that are being placed on general aviation operations--e.g., the need to compute and execute fuel efficient horizontal and vertical flight profiles, increase the efficiency of use of crowded airspace, and operate in a wider range of weather conditions.

Optimism over the potential of new displays to enhance pilot performance, however, must be tempered with concern that the introduction of EFIS may create new, unforeseen pilot performance problems. Reasons for such concern will be described in detail in Chapter II. It is sufficient here to make the general observation that the introduction of innovative equipment into any complex man-machine system frequently tends to create a variety of personnel problems. Such problems may arise from the failure of the designers of new equipment to consider the capabilities of the operators of the equipment or, conversely, the failure of the operators to be properly prepared to meet demands associated with the use of the new equipment.

The dangers of such problems are recognized by avionics manufacturers, the Federal Aviation Administration (FAA), and other segments of the general aviation community. As such, there is a general consensus within the aviation community that most changes within general aviation (and, for that matter, all of civil aviation) should be of an evolutionary, rather than a revolutionary, nature. That is, change associated with progress should be encouraged, but moderated so that the system will adjust to it.

Reflecting this philosophy, the first generation of EFIS that will be installed in general aviation (and air transport) aircraft will produce flight displays with formats that in many cases are very similar to those of existing electromechanical flight instruments. Such similarity is intended to reduce problems

¹The following discussion focuses on the potential impact of displays generated by EFIS on pilot performance. Discussion of equipment-related aspects of the EFIS can be found in Appendix A and in the references cited therein.

that pilots may have in learning to use the new system, and to increase pilots' acceptance of and confidence in the EFIS.

Most versions of the first generation EFIS, however, will generate at least some display formats that are truly unique, or that represent substantial modifications of similar existing formats. The availability of these new and modified formats, as well as additional differences such as those that are associated with the way the EFIS displays are accessed, can result in significant differences between the performance of pilots in aircraft equipped with EFIS and their performance in aircraft equipped with more conventional flight instruments.

Unfortunately, it is difficult to predict the exact impact that the first generation general aviation EFIS will have on pilot performance. Unlike EFIS for air transport aircraft, which are the products of years of research on display formats, there has not been extensive research specifically devoted to the design of the general aviation EFIS. Because of this and the potential for unpredicted adverse effects on pilot performance, exploratory research is needed that will evaluate the ability of pilots to operate general aviation aircraft equipped with first generation EFIS. The knowledge that would be obtained from these exploratory evaluations would fulfill a variety of information needs associated with the development of (1) EFIS operating procedures; (2) training for pilots who will use the EFIS; (3) design recommendations for future generations of such systems; and (4) assessment procedures for use in research on these systems, or in the certification by the FAA of the airworthiness of the aircraft in which EFIS are installed. Further, the exploratory evaluations could be designed in such fashion that the benefits that may accrue from use of the new systems could be identified. If the EFIS enhance pilot performance, this information would be vitally important in promoting acceptance of the EFIS displays and in building pilot confidence in them.

The design of such evaluations, however, raises a number of critical and complex technical issues. Some of these issues are derived from basic questions related to pilot performance evaluation that have long been studied and debated. Others are unique to the decisions that need to be made relevant to specific aspects of measuring pilot performance in general aviation aircraft and evaluating pilots' use of the EFIS. Yet other issues arise from concern that the advent of advanced cockpit technology--such as automatic flight control systems, flight management systems, as well as EFIS--has changed the fundamental role of the pilot and, as a consequence, has altered requirements for measuring and evaluating pilot performance.

These issues should not be considered simply as theoretical complexities that are of concern only to researchers who are interested in the development of evaluation methodology. Rather, such issues represent practical constraints on the acquisition of information concerning the potential safety of aircraft equipped with EFIS and other advanced cockpit display and control technology. Without their resolution, effective evaluation studies cannot be performed. In turn, without such studies, we cannot accurately assess the safety benefits that may accrue from the use of new systems (such as the EFIS), nor, more importantly, can we anticipate and prevent critical safety problems that may arise in future years.

B. APPROACH.

In recognition of the need for information concerning the ability of general aviation pilots to operate EFIS-equipped aircraft, the FAA Technical Center and the FAA's Office of Systems Engineering Management have initiated a two-phased research project devoted to planning and conducting the exploratory evaluations discussed in the preceding subsection. These evaluations will compare the performance of pilots flying aircraft equipped with the first generation EFIS with that of pilots flying aircraft equipped with conventional electromechanical flight instruments.

OBJECTIVES OF THE FIRST PHASE. The first phase of the project was completed with this report. The two major objectives of this phase were to determine how the exploratory evaluations should be designed, and to develop general guidance--i.e., a conceptual approach--for the conduct of such evaluations. The conceptual approach that was developed in this phase is specific to the exploratory evaluations that are being planned. A secondary objective, however, was to structure the discussion of issues in the design of the evaluations so that the work reported here would be relevant to the planning of similar evaluations for other purposes--e.g., comparing alternative formats of advanced displays, testing EFIS-equipped aircraft to ensure their airworthiness, and assessing the effectiveness of pilot training. An additional secondary objective was to identify evaluation issues that warrant further study before conclusive guidance can be developed.

OBJECTIVES OF THE SECOND PHASE. The second phase of the project will accomplish three major objectives. The first objective will be to implement the approach developed in the first phase and conduct the planned evaluations. The second objective will be to refine the conceptual approach using experience gained during the conduct of the exploratory evaluations. This information will then be used to generate general guidance for the conduct of other types of evaluations that are concerned with assessing the performance of general aviation pilots as they operate aircraft equipped with EFIS and other advanced cockpit control and display technology. The third objective will be to analyze the results of the exploratory evaluations to identify potential benefits and possible pilot performance problems that may be associated with the use of EFIS in general aviation aircraft.

STEPS IN ACCOMPLISHING THE FIRST PHASE. Since the second phase had not been initiated when this report was written, this report is focused on the analyses performed during the first phase. The initial step in accomplishing the objectives of the first phase was to construct a model of the general activities involved in planning evaluations of pilot performance. This model served as a framework for identifying and organizing the analyses performed in the first phase. The second step was to acquire the information needed for the analyses to be conducted. The final step was to perform these analyses and develop guidance for planning the exploratory evaluations--i.e., develop the conceptual approach.

In the remainder of this approach section of the report, (1) the model of the evaluation planning process is briefly described; (2) the methods used to acquire information are reviewed; and (3) the organization of the remainder of this report, which contains the general guidance (conceptual approach) developed during the first phase, is outlined.

A MODEL FOR PLANNING EVALUATIONS OF PILOT PERFORMANCE. A model of the general activities involved in planning evaluations of pilot performance was developed to aid in the identification of issues in the design of the exploratory evaluation and to structure the development of the conceptual approach. The model was also used to organize the description of the conceptual approach in this report.

The general planning model is presented in Figure 2. The activities involved in developing the conceptual approach for an evaluation are grouped into five main phases--i.e., (1) analysis of information needs; (2) determination of the general design of the evaluation; (3) determination of requirements for performance measurement and data analysis; (4) determination of requirements for test facilities and equipment; and (5) development of procedures for selecting and training evaluation subjects. While these phases occur, to a certain extent, in sequence, many of the activities within each phase extend into or overlap with other phases. Additionally, many of the activities within the earlier phases are iterative and often must be performed again when related decisions are made in later phases.

ACQUISITION OF INFORMATION. Development of general guidance for the conduct of the exploratory evaluations necessitated the review of a very broad range of information related to such diverse topics as (1) conduct of evaluations of human performance in complex man-machine systems; (2) measurement and evaluation of pilot performance (in research as well as operational settings); (3) design of flight tests; (4) use of simulation in the assessment of pilot performance; (5) research on the design of advanced flight displays; (6) aviation safety; and (7) the nature of general aviation pilots, aircraft, avionics (especially EFIS), and flight operations.

The considerable breadth of the information sought necessitated the review of material in a wide range of published sources (e.g., research and technical reports; aviation journals and periodicals; and FAA regulations, policy statements, and advisory documents). Moreover, to supplement this review, a variety of personnel were interviewed who were involved in operational or research activities that were related to the areas of interest in this project.

Literature Search. Both automated and manual searches were used in pursuit of comprehensive coverage of the published literature. The DIALOG Information Retrieval Service was used to access several automated reference systems. The data bases that were searched included (1) the National Technical Information Service, which lists all reports performed or sponsored by the federal government; (2) Psychological Abstracts, a listing of the psychological research literature; and (3) COMPENDEX, a computerized listing of the Engineering Index.

An automated search was also made using the facilities of the Control Display Information Center library at the Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio. This library has a unique collection of research on flight displays and aircrew performance not normally found in the open literature. These searches were augmented through the examination of a computerized list of selected aviation-related references in the libraries of the Seville Research Corporation and Embry-Riddle Aeronautical University.

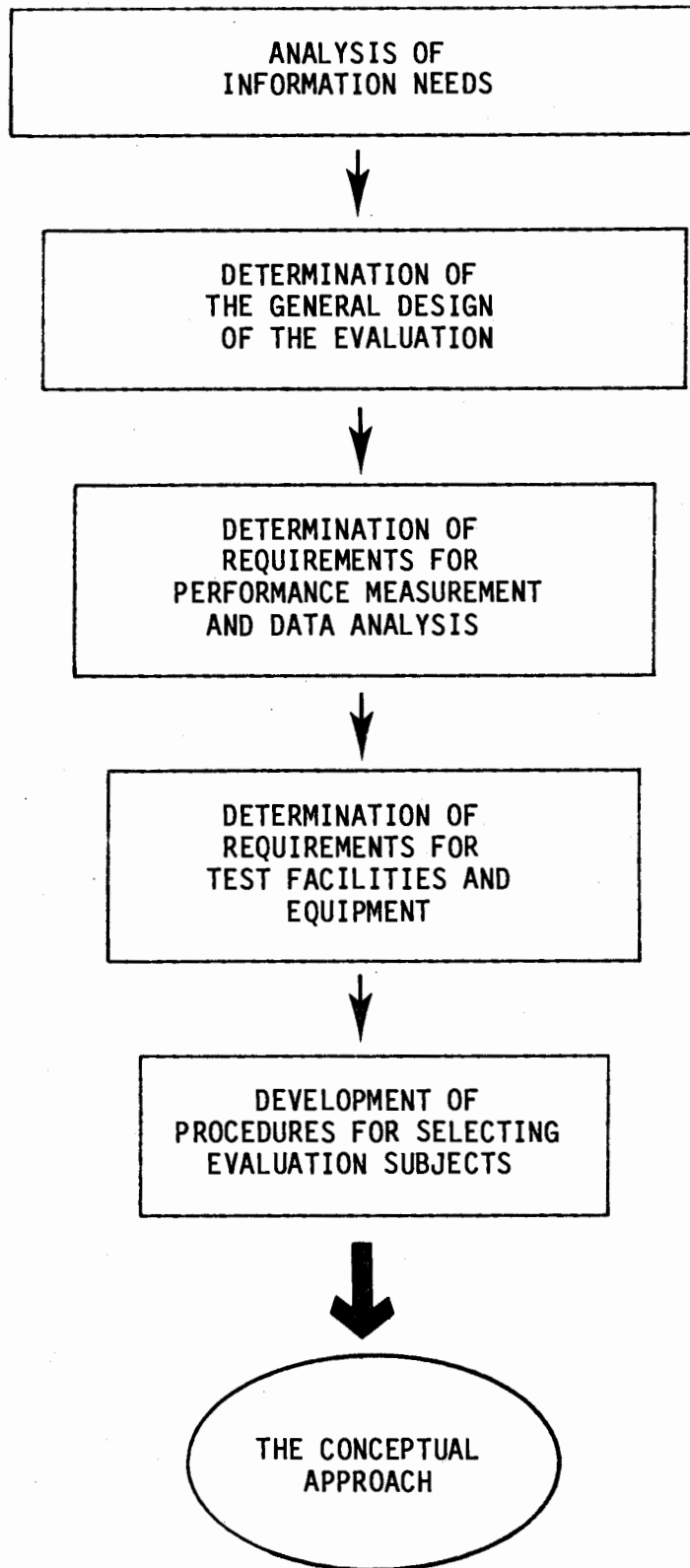


FIGURE 2.--ACTIVITIES INVOLVED IN PLANNING EVALUATIONS OF PILOT PERFORMANCE.

Following acquisition of the reports selected on the basis of the automated searches, the literature search was extended manually through the review of references listed in these reports. Other potentially relevant references were identified by personnel who were interviewed as part of this project.

Interviews. Individuals within a variety of private and government organizations were interviewed, in person or by telephone, to obtain more information concerning the EFIS. (The specific organizations which were visited or contacted by telephone are listed in Appendix B.) The purpose of such interviews was to gain a better perspective concerning design and evaluation issues as they are perceived by those working directly with EFIS or in closely related areas. Generally, those interviewed were persons involved in activities such as:

- (1) development of EFIS for general aviation aircraft;
- (2) development of EFIS for air transport and military aircraft;
- (3) the testing and certification of air transport and general aviation aircraft in which EFIS are installed;
- (4) development of documents that will be used as guidance for evaluating the design of EFIS in general aviation aircraft (such documents are discussed in Chapter II);
- (5) development of documents that serve as general guidance for the design and evaluation of flight displays in other types of aircraft, and of displays in other types of man-machine systems;
- (6) the conduct of general aviation flight operations; and
- (7) the evaluation of pilot performance, either for operational purposes--such as airman certification--or research.

ORGANIZATION OF THE REMAINDER OF THIS REPORT. Chapters II through VI cover various aspects of the conceptual approach developed for the exploratory evaluations. The content of each chapter corresponds to a major phase or category of activities involved in the evaluation planning process (shown in Figure 2). The chapter topics are as follows:

- II. ANALYSIS OF INFORMATION NEEDS
- III. DETERMINATION OF THE GENERAL DESIGN OF THE EVALUATION
- IV. DETERMINATION OF REQUIREMENTS FOR PERFORMANCE MEASUREMENT AND DATA ANALYSIS
- V. DETERMINATION OF REQUIREMENTS FOR TEST FACILITIES AND EQUIPMENT
- VI. DEVELOPMENT OF PROCEDURES FOR SELECTING AND TRAINING EVALUATION SUBJECTS

An additional introductory comment is needed before beginning the next chapter. The intended primary audience of this report includes the engineers, pilots, and

other personnel involved in the development of general aviation EFIS; and FAA personnel involved in the certification of EFIS-equipped general aviation aircraft. As such, the report assumes, for the sake of brevity, that the reader is familiar with most of the aviation-related terms and concepts presented in the following chapters. Further, while the technical concepts related to human factors aspects of designing visual displays and evaluating pilot performance are discussed at a relatively basic level, the need for brevity also prevents the extensive definition and description of such concepts. Thus, numerous references are provided to aid the reader in pursuing concepts that are of specific interest.

II. ANALYSIS OF INFORMATION NEEDS

The first step in the evaluation planning model, as presented in Figure 2, is that of defining the information that will be needed from the evaluations. The major purpose of the activities in this step is to determine the objectives of the evaluation, i.e., determine the functions that the evaluation will serve. Such a determination includes the identification of why information is needed, what type of information is required, and how the information is to be used.

Since the evaluations that were planned in the present project are of an exploratory nature, the conceptual approach that was developed had to be designed to address a wide range of information needs. The general nature of these needs was identified through the analysis of the functional requirements implied by the stated goals of the exploratory evaluations. One of these goals was to identify the benefits and pilot performance problems that may be associated with the use of the first generation of EFIS installed in general aviation aircraft; the other goal was to develop general guidance for conducting evaluations of the ability of pilots to operate aircraft equipped with EFIS and other advanced cockpit technology.

This chapter is devoted to the analysis of the implications of these goals with respect to the information needed from the exploratory evaluations. Major sections are as follows:

- A. DETERMINATION OF POTENTIAL BENEFITS
- B. IDENTIFICATION OF POTENTIAL PILOT PERFORMANCE PROBLEMS
- C. SOURCES OF INFORMATION CONCERNING EFIS DISPLAYS
- D. INFORMATION NEEDS IN EVALUATION DESIGN
- E. CONCLUSIONS

Sections A and B address the problem of identifying potential benefits and pilot performance problems that may accrue from use of the EFIS. These sections contain discussions of the nature of benefits and problems that might be expected, and of the information needed to describe them and document their existence.

Supplementing the discussions in Section A and B, Section C contains a review of sources of information that have been or will be employed during the development of the EFIS to aid in predicting the potential impact of these systems on pilot performance. Examination of other sources of information is prudent because the process by which new aviation equipment is introduced into operational use already includes several activities devoted to evaluating, directly or indirectly, the pilot's ability to use the equipment--e.g., research during the development of the EFIS, analyses of the extent to which the EFIS meets standards specified in technical documents and regulations, and flight tests of EFIS-equipped aircraft that are conducted by industry and the FAA. Only after identifying and evaluating existing information can the needs for additional information from the exploratory evaluations be articulated. Information needs

can then be identified and described in detail to aid in obtaining support for required research.¹

Section D discusses the information that is needed from the exploratory evaluations to support the development of general guidance for planning pilot performance evaluations. The focus here is on identifying requirements for data and statistical analyses that will aid in selecting test conditions and performance measures that are the most useful for evaluating the ability of pilots to operate aircraft equipped with EFIS and other advanced cockpit technology.

Section E contains conclusions that were drawn concerning the nature of information needed from the exploratory evaluations and a discussion of the objectives of the evaluations. Further, since all of the information needs that were identified could not be addressed within the scope of the present project, this section also includes a description of issues that need to be addressed in subsequent evaluations. (Such evaluations could be planned using the guidance developed during the present project.)

A. DETERMINATION OF POTENTIAL BENEFITS.

The need for new flight displays, regardless of how they are generated, has been created, in part, by shortcomings in the design of existing electromechanical flight instruments that can create untoward demands on the pilot or fail to relieve him of such demands when they arise from other sources. As such, these existing instruments may contribute to a variety of pilot performance problems. New flight displays are also needed to facilitate and, in some cases, enable the pilot to perform functions related to new requirements that are being imposed on general aviation flight operations--e.g., requirements for the computation and execution of complex and more precise flight profiles as a result of the need to save fuel. The evaluation of benefits that may accrue from use of the EFIS should be based, then, on the determination of the extent to which the EFIS displays (1) prevent pilot performance problems that may be attributed to the shortcomings in existing flight instruments, and (2) facilitate the performance of pilot functions associated with new operating requirements.²

SHORTCOMINGS IN THE DESIGN OF CONVENTIONAL FLIGHT INSTRUMENTS. The designs of early flight instruments were limited by engineering constraints associated with the technology that was available during their development. For example, the information content of these displays was restricted by the limited capabilities of early aircraft sensors and navigation systems. Further, the form in which this information was presented also was limited by the physical constraints imposed by mechanical and electromechanical display technology (e.g., dial and

¹Indeed, part of the impetus for conducting the present project in two parts--one for planning and one for conducting the exploratory evaluations--was to allow the need for the evaluations to be assessed fully before resources were committed to its conduct.

²The EFIS may provide numerous other benefits that are not directly related to their impact on pilot performance--e.g., reduced acquisition or maintenance costs. While such benefits are of obvious importance, they are not of direct concern here.

pointer display formats or gimballed movement mechanisms). Moreover, few of these flight instruments were designed on the basis of a systematic analysis of their potential effect on pilot performance.¹

Many current flight instruments are modeled on these earlier displays, and, as such, suffer from design shortcomings that were inherent in those displays. These shortcomings have remained in some instances because even the most advanced electromechanical display technology still limits the form in which information can be displayed. In other instances, displays that could have been modified have not been altered significantly due to the reluctance of some pilots to switch to new formats.²

The shortcomings of existing electromechanical flight instruments can be conceptualized in a number of ways. Some of the shortcomings represent violations of general principles of display design that derive from years of research on human perceptual capabilities and the visual presentation of information. Most of these principles concern basic design variables related to the legibility of displays. Examples of such variables include symbol size, viewing distance, viewing angle, symbol brightness and contrast (with its background), display size, information coding strategies, and symbol dynamics.³

Deviations from these principles can result in displays that are hard to see and interpret, especially in environmental conditions that are commonly encountered in aircraft--e.g., poor lighting conditions, structural vibration, and acceleration forces. Such difficulties, in turn, lead to errors in interpreting displayed information and to a general increase in the task demands placed on the pilot.

Many current flight instruments also deviate from principles of display that have been developed specifically for flight instruments as a consequence of extensive research on conventional and experimental flight displays. Such principles concern complex design variables that influence the ability of the pilot to process information presented to him and to perform related control tasks. One such principle, for example, is that movement of the indicator in a flight display should reflect movement of the aircraft relative to the ground rather than movement of the ground relative to the aircraft. This principle is based on research showing that pilots have less difficulty using displays in which this principle is followed (e.g., conventional vertical speed indicators) than

¹Nicklas (1958) provides an excellent description of factors influencing the evolution of many early flight instruments that have served as models for current displays.

²The slow acceptance of improved versions of altimeter displays is an excellent example of such resistance. Problems with earlier altimeter display formats and the advantages to be gained from use of some of the newer (albeit electromechanical) displays are discussed in numerous references (e.g., Hill and Chernikoff, 1965; Mitchell, 1972; Spady, 1980).

³Comprehensive descriptions of such display design principles can be found in the display design standards which are referenced in Section C of this chapter.

when using displays that do not conform to it (e.g., conventional attitude indicators). A comprehensive review of many of these principles and their relation to pilot performance can be found in Roscoe (1968; 1980).

Other shortcomings of conventional display technology are related to limitations in the type and accuracy of information that is presented to pilots.¹ In many cases, such information is only indirectly related to the pilot's real needs. Thus, the pilot is forced to compute the information that is really needed using mental calculations and computational aids. Further, related information is frequently segregated across several independent displays in current cockpits. Thus, the pilot has to expend considerable effort to scan the separate instruments and integrate information from across the different sources. The need for performing these mental calculations and scanning the different sources of information increases the general level of task demands placed on the pilot. The existence of high demands, in turn, increases the probability of pilot errors that can threaten flight safety.

Such demands are particularly troublesome in aircraft flown by a single pilot, as opposed to two-man crews. In such cases, the single pilot must meet all the demands himself. Further, unlike in aircraft flown by two pilots, the single pilot usually does not have anyone to monitor his actions and detect his errors.

Yet other shortcomings in existing flight instruments are associated with a lack of standardization across aircraft with respect to the design of individual flight displays that provide similar information, and to the layout of these displays and associated controls. The lack of such standardization can create problems for pilots who are transitioning into new aircraft or who frequently fly different aircraft, as is often the case in general aviation (Ontiveros, Spangler, and Sulzer, 1978). Such problems, for example, may arise from momentary confusion over where to look for a given display, delays in interpreting displayed information, or even the mistaking of one display for another.

The claim that existing flight instruments suffer from design shortcomings may appear at first to be difficult to support, given that several thousand pilots routinely and safely fly aircraft equipped with these displays. However, evidence of pilot performance problems associated with these shortcomings has been derived from a number of sources. Such sources include analyses of--

- aircraft accidents and incidents (e.g., Forsyth and Shaughnessy, 1978; Hoekstra, Perry, and Huang, 1972);
- reports by pilots of performance problems that they have experienced (e.g., Advisory Group for Aerospace Research and Development, 1968; Bolz and Eisele, 1979; Fitts and Jones, 1947; NASA, 1977; 1980; Ontiveros et al., 1978); and

¹Such limitations are mostly due to constraints associated with aircraft sensors and navigation systems normally employed with electromechanical flight instruments. While discussion in this report is focused on the EFIS, it is difficult, or, at least, often tedious to separate the capabilities associated with the EFIS from those associated with advanced avionics systems that frequently will be installed with the EFIS.

- results of research on the use of conventional flight instruments, such as investigations of alternative versions of conventional altimeter displays (e.g., Hill and Chernikoff, 1965; Ontiveros, 1968; Shrager, 1972; Smith, 1979; Spady, 1980).

It should be noted that it is very difficult to use accident and incident data, particularly for general aviation aircraft, to identify and analyze many types of pilot performance problems.¹ With respect to problems associated with the use of flight instruments, it is often difficult to determine if a pilot erred in using an instrument because the pilot is unavailable to interview. In other cases, the pilot may not even realize that he made an error. Moreover, it is difficult to determine from such data if many types of accidents would have been prevented if improved displays were available to the pilot. Such accidents may be attributed to other "causes"--e.g., spatial disorientation, excessive workload, improper IFR operations, lack of familiarity with aircraft instruments, or even poor pilot judgment.

Evidence that improved displays may serve to reduce accidents that may be indirectly related to flight instrument design, as well as accidents directly attributable to errors in use of flight instruments, has been generated as a result of research on experimental flight displays.² Several such displays have been developed in past years as part of research attempting to discover ways to enhance pilot performance. While results of this research are mixed--the benefits to be derived, if any, depend on the specific display being studied--they demonstrate that it is possible to improve pilot performance using flight displays that may be quite different from existing flight instruments. Such improvements, when they were observed, were related not only to enhancement of the ability of the pilot to process information from flight displays and to perform related flight control tasks, but also to reductions in the overall level of task demands placed on the pilot and concomitant increases in the ability of the pilot to perform other tasks critical to safety of flight.

The results of that research do not, of course, imply that the EFIS displays, or any other new flight displays, will automatically enhance pilot performance. Such results, however, do indicate that the development of improved flight displays is one way to reduce or restructure task demands so that pilot performance is enhanced. One general criterion, then, by which new displays should be evaluated is their ability to prevent or reduce the diverse problems that are associated with the various shortcomings of existing flight instruments.

THE IMPACT OF TASK DEMANDS ARISING FROM NEW OPERATING REQUIREMENTS. Concern over pilot performance problems associated with the shortcomings of existing flight instruments has recently intensified due to several trends in general aviation aircraft and flight operations that are creating a growing dependence by pilots on their flight instruments as major sources of information. These trends are also creating new information processing demands that often can

¹Reasons for such difficulty are discussed in detail in Shelnutt et al., (1980). Briefly, they relate to deficiencies in the way accident and incident data that concern pilot performance problems are acquired, coded, accessed, and analyzed.

²Such research is discussed in Section C.

exceed or severely tax the capability of the pilots--particularly in aircraft flown by single pilots--when they are using conventional flight instruments.

One such change, for example, is that now the majority of general aviation flight operations are conducted for business purposes rather than for personal travel or recreation (Fink, 1980). Indeed, in the last few years, one of the most rapidly growing segments of general aviation has been corporate or executive aviation. As a result, a large part of the growth in the dollar value of general aviation aircraft sales has centered on the high performance turboprop and turbine powered aircraft used in corporate aviation (North, 1981).¹

In general, these high-performance aircraft are much more demanding to fly than other modern, but less complex aircraft. They must, for example, be flown with great precision in many operating regimes in order to maintain controlled flight. Such precision is required because the high performance aircraft are often less "forgiving" of pilot control errors than are less complex, slower aircraft. As a result of this need for greater precision, pilots may be forced to depend more on their flight instruments for the quantitative, precise information that they need for safe flight. Pilot task demands are complicated further by other characteristics of these aircraft--e.g., the time stress placed on the pilot due to the faster operating speeds of these aircraft, and/or demands placed on the pilot due to the need to operate the numerous, complex subsystems usually installed on these aircraft.

Business travel requirements for enhanced operational capabilities and flexibility have also resulted in changes in the nature of general aviation flight operations. The number of flights under instrument flight rules (IFR) has increased steadily in the past few years in corporate and most other segments of general aviation. IFR flight, particularly when conducted in increasingly crowded airspaces, normally requires much more precise navigation than flights under visual flight rules (VFR). Further, IFR flight is often conducted in instrument meteorological conditions (IMC) which prevents the use of external visual references.

Many of the factors that are acting to increase the pilot's dependence on flight instruments are also creating new demands that the pilot may not be able to meet consistently and safely with existing flight instruments. The rising price of fuel, for example, has resulted in the need to compute and execute precise horizontal and vertical flight profiles that minimize fuel consumption. The desire to save fuel is also increasing the demand for and use of area navigation (RNAV) routes and terminal procedures. Use of vertical and RNAV flight profiles increases task demands associated with navigation and control of the aircraft. Further, since the national airspace is not yet structured to enable the execution of such profiles without some deviations due to interfering air traffic or weather, demands associated with this form of navigation are complicated by the need for constant revision of the desired flight profile.

Vertical and RNAV flight operations are only the beginning of changes that may occur in general aviation in the 1980s--the decade in which the first generation EFIS will be used. Increased air traffic at many airports and in many enroute

¹Corporate aircraft, as previously stated, will be the first general aviation aircraft in which the EFIS will be installed.

corridors is resulting in the need for reorganizing airspace structures and instrument flight procedures. Such reorganization is required to increase efficiency and maintain the safety with which the crowded airspace is used. Many such changes are being planned, considered, and vigorously debated--e.g., the use of four-dimensional navigation (i.e., arrival of an aircraft at a selected point in space at a specified time) to permit precise metering and spacing of aircraft in controlled airspaces; the use of curved and other non-conventional approaches to landings to facilitate use of crowded airspace and airports; and the delegation of part of the responsibility to the pilot for monitoring and/or maintaining aircraft separation in instrument meteorological conditions.

Changes such as these will modify the information processing demands that must be met by the pilot-aircraft system. In some cases, such demands necessitate new sources of information and new displays. For example, the pilot will need new displays (e.g., threat-alerting and collision avoidance system displays, cockpit displays of traffic information) to be able to accept more responsibility for maintaining aircraft separation in instrument meteorological conditions. In other situations, it may be possible for pilots flying conventionally equipped aircraft to perform tasks that arise from new operating requirements, but there is the serious possibility that they may make more frequent and serious errors than they would using advanced flight displays designed to facilitate the performance of such tasks. Research on the use of RNAV systems, for example, has shown that in situations where there are reasonably high cockpit workloads, the incidence of serious navigation errors made by the pilot was much higher with conventional flight instruments than with experimental displays (Roscoe, Smith, Johnson, Dittman, and Williams, 1950; Jensen, Vanderkolk, FitzHenry, Rose, and Roscoe, 1971; Jensen and Roscoe, 1973; Kraus and Roscoe, 1972). Other research has shown that some non-conventional approaches to landing--e.g., curved, decelerating flight paths--cannot be flown with acceptable accuracy and safety using conventional flight instruments, but that they can be executed safely using certain experimental displays (Jensen, 1979; Duning, Hemesath, Hickok, Lammers, and Goemaat, 1973).¹

In summary, an evaluation of the ability of pilots to operate EFIS-equipped aircraft should include an assessment (and demonstration) of the benefits that may accrue from the use of such systems. Such an assessment should include the determination of whether the EFIS displays (1) prevent or reduce the occurrence of problems that have been attributed to shortcomings of existing flight instruments, and (2) facilitate the performance of tasks arising from new operating requirements that have been placed in general aviation flight operations.

The implications of these requirements with respect to the objectives of the exploratory evaluation will be discussed further in Section E of this chapter. However, it is clear that information concerning such benefits is of crucial

¹An additional source of new demands that have been placed on the pilot of modern corporate aircraft--the need to operate aircraft equipped with sophisticated autopilots and other advanced avionics systems--is described in Section B of this chapter. As discussed in that section, the use of such equipment also changes the pilot's need for information.

importance to the acceptance of the EFIS by general aviation pilots,¹ to the development of pilot confidence in these systems, and to the advocacy of effective utilization of their full capabilities.

B. IDENTIFICATION OF POTENTIAL PILOT PERFORMANCE PROBLEMS.

Optimism over the potential of the EFIS to produce safety benefits should be tempered, as stated earlier, with concern over the possibility that new, unforeseen pilot performance problems may arise when these systems are put into operational use in general aviation aircraft. There is, of course, no direct evidence at this time that such problems will arise. No accidents--the major criterion for identifying safety problems--have been attributed to the use of EFIS because there have not as yet been any opportunities for such accidents in civil aviation.

The key to improving general aviation safety, however, lies in assuring that significant changes in general aviation aircraft actually serve to enhance pilot performance or, at least, do not create new or aggravate current pilot performance problems. The best way to achieve this goal is through the use of research to (1) identify such problems before they occur in sufficient numbers to produce a disastrous accident trend, and (2) develop ways to prevent the problems and the accidents that otherwise would result from them. The need for securing evidence as to the likelihood that such problems may occur before they actually occur lends additional impetus to the need for exploratory evaluations --and to the need to plan them carefully to assure that they will produce evidence that the general aviation community will accept.

PERSONNEL PROBLEMS ASSOCIATED WITH IMPLEMENTATION OF INNOVATIONS. Concern over the potential for pilot performance problems derives, in part, from the general observation that the introduction of innovations into any complex man-machine system tends to create personnel problems. Change has become a major characteristic of modern American society, and the problems associated with such change, particularly the human problems, have received considerable public attention, as indicated by best selling books such as Future Shock (Toffler, 1970). Such changes have also been the subject of considerable research because of the problems they have created in numerous jobs in industry, government, and the military (Thomas and Bennis, 1972; Dalton, Lawrence, and Greiner, 1970). Change in many jobs has resulted from the increased use of computers to automate, semi-automate, or, at least, restructure job tasks that were previously performed manually. The impact of such innovative changes has been studied

¹Such acceptance is, of course, crucial to the marketing of such systems. While EFIS sales are of obvious interest to avionics manufacturers, promotion of the EFIS, if they do enhance pilot performance, is also in the interest of public safety. Indeed, many aircraft design features that have been developed to improve safety have failed to do so because they were not accepted in the marketplace.

extensively in a variety of jobs, and several sources of personnel problems have been identified.¹ Such sources include:

- failure to develop appropriate operating procedures for directing use of the new equipment;
- failure to develop effective programs to train workers to use the new equipment, especially workers who have used older equipment for an extensive amount of time;
- occurrence of high personnel turnover following the introduction of new equipment because incumbent or even newly selected workers did not have abilities required to use the new equipment; and
- failure of equipment designers to consider the total demands that would be placed on the worker once the equipment was put into operational use, or to anticipate and accommodate the capabilities of the workers who used the equipment.

Relevant to the use of EFIS, it is interesting to note that many of the problems associated with the use of new computer-based systems have been attributed to deficiencies in design of their video display terminals.² These terminals, like the EFIS, usually contain cathode ray tubes and associated input devices (e.g., keyboards). Examples of these deficiencies include (1) displays with visual characteristics that hinder perception of displayed information (e.g., jitter, illegible symbols); (2) poorly formatted, often highly cluttered displays that make location and interpretation of information difficult; (3) lack of appropriate subsets of information in integrated displays (e.g., information is grouped in ways that are meaningful to the engineers and programmers who developed the system, but not to the operator); and (4) poorly designed input devices and confusing operating logic that make the selection of display modes and other control tasks more difficult than necessary.

The history of aviation, which is a high technology area, contains several examples of pilot performance problems that have arisen following the introduction of innovative aircraft or avionics. Perhaps the classic example of such problems occurred when jet propulsion systems were first introduced into military and air carrier aircraft. Many experienced pilots had great difficulty learning to fly these new aircraft because their handling characteristics were markedly different from those of propeller-driven aircraft. Indeed, many older pilots with extensive flight experience were never able to make the transition successfully.

More recently, a major business jet manufacturer instituted a comprehensive refresher training program for pilots of their aircraft because they felt that

¹Reviews of literature on automation and the use of computers can be found in Ramsey, Atwood, and Kirshbaum (1978); Ramsey and Atwood (1979); and Smith and Dieterly (1980).

²Such deficiencies and their relation to personnel problems are reviewed in Cakir, Hart, and Stewart (1980); Grandjean and Vigiliani (1980); Matula (1981); and Ramsey and Atwood (1979).

many pilots were using inappropriate operating procedures (Moll, 1981). In their opinion, lack of use of appropriate procedures had resulted in a number of accidents which, in some cases, had been unfairly attributed to the design of the aircraft. They developed the program themselves, because they felt that recent technological improvements in business jets have outdistanced the ability of all but the very best training programs to provide pilots with such instruction.

Additional insight into the sources of problems caused by innovations in aviation has been developed through research by NASA on automation-induced problems in air carrier aviation (Wiener and Curry, 1980). At a recent NASA industry workshop on this topic, numerous problems were identified that either already had been encountered in air carrier flight operations or were projected to occur in the future as the use of automation increased (Boehm-Davis, Curry, Wiener, and Harrison, 1981). Examples of the sources of such problems included (1) difficulties in training pilots to use new systems, especially when the new systems were more complex to operate than the systems that they replaced; (2) failure of pilots flying advanced aircraft to maintain manual skills needed when automated systems failed or were not used, or when they transitioned back to less advanced aircraft; and (3) development of procedures that encouraged the use of a new automated system to expand operational capabilities to such an extent that a heavier workload was created than that associated with the manual systems which were being replaced.

In general, personnel problems following the introduction of new equipment can be attributed to failure to redesign the entire man-machine system to accommodate changes that are associated with the implementation of innovations in the man-machine interface. As discussed in Chapter I, changes in the design of the aircraft (or its subsystems) need to be accommodated by coordinated modifications of other factors influencing both task demands and pilot capabilities. If such changes are not accommodated, incongruities may develop between new task demands created by the innovative equipment and the capabilities of pilots to meet these demands. In turn, new operator performance problems may be created.

Simply stated, the introduction of new equipment must be coordinated with the entire system of factors that influence pilot performance. If personnel problems do arise, they must be examined with respect to all of the factors that may be interacting to influence pilot performance--not just with respect to the design of the equipment.

It should be noted that general aviation is a much more loosely organized "system" than air carrier or military aviation. As discussed in Shelnutt et al. (1980), general aviation is characterized by extreme diversity with respect to pilots, aircraft, flight operations, and pilot training programs. Further, most of the organizations and agencies within the general aviation community are small relative to their counterparts in military and air carrier aviation--e.g., airframe manufacturers, avionics manufacturers (at least the divisions within these businesses that are devoted to general aviation), and pilot training organizations. As such, these organizations are unable to devote as much time, money, and manpower to research and development efforts. In short, the diversity within general aviation and the relatively small size of the industry can, at times, hinder the coordination of factors influencing task demands and pilot capabilities, particularly when innovative changes are introduced in the design of the aircraft and its systems.

INNOVATIVE CHARACTERISTICS OF GENERAL AVIATION EFIS. The introduction of the EFIS into general aviation aircraft will constitute a major innovative change. While many of the display formats generated by the new systems may appear similar to those of existing electromechanical flight instruments, most versions of the EFIS will contain some formats that are truly unique.

For example, perhaps the most significant new display format is the moving map display (which is described in Appendix A). Research has shown that such displays, in general, can dramatically reduce navigation errors, especially in situations where the pilot is operating in high workload conditions (McGrath, 1969; Ontiveros, 1968; Roscoe et al., 1950). These displays are effective in enhancing pilot performance because they (1) correspond to the image of the navigation situation that the pilot has in his head and in his hands, in the form of charts and plates; (2) reduce the need for pilots to integrate information from different flight instruments, to calculate information needed to determine actual and desired course, and to refer to printed documents; and (3) clearly illustrate the nature of deviations of the actual flight path from the desired flight profile, and the future consequences of such deviations.

In short, the moving map displays will provide general aviation pilots with a valuable new resource. Many of the other innovative displays that the EFIS will be capable of presenting will also constitute new resources for the pilot--e.g., tabular presentations of navigation data, checklists, emergency procedures, and aircraft performance data. All of these new resources have the potential to influence the efficiency and effectiveness with which pilots execute a wide variety of flight tasks.

In addition to the moving map and the other innovative displays, there are several other differences between the EFIS and existing flight instruments that have the potential to influence pilot performance. For instance, many of the EFIS displays that are modeled directly after conventional displays have features that are not available in conventional displays--e.g., electronic attitude director indicators have supplemental information within their display that is not available on most electromechanical attitude director indicators. While such changes may seem minor, they have the potential to influence the way in which pilots acquire information, how they interpret the information, and even how they use it.

Yet another difference between the EFIS and conventional systems is that pilots will have the capability to select subsets of information that they want displayed at a given location. In some cases, for instance, pilots will be able to select several different displays on the cathode ray tube used to provide navigation information--e.g., moving map displays, reproductions of conventional horizontal situation indicators, and partial and complete compass roses. Pilots will also be able to "declutter" other displays by selecting subsets of information appropriate for the flight tasks being performed at a given point in time--e.g., remove information used for flying approaches to landings during enroute navigation. Further, given failures in one or more of the cathode ray tubes, pilots will be able to select displays normally presented in a disabled location at other locations, or special combined displays on the cathode ray tubes that are still functioning.

The selection of displayed information is, for the most part, a new function for general aviation pilots. To be able to perform this task effectively, they must

be able to remember the information presented in the various display modes and select modes that are best suited for their current situation. Additionally, they must be able to use keyboards and other input devices to access the displays and communicate with the onboard computer for various other reasons (e.g., to select radio frequencies and input flight plan information). These new tasks impose new demands on the general aviation pilot, in terms of both psychomotor and mental skill requirements.

The EFIS displays will differ from existing electromechanical flight instruments in numerous other ways. There are obvious perceptual differences, for example, involved in viewing displays on flat cathode ray tubes as opposed to painted three-dimensional metal surfaces. Additionally, the projected higher reliability of the new systems means that the pilot will be confronted with instrument failures on fewer occasions. Perception of the increased reliability will probably result eventually in increased pilot confidence in the new systems. Other differences may be identified by reviewing the description of the EFIS in Appendix A.

In summary to this point, the EFIS displays will differ in a number of ways from the existing flight instruments that they will replace. The new displays will represent a significant new subset of resources for the general aviation pilot. Use of these new resources will influence the performance of not only the psychomotor tasks involved in control of the aircraft, but also procedural tasks--either as a result of inclusion of procedures for use of the EFIS, or by the provision in the new displays of aids for the conduct of other normal and emergency procedures.

Perhaps most importantly, the availability of these new resources has the potential to influence many of the decisions--the judgments so crucial to the safety of flight--that the pilot makes (e.g., the detection and assessment of expected and unexpected flight conditions; the evaluation and adjustment of mission priorities to match these conditions; and the determination of revised flight plans). The failure of some general aviation pilots to exercise good judgment has been the subject of intense interest in recent years (Berlin and Holmes, 1981; Flathers, Giffin, and Rockwell, 1981; Jensen and Benel, 1977). Most attempts to address this problem have focused on modifying pilot capabilities through the use of judgment training. The EFIS provides another way to approach the judgment problem by increasing the amount of information available to the pilot to aid him in determining the risk to safe flight associated with a given flight situation. Further, if properly designed, the EFIS will reduce the total level of task demands imposed on the pilot and provide him with more time to devote to making decisions.

On the other hand, the EFIS and their displays represent a new resource for the pilot to manage. As such, use of the EFIS will place several new demands on the pilot and, in many cases, substantially restructure demands that are placed on him by the use of conventional flight instruments. Further, use of the EFIS will also indirectly affect the performance of almost all the tasks that the pilot performs, since such use will result in changes in the nature of overall task demands.

THE CHANGING ROLE OF THE PILOT. The new task demands placed on general aviation pilots by the introduction of the EFIS constitute only part of the changes that are occurring in the pilot's role. While the general aviation community and the

FAA take great care to assure that the general aviation system evolves slowly enough to accommodate change, the considerable progress enjoyed by general aviation is producing substantial--and rapid--change in a number of other factors influencing the task demands placed on the pilot.

As previously discussed, a number of current trends in general aviation (e.g., more sophisticated aircraft, the need for fuel conservation, an increasingly structured airspace) have increased the complexity of navigation and flight control tasks performed by many general aviation pilots. The changes will, of course, directly influence the demands made on the pilot. Moreover, to aid or, in some cases, enable pilots to meet these new task demands, avionics manufacturers are taking advantage of substantial advances in electronics and computer technology and are providing their customers with increasingly sophisticated avionics. Their customers have been buying this equipment because they need it and can afford it. The increased costs for avionics is more readily accepted as general aviation aircraft themselves become more expensive (Quinby, 1980).

In addition to the EFIS, examples of such technology include (1) advanced automated flight control systems with higher reliability, greater capabilities, and more modes of operation than previous autopilots; (2) sophisticated digital computers that perform rapid computations of complex flight profiles, assess aircraft status with respect to desired profiles, and compute commands directing flight control corrections that can be transmitted to autopilots and flight displays; (3) flight management systems that automatically integrate numerous flight control and navigation functions; (4) engine indicating and caution alerting systems that automatically integrate functions related to the operation of power plants and aircraft subsystems, as well as provide centralized displays and input devices for manual functions performed by the pilot; and (5) advanced flight reference and navigation systems that provide more, and more accurate, information concerning the aircraft's status and the desired flight profile.

These current trends in cockpit technology foreshadow even more extensive advances that may occur in the 1980s. Such advances are projected to include (1) subsequent generations of EFIS with display formats unlike any current displays;¹ (2) even more sophisticated automated flight control systems as well as autothrottle systems and active flight control systems; (3) more powerful flight computers and flight management systems; (4) better flight reference systems and ground- (or satellite-) based navigation systems (e.g., microwave landing systems, the Global Positioning System); (5) a variety of new control and input devices--e.g., keyboards with new formats, touch panels directly on display screens, and possibly even automated voice recognition systems; (6) data link receivers and transmitters which, when combined with ground or airborne systems, will be used to communicate a variety of navigation, weather, and air traffic information to the pilot.

The list of projected advances in cockpit technology is lengthy, and many more examples of current and near-future advances are available in the aviation research literature (e.g., McIver and Hatfield, 1978). Such advances in cockpit technology, when taken as a whole over time, will constitute a revolutionary

¹Several EFIS manufacturers, for example, have announced plans to introduce new flight display formats once the first generation systems have been certified by the FAA and accepted by general aviation pilots.

change in the pilot's role in the very near future. While this change is occurring gradually, it is occurring with unprecedented speed due to pressures for progress within general aviation and the extraordinarily rapid pace with which new electronics technology is being developed. Indeed, the next few years may be viewed as a period of relatively rapid transition in the nature of task demands placed on the general aviation pilot (at least for the pilots of the more expensive general aviation aircraft).

The pilot's role is changing in a number of different ways. The increasing use of advanced autopilots, for example, is reducing the amount of time and effort the pilot devotes to tracking primary flight displays and controlling the aircraft's flight path. These tasks require substantial time, effort, and skill in aircraft with only simple or no autopilots. Further, these autopilots often can be coupled to advanced flight management systems. Such coupling enables pilots to control the aircraft indirectly by programming desired flight maneuvers or even major portions of entire flight profiles in advance of their actual execution. In short, the pilot is becoming more removed from the direct flight control loop. Not only does the advanced autopilot control the aircraft during steady-state portions of a flight (e.g., holding altitude and heading), but it also is able, via "pre-select" functions and more advanced programming capabilities, to control periods of transition in the flight profile.

While the general aviation pilot has become less involved in the direct control of the flight path of the aircraft, he has become more involved with management of the much larger array of equipment common in more sophisticated aircraft--e.g., the autopilots themselves; flight management computers; complex radio navigation systems and other flight reference systems; communications systems; EFIS or, at least, complex electromechanical flight instruments; and support systems such as cabin pressurization, hydraulic and electrical systems. Simply put, the pilots of modern high performance corporate aircraft have almost everything that is on less complex, older corporate aircraft and more--more information available to the pilot; more ways to get the information; more ways to control the aircraft; more systems to operate; more controls and input devices to use; more equipment that can malfunction; more actions to take to counter malfunctions; and more decisions to make concerning how to use and manage all of the new resources that are available to them.

Thus, while automation may aid the pilot, the restructuring of the pilot's role may also give rise to new pilot performance problems. The previously cited research on the use of automation in air carrier aviation, for example, has revealed a number of problems that appear to be associated with the use of advanced avionics (Boehm-Davis et al., 1981; Wiener and Curry, 1980). Such problems include (1) the occurrence of new types of errors in actual flight operations that occurred infrequently (or could not occur at all due to the lack of opportunity) with older systems--e.g. errors in the programming of flight maneuvers, and errors in which the pilot incorrectly believes the autopilot is performing certain control tasks;¹ (2) the failure of pilots to detect

¹The National Transportation Safety Board, for example, attributed a serious incident involving an Aeromexico DC-10-30 to improper operation of the autopilot and autothrottle systems (Climb Procedures Cited in Incident, 1981). Simply put, the autopilot and autothrottle were put into antagonistic modes that resulted in the loss of flying speed and control of the aircraft. The description of the events that occurred during this incident are illustrative of problems that may arise with the use of advanced systems.

autopilot failures and/or have sufficient awareness of the flight situation to be able to take over for failed systems; and (3) the failure of the pilots to use the full capabilities of the new automated flight control systems, even when such use would provide much needed reduction in the task demands placed on them in critical flight situations.

Research in another program, which was focused on general aviation aircraft, found that pilots who were using advanced autopilots tended to lose track of their flight situation more frequently than did pilots who were flying manually or using only simple autopilots (Bergeron, 1980a). As a result, the pilots with the advanced autopilots deviated more frequently and to a greater degree from their desired flight path. Many of the critical flight path deviations occurred because the pilots failed to set up their autopilots correctly. Such errors were then compounded by the failure of the pilot, due to the lack of situation awareness, to detect flight path deviations until after the aircraft had departed from its assigned airspace.

It should be noted that the pilots in this study did not have copilots who could monitor their operation of the aircraft and detect deviations from the desired flight path. Such single pilot operations are common in general aviation. In contrast with air carrier aviation in which all aircraft are flown by two or three pilots, single pilot operations represent a unique factor that should be considered in the study of the impact of new equipment on general aviation pilot performance.

In conclusion, changes in the pilot's role as a result of the increased use of automated systems raise a number of serious questions. Many of these questions relate directly to the impact of these changes on pilot performance. Of more interest in the present context, however, are questions that arise as a result of these changes in terms of the pilot's need for information from flight displays.

Research on flight displays has revealed that the influence of these displays on pilot performance is moderated by the nature of the control tasks that the pilot is performing (Roscoe and Bergman, 1980). Thus, changes in the nature of the pilot's flight control functions have extensive implications for the design of EFIS. Such implications have been recognized by the designers of the EFIS (Fadden and Weener, no date given). They have included many features that they believe will alleviate the adverse effects of removing the pilot from the direct control loop as well as facilitate performance of new system management tasks. For example, some of the new display formats--e.g., the moving map display and the multifunction display (see Appendix A)--are intended to increase the pilot's awareness and understanding of more complex flight situation, and prevent problems associated with the loss of such awareness due to the use of advanced autopilots. Further, other new display formats are designed to aid the pilot in performing procedural tasks and making decisions related to use of the new systems--e.g., the provision of checklists and information concerning the status of different subsystems.

Whether the EFIS displays will achieve these and other related design goals when they are used in actual flight operations--and whether their use will create new problems--is of obvious concern to the personnel involved in the design of the

EFIS. As a result, the avionics manufacturers have performed several formal and informal analyses during the development of the EFIS to aid in identifying alternative design ideas and selecting the most promising concepts for their prototype systems. These analyses drew on several sources of information that could be used to support predictions of the impact of different design concepts on pilot performance.

The next section (Section C) reviews the general nature--and limitations--of information that was available from these sources. As such, in combination with discussions already presented in this section and Section A, it provides the foundation for identifying the information needed from the exploratory evaluations to aid in determining the benefits and problems that may accrue from use of the EFIS. The implication of such needs with respect to the design of the evaluations will be discussed in Section E, the final section in this chapter.

C. SOURCES OF INFORMATION CONCERNING EFIS DISPLAYS.

Personnel involved in the development of display formats for the first generation of the general aviation EFIS had access to several sources of design information. Such sources included (1) the results of past research on experimental flight displays; (2) display design standards and other design guidance that was available in regulatory documents and technical reports; (3) specifications for the EFIS that will be installed in air transport aircraft; and (4) the results of in-house analyses and tests of prototype general aviation EFIS conducted by the avionics manufacturers.¹ The design of the general aviation EFIS will also be influenced indirectly by tests conducted as part of the certification of the airworthiness of aircraft in which EFIS are installed. (Since EFIS-equipped aircraft had not yet been submitted for certification, such tests had not been conducted when this report was written.)

Interviews conducted during the present project revealed that there are no established procedures for acquiring and using information from the above sources. Each manufacturer is proceeding in a different way depending on the composition and experience of its design staff, the extent of its resources for research and development, and the nature of its design and marketing goals.

The variability in EFIS development procedures makes it impossible to assess the specific impact that any one source of information may have had on the design of first generation EFIS displays (or will have on the design of subsequent generations). However, a review of the nature--and general limitations--of the information that can be obtained from these sources can provide a better understanding of certain constraints inherent in the display design process. These constraints, and the uncertainty that they create in design decisions, give further support to the need for exploratory evaluations.

¹Another source of information is potentially available--i.e., the use of computer models of pilot performance to simulate the response of the pilot, through the use of mathematical algorithms, to different display configurations (Baron and Levison, 1977). While such models have considerable potential, they are still in the early stages of development, and, at present, are of limited practical value with respect to assessing the adequacy of alternative EFIS display formats.

PAST RESEARCH ON FLIGHT DISPLAYS. An extensive review was made of past research on experimental flight displays and other literature related to the design of flight displays, such as display design standards. The goals of this review were to (1) evaluate the utility of this literature with respect to resolving specific issues in the design of displays that will be produced by the first generation of general aviation EFIS; and (2) identify experimental techniques and measurement methods that could be used in developing conceptual approaches for exploratory evaluations. The following subsection focuses on the results of the review that pertain to the first goal.¹ The results of the review that pertain to the second goal are discussed, as relevant, in subsequent chapters devoted to describing specific aspects of the conceptual approach that was developed.

Based on the research reviewed, several general observations can be made concerning the display design process and the information that is needed to support it. To begin with, a very large number of independent display design variables have been identified that directly influence the ability of the pilot to use a given display and, more indirectly, his ability to operate an aircraft safely and efficiently. The numerous research reports that are cited in Appendix C, for example, illustrate the large number of research issues that have been addressed in past investigations of flight displays.² Discussion of these issues is beyond the scope of this report. It is sufficient to conclude here that (1) the display developer is faced with a large number of design decisions that have the potential to influence how the pilot responds to a given display; and (2) information concerning these potential influences should be considered along with other design criteria (e.g., cost) in making these decisions.

The results of research on flight displays have revealed, however, that the development of such information is complicated not only by the large number of independent display design variables that should be considered, but also the existence of interactions among display design variables that modify the influence of any one variable. The interactions among display design variables are of particular interest when, as is often the case, the combined effect of two or more variables cannot be predicted from knowledge of the independent effects of the component variables.

For example, the ability to discriminate among symbols presented in a display is influenced by the complex interaction among such variables as the overall luminance of the display and the lighting characteristics of the surrounding environment; the duration for which the symbols are present; the color, contrast (with their background), and movement of the symbols; the location of the symbols within the display; and even the meaningfulness of the symbols and the pilot's familiarity with them.

¹Since the analysis of generic display design issues addressed in past research is not of direct interest in the present project, a review of specific research findings that pertain to such issues is not presented here. However, since such literature provides insight into the complexity of the display design process, references for selected studies that have been conducted on experimental flight displays are presented in Appendix C.

²The topics in the subject index that is included in Appendix C illustrate many of these general research issues.

A number of other factors interact with the design of a given display to influence pilot performance. Examples of such factors include (1) the nature of the flight control task that the pilot must perform (as determined by the aircraft's handling qualities, the design of automated flight control systems, and the type of flight operations that are being performed); (2) the characteristics of other tasks the pilot is performing and the total level of task demands that are placed on the pilot; and (3) the capabilities of the pilot, as determined by past flight experience and training, and by temporary changes in the pilot's condition due to such factors as fatigue, boredom, and time stress.

In their quest for information concerning the impact of the numerous display variables, their interactive effects, and the influence of other factors on the use of a given display, developers of the general aviation EFIS or any other flight displays often turn for aid to the results of previous governmental research on such factors.¹ For purposes of the present discussion, such research can be divided into two major categories: (1) programmatic research devoted to development of generic flight displays for specific types of aircraft (e.g., air transport or fighter aircraft); and (2) other research projects that have also focused on general display design issues.

PROGRAMMATIC RESEARCH ON GENERIC DISPLAYS. The development of EFIS for both military and civilian air transport aircraft has been aided through the conduct of a variety of government-sponsored research programs. Current or recent examples of such efforts include military programs such as (1) the Air Force's Digital Avionics Information System (DAIS) (Mason, Price, Rich, Slightam, Stautbery, Whalen, and Wilent, 1979); (2) the Navy's Advanced Integrated Display System (AIDS) (Elson, 1977; Greer and Hanking, 1977); and (3) the Army's Integrated Avionics Control System (IACS) (DeBellis, 1980); and civilian air transport aircraft programs such as (4) NASA's Terminal Configured Vehicle (TCV) and (5) STOLAND programs (McIver and Hatfield, 1978). Examples of earlier such efforts include the Army-Navy Instrumentation Program (ANIP) (Baker, 1961); its successor, the Joint Army-Navy Aircraft Instrument Research (JANAIR) Program (Cundari, 1968); and the Department of Transportation/FAA Supersonic Transport (SST) technology development program (McIver and Hatfield, 1978).

Such programs, while costly, provide a number of economic benefits. For example, they allow industry and government to share the substantial expenses incurred in such research. They also enable researchers from different organizations to share the use of expensive research simulators, aircraft, and other facilities.

More importantly, these programs provide numerous technical benefits, since they enable researchers to take a systematic approach to the development of integrated cockpit systems. Such an approach provides several advantages with respect to the development of hardware and software technology (as discussed in Hatfield, Robertson, and Batson, 1979). Of interest here, however, are advantages that accrue with respect to the systematic development of display formats.

¹The research that is referenced here was usually government sponsored and focused on general issues in the design of experimental flight displays. In-house industry research that supported the development of specific EFIS displays is discussed in the next subsection.

Programmatic research on the design of such formats facilitates the systematic development and evaluation of alternative display design concepts specifically suited to the aircraft (and pilots) that are being studied. As such, researchers are not only able to gain information concerning the effects of different display variables, but also the impact of interactions among such variables with respect to specific design concepts that are proposed. Moreover, by focusing on specific displays, aircraft, pilot populations, and flight operations, researchers are able to analyze systematically the numerous factors that interact with the design of the display to influence the pilot's ability to use the display and fly the aircraft.

The findings of programmatic research on generic displays are often related to many of the specific display design questions raised in the development of prototype displays by industry. That is, general knowledge gained from such research is easily transferred to, and provides a comprehensive foundation for, in-house analyses and test efforts that support the design of prototype and, eventually, production display systems. A prime example of this transfer of knowledge is provided by the extensive use that was made by the air transport airframe manufacturers of information obtained from research on the TCV and SST research programs (Fadden and Weener, no date given). This research provided these manufacturers with a comprehensive technology base for the development of primary specifications for the EFIS that will be installed on the next generation of air transport aircraft--e.g., the Boeing 757 and 767 aircraft.

At present, however, there are no comparable research programs that are devoted to the systematic study of the displays that will be produced by the first (or subsequent generations) of general aviation EFIS. Some existing programs have begun to explore issues in the development of hardware and software technology related to these EFIS--e.g., the FAA's Advanced Integrated Flight Systems (AIFS) program and NASA's Demonstration Advanced Avionics Systems (DAAS) program. Other projects are investigating display design in the context of certain types of pilot performance problems--e.g., NASA's Single Pilot-IFR program and General Aviation Terminal Area Research program. While this research has produced some interesting preliminary findings and has led to the development of research aircraft and simulators that can be used in the study of general aviation EFIS, it has not produced the comprehensive data base needed to evaluate the impact of the first generation of general aviation EFIS.

Given the lack of such research, the personnel engaged in the development of general aviation EFIS have drawn on the findings of programmatic research performed on air transport EFIS. The use of these findings, however, is hindered by the existence of differences between the aircraft, avionics, pilots, and flight operations characteristic of air carrier aviation and general aviation.

The first generation of general aviation EFIS, for example, most likely will differ from the air transport EFIS in terms of the content and format of their displays, and in the way the displays are accessed. Since this report was written before details of the display formats in either type of system were released to the public, a specific description of such differences is necessarily limited. In general, however, it can be stated that general aviation displays probably will contain less information, some of the information that is presented by the general aviation systems probably will be less accurate than similar information generated by the air transport systems, some perceptual characteristics of the displays likely will differ, and some information

probably will be coded in different ways (e.g., shape, size, color, and location coding).

Such potential dissimilarities are due to a number of factors. For example, there very likely will be differences in the hardware and software used in the two types of EFIS as a function of cost, weight, and size factors. There also probably will be differences in the availability of input data for these systems, given that the air transport aircraft likely will have more expensive and sophisticated navigation and flight reference systems, and more advanced avionics systems that will be integrated with the EFIS--e.g., flight management systems, automatic flight control systems. Finally, there is the desire of the avionics manufacturers to tailor their systems to requirements specified by their general aviation customers. Further, some of the general aviation EFIS will be designed to meet different specifications and design standards that are different from those used to guide design of air transport EFIS. (These design standards will be discussed later in this section.)

In addition to the differences between EFIS that will be installed in general aviation and air transport aircraft, there are also numerous differences among the aircraft themselves, the pilots who fly them, and the flight operations that are performed. Such differences complicate the generalization of knowledge gained from research or operational experience from air carrier aviation to general aviation. These differences are described in detail in another report produced earlier during the present research project. This earlier report is presented in Appendix D of the present report. Basically, general aviation differs from air carrier aviation in that--

- the type of aircraft flown is usually less complex;
- there is often only one pilot on non-turbojet aircraft;
- the pilots are usually less experienced;
- the pilots transition more often across aircraft;
- there is usually less assistance available to the pilot in preflight planning and aircraft dispatch;
- there is usually less assistance available to the pilot while aloft;
- the schedules flown are more flexible;
- the origins and destinations are often remote, and there are fewer air traffic control services and navigational aids during critical portions of the flight; and
- the smaller airports often used by general aviation aircraft have fewer instrument and visual landing aids and often have runways with characteristics that make them difficult to use--e.g., they are often short and have nearby obstacles.

The existence of such differences between air carrier aviation and general aviation reduces the direct value of the programmatic research on air transport EFIS as support for decisions related to the design of general aviation EFIS.

While research is still of considerable value, it does not provide a systematic knowledge base related to specific general aviation flight display design questions. Further, there are additional constraints that confound the use of the findings of this research and increase the uncertainty of design decisions based on the extrapolation or generalization of such findings. Since these constraints apply to the use of the findings of all types of research projects, they are described in the next subsection, which discusses other research that has been conducted on experimental flight displays.

Other Research on Flight Displays. In addition to the programs cited above, a large number of other research projects have investigated issues in the design of different experimental flight displays. (Numerous examples of such projects are cited in Appendix C.) These projects have been initiated for a variety of reasons--e.g., as part of (1) basic research to discover the type of information that is required by the pilot to operate the aircraft; (2) systematic investigations of innovative display design concepts--such as new display formats; (3) investigations of factors affecting display legibility; and (4) studies to aid in the development of models or less formal explanations of pilot performance.

As with the programmatic efforts, the findings of these research projects can be of considerable value to personnel engaged in the development of EFIS displays. Such findings may be accessed by these personnel in two ways. They may review the original reports of each of the studies that are of interest, or they may consult summaries of research findings that are given in secondary reference sources, such as display standards, formal design guidelines, textbooks, and other forms of display design guidance. The use of secondary sources, which was reported to be the preferred method of acquiring design data, is discussed in the next subsection.

Some of the design personnel who were interviewed in the present study, however, stated that they had frequently reviewed the original reports of research on experimental flight displays when they felt such investigations focused on issues that were particularly relevant to their specific design questions, or when they wanted to identify the specific conditions under which the studies were conducted, as to evaluate the adequacy of techniques used to collect and analyze performance data. They felt such findings aided them in the identification of promising design concepts, particularly for new display formats. Some interviewees noted, however, that many experimental flight displays had formats that were radically different from conventional displays--e.g., pictorial vertical situation displays such as those studied by Roscoe and his associates (Roscoe, 1980). Since the formats of the first generation EFIS displays were modeled, in part, on conventional flight instruments, they felt that such research might be of greater use in the design of subsequent generations of EFIS displays than it has in the first generation.

Interviewees also reported that the findings of past research aided them in the preliminary evaluations of alternative design configurations, particularly with respect to issues related to information coding and display legibility. They also observed, however, that the use of such findings for identifying and evaluating display design concepts was limited by certain difficulties associated with obtaining reports of past research and interpreting the results that are presented therein. It is interesting to note that many of their comments coincided with the findings of studies that have been conducted on the use of

research results by engineers and other operational personnel involved in the design of man-machine interfaces (McClelland, 1968; Lyons, 1966).

To begin with, it is often difficult for personnel who have not been trained in human factors or psychology to identify and obtain reports of psychological research on the design of experimental flight displays. Such research, which is often published in technical reports rather than professional journals, is often categorized in reference systems in abstract psychological terms that "disguise" the operational characteristics of the study. Further, time constraints common in operational development activities restrict the ability of design personnel to seek and read individual reports (hence the relative popularity of secondary sources).¹

In addition to these difficulties, use of research findings was also hindered by the lack of research that focuses on the specific design questions that were of operational interest (e.g., specific combinations of design variables in a prototype display). Also, there is the problem of extrapolating from the general abstract issues that were studied (which are often formulated in terms of theoretical constructs related to human behavior) to specific design questions that were concerned with the physical parameters of the display. In addition, such research often does not provide performance data that are related to decision criteria employed in the design process. While such limitations can be overcome, in part, by the use of personnel trained in human factors or psychology (which indeed was the case in some organizations), they still constrain the use of research findings.

DISPLAY STANDARDS, DESIGN GUIDELINES, AND OTHER GUIDANCE. The knowledge gained from past research on experimental flight displays and other types of visual displays has also served as part of the basis (in conjunction with expert judgments and other subjective analyses) for the development of display standards, design guidelines, and other forms of display design guidance. Such standards and guidance, which are available in numerous technical reports and regulatory documents, vary in the extent to which they pertain to specific issues in the displays that will be produced by general aviation EFIS.

Table 1 contains examples of different sources of such display design guidance. For purposes of the present discussion, these sources have been grouped into four categories.² These are standards and other forms of guidance for the design of (1) all types of visual displays; (2) computer-generated, cathode ray tube displays (which are of particular interest with respect to the design of EFIS displays); (3) flight displays in general, particularly electronic flight displays; and (4) the specific displays that will be presented by the general aviation EFIS.

The information presented in the reports cited in Table 1 circumvents, to varying degrees, some of the shortcomings just described with respect to

¹A number of respondents felt that relevant FAA and NASA reports should be disseminated aggressively to industry to promote better utilization of research findings.

²Some of the reports that are cited contain guidance that pertains to more than one category.

TABLE 1.--EXAMPLES OF SOURCES OF DISPLAY STANDARDS AND OTHER DESIGN GUIDANCE

1. GENERAL STANDARDS AND GUIDANCE FOR THE DESIGN OF VISUAL DISPLAYS
 - Visual Presentation of Information (Baker and Grether, 1954)
 - Perception of Displayed Information (Biberman, 1973)
 - Air Force Systems Command Design Handbook 1-3, Human Factors Engineering (Department of the Air Force, 1977)
 - Human Engineering Design Criteria for Military Systems (Military Standard 1472C) (Department of Defense, 1981)
 - Human Engineering Design for Army Materiel (Military Handbook 759) (Department of the Army, 1975)
 - Fundamentals of Display Systems (Sherr, 1970)
 - Bioastronautics Data Book (Parker and West, 1973)
 - Human Engineering Guide to Equipment Design (Van Cott and Kinkade, 1972)
 - Guide to Human Engineering Design for Visual Displays (Meister and Sullivan, 1969)
 - Human Factors Design Handbook (Woodson, 1981)
2. STANDARDS AND GUIDANCE FOR THE DESIGN OF COMPUTER-GENERATED DISPLAYS
 - How To Make Displays Legible (Shurtleff, 1980)
 - A Review of the Literature on the Legibility of Alphanumerics on Electronic Displays (Buckler, 1977)
 - Human Engineering Design Criteria for Modern Control/Display Components and Standard Parts (TR-RS-CR-80-1) (Elke, Malone, Fleger, and Johnson, 1980)
 - A Human Engineering Specification for Legibility of Alphanumeric Symbology on Video Monitor Displays (revised) (Gorrell, 1980)
 - Human Factors in the Design of Computer-Controlled CRT Displays (Gould, 1968)
 - Human Engineering Design Criteria for Modern Control/Display Components and Standard Parts (TR-RS-CR-80-2) (Woodson and Coburn, 1980)
 - Color Display Design Guide (Krebs, Wolf, and Sandrig, 1978)
 - Readability of Electronic Displays (Winkler, 1979)
 - Human Factors in Computer Systems: A Review of the Literature (Ramsey and Atwood, 1979)

(Continued)

TABLE 1.--Continued

- Visual Display Terminals (Cakir, Hart, and Stewart, 1980)
 - Ergonomic Aspects of Visual Display Terminals (Grandjean and Vigliani, 1980)
3. GENERAL STANDARDS AND GUIDANCE FOR THE DESIGN OF FLIGHT DISPLAYS
- Analysis of Human Factors Data for Electronic Flight Display Systems (Semple, Heapy, Conway, and Burnette, 1971)
 - Aircraft Alerting Systems Criterion Study: Vol. II. Human Factors Guidelines for Aircraft Alerting Systems (Boucek, Veitergruder, and Smith, 1977)
 - Aerospace Human Factors Engineering (Denisov and Onishchenko, 1973)
 - Airborne Displays for Flight and Navigation (Roscoe, 1968)
 - Display-Control Synthesis (Roscoe, 1980)
 - Electronic and Optically Generated Aircraft Displays: A Study of Standardization Requirements (Ketchel and Jenney, 1968)
 - Approval of Area Navigation Systems for Use in the U.S. National Airspace System (AC 90-45A)
 - Aircrew Systems Controls and Displays for Fixed Wing Aircraft (Military Standard - 203)
 - Aircrew Station Geometry for Military Aircraft (Military Standard - 1333)
 - Flight Deck Instrumentation and Display Design Objectives for Transport Aircraft (ARP 1068) (Society of Automotive Engineers, 1981a)
 - Flight Deck Visual, Audible, and Tactile Signals (ARP 4500) (Society of Automotive Engineers, 1981b)
4. STANDARDS AND GUIDANCE FOR THE DESIGN OF GENERAL AVIATION EFIS
- Airborne Electronic Displays, Draft (AS-8034) (Society of Automotive Engineers, 1981c)
 - Minimum Operational Performance Standards-Airborne Weather and Ground Mapping Pulsed Radars (DO-173) (Radio Technical Commission for Aeronautics, 1981)
 - Airworthiness Standards, Normal, Utility, and Acrobatic Category Airplanes (FAR, Part 23)
 - Airworthiness Standards, Transport Category Airplanes (FAR, Part 25)
-

findings of individual research reports. Such guidance provides, for example, a unified, more easily obtained source for data related to several different design variables. Further, many of the reports are specifically designed to support the design process--e.g., issues are stated in terms of specific display design variables, and conclusions are stated in terms that are intended to be meaningful to designers. Not surprisingly, personnel who were interviewed during the present project frequently stated that they found such reports useful in the development process, although there was some disagreement in terms of which sources were useful and the extent to which they were of use.

While the value of the existing guidance should not be minimized, the purpose of the present discussion is to identify constraints inherent in this guidance that prevent designers from obtaining conclusive support for their decisions. The display standards, guidelines, and other forms of display guidance suffer from several general limitations. Such limitations pertain to some of the same problems cited with respect to the research literature--e.g., the lack of information concerning specific design configurations of interest to the designers of the EFIS displays, the lack of performance data relevant to design decision criteria, and the lack of information concerning the effects of interaction among display design variables as well as the impact of nondisplay factors that influence the use of displays.

Other general limitations were identified that can be traced to more global problems that are associated with broader issues in the development of human factors standards and guidance, and their use in the design of man-machine interfaces. These include (1) limitations in the empirical data bases on which such guidance is based and an overdependence on unverified expert opinions; (2) deficiencies in the way such standards are formatted and presented; and (3) operational constraints that frequently restrict or even inhibit the use of this information in the development process. Such limitations, since they represent more global problems, are discussed in detail in numerous other reports (e.g., Egan and Goodson, 1978; Meister, 1971; Meister and Farr, 1966; Meister and Sullivan, 1967; Rogers and Armstrong, 1977; Rogers and Pegden, 1977).

On a more specific level, the design standards and guidance that are (or soon will be) available for the general aviation EFIS displays also suffer from certain limitations. For example, the formats of flight instruments in general aviation aircraft are governed by parts of Federal Aviation Regulations (FARs) that are used as the basis for certifying the airworthiness of aircraft in which those instruments are installed (i.e., Part 23 for smaller aircraft, and Part 25 for some of the larger and heavier business jets). At present, these regulations do not contain any guidance specific to the design of the formats of the general aviation EFIS displays. Rather, they contain some general guidance for designing the markings of certain conventional flight instruments (e.g., indications of critical values on airspeed indicators), and the general location and arrangement of flight instruments on the instrument panel (only for aircraft weighing over 6000 pounds).

To provide guidance that is more specific to the design of the general aviation EFIS displays, the A-4 Committee (Aircraft Instruments) of the Society for Automotive Engineers has formed a subcommittee (the A-4 Subcommittee on Electronic Displays) that is preparing an Aerospace Standard (cited in Table 1)

that specifies minimum performance standards for all airborne electronic displays (except for single purpose/single function displays). Additionally, the Radio Technical Commission for Aeronautics has developed Minimum Operational Performance Standards for airborne weather and ground mapping pulsed radars.¹ This document, which is more limited in coverage than the Society for Automotive Engineer's Aerospace Standard, will include guidance related to the presentation of alphanumeric (e.g., checklists) and graphic (e.g., RNAV waypoints) data on weather radar displays.

Much of the guidance that is provided in these documents pertains to questions related to development and testing of the hardware and software in the EFIS--e.g., environmental testing requirements to assure resistance to humidity, vibrations, and heat. Guidance that pertains to design questions more directly related to pilot performance is mostly limited to physical parameters influencing perception of the displays such as viewing angle, symbol alignment, jitter, symbol quality, photometric, and luminance characteristics. These documents do not address the more complex display design issues (e.g., information content and coding). Moreover, some of the guidance that is provided concerning physical parameters is vague, and the tests of compliance that are specified leave considerable latitude in the determination of whether displays meet the specified criteria.

The level of detail and comprehensiveness of these documents is constrained in part by the general limitations inherent in human factors standards and guidance that were discussed above. Such constraints can also be attributed to the fact that these documents will be employed, either directly or indirectly, in the certification of EFIS-equipped aircraft. It is the desire of the avionics manufacturers as well as the FAA to keep such documents from being so detailed that they unnecessarily restrict the design of the EFIS (Quinby, 1980). If the content and format of a given display were to be precisely specified, for example, then it would be difficult, given the cumbersome nature of the regulatory process and of procedures for changing this process, to get an improved display approved by the FAA. Further, the avionics manufacturers believe that excessive standardization would reduce beneficial competition in their industry.

Thus, there is considerable agreement within general aviation industry that restrictive display design standards should not be formulated by the FAA for use in airworthiness certification (Quinby, 1980). There is, however, more support for the use of so-called "functional" or "performance" standards. Such standards specify minimum levels of acceptable system performance as guidance for evaluating aircraft and avionics. For example, Advisory Circular AC 90-45A (which is cited in Table 1) established procedures that equipment manufacturers could use to demonstrate that their RNAV systems were in compliance with accuracy requirements for RNAV navigation (i.e., that aircraft equipped with their systems could stay within assigned airways).

¹As a point of interest, a special committee of the Radio Technical Commission for Aeronautics is preparing a document that will provide guidelines for the development and validation of software for digital avionics. While not directly related to pilot performance, software verification is of substantial importance to assuring the reliability of the EFIS.

Briefly, AC 90-45A establishes airway route widths for certain RNAV flight operations. Further, it establishes a "system error budget" which is the maximum permissible deviation from the route centerline as measured under certain situations. AC 90-45A is unique in that it specifies that pilotage or tracking error (referred to as "flight technical error") be included in the "error" budget along with other sources of system inaccuracies. Thus, whether an RNAV system is acceptable depends, at least in part, on how well the pilot can use the system. While AC 90-45A has certain limitations (e.g., the system error budget does not include procedural errors made in operating the RNAV systems), it does provide an objective basis for evaluating the performance of pilots, albeit indirectly, as part of the evaluation of system performance. Unfortunately, no counterparts to AC 90-45A exist for evaluating other aspects of the performance of EFIS-equipped aircraft.

IN-HOUSE INDUSTRY ANALYSES AND TESTS. Information shortfalls resulting from the types of constraints cited can sometimes be circumvented by in-house analyses and tests that are conducted during the development of specific EFIS models by avionics and airframe manufacturers. For example, development of the air transport EFIS was substantially supported by the major air transport airframe manufacturers, such as Boeing. These manufacturers devoted considerable manpower, time, and money to the development of primary specifications for these systems, and the evaluation of various levels of prototype systems.

The large design staffs employed by the air transport manufacturers included engineers, human factors personnel, test pilots, and other professionals who had gained extensive experience in the development of EFIS as a result of their work in the development of avionics for previous aircraft (e.g., Boeing personnel had worked on EFIS systems for prototype aircraft, such as the YC-14 and B-1) and participation in programmatic research on air transport EFIS (e.g., the TCV and SST programs cited previously in this report). Thus, the airframe manufacturers were able to draw on the considerable expertise of these individuals and on a substantial "corporate memory" as well.

The air transport airframe manufacturers also received aid from the airlines who were planning to purchase the EFIS-equipped aircraft. In addition to providing reviews of alternative display formats, airline personnel also worked closely with the airframe manufacturers to develop operating procedures for the new aircraft and related pilot training programs. Such efforts serve to promote congruence between the demands that will be imposed by the EFIS (and other new cockpit technology) and the capabilities of airline pilots who will fly the EFIS-equipped aircraft.

In contrast, the smaller size of the general aviation avionics market, relative to air carrier aviation, constrains the resources that can be devoted by the avionics manufacturers to the development of general aviation EFIS. Similarly, the general aviation airframe manufacturers also have been constrained by the relatively limited resources (compared to air transport airframe manufacturers) that they could devote to the development of specifications for EFIS and the evaluation of prototype systems. Such limitations also extend to the customers who will purchase the general aviation aircraft equipped with EFIS.

As a result, the avionics manufacturers employed in some degree the specifications for air transport EFIS to support the development of preliminary specifications for the formats of the displays that will be presented by the general

aviation EFIS. Use of the air transport EFIS specifications was constrained by the substantial differences between the hardware and software used in the air transport and general aviation EFIS. In addition, it was influenced by the desire of the avionics manufacturers to tailor their systems to the wants and needs of their major general aviation customers, and by the differences between air carrier and general aviation aircraft, pilots, and flight operators discussed earlier.

CERTIFICATION FLIGHT TESTS. The final examination of the general aviation EFIS will be conducted as part of the flight tests and other assessments made during the certification by the FAA of the airworthiness of EFIS-equipped aircraft. Descriptions of the certification process can be found in Federal Aviation Regulations (FARs), particularly FAR 23 and 25, and in other FAA documents such as FAA Flight Test Guides. At present, the FAA is planning to use current regulations and existing advisory documents to guide the certification of the aircraft with the first generation EFIS (with the possible addition of RTCA and SAE standards).¹ Provisions for examination of the potential impact of the EFIS on pilot performance are included in these test procedures in the form of general, flexible criteria for assessing the flight characteristics and performance of the aircraft being tested. While such criteria provide considerable leeway to the flight test pilots in their review of the aircraft, industry and FAA personnel feel that such leeway is necessary to avoid excessive restriction on the development of the EFIS and their adaptation to customer needs.

There is, of course, no evidence at present that suggests the certification flight test procedures will be inadequate for such purposes. As such, there is no reason to delay the certification of the general aviation EFIS or, in any other way, hinder the introduction of these EFIS-equipped aircraft into actual operations.

On first inspection, then, it may appear that the conduct of certification flight tests would eliminate the need for any additional evaluations. Compelling reasons still exist, however, for the conduct of such exploratory research. The certification tests are, by their charter, very specific and narrow in their focus. They are designed to assess the adequacy (i.e., airworthiness) of the design of the aircraft and its component systems. They do not specifically attempt to identify problems that might arise due to incongruities that may develop among factors affecting task demands and pilot capabilities when the aircraft is put into actual use.

Further, such tests do not include provisions for diagnosing the specific display design problems or any other problems that may underlie major performance difficulties that are identified. The certification tests are also restricted to the determination of whether a new or retrofitted (with EFIS) aircraft is equivalent in safety to existing aircraft that have been certified under the same regulations. Thus, the tests are not designed to identify, quantify, and describe any benefits that accrue from the use of the EFIS, nor are they designed to investigate any pilot performance problems that may arise.

¹ Additional guidance will also be provided by documents devoted to hardware and software issues (e.g., software verification).

Finally, the change in the role of the pilot due to the introduction of the EFIS, sophisticated automated flight control systems, flight management systems, and other advanced avionics has prompted some knowledgeable personnel to question the adequacy of current flight test procedures for assessing the impact of such innovative equipment on the pilot performance (McLucas, Drinkwater, and Leaf, 1981).¹ In brief, these personnel feel that the shift in the pilot's role from direct involvement in the control of aircraft attitude and flight path to that of systems manager has changed requirements for measuring and evaluating pilot performance. As such, traditional flight tests may no longer be sufficient (though still necessary), because they tend to focus on the determination of flight characteristics and performance of the aircraft by flying the aircraft manually through standard flight maneuvers. Test pilots may perform flight evaluations that are based on the simulation (in the aircraft) of actual line operations, such as the "mini-airline" tests performed during the certification of some transport category aircraft. Many regular pilots, however, still believe that the test pilots, who have considerable expertise, may not experience or identify problems that may occur with the average (or less than average) pilot.²

FINAL COMMENTS. The intent of this section (Section C) has been to illustrate the need for information that would be obtained from exploratory evaluations of pilot performance in aircraft equipped with first generation EFIS. The display formats that will be produced by these systems need to be subjected to such empirical evaluations due to limitations in the information that has been available to support design decisions. Simply put, these formats represent a highly educated "best guess" of the designers. There is no way to confirm the impact of the displays on pilot performance other than through the use of empirical evaluations.

The preceding discussion is not meant to belittle the efforts of the numerous experienced professionals who are involved in the display design process. Their competence is not questioned. Rather, the concern that is expressed is derived from recognition that the design of innovative equipment such as the EFIS is extraordinarily complex, and the problems that may arise may be due to several sources. This concern is also derived from the observation that no one, as yet, has any experience building EFIS for production in general aviation aircraft. Such lack of experience is a decided change from past evolutions of general aviation avionics.³

¹While such questions have been raised in the context of testing air transport aircraft, they are equally valid for general aviation EFIS-equipped aircraft.

²All aircraft cannot and should not be designed to be flown by the "mediocre" or "marginal" pilot. It is important, however, to identify problems that may occur with such pilots in order to (1) specify type ratings that would prevent such pilots from operating aircraft that exceed their capabilities; or (2) develop training that would enhance their capabilities.

³Indeed, the shift from electromechanical to electronic (digital microprocessors and cathode ray tubes) technology has considerably changed the nature of requirements for design personnel--e.g., from mechanical engineers to computer programmers, systems analysts, and electrical engineers.

The preceding discussion of limitations in the use of existing research findings and display guidance is not meant to downgrade the contribution that these sources of information have made or have the potential to make. Indeed, such research is a prime source of ideas for innovative design concepts. As Roscoe and his colleagues have noted, the power and flexibility of the EFIS will enable promising design concepts--ones which have been shown to enhance pilot performance--finally to be implemented (Roscoe, Corl, and Jensen, 1981). Moreover, such information represents the best basis on which to make many design decisions. Perhaps most importantly, such research and guidance dramatically underscore the need to ask questions concerning the impact of different design variables on pilot performance. It also identifies which questions to ask as well as what type of answers should be obtained.

Finally, advocacy of the need for an exploratory evaluation should not be construed to be criticism of current FAA type certification or supplemental type certification procedures. As previously stated, the goals of the certification tests are, by their charter, more restrictive than the goals of the exploratory evaluations planned in the present project. Further, part of the purpose of the exploratory evaluations is to determine the need for modifying certification procedures to accommodate the shift in the pilot's role due to changes in general aviation operating requirements, aircraft, and avionics.

For example, the proposed exploratory evaluations may be used to define objective system performance standards that can be used to evaluate EFIS (similar to the standards specified in AC 90-45A for RNAV systems). Such standards may be of considerable value in future years if subsequent generations of EFIS present display formats that are quite different from those presented by the first generation systems, and if different versions of EFIS displays continue to proliferate as manufacturers compete for a highly varied market.

D. INFORMATION NEEDS IN EVALUATION DESIGN.

Sections A, B, and C of this chapter have dealt with information needs related to one goal of the exploratory evaluations--i.e., the identification of benefits and problems that may accrue from use of the EFIS. Another goal of the evaluations is to generate information that will aid in the development of general guidance for designing other similar evaluations that may be conducted in other research programs or in operational contexts. Such evaluations, for example, may be conducted as part of (1) other exploratory investigations of general aviation EFIS that address research needs not studied in the present project;¹ (2) flight checks designed to certify that individual pilots have acquired (or retained over time) the skills needed to fly EFIS-equipped aircraft; (3) research to develop and evaluate innovative design concepts for subsequent generations of EFIS displays; or (4) flight tests of EFIS-equipped aircraft.

As stated in Chapter I, the conceptual approach developed in the present project was, in part, designed to be used as a general model for the design of such evaluations. Certain questions arose, however, during the development of this approach that warrant additional, empirical study. These questions pertained to (1) the identification of flight situations that should be employed in the type

¹Such needs are identified in Section E of this chapter.

of evaluations of interest here, and (2) the determination of efficient procedures for measuring and assessing pilot performance in such evaluations.

IDENTIFICATION OF CRITICAL FLIGHT SITUATIONS. Corporate aircraft are employed in a wide variety of flight operations in diverse geographical locations throughout the country (and the world). These operations include VFR and IFR flight in the crowded airspace surrounding major airports and use of such airports, as well as VFR and IFR flight in isolated locations with no usable ground-based navigational aids or air traffic services, and use of remote airports with short, poorly marked runways. As a consequence, the pilots of these aircraft are required to perform a quite wide variety of tasks necessary for the safe and efficient operation of their aircraft. Such tasks include not only the normal demands imposed by these operations, but also additional demands arising from abnormal or unanticipated events.

In theory, tests of the pilot's ability to operate an aircraft should include the broad range of flight situations--and associated task demands--that the pilot may be expected to encounter in actual flight operations. In actuality, however, the total set or population of such flight situations is too large to be investigated thoroughly. Thus, any test must employ only a subset or sample of flight situations.

The size of the sample is constrained by the resources available for a given test. Such constraints are particularly acute in general aviation (in comparison with military and air carrier aviation) due to the small size and relatively limited economic base of the general aviation community--and to the relatively limited funds available for research on general aviation. In the present context, such constraints impose different requirements than might be experienced in the planning of similar evaluations involving large air transport or military aircraft. Given such constraints, it is necessary to select a sample for the exploratory evaluations that is small enough to be feasible to administer, yet sufficiently broad to yield the data needed to support general conclusions regarding the overall impact of the EFIS on pilot performance.

Two major considerations underly the selection of such a sample. First, the sample should contain flight situations that require the full range of demands that the pilot may realistically be expected to encounter in actual operations. However, some of the most common flight situations (e.g., flying straight and level while enroute) are not situations in which pilot errors are most likely to occur. Thus, as a second consideration, emphasis should be placed on the use of flight situations that are likely to create problems for pilots flying aircraft equipped with either conventional flight instruments or EFIS. By creating situations that are difficult for pilots with conventional flight instruments, it will be possible to determine if the EFIS will prevent pilot performance problems that are occurring at present or that may arise out of future operating requirements (as discussed in Section A). The identification of situations that are most likely to elicit errors from pilots flying EFIS-equipped aircraft will provide insight into the nature of incongruities between pilot capabilities and task demands that are created by the use of the EFIS.

It is possible, to a certain extent, to select a sample of such flight situations through the use of rational analyses (i.e., logical reasoning and expert judgments). Procedures for such analyses, which are discussed in greater detail in Chapter V, make use of general knowledge concerning typical pilot performance

in various flight situations. Such knowledge has been developed as a result of research concerned with the development of techniques for assessing pilot performance, as well as investigations of the use of conventional flight instruments and experimental flight displays. In addition, it reflects expertise gained through years of operational experience in the conduct of flight checks and information yielded by analysis of general aviation and other aviation accidents and incidents.

Such rational analyses, however well supported, still represent simply the best estimate of which situations should be employed in an evaluation. The validity of such estimates can be determined by assessing the actual performance of the pilots in the flight situations that are selected. Such knowledge can then be used to guide the selection of an efficient sample of flight situations for other evaluations.

The sample of flight situations that will be employed in the exploratory evaluations was selected using a rational procedure that is described in Chapter V. These procedures and the actual sample of situations that was selected provide general guidance that can be used to guide the selection of samples in other evaluations. However, statistical analyses of the data obtained in the exploratory evaluation can be used to identify situations which are actually the most useful for determining the benefits and problems that may accrue from use of the EFIS. Such information could then be used to refine guidance concerning the selection of flight situations. Given the premium placed on sampling efficiency in general aviation research, such refinement would be extremely beneficial.

DETERMINATION OF EFFICIENT MEASUREMENT AND ASSESSMENT PROCEDURES. As will be discussed in Chapter V, the performance of the pilot can be measured in numerous ways.¹ His performance, for instance, can be measured along a number of broad dimensions related to the control of the aircraft and operation of its subsystems. It may also be measured directly in terms of pilot behavior (e.g., rudder and control stick movements) or system performance (e.g., the deviation at a given point in time of the aircraft from its desired position in the flight path).

Numerous procedures exist for assessing the adequacy of pilot performance and such assessments can be made on several levels. Objective performance standards, for example, may be defined for any parameters that are measured--e.g., the maximum permissible deviation (4 miles) from centerline track during enroute RNAV navigation that is defined in AC 90-45A. These standards can be used to determine when an error has occurred and to assess the criticality of the error. Additionally, scoring strategies may be developed for summarizing the adequacy of the overall performance of a pilot--i.e., methods for summarizing the number and nature of the errors that an individual pilot makes--and for determining if

¹In the following discussion, "measuring" refers to the act of assigning numbers to describe and quantify pilot or aircraft performance--e.g., the aircraft was five miles to the side of the desired flight path. The "assessment" of performance refers to assigning a value to such data that indicates the degree to which performance that is measured is acceptable or unacceptable--e.g., the assignment of a letter grade to a pilot's overall performance during a flight check, and the establishment of a minimum grade for acceptable performance.

his overall performance is "acceptable" or "unacceptable." The various procedures for making such assessments are described in more detail in Chapter V.

The selection of procedures for measuring and assessing performance can be accomplished in three ways. First, such procedures may be determined using rational analyses. Such analyses employ general information that is available from research on pilot performance measurement and evaluation, investigations of conventional and experimental flight displays and expertise gained from experience in conduct of flight checks for operational purposes. This method of developing procedures is straightforward, and, due to the dependence on expert judgment, relatively quick and inexpensive. As a result, it is often employed in the construction of evaluations that are performed for operational purposes. This method is limited, however, due to the lack of conclusive information concerning the reliability, validity, and utility of the procedures that are developed with respect to the specific context in which they are used.

A second approach is to use strictly empirical techniques to develop measurement and assessment procedures. Such techniques have been developed as a result of research on pilot performance measurement (Vreuls and Wooldridge, 1977; Waag and Knoop, 1977), and their use has thus far been restricted to such research. Stated simply, the basic strategy employed in these techniques is to measure almost everything that can be measured while the pilot is performing required flight operations. Statistical analyses are then performed to determine which data are useful in the specific context in which the measures were obtained and develop performance standards that can be employed to assess performance. Such procedures suffer from certain technical limitations (discussed in Waag and Knoop, 1977) as well as serious practical constraints--e.g., they are simply too expensive and time consuming to use in general aviation research.

A third approach is to combine rational and empirical techniques for developing measurement and assessment procedures (Vreuls and Wooldridge, 1977). In such an approach, expert judgment (based on the information sources cited in the first approach) is used to identify a small set of procedures that appear to be useful for the specific type of evaluation that is of interest. A preliminary evaluation is then conducted. The procedures developed using rational analyses are employed to determine which measures should be taken, and how the data should be assessed and scored. The data collected are then analyzed statistically to determine their reliability, validity, and utility with respect to the specific objectives of the evaluation. Based on the results of these statistical analyses, a final set of procedures is developed for measuring and assessing performance. Use of this combined approach increases the efficiency (and lowers the cost) of the development process. It also provides specific information concerning the utility of procedures that were developed.

In the present project, the first approach, the strictly rational approach, has been used because of certain operational constraints that restrict the conduct of extensive preliminary testing (which is needed in the other two approaches).¹ However, the data collected during the exploratory evaluations

¹As described in Chapter V, some "feasibility" testing will be conducted prior to the actual conduct of the exploratory evaluation. Such testing, however, will be very informal and far less extensive than the preliminary tests described in the second and third approaches.

can be analyzed statistically to assess the utility of the procedures that were employed to guide measurement and assessment of performance. The knowledge gained from these statistical analyses, while not of direct use during the exploratory evaluations, will aid in developing guidance that can be used to design other evaluations.

E. CONCLUSIONS.

The following conclusions were drawn as a result of the analysis of information needs discussed in this chapter. The first set of conclusions pertains to general information needs that were identified. The second set pertains to the specific objectives of the exploratory evaluations that will be conducted in the second phase of this project. The third and final set of conclusions pertains to specific information needs that cannot be studied in this project due to resource constraints, but that should be addressed in other evaluations.

GENERAL CONCLUSIONS. The following general conclusions were drawn concerning the need for information about the potential impact of the general aviation EFIS.

1. Exploratory investigations are needed to evaluate the ability of pilots to operate general aviation aircraft equipped with first generation EFIS. The need for these investigations, as discussed in this chapter, is very real and critical.

2. The need for such evaluations exists in part because some of the formats of the displays that will be presented by the first generation of general aviation EFIS will be significantly different from those of conventional flight instruments. While some similarity exists among conventional flight instruments and EFIS displays, there are certain differences in display content and format, and in the way the displays are accessed. Such differences will modify the nature of a wide variety of psychomotor, procedural, and decisional task demands that are placed on pilots.

3. The need for such evaluations also exists because of certain general limitations in present knowledge concerning the potential impact on pilot performance of the general aviation EFIS and the uncertainties that such limitations create in the EFIS development process. While an abundance of general information is available to guide the design of new flight displays, the development process is extraordinarily complicated due to the large number of display design variables (and interactions among such variables) that must be considered. Such considerations require specific information, which unfortunately is limited at present, concerning the impact of the general aviation EFIS displays on the performance of general aviation pilots.

4. The exploratory evaluations need to assess the benefits that may accrue from use of the EFIS. Such benefits may be derived from the prevention of pilot performance problems that have been associated with use of conventional flight instruments and the enhancement of the ability of the pilot to perform functions associated with new operating requirements.

5. Such evaluations should also identify pilot performance problems that may arise when the EFIS are used in actual general aviation flight operations. Such problems may arise if new task demands associated with the use of EFIS are

not matched by the capabilities of the pilots who use these new systems. Whether such problems may be prevented by modifying the design of the first generation EFIS, the specification of new operating procedures, the development of improved pilot training, or other means is a subject for further evaluation. It is critically important, however, to identify and examine such problems now before they occur in actual flight operations.

6. The evaluations also need to assess the impact of changes in the pilot's role--due to the increased use of automated equipment and other advanced avionics--on his ability to operate aircraft equipped with either conventional flight instruments or EFIS. Such changes will influence not only the pilot's need for information from his flight instruments, but also the type of errors he is most likely to make and requirements for measuring and assessing pilot performance.

7. The evaluations should employ general aviation pilots whose skills are typical of the range of capabilities that may be found in corporate aircraft pilots. Such pilots should be used, rather than experienced test pilots, to enable factors affecting pilot capabilities as well as task demands to be examined.

8. The flight situations that are employed in the evaluations should reflect the full range of situations that corporate pilots may realistically encounter, but emphasis should be placed on those situations in which pilots are more likely to have problems. Some of the most common flight situations are not situations in which pilot errors are most likely to occur. While a broad sample of representative situations should be included to assure coverage of the wide variety of task demands that are placed on corporate pilots, the situations in which problems are likely to occur should be given extra emphasis.

OBJECTIVES FOR THE EXPLORATORY EVALUATION. The following conclusions pertain to the needs for information from the exploratory evaluations that will be conducted in the second phase of this project. As such, they describe the specific objectives of these evaluations. These objectives reflect, in part, several of the most critical needs for information that were identified during this, the first phase of the project. The capability of the exploratory evaluations to address other needs, many of which were equally critical, was limited by constraints on the resources that are potentially available for the second phase of the study.

1. The exploratory evaluations should compare the performance of pilots flying corporate aircraft (or aircraft simulators)¹ equipped with displays that are characteristic of the first generation EFIS and conventional electromechanical flight instruments that would normally be installed in such aircraft. Such a comparison will enable salient benefits and problems that may accrue from use of the EFIS to be identified and analyzed. Additionally, the conceptual approach that is developed for such a fundamental comparison will have sufficient generality to be useful as guidance for other related types of evaluations.

¹As will be discussed in Chapter V, there are several advantages to using a high fidelity aircraft simulator for the planned exploratory evaluation.

2. The evaluations also should assess the impact on pilot performance (particularly on use of the EFIS) of automated flight control systems. The evaluations should, of course, assess the performance of pilots while they manually fly the aircraft. However, given the shift of the pilot's role away from direct involvement in the flight control loop, the evaluations should also assess the use of automated flight control systems. Such systems should represent major generic types of equipment that are commonly found in corporate aircraft. One system, for example, might represent an autopilot that the pilot simply sets to hold a desired horizontal track (e.g., coupled to the directional gyro, radio navigation, or RNAV systems). The other system, representing more sophisticated equipment, might be part of an advanced flight management system.

3. The evaluations should employ an aircraft that is normally flown by only a single pilot. Single pilot operations are quite common in general aviation. They constitute a unique influence on the use of general aviation EFIS. Given that most past research on civil aviation EFIS has been conducted in the context of at least two-man cockpit crews, it is essential that use of the general aviation EFIS be evaluated in an aircraft that is normally flown by only one pilot.

4. The data collected during the evaluations should be analyzed to determine which flight situations had the greatest utility with respect to determining benefits and problems that may accrue from use of the EFIS and which measures of pilot performance and procedures for assessing such performance are most useful for making such determinations. It is possible, using available information that is discussed in Section D, to identify candidate flight situations and measures that have the most potential value for use in the planned evaluation. Indeed, such situations and measures are identified in Chapter IV. However, the results of the exploratory evaluations will aid in refining guidance for the conduct of subsequent evaluations by providing empirical confirmation of the procedures used to collect data.

OTHER NEEDS THAT SHOULD BE ADDRESSED. The following conclusions summarize other highly critical information needs that should be addressed. Since some of these needs partially overlap one another, it would be beneficial to address them as part of an integrated research program. Such research would investigate the impact on pilot performance of EFIS as well as other advanced cockpit technology that has been or soon will be introduced into general aviation aircraft. The process of designing many of the studies that would be conducted as part of such a research program would be facilitated through the use of guidance that was developed as part of the present project.

1. Benefits and problems need to be identified that may be associated with the use of different versions of the EFIS that will be installed in general aviation aircraft. The exploratory evaluation in the second phase of this project will only address one "representative" version of the first generation of general aviation EFIS. As discussed in Appendix A, several versions of the EFIS probably will be produced. Furthermore, subsequent generations of the EFIS may generate displays with formats that are quite different from those presented by the first generation. All such displays should be evaluated to assure they do not create new and critical pilot performance problems.

2. A study should be made of the impact on pilot performance of various combinations of different versions of the EFIS, and different versions of automated flight control systems, autothrottles, flight management systems, and other advanced avionics systems. The exploratory evaluations that were planned in this project address only three types of flight control systems. In actuality, the EFIS will be installed with a variety of other equipment. For example, some versions of the EFIS will be made as part of an advanced fully-integrated flight management system. Other versions will be sold separately and may be installed in cockpits with a variety of older, more conventional equipment. The impact on pilot performance of different combinations of equipment should be assessed systematically. While it should be recognized that constraints inherent in general aviation research prevent a thoroughly comprehensive assessment, such constraints should not prevent the identification and investigation of at least some of the more global issues.

3. An assessment should be made of the need for different types of EFIS display formats and the potential problems that may arise when pilots transition across aircraft equipped with different versions of the EFIS--or with EFIS and conventional flight instruments. Different formats for similar displays may be required for different aircraft, flight operations, and even pilots. Pilot preferences for various formats will surely differ (as they do now). However, most general aviation pilots fly several aircraft in their careers, many of which are flown alternately during the same time period. The proliferation of EFIS display formats across models may create problems for pilots when they transition or switch from one EFIS-equipped aircraft to another equipped with a different model of EFIS. Further, such pilots may also experience problems when they transition or switch from an EFIS-equipped aircraft to one with conventional instruments.¹

4. Research is needed to assess the impact of EFIS and other advanced systems on the performance of two-man aircrews. Many top-of-the-line general aviation aircraft (e.g., most business jets) are normally flown by two pilots. The use of EFIS and other advanced systems will significantly change the resources available to these pilots. Research is needed to determine how such changes influence crew interactions as well as the performance of each pilot in the crew.

5. An investigation is needed that will examine the impact of EFIS and other advanced cockpit technology on the training of general aviation pilots. Given the fundamental changes that are occurring in the pilot's role due to the use of advanced cockpit technology, it would be beneficial to reassess pilot training requirements. Additionally, use of the EFIS may necessitate changes in the FAA's airman certification and rating structure--e.g., change requirements for the instrument rating.

¹The exploratory evaluation performed in the present project will assess problems associated with transitioning from aircraft with conventional instruments to EFIS-equipped aircraft since the pilots who will be employed in the study will have experience with aircraft with conventional instruments.

6. Research is needed that will assess the impact on the retention of flight skills of the long term use of EFIS and other advanced cockpit technology that will be installed in general aviation aircraft. As has been discovered in air carrier and military aviation, manual flight skills not frequently employed by pilots due to the use of automated equipment are often not retained. The non-retention of such skills can cause problems when the automated equipment fails or is not used for other reasons.

7. Research is also needed that will assess the impact of extreme fatigue and other stressful conditions on use of the EFIS and other advanced cockpit technology. Many accidents occur when the capability of the pilot is temporarily lowered by stressful conditions or other problems (e.g., alcohol). Knowledge of the effects of such conditions will aid in convincing pilots not to fly when they experience such conditions and redesigning the man-machine interface to prevent some of the problems caused by these temporary conditions.

III. DETERMINATION OF THE GENERAL DESIGN OF THE EVALUATION

The analyses that were discussed in the preceding chapter defined the information needed from the proposed exploratory evaluations. The evaluation design that is described in this chapter defines the general procedures that will be used to obtain such information. On the most fundamental level, these procedures specify how pilots will be tested during the evaluations. That is, they define the general nature of the individual performance demonstrations or checks that will be used to evaluate the ability of pilots to operate aircraft equipped with the different flight instrument and flight control systems.

On a more abstract level, these procedures also structure the administration of the performance checks--e.g., they determine how many checks will be given to each pilot, when each pilot is to be given a certain check, and which flight instrument and flight control systems will be employed by the pilot in each check. Such structuring is needed to assure that data are collected systematically under conditions that will enable the use of appropriate statistical analyses to aid in interpreting the data and that will sustain, rather than confound, conclusions that are drawn concerning factors influencing pilot performance.

The first section of this chapter (Section A) discusses the major considerations that governed the design of proficiency checks for the exploratory evaluations. It also contains a description of the basic nature of the proficiency checks that will be used in the evaluation. As such, Section A provides a general foundation for the discussion in Chapter IV of specific activities involved in the design of these proficiency checks--e.g., the steps in determining what should be measured, how it should be measured, and how performance should be assessed and analyzed.

Section B focuses on considerations related to the systematic structuring of the proficiency checks. Such considerations are derived from more general principles that have been developed to structure the design of scientific experiments and direct the application of statistical analyses to data that are collected. Extensive research has been devoted to the development of such principles and of associated statistical analyses, particularly within the behavioral sciences. Extensive guidance is readily available concerning such general principles of experimental design (e.g., Cochran and Cox, 1957; Lee, 1975; Meyers, 1966; Winer, 1962), and the application of these principles to basic and applied studies of human performance (e.g., Kirk, 1968; Parsons, 1972; Simon, 1977). Thus, since sufficient guidance exists in such sources, Section B presents the specific experimental design that was developed for the proposed exploratory evaluation without exploring all aspects of experimental design rationale, and briefly reviews some of the major considerations underlying the selection of that design.

A. DESIGN OF PROFICIENCY CHECKS.

The development of effective and efficient proficiency checks is of obvious importance to flight instructors and other personnel who are tasked with certifying or assessing the proficiency of pilots, as well as to researchers who want to assess the influence of different factors on pilot performance. For

these reasons, a substantial amount of research has been devoted to the development of techniques for measuring and assessing pilot performance.¹ Additionally, considerable effort has been devoted to the development of flight tests for use in pilot training programs, and for FAA certification and rating checks.

Proficiency checks that have been developed as a result of these past efforts may be divided into two basic categories. These are (1) "maneuver-oriented," and (2) "operations-oriented" proficiency checks. Such a dichotomy is an oversimplification, since various types of checks may be differentiated along multiple dimensions, and many checks that are conducted have characteristics from both categories. Use of these categories, however, simplifies discussion of major differences among proficiency checks. Further, as will be discussed below, these two categories roughly correspond to major operational distinctions made by the civil aviation pilot community.

MANEUVER-ORIENTED PROFICIENCY CHECKS. Maneuver-oriented proficiency checks are so named because they focus on the use of flight maneuvers as basic units for observing, measuring, and assessing pilot performance. While the scope of what may be defined as a maneuver varies greatly, most maneuver-oriented checks share several common characteristics. Such characteristics include (1) each of the maneuvers has a discrete beginning and end that serve as boundaries for assessments that are made of pilot performance during execution of the maneuver; (2) assessments that are made of pilot performance are independent of assessments made during other maneuvers; (3) the pilot's ability to perform a maneuver is assessed with respect to criteria that are determined by standard or commonly accepted operating procedures (although such criteria vary greatly in the extent to which they are objective and explicitly stated); (4) the pilot starts each maneuver from a neutral or appropriate point--i.e., consequences of errors made in one maneuver are usually corrected and not carried into the next maneuver; and (5) the pilot is told which maneuvers to perform and how he should perform the maneuvers (e.g., fly it manually, use the autopilot).

Flight checks for FAA certificates and ratings tend to be predominantly, but not completely, maneuver-oriented. Such predominance is exemplified by guidance for the conduct of maneuver-oriented checks in FAA flight test guides for various rating and certificates, such as the commercial pilot certificate (Advisory Circular 61-55A) and the instrument rating (Advisory Circular 61-56A). Maneuver-oriented checks are also commonly employed in investigations of factors influencing pilot performance (although much of this research often employs only one or two selected maneuvers).

Maneuver-oriented proficiency checks are frequently used in operational and research situations because they constitute an efficient method of assessing a wide range of psychomotor, procedural, and judgmental flight skills that are believed to be necessary for safe and efficient flight. Such efficiency is derived from the ability to select maneuvers for a given check that represent a broad range of task demands that would normally be experienced by the pilot if he flew several different routine flights. For example, several different instrument approaches may be flown during one check, but a pilot would normally experience only one (if any) approach per leg of a regular flight operation. Maneuvers may also be selected on the basis of specific test requirements rather

¹Such research is reviewed in Forrest (1970) and Roscoe and Childs (1980).

than on the basis of operating requirements imposed by the need to complete a given flight operation. Additionally, most regular flight operations contain substantial amounts of "dead time" in which the aircraft is flown in a steady-state condition and the pilot has relatively little to do, such as in enroute (cruise) portions of a flight where the aircraft is flown straight and level. Such "dead time" is eliminated in maneuver-oriented checks.

As a consequence of the frequent use of maneuver-oriented proficiency checks in operational situations and in the study of factors influencing pilot performance, most research on techniques for measuring and assessing pilot performance has focused on this type of check. While most of the relevant aspects of this research are reviewed in Chapter IV, one general consideration arising from such research needs to be discussed here since it relates to the overall nature of the proficiency check. The point to be raised concerns the need for objectivity in this type of test.

As previously stated, most flight checks conducted in operational situations are maneuver-oriented. The procedures employed in such checks are commonly characterized by a high degree of subjectivity. That is, the person examining pilot performance often must use his own expert, but still subjective, judgment to (1) select maneuvers to be tested; (2) assess the adequacy of the pilot's ability to perform a given maneuver; (3) determine what aspect, if any, of the pilot's performance should be recorded and how it should be described; and (4) determine if the pilot passes or fails the overall check. In some cases, FAA flight test guides for certain certificates and ratings do provide some objective guidelines for identifying maneuvers to be tested and determining the acceptability of performance on a maneuver. Many critical decisions, however, are left to the discretion of the examiner.

Such procedures are usually adequate for the operational purposes for which these flight checks are conducted. However, the data requirements imposed by the design of an exploratory evaluation of EFIS necessitates the use of more objective procedures. As will be discussed in detail in Chapter IV, such procedures need to state explicitly (1) which maneuvers are to be tested; (2) which dimensions of pilot or aircraft performance should be measured; (3) the criteria that are to be used to determine if a pilot makes an error while performing a maneuver; (4) what performance data should be recorded; (5) the method that should be used to summarize quantitatively the pilot's overall performance; and (6) the criteria for determining if the pilot passed the check.

The use of objective procedures standardizes the conduct of flight checks across examiners, and across pilots assessed by the same examiner. Research has shown that such standardization is necessary to assure that the flight checks provide reliable indications of pilot performance (Caro, 1968). That is, well defined standard procedures are required to assure that the performance of all the pilots who are evaluated is measured and assessed in the same way, independent of who performs the evaluations. If this condition is not met, differences in the way pilot performance is assessed will confound or, perhaps, even bias the analysis of differences in pilot performance due to the use of different types of flight instruments and other equipment. Further, use of objective procedures aids in assuring that sufficient information will be available to diagnose the specific nature of any performance problems that an individual pilot may have, and to identify trends in such problems across pilots.

In conclusion, several characteristics of the maneuver-oriented check procedures make them well-suited for use in the exploratory evaluations. Such procedures provide an extremely efficient method of exploring a broad sample of normal flight situations, as well as operations under abnormal, unexpected, or otherwise difficult conditions.¹ Further, when appropriate objective procedures are employed, this approach (as contrasted with operations-oriented or subjective maneuver-oriented checks) also provides the most reliable method of acquiring detailed pilot performance data. The availability of such data, in turn, facilitates the diagnosis of pilot performance problems by enabling appropriate statistical analyses to be employed to aid in detecting and interpreting major performance trends.

OPERATIONS-ORIENTED PROFICIENCY FLIGHT CHECKS. Maneuver-oriented proficiency checks can provide much of the data that is necessary to address the information needs that were identified in Chapter II. This type of check, however, suffers from certain inherent limitations that prevent the resultant data from being sufficient to address all such needs. For example, some of the abnormal or otherwise unexpected conditions to which the pilot responds develop slowly over many different segments (maneuvers) of a given flight (mission). The pilot, if he is aware of the condition, slowly accumulates information about the condition as it unfolds in real time. Using his aeronautical knowledge (and his flight instruments), the pilot develops, and, as time goes on, revises hypotheses concerning what may be happening. His response, and the timing of his actions, then, are often based on not only immediate conditions, but also on his hypotheses concerning past and possible future conditions, and his plans to avoid any complicating events that may occur. Further, his total response to a problem may also slowly evolve over several segments of the flight operation.

As discussed in the preceding subsection, it is possible to assess the reaction of the pilot to abnormal and other unexpected situations using a maneuver-oriented proficiency check. By definition, however, such checks cannot be used to assess the pilot's response to multiple, often complex, conditions that evolve slowly over the entire flight operation. Thus, the capability of the pilot to meet such demands must be assessed using a check that encompasses and focuses on the total flight operation.

Some versions of such operations-oriented checks have long been used in civil aviation. "Line checks" or other similar checks conducted in aircraft during actual flight operations have been performed through the history of aviation. During such checks, the proficiency of a pilot is assessed, formally or informally, by a senior pilot, instructor, examiner, or other experienced pilot while the pilot performs an actual flight operation from start to finish. Such an operation may be part of a flight operation conducted for other purposes (e.g., a "revenue-producing" flight), or it may be conducted strictly for the purpose of assessing the pilot.

¹Maneuver-oriented checks may, of course, be performed in aircraft or simulators. The requirement to simulate situations in which performance problems are likely to occur, however, increases the need for control over the testing situation--as well as increasing the risk of accidents in aircraft. As such, it is recommended that a high fidelity simulator with a motion base be employed in the exploratory evaluation. Considerations in the selection of a test vehicle are discussed in detail in Chapter V.

These line checks, however, are limited in the sense that only those maneuvers required by the selected flight operation are performed. Additionally, the selection of conditions under which the flight is performed is also limited. In some cases, the examiner may simulate some unexpected conditions if they are not too dangerous or impractical. For the most part, however, the conduct of such checks in aircraft does not permit a broad sampling of maneuvers and conditions and, thus, may omit some maneuver or performance requirements that are considered unique and critical for other situations.

Some of the problems constraining the conduct of operations-oriented flight checks in aircraft may be circumvented if such checks are conducted in aircraft simulators. Flight operations may be selected, for example, that impose demands that are specifically related to information needs and test requirements. Further, abnormal conditions can be employed that would be difficult, dangerous, expensive, or otherwise impractical to perform in an aircraft.¹

Unfortunately, early aircraft simulators had certain limitations that constrained their use as tools for assessing pilot proficiency as well as for training. For example, these early devices did not faithfully simulate the handling qualities of associated aircraft. Further, they did not have systems capable of simulating the motion cues experienced by pilots during actual flight, or providing the visual cues normally available to the pilot from the environment outside the aircraft. In recent years, however, advances in simulation technology have resulted in the development of high fidelity aircraft simulators with sophisticated motion and visual systems that have much more extensive training and proficiency assessment capabilities.

To take advantage of this advanced technology, many air carrier and military training organizations are currently exploring the use of high fidelity aircraft simulators for the conduct of "line-oriented flight training" (LOFT) (Lauber and Foushee, 1981a; 1981b). Such training is characterized by (1) the use of the full complement of airmen who would be in the cockpit² on a normal flight; (2) the structuring of the training scenario so that it simulates the conduct of an entire flight operation (mission) that normally might be flown by the pilots; (3) the simulation of routine preflight events (e.g., weather briefs, flight planning, preflight checks); (4) the simulation of communications from other personnel--e.g., flight attendants and air traffic controllers;³ (5) requirements for the performance of all of the functions that the pilots would normally perform on such a flight; (6) the conduct of the training in "real-time"--i.e., events are timed to occur exactly as they would in an actual flight; (7) the introduction of unexpected, but realistic conditions that require the pilots to reconsider and revise their planned operations; (8) constraints on the examiners that keep them from correcting errors that the pilots have made, or of otherwise

¹Considerations related to the use of simulators in pilot proficiency assessment are discussed in Chapter V.

²In maneuver-oriented training, pilots (aircraft commanders or captains) are often trained with other pilots, and copilots (First Officers) are trained with other copilots.

³Such simulation may include the joint use of two or more simulators--e.g., air traffic control and aircraft simulators.

interfering with their actions; (9) given the lack of such corrections, the simulation of the consequences of such errors as additional conditions for subsequent portions of the flight; and in some cases (10) the simulation of critical consequences--e.g., loss of control of the aircraft or controlled flight into the ground.¹

LOFT is well accepted within some training organizations because their pilots and instructors believe that it provides a way to train higher-order flight skills that cannot be addressed adequately using maneuver-oriented procedures. Such skills are related to the management of the resources available to the pilot--including the use of flight instruments, autopilot, and other cockpit systems. LOFT is also believed to be particularly well-suited to training decision-making and other higher-order cognitive skills, as well as interpersonal skills necessary for crew coordination.

In almost all training programs, the use of LOFT is intended to supplement, rather than replace, maneuver-oriented instruction. Maneuver-oriented procedures still provide the most efficient method for training many flight skills--particularly psychomotor and procedural skills. Further, with the exception of one or two organizations, LOFT is used strictly for instructional purposes. Many pilots are reluctant to use LOFT-type procedures--more generally referred to as "line-oriented" simulation (LOS)²--for formal proficiency checks. They believe that it would be too easy for an examiner to create situations in the simulator that would be too difficult for even the best pilot to handle and that have an extraordinarily low probability of occurring in the aircraft. Such situations would constitute unfair tests of pilot capabilities. Such criticism may be countered, however, through the use of well-considered procedures for constructing LOS scenarios (Lauber and Foushee, 1981a). However, until more is known about the use of LOS for assessing pilot proficiency, most formal simulator-based proficiency checks will remain maneuver oriented.

LOS has also been used in informal and formal research. Some air carriers, for example, have found that use of LOS enables them to assess the adequacy of operating procedures that they specify for use in various normal and emergency flight situations. LOS is useful for such investigations because it allows the ultimate consequences of pilot actions--i.e., accidents or safe flight--to be evaluated in the safety of simulators.

On a more formal basis, NASA researchers have used LOS procedures to structure a study of the performance of air carrier aircrews in selected low and high

¹As with maneuver-oriented procedures, the characteristics of line-oriented flight training vary considerably across organizations. Discussion of such variation may be found in Lauber and Foushee (1981a; 1981b).

²LOS is a term often used to refer to the simulation of complete flight operations (missions). As such, it is synonymous with "full mission simulation," another term frequently used to refer to such simulations (Del Balzo, 1980). LOFT is simply LOS used for training purposes. The broader term--"operation-oriented" proficiency check--is used in this report to refer to the use of LOS for checks in simulators, as well as to similar checks in aircraft--e.g., line checks.

workload conditions (Smith, 1979; Schofield and Giffen, 1981). Additionally, modified LOS procedures have been employed to assess the reaction of general aviation pilots to critical inflight events (Rockwell and Giffen, 1981). This research represents an attempt to develop techniques for assessing pilot "judgment." Researchers at NASA who have used LOS procedures feel that they can be employed in a wide range of research (Lauber and Foushee, 1981a). Indeed, they feel such procedures may be of considerable use in the assessment of the use of advanced avionics, such as the EFIS and advanced automated flight control systems. The use of LOS, for example, enables the assessment of how these systems affect resource management, decisional, and other higher cognitive skills. Assessment of such skills is of particular interest, given the shift of pilot's role away from direct involvement in control of the aircraft and toward a greater involvement with the more cerebral functions associated with system management.

In conclusion, evaluations of the ability of pilots to operate aircraft equipped with EFIS and other advanced avionics should include the use of operations-oriented procedures for assessing pilot proficiency. Such procedures can be employed in aircraft and simulators. However, as will be discussed in Chapter V, certain advantages associated with the use of high fidelity simulators make it beneficial to use such devices for the conduct of operations-oriented (as well as maneuver-oriented) proficiency checks that will be part of the proposed exploratory evaluations.

B. DESIGN OF THE EVALUATION.

Given the decision to use maneuver- and operations-oriented check procedures, it was necessary to determine how to structure the administration of these checks. Basically, the exploratory evaluations are being performed to assess and compare the performance of pilots flying aircraft equipped with (a) either EFIS or conventional flight instruments; and (b) either a manual flight control system, a relatively "basic" autopilot, or an advanced, integrated flight control system. Thus, the administration of the proficiency checks must be structured to enable these comparisons to be made, and to facilitate the analysis and interpretation of the data that are collected.

There are several approaches that can be employed to make such comparisons, and several advantages and disadvantages associated with each approach. The approach that was selected is illustrated in Table 2. Such a design is called a "completely randomized, two-factor" design (Meyers, 1966). Simply stated, six groups of pilots will be employed in the evaluation (procedures for determining the number of pilots in each group are discussed in Chapter VI). As shown in Table 2, each group will be tested in only one of the six possible evaluation situations--e.g., one group will be tested using the EFIS and a manual control system, another will be tested using EFIS and a basic autopilot, and so on. Each group of pilots will be given a maneuver-oriented check (or actually, as discussed in Chapter IV, a set of such checks) and then an operations-oriented check.

TABLE 2.--DESIGN OF THE PROPOSED EXPLORATORY EVALUATION

EFIS			CONVENTIONAL FLIGHT INSTRUMENTS		
<u>Manual Control</u>	<u>Basic Autopilot</u>	<u>Advanced Autopilot</u>	<u>Manual Control</u>	<u>Basic Autopilot</u>	<u>Advanced Autopilot</u>
Group 1	Group 2	Group 3	Group 4	Group 5	Group 6

The main reason this design was selected was to prevent the pilots from becoming too familiar with the proficiency checks. Many of the maneuvers that will be employed in the maneuver-oriented checks will have conditions that include equipment malfunctions or other unexpected events. Additionally, the operations-oriented scenario will also include unexpected conditions. If a pilot is repeatedly exposed to such conditions, he would begin to expect and prepare for their occurrence.

The use of separate groups of pilots in each experimental situation requires more pilots than designs in which pilots are given repeated checks in different evaluation situations. However, the use of "unexpected" conditions in which pilot performance problems are likely to occur is crucial to the objectives of the planned evaluations.

In conclusion, the use of a completely randomized, two-factor design is recommended for the exploratory evaluations. While such a design is simple and relatively inefficient, it best meets the objectives of the exploratory evaluations. In subsequent evaluations, such as those discussed in Section E of Chapter I, more elaborate and efficient designs may and probably should be employed to obtain more specific information concerning use of the EFIS and automated flight control systems.

C. CONCLUSIONS.

This chapter discusses the general nature of the proficiency checks that will be used in the exploratory evaluations to assess pilot performance, as well as how these checks will be administered. Major conclusions concerning the nature of and procedures for administering these checks are summarized below.

1. Maneuver-oriented check procedures should be one of the methods employed in the exploratory evaluations to obtain pilot performance data. Such procedures provide the most efficient method of exploring a wide range of normal and abnormal flight situations. Sampling such a range of situations is necessary to accomplish the objectives of the exploratory evaluations.

2. Objective procedures should be used to structure administration of the maneuver-oriented proficiency checks conducted during the exploratory evaluations. Most flight checks that are conducted in operational situations tend, to a certain extent, to be nonstandardized and subjectively scored. Requirements for data in the exploratory evaluations, however, necessitate the use of formally defined, objective procedures. Such procedures are described in Chapter IV.

3. Operations-oriented check procedures should also be employed in the exploratory evaluations to obtain pilot performance data. Such procedures, particularly when they include "critical events" to increase the demands made on the pilot, appear to facilitate the assessment of certain high-order pilot skills. While such procedures can be employed in both aircraft and simulators, certain benefits that accrue from use of unique characteristics of the simulator make it advantageous to use such devices for these, as well as maneuver-oriented checks. (Considerations related to the selection of a test vehicle are discussed in Chapter V.)

4. A completely randomized, two-factor design should be employed in the evaluations. In such a design, six groups of pilots would be employed in the evaluations. Each group would be tested in only one of six possible evaluation situations. Such a design is needed to assure that pilots who serve as subjects do not become "test-wise."

IV. DETERMINATION OF REQUIREMENTS FOR PERFORMANCE MEASUREMENT AND DATA ANALYSIS

As described in Chapter III, data will be collected during the exploratory evaluations using both (1) maneuver-oriented and (2) operations-oriented proficiency checks. This chapter contains a description of the procedures that were developed during the present project for conducting these checks and analyzing data that are collected. Further, it contains a discussion of the major considerations that governed the development of those procedures.¹ The discussion of such considerations is intended to provide general guidance for the design of checks for other similar evaluations.

A. DEVELOPMENT OF MANEUVER-ORIENTED PROFICIENCY CHECKS.

The diagram in Figure 3 delineates five general steps in the development of maneuver-oriented evaluations and the major activities within each of these steps. The five subsections that follow will be devoted to the steps shown in Figure 3--i.e., (1) maneuver analysis, (2) measure development, (3) scoring, (4) data collection, and (5) data analysis. Within each subsection, the major activities in each step will be discussed in terms of the decisions that need to be made, various alternatives that exist for such decisions, and considerations that governed the selection of alternatives for the exploratory evaluation. The final part of each subsection contains a description of aspects of the conceptual approach for the exploratory evaluations that are related to the activities discussed in that subsection.

MANEUVER ANALYSIS. As discussed in Chapter III, maneuver-oriented check procedures are employed frequently in evaluations of pilot performance because they provide an efficient way to sample the wide range of situations that the pilot may encounter in actual flight operations. The first step, then, in the development of such checks involves the selection of the sample of maneuvers to be performed in the check, as well as the conditions under which they are to be performed. Additionally, this step involves the segmentation of the selected maneuvers into smaller, more easily managed units to aid in structuring the collection of performance data. Such segments also facilitate the analysis of performance within a maneuver.

Select Maneuvers. With respect to the planned exploratory evaluation, the criteria for selection of the maneuvers, as discussed in Chapter III, were: (1) provision of comprehensive coverage of skills needed by corporate pilots; and (2) selection of maneuvers and conditions likely to create or reveal pilot performance problems in the use of displays and information. Thus, general criteria for maneuver selection were based upon the analysis of the total scope of flight skills required for operation of corporate aircraft. In part, these skills were identified from a review of FAA and industry

¹As stated in Chapter III, it is recommended that both the maneuver- and operations-oriented checks be carried out in simulators during the exploratory evaluations. Thus, the procedures that are presented here are optimized for such devices. In some cases, however, the use of appropriately equipped aircraft is possible. Requirements for simulators and aircraft are discussed in Chapter V.

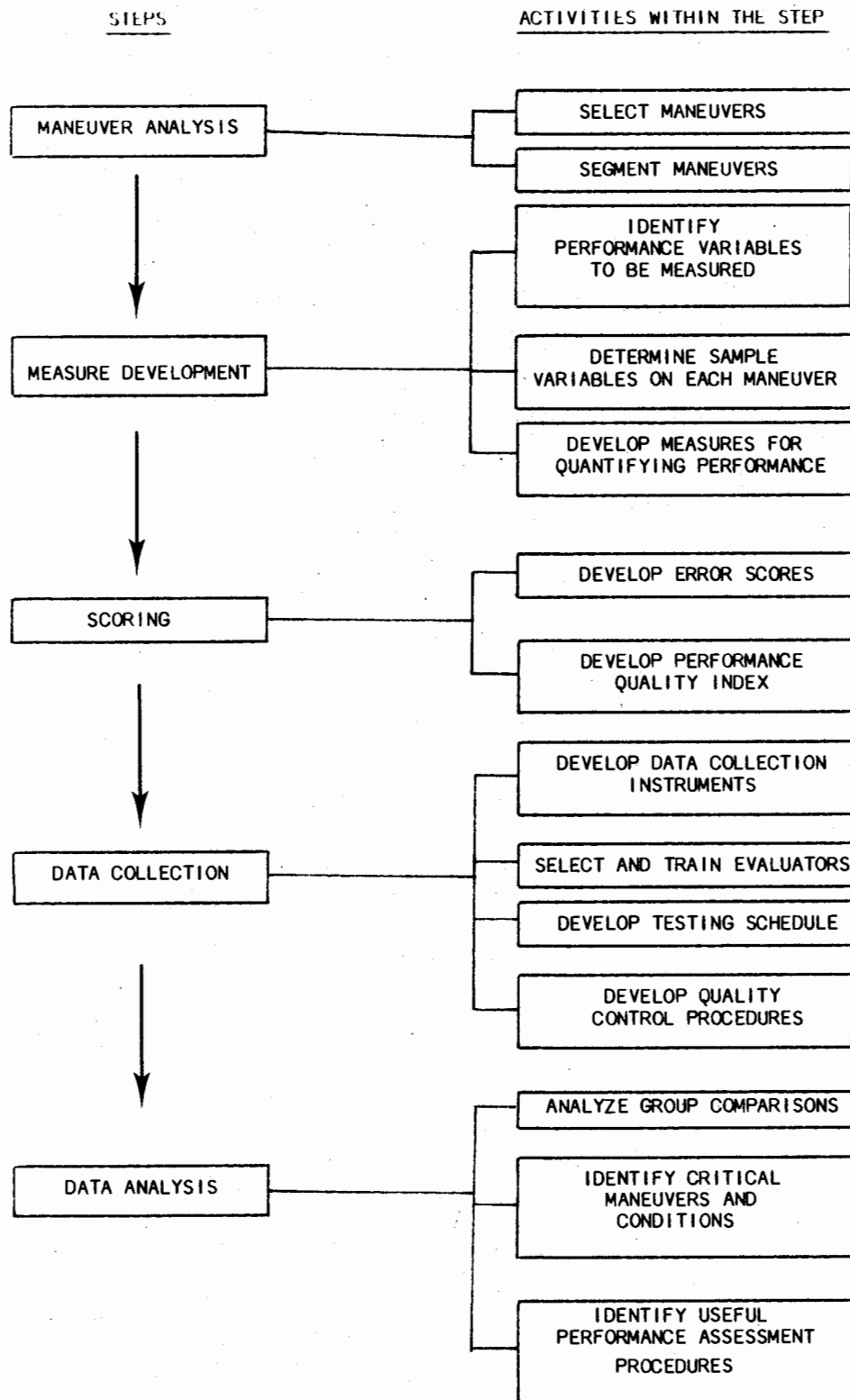


FIGURE 3.--MAJOR STEPS AND COMPONENT ACTIVITIES INVOLVED IN PLANNING MANEUVER-ORIENTED EVALUATIONS.

material describing training and performance requirements for pilots who are most likely to fly corporate aircraft--e.g., those who hold commercial and/or airline transport pilot certificates with multiengine and instrument ratings as well as aircraft type ratings for common corporate airplanes. Material reviewed included:

(1) requirements for relevant pilot certificates and ratings as defined in FAR Part 61;

(2) FAA flight test guides for certificates and ratings--e.g., FAA Advisory Circulars AC 61-55A and 61-56A;

(3) training program documents--e.g., The Instrument Flight Manual (Kershner, 1977); The Instrument Flying Handbook (FAA, 1968);¹

(4) analyses of flight tasks that are performed during the operation of general aviation aircraft--e.g., Bolz and Eisele (1979); Eggspuehler and Weislogel, (1968); Hinton and Shaughnessy (1978); Hudock and Hudock (1970); Weislogel and Miller (1970);

(5) research on factors influencing performance of general aviation pilots in which comprehensive maneuver-oriented proficiency checks were used to collect data (e.g., Shelnutt, Spears, and Prophet, 1981; Childs, Prophet, and Spears, 1981; Holmes and Childs, 1982); and

(6) research on development of objective, maneuver-oriented proficiency checks (e.g., Greer, Smith, and Hatfield, 1962; Forrest, 1970; Roscoe and Childs, 1980).

In addition to the review of the above sources, an analysis was performed of missions considered to be representative of those routinely flown by corporate pilots. Part of this analysis was treated in a report written earlier in the present project, entitled General Aviation Pilot Task and Information Needs. (This earlier report is presented in Appendix D of this report.) This analysis provided a comprehensive framework for assessing total skill requirements.

To identify maneuvers and conditions that are likely to create pilot performance problems, an extensive review was made of literature which describes such problems. This literature included:

(1) National Transportation Safety Board, special studies and summaries of general aviation accidents--e.g., NTSB (1972a; 1972b; 1972c; 1978; 1979a; 1979b);

(2) other analyses of general aviation accidents--e.g., Editors of Flying Magazine (1977); Schiff (1980); Forsyth and Shaughnessy (1978); Connor and Hamilton (1979); McCourt and Hewin (1979); Jensen and Benel (1977); Bolz and Eisele (1979);

¹ In addition to the general documents cited above, material was reviewed from relevant Embry-Riddle Aeronautical University training courses (e.g., commercial pilot, airline transport pilot, basic instruments, advanced instruments, multiengine, and Cessna Citation type rating courses).

(3) reviews of air transport accidents attributed to pilot performance problems considered to be similar to the pilot performance problems that occur in general aviation--e.g., Kowalsky, Masters, Stone, Babcock, and Rypka (1974); Trammel (1980);

(4) reviews and analyses of general aviation and relevant air carrier aviation incidents--e.g., Bergeron (1980b); Loomis and Porter (1981); NASA (1977; 1978); and

(5) research on factors influencing pilot performance which has attempted to create flight situations in which pilot performance problems are likely to occur, such as research on experimental flight displays and automated flight control systems.¹

Two sets of maneuvers and associated conditions were selected for the planned exploratory evaluations. The first set, which is presented in Table 3, contains maneuvers that will be evaluated under favorable conditions (e.g., good daylight visibility, no wind or turbulence, little or no traffic, straightforward and timely air traffic control instruction, and all aircraft equipment operating normally). Maneuvers in this set range from basic (e.g., standard rate turns, climbs, steep turns) to more advanced flight tasks (e.g., ILS, NDB, and RNAV approaches). In part, the basic maneuvers can be viewed as components of more advanced maneuvers which, in turn, may be viewed as components of many general aviation flight operations.

While the basic maneuvers will be assessed, for the most part, as portions of the advanced maneuvers, they also are included as separate check items to obtain baseline data on the capability of pilots to control aircraft attitude and flight path--i.e., to assess what might be termed as "primary" flight skills.² Thus, the basic maneuvers are employed to assess fundamental differences in baseline performance among the evaluation groups (i.e., the six groups of pilots, as shown in Table 2, flying aircraft equipped with the different flight instrument and control systems that are of interest).³ Additionally, in some cases, data describing performance on the basic maneuvers also can be compared with data obtained for related components of more advanced maneuvers--e.g., data can be compared for standard rate turns performed in isolation with data for such turns when they are part of certain holding patterns. Such comparisons will be useful for diagnosing pilot performance problems on the advanced maneuvers, as well as for identifying critical maneuvers and conditions for use in future evaluations.

¹Examples of such research can be found in Appendices C and E.

²Such skills include setting up the autopilot to perform the basic maneuver as well as manual flight control skills. It should be noted that the autopilots cannot be used on some basic maneuvers--e.g., unusual attitude recoveries.

³For example, pilots recovering from certain types of unusual attitudes frequently make basic control reversals (they roll the aircraft in the opposite direction from which they should) due to misinterpretation of attitude indicators (Roscoe, 1968). As such, this basic maneuver provides an excellent opportunity for determining if different displays prevent this problem.

TABLE 3.--LIST OF CANDIDATE MANEUVERS TO BE PERFORMED UNDER FAVORABLE CONDITIONS^a

-
- Airspeed change during straight and level flight (acceleration and deceleration)^b
 - Constant airspeed climb and descent^b
 - Standard rate turn^b
 - Climbing (and descending) turn (to predetermined headings)^b
 - Steep turn^b
 - Instrument takeoff^b
 - Slow flight (flaps up)^b
 - Traffic pattern (uncontrolled airport)^c
 - Short field landing^c
 - Maximum performance takeoff (obstacle clearance)^c
 - Noise abatement takeoff and climbout^c
 - Holding pattern (NDB fix)^d
 - Holding pattern (VOR fix)^d
 - Holding pattern (RNAV fix)^d
 - Procedure turn (VOR)^d
 - Procedure turn (ADF)^d
 - VOR enroute navigation (track intercept, track to and from station)^d
 - ADF enroute navigation (interception of predetermined magnetic bearing, track inbound to and outbound from station)^d
 - RNAV enroute navigation (direct course, offset track)^d
 - Energy efficient climb and descent profile (RNAV)^d
 - VOR/DME approach and missed approach^d
 - NDB approach and missed approach^d
 - ILS approach and missed approach^d
 - LOC approach and missed approach^d
 - LOC backcourse approach and missed approach^d
 - RNAV approach and missed approach^d
 - PAR approach and missed approach^d
-

^aA glossary for the abbreviated terms is included in Appendix D.

^bPerformed with reference to pitch, bank, and power instruments only.

^cComposite flight (operations with reference to external cues and flight instruments).

^dInstrument flight.

The assessment of performance on the more advanced maneuvers, when such maneuvers are performed under favorable conditions, will furnish baseline data concerning the capability of pilots in the different evaluation groups to perform flight operations that are, or soon may be, routinely performed in corporate aircraft equipped with EFIS. Use of a broad sample of these maneuvers will enable their relative difficulty to be assessed across the evaluation groups (i.e., assessment of specific differences in group performance with respect to various types of approaches).

It should be noted that the more advanced maneuvers in Table 3, such as the various types of instrument approaches, may be performed in a number of ways, depending on the nature of specific procedures that are prescribed for them, and the location of the navaid relative to the airport. VOR approaches, for example, differ in terms of the location of the VOR (e.g., on or off the airport); the presence or absence of a final approach fix; the type of initial approach segment (e.g., segments based on straight courses and arcs with positive course guidance, dead reckoning, procedure turns, or high altitude teardrop penetrations), intermediate approach segment (e.g., segments based on straight courses, arcs, or procedure turns), and final approach segments (e.g., straight-in or circling); and altitude and visibility minima. Selection of specific types of approaches and other advanced maneuvers will be accomplished in the development of a detailed technical approach for a specific evaluation situation.

Performance on the advanced maneuvers under favorable conditions can be compared to performance on the same maneuvers under more difficult conditions. In order to evaluate performance under more difficult conditions, a set of advanced maneuvers (in Table 3) was selected to be performed under conditions that have been associated with pilot performance problems. Such conditions might include adverse weather, aircraft malfunctions, air traffic complications, and similar factors that may precipitate problems and pilot performance decrement. A list of candidate conditions for this set is presented in Appendix E.

The maneuvers and conditions in this second set were selected based on the analysis of the literature on pilot performance problems that was cited previously in this section. In general, the maneuvers and associated adverse conditions were selected to create difficult but realistic test situations that were designed to enable the study of specific types of pilot performance problems. To aid the reader in understanding why specific maneuvers and conditions were selected, Appendix E contains a detailed description of the conditions as well as a comment column that provides a brief discussion of the rationale underlying the selection of specific maneuvers and conditions. The comment column also contains references to accident reviews, research reports, and other publications that provided information supporting the selection of the maneuvers and conditions. Such publications can be reviewed to obtain additional information concerning those maneuvers and conditions, and the pilot performance problems that are believed to be associated with them.

The maneuvers and conditions in Table 3 and Appendix E are intended as candidate sets from which proficiency checks would be constructed for the planned exploratory evaluation (or any similar evaluations). As such, they reflect the conceptual approach that was developed for maneuver selection in the present project. The selection of actual maneuvers for the exploratory

evaluation will depend on the operating requirements and constraints that are present when it is actually conducted. Procedures for determining the number of maneuver-oriented checks to be conducted and how they should be constructed are discussed in a later subsection entitled "Develop Testing Schedule."

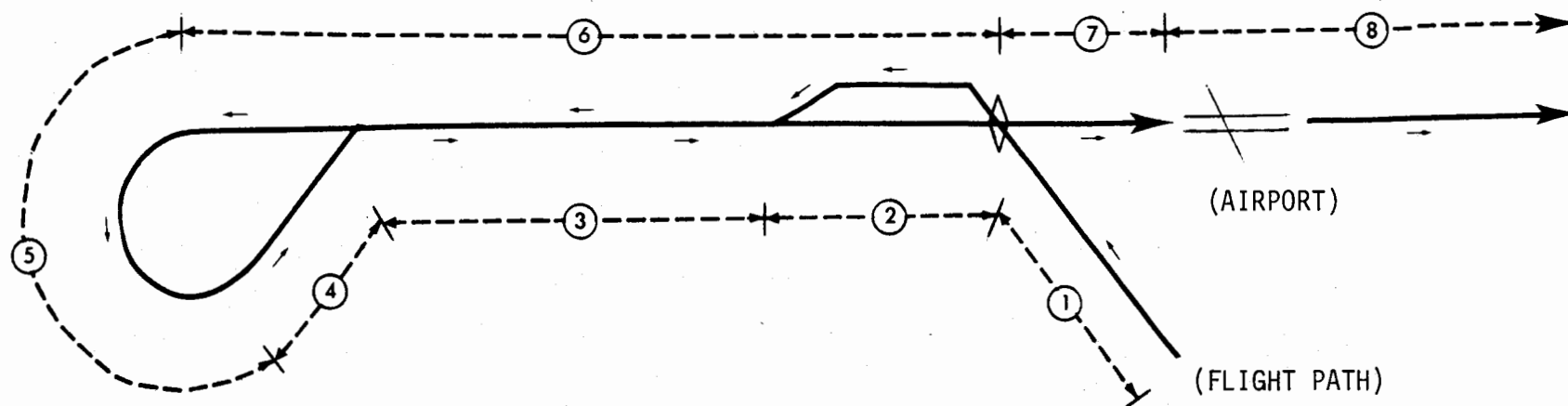
Segment Maneuvers. In some maneuver-oriented evaluations that are conducted for operational purposes, pilot performance is assessed, recorded, and scored with respect to an entire maneuver--e.g., the pilot receives a separate grade or score for each maneuver. However, numerous research studies that have employed maneuver-oriented evaluations have sought to increase measurement precision by reducing each maneuver, through rational analysis, into a series of discrete segments (e.g., Childs et al., 1981; Childs, 1979a; Carter, 1977; Vreuls, Wooldridge, Obermayer, Johnson, Norman, and Goldstein, 1975; Hagin, Harrington, and Haygood, 1977; Brecke, Gerlach, and Schmid, 1976; Seiring, Ruffner, and Childs, 1980; Shelnutt et al., 1981; Long, Shannon, and Waag, 1972; Prophet and Jolley, 1969; Greer et al., 1962; Smith, Flexman, and Houston, 1952). Examples of segments for an advanced maneuver--i.e., an ILS approach--are presented in Figure 4.

Maneuver segmentation increases the manageability of performance evaluations because each maneuver is reduced into elements that more readily can be observed and recorded. An additional advantage of segmentation, one that is crucial for the planned exploratory evaluation, is that the use of such segments aids in the diagnosis and analysis of pilot performance problems. With respect to deriving indices to describe overall performance on a given maneuver, it is assumed that the data recorded for the component segments can be integrated hierarchically into scores for more comprehensive blocks of performance.

The criteria for the definition of segments are observable transitions in control input as well as temporal or spatial parameters defined on the basis of analysis of performance requirements (Shipley, Gerlach, and Brecke, 1974).¹ While segment definition may appear to be straightforward, real-time measurement of flight maneuver segments is sometimes obscured by confusion as to when one segment terminates and the next begins. Therefore, segmentation "start/stop logic" (Vreuls and Wooldridge, 1977) needs to be addressed, regardless of how the data are to be recorded--e.g., manually by evaluators or automatically by computer-based systems.

Sources of criteria for selecting and segmenting maneuvers include the past research cited previously in this subsection, as well as FAA flight test guides for selected pilot certificates and ratings--e.g., commercial pilot certificate and instrument rating. Additionally, to aid in developing and describing the conceptual approach for the planned exploratory evaluations, an analysis was conducted of a selected subset of the maneuvers listed in Table 3. The segments that were defined for these maneuvers are described in Appendix F. This appendix contains a prototype data collection instrument that was developed to illustrate not only the segmentation of maneuvers, but

¹It is important to note that initial, intermediate, and final approach segments that are defined by operational criteria for many instrument approaches (FAA, 1976) may not be the same as maneuver segments defined for measurement purposes.



SEGMENTS	
1. INITIAL TRACK TO STATION	5. PROCEDURE TURN INBOUND
2. BEACON OUTBOUND	6. LOCALIZER TRACK INBOUND
3. LOCALIZER TRACK OUTBOUND	7. GLIDESLOPE INTERCEPT INBOUND
4. PROCEDURE TURN OUTBOUND	8. MISSED APPROACH

FIGURE 4.--ILS APPROACH MANEUVER SEGMENTS.

also other aspects of the conceptual approach to assessing performance that are discussed elsewhere in this chapter.

MEASURE DEVELOPMENT. The second step to be taken in planning maneuver-oriented evaluations involves the development of procedures for measuring and assessing pilot performance. Component activities within this step are (1) the identification of the type of performance variables that are to be measured; (2) determination of how to sample such variables with respect to each maneuver that is included in a check; and (3) determination of how to quantify performance on each variable that is sampled within a maneuver.

Identify Performance Variables to be Measured. There are numerous ways of measuring performance. Such measures emphasize relatively objective observable indices of pilot performance. There are, of course, other conceptions that emphasize indices (or evaluations) of performance that are not so directly observable by an outside agent. Table 4 presents examples of some of the maneuver performance variables that have been measured in past research projects.¹ Such variables can be measured relative to the pilot (e.g., movements of cockpit controls or recordings of eye scan patterns), aircraft flight path (e.g., altitude or glideslope), aircraft configuration (e.g., flap or elevator displacement), or any of a number of other referents. For example, considerable interest has been shown in the measurement of pilot workload (Rehmann, 1982; Rosenberg, Stein, and Rehmann, In Preparation; Wierwille and Williges, 1980). However, workload indices reflecting the "effort" required to perform a given flight maneuver will not be considered as primary variables in the evaluations to be conducted. It was deemed more important for present purposes to utilize more objective means to identify pilot performance problems associated with the use of EFIS or conventional display. No current workload data or models were considered sufficient to enable reliable predictions of such performance problems.

If maneuver-oriented evaluation is to aid in rendering valid performance discriminations, the measurement focus should be upon aircraft state resulting from pilot responses. As noted earlier, increases in technology such as EFIS have provided potential benefits to pilots by unburdening them from some of the conventional psychomotor (e.g., flight control) and procedural (e.g., navigation) tasking. However, this technological growth not only has obscured the pilot's role, but it has complicated the evaluation of pilot behavior in the pilot-aircraft interface, since there are more and different functions that can be allocated to computer mediated and controlled onboard systems. The outgrowth of this increased complexity resulting from the introduction of the computer into the loop is that the already substantial range of pilot behavior that may lead to a designated system outcome has become an order of magnitude greater than before. For example, an aircraft may deviate from course because of a tracking error made by the pilot as he controls the aircraft manually, or because the pilot operated the autopilot incorrectly.

In the maneuver-oriented checks that are planned for exploratory evaluation, however, the pilots will be told which control systems to use (as

¹The list in Table 4 is based on a comprehensive review of methods of measuring pilot performance that was conducted by Mixon and Moroney (in press) and cited in Mixon (1981). Readers are referred to these documents for a more detailed discussion of the variables listed in Table 4.

TABLE 4.--EXAMPLES OF PERFORMANCE VARIABLES THAT
HAVE BEEN MEASURED IN PAST RESEARCH

Acceleration

Aileron displacement

Airspeed (indicated, calibrated, and true)

Altitude (absolute and true)

Angle of attack

Approach glideslope (deviation from desired)

Approach localizer (deviation from desired)

Automatic Director Finder (ADF) indications

Checklist compliance

Closing speed course error

Course Deviation Indicator (CDI) indications

Deviations from ideal flightpath

Distance Measuring Equipment (DME) indications

Distance traveled

Elevator displacement

Emergency detections

Engine Pressure Ratio (EPR)

Engine RPM

Flap displacement

Fuel flow

Inclinometer indications

Landing (distance to ideal touchdown point)

Landing gear status

Magnetic heading (on magnetic compass)

Pitch

Pitch/roll coordination

Procedural compliance (communications, subsystem operations)

Roll

Rudder displacement

Sideslip

Speed brake status

Takeoff position error

Throttle displacement

Turn rate

Vertical velocity

well as which EFIS modes, when applicable). It may be, therefore, less beneficial for maneuver evaluation purposes to attempt to measure what the pilot does in the interface than to measure what the aircraft does in response to pilot decisions and inputs (Childs, 1979b). Pilot behavioral measurements are appropriate for diagnostic applications when the pilot has not been instructed to perform a maneuver in a certain way, such as in the operations-oriented evaluation. Thus, such measurements will be employed relative to the operations-oriented flight check described in the following section. However, for the maneuver-oriented applications, aircraft measures provide necessary and sufficient data concerning the relationship between desired and actual states of the pilot-aircraft interface. Further, procedural compliance by pilot subjects will be assessed by evaluating subsystem states during the maneuver.

Given that the focus of maneuver-oriented evaluation is to be upon objective system measures and procedures as reflected by aircraft state, the next consideration relates to the course of action to be followed in identifying the number and type of aircraft variables to be measured.

It is often possible to capture the critical performance requirements of a basic flight maneuver with a few generally comprehensive variables such as altitude, heading, and airspeed (Roscoe and Childs, 1980; Childs, 1979b; Hagin, Herrington, and Haygood, 1977). However, some maneuvers whose execution requirements are more complex and intricate in nature may require numerous specific variables to provide a sufficient evaluation profile (Vreuls and Wooldridge, 1977; Kelly, Hennessy, Vreuls, Barneby, Wooldridge, and Cotton, 1978). Most of the maneuvers performed by general aviation pilots do not appear to fit in this latter category, however. The selection of the number and type of aircraft state variables reflects the measurement precision desired as well as the flight skills to be assessed.

It should not be assumed that measuring more variables necessarily provides better or more complete information. Indeed, measuring "everything that moves" (Vreuls and Wooldridge, 1977) can be wasteful of time, money, and effort. Experience has shown that a substantial portion of performance variance in certain complex flight situations can be described adequately by fewer than 15 performance variables (Vreuls et al., 1975). The problem is to identify which of these variables are critical to the successful outcome of a maneuver and to do so as early as possible in the measure development process. This can largely be accomplished by a thorough and careful front-end analysis of maneuvers as discussed above. Such analysis may draw heavily upon Pilot Operating Handbooks for the aircraft in question, material from related pilot training courses, requirements for related FAA pilot certificates and ratings, and other published material. However, identification of critical performance variables can ultimately be achieved only by an iterative process involving empirical data collection and analysis followed by measure refinement (Vreuls and Wooldridge, 1977). The reader is referred to Section B of this chapter as well as to Chapter III for further information on these points.

Specific aircraft-referenced variables to be measured in the planned exploratory evaluations are included in the maneuver data collection instruments shown in Appendix F. These variables are objective, in that they are constituted from observable aspects of system and subsystem performance.

Determine Sample Variables on Each Maneuver. After variables to be measured have been identified, the next task is to specify how and when they

are to be sampled. A method should be devised for sampling those variables that are most important for describing, understanding, and predicting system performance (Vruels and Wooldridge, 1977).

In the selection of a sampling procedure, points or intervals of performance that are to be sampled must be carefully identified and defined. The reason is that variables to be sampled for one maneuver segment may not be the same as those sampled for another segment of that same maneuver. Further, observations at some sampling points within a maneuver will correlate more highly with performance outcome than will observations at other sampling points (Roscoe and Childs, 1980). The benefits derived from a judicious selection of sampling points include savings in time and cost of data collection.

Tentative selections of sampling rates and durations can be made through a process of logical analysis, followed by empirical validation or adjustment as necessary. For instance, in a one-minute turn, a logical time-based sampling rate for altitude might be every fifteen seconds. Such an interval would provide measurement at the beginning and end of the maneuver, as well as at two control transition points within the maneuver (i.e., the segment of the turn after completion of the rolling, and the segment just prior to the initiation of rollout).

The most common system state referents for definition of sampling points are time and position. For example, in executing a standard rate turn (3 degrees per second) to the right from an initial heading of North, the desired value for aircraft heading should be 135 degrees precisely 45 seconds after starting the turn. Such a sampling procedure is time-based, in that observations and recordings are made at designated times within the maneuver execution, and observed performance values are compared to desired performance values at those times. Many instrument maneuvers lend themselves to this time-based sampling approach. Certain other maneuvers, more operational in nature (e.g., Standard Instrument Departures), or those that require external visual cues such as ground referenced maneuvers, are less amenable to this approach, but they may be evaluated by sampling and recording points defined relative to desired aircraft positions in space rather than time. A flight variable will be sampled only once during a maneuver segment, but may be sampled during more than one segment. Since segments are defined according to required control inputs and procedures, the performance requirements that are identified during maneuver analysis will dictate the specific flight variables to be sampled within each segment. The sampling intervals in the planned exploratory evaluations were defined by maneuver segments and are shown in Appendix F.

Quantify Performance. The final task in measure development consists of identifying measures that are to serve as performance descriptions. Many such measures have been employed in performance evaluation contexts. Among them are time out of tolerance, maximum value out of tolerance, response time, rise time, overshoot, tolerance band deviation frequencies, means, standard deviations, minimum/maximum values, root-mean-squared error, segmentation sequences, and procedural/decisional sequences (Vreuls and Wooldridge, 1977).

The performance measures selected for the exploratory evaluations all relate to error as defined by deviations of observed aircraft-referenced states or values from those that are desired for a given performance variable. Of primary interest are the frequency and magnitude of such errors. Error direction

is usually of secondary interest, though in some situations it may become primary. These error characteristics were selected because they are best suited to the objectives of the study (i.e., identification and quantification of general pilot performance problems). By focusing on performance error, resources that are necessary to collect, reduce, and analyze the data are decreased. Further, this increase in measurement efficiency enables a wider range of maneuver tasking to be addressed.

To define error parameters--i.e., to define instances of pilot performance that will be classified as errors--it is necessary to generate definitions of desired values and tolerance levels for as many performance variables as possible. It is on this basis that performance error is defined. The task of specifying desired values of sampled performance variables and tolerance levels for those values should be performed in conjunction with maneuver segmentation and sampling. For example, in the takeoff maneuver, the climbout segment may include a measure of airspeed. For a given aircraft, the desired value of airspeed during climbout might be 88 knots with a tolerance level of ± 5 knots. Observed airspeed values that are outside of this tolerance band during this maneuver segment would be considered as errors.

The generation of specific desired values and tolerance levels across all sampling points of each maneuver is a formidable task. The approach used in the present study was to identify a candidate set of desired values and tolerances by reviewing standards and guidelines for evaluating pilot performance in operational settings. Operational performance standards as set forth in the Federal Aviation Regulations, in aircraft operator's manuals and handbooks, in various books on precise flight control (e.g., Taylor and Guinther, 1978), and in certain advisory circulars (e.g., AC 90-45A for Area Navigation Systems) were employed. Another source of general desired values and tolerances consisted of FAA flight test guides for evaluating pilot proficiency relative to the issuance of various certificates and ratings (e.g., AC 61-54A for the issuance of a private pilot certificate). These flight test guides provide acceptable performance guidelines which consist of general tolerance bands such as ± 100 feet of altitude and ± 10 degrees of heading for various flight maneuvers. An example listing flight variables to be sampled for a VOR approach segment and desired values and tolerances for those variables is shown in Table 5.

TABLE 5.--FLIGHT VARIABLES, DESIRED VALUES, AND TOLERANCE LEVELS FOR A VOR APPROACH SEGMENT

<u>Flight Variables</u>	<u>Desired Values</u>	<u>Tolerance Levels</u>
● VOR Course (216°)	Rollout on Course (216°)	$\pm 5^\circ$
● Track to Station	CDI Needle Centered	± 1 dot from center
● Airspeed	120 knots	± 5 knots
● Vertical Speed	500 feet per minute	± 50 feet per minute
● Minimum Descent Altitude	660 feet	+ 50, -0 feet

After candidate sets of desired values and tolerance levels are specified on the basis of analysis and expert opinion, it is vital that they be empirically refined and validated against "real-world" standards. In the planned study, desired values and tolerances will be refined empirically through preliminary simulator tests. Additionally, data analyses (described in a later subsection) will be designed to refine these parameters. It has long been known that desired values may change as a function of a number of operational factors (e.g., contingencies related to equipment failure, traffic, or weather). Similarly, tolerance levels within a given maneuver fluctuate from one sampling point to the next and, more importantly, vary from one maneuver to another. For instance, ± 50 feet of altitude generally is not considered as critical to the safety of a flight operation during an enroute segment as during an approach segment.

The task of defining desired values and tolerances must not be ignored or shortchanged in the measure development process. It is their definition that forms the basis for making decisions as to whether or not "indices of desired performance" (Williams, 1947; Roscoe, 1980) or "specific behavioral objectives" (Carter and Semple, 1974) have been met.

It has been noted that much of the importance of carefully determining desired values and tolerances stems from their involvement in error definitions. Specifically, performance error may be viewed as the inverse of desired performance. In the planned effort, a sample of variables has been selected on which performance is to be observed. Tolerance levels have been defined for each of these variables. In some cases the tolerances are quantitative, and in others they are largely qualitative. Given adequate definitions of such tolerances, performance error is automatically defined. Each variable within a maneuver and for all maneuvers comprising a flight check will be observed and recorded as either within or out of prescribed tolerance limits. This level of error will be designated "Type A error." Thus, performance for maneuvers, maneuver segments, or the entire flight check can be characterized by the frequency or rate of Type A errors.

However, Type A error frequencies provide only part of a valid evaluation profile. Subject matter experts and research personnel recognize that the unitary equating of one error with another does not provide an accurate qualitative indication of performance. Certain errors are much more critical than others to the safe outcome of a maneuver performance, despite the fact that all Type A errors carry equal weighting when simple error frequencies or rates are computed. Therefore, some errors (designated "Type B errors") will be examined in the context of their criticality to flight safety. An error becomes designated as a Type B error either on the basis of prior analysis and definition (e.g., descent below MDA) or because of situational factors that become pertinent to the maneuver outcome (e.g., uncorrected errors that result in dangerous flight situations). In the planned evaluations, both Type A and Type B errors will be recorded and quantified. Thus, performance quality will be indicated not only by the frequency of Type A errors, but also by the frequency of Type B errors.¹

¹ An accident can be considered as the most serious form of error, but in actuality is the outcome of one or more Type B errors. Such aircraft occurrences will be recorded and will provide further performance data. A discussion of the scoring of accidents as they relate to error is contained in a later subsection (see Develop Performance Quality Index).

SCORING. Upon selecting and segmenting maneuvers and developing the measures to be taken on them, the next step in the evaluation process consists of determining how performance scores will be derived from the measures. Two general considerations of scoring maneuvers will be addressed. The first relates to the overall quantification of a series of maneuver error scores. These scores are descriptive and are useful for performance discriminations, but are limited for predicting operational safety. The second consideration concerns the attempt to identify and use pass/fail scores which are thought to carry more operational significance than error scores and may serve as criteria of acceptable performance. Such scores are referred to in this report as the "Performance Quality Index."

Develop Error Rate Scores. After performance measures are acquired, they must be transformed into scores for subjects or groups to enable meaningful tabulations and comparisons of the data to be made. Generally, scores are tabulated for purposes of comparing the performance of one individual or group with that of another on a given maneuver.¹ The most common means of comparing groups on maneuver-oriented scores involves comparisons of mean error percentages or rates. Error rate is computed by dividing the number of measured variables in a given maneuver into the number of variables that are in error (as determined by deviations from defined tolerance) and multiplying the resulting fraction by 100.

One example of a procedure and scoring form for quantifying performance error rates on flight maneuvers is that of the Pilot Performance Description Record (PPDR) developed by Smith (1952), and refined by Greer, Smith, and Hatfield (1962), and by Prophet and Jolley (1969). The PPDR involves a standard administration sequence for maneuvers to be evaluated and a standard order of segments comprising each maneuver. Each segment contains a number of measured variables which are recorded objectively by reference to instrument readings or external flight status indicators. Where observed performance exceeds permissible deviations from desired values or states of variables, errors are noted on the scoring form by marking a scale or category accordingly. Where judgments by evaluators are required, they are structured in terms of observable performance. An example of a completed PPDR scoring form for VOR orientation, approach, and missed approach segments is given in Figure 5. It can be seen that five of the thirteen measured variables were performed in error, resulting in an error rate of 38 percent for this maneuver.

Error rates may also be computed for each maneuver segment. In the example in Figure 5, for example, two of the five variables for the orientation segment are in error, resulting in an error rate of 40 percent for that particular segment. However, the reader is cautioned concerning the potential problems that can result from attempting to use error rate indices that are based on

¹An alternative purpose of these scores is to compare performance of individuals or groups on one maneuver to the same individual or group performance on another maneuver. Such comparisons yield gross indices of maneuver "difficulty" and relate to workload considerations which are not addressed in this study. Still another use could be to define a passing grade for a rating or certificate (e.g., not more than X percent error). However, this is a matter of evaluation and is discussed in another subsection.

VOR

ORIENTATION

RESET DG

NO

YES

STATION TUNED,
IDENTIFIED

NO

YES

CDI NEEDLE CENTERED

NO

YES

ASSIGNED
ALTITUDE

-100

-50

+50

+100

ASSIGNED
HEADING

-10°

-5°

+5°

+10°

APPROACH

ROLLED OUT
ON COURSE (+5°)

NO

YES

TRACK

NO

YES

MDA (+100 ft)

NO

YES

AIRSPED

-10

-5

+5

+10

MISSED APPROACH

TIMELY COMPLIANCE
WITH ALL PROCEDURES

NO

YES

REPORT

NO

YES

AIRCRAFT CONTROL

NO

YES

COMPLIANCE WITH ALL
ATC INSTRUCTIONS

NO

YES

FIGURE 5.--EXAMPLE OF A COMPLETED PILOT PERFORMANCE
DESCRIPTION RECORD (PPDR).

too few items to be reliable. Without an understanding of their statistical properties, the resulting error scores can be practically meaningless and even misleading for making performance discriminations.

Additionally, error rates may be calculated for a given flight variable (e.g., altitude) across segments or maneuvers, and they may be derived for the entire set of maneuvers that comprise a flight check. Such applications would seem to be particularly appropriate to the planned evaluation of EFIS.

The major advantages of scoring procedures such as those described for the PPDR lie in their standardization, objectivity, and comprehensiveness. Another advantage is their potential for yielding (through multiple data analyses) subsets of "critical" variables (i.e., those variables that, when performed in error, tend to result in unsafe or otherwise ineffective overall performance).

A disadvantage of PPDR-type scoring used for past research and training applications is that the overall error rate derived does not reflect error criticality. However, the PPDRs to be adapted for the planned evaluation of EFIS will include assessment of Type B (i.e., critical) errors as well as those (Type A) errors that exceed tolerance limits but do not result in an excessively high level of risk. Additionally, PPDR scoring tends to be aircraft control oriented and often fails to account for the full range of cognitive and decisional skills deemed necessary for safe and efficient maneuver execution. Finally, error scores derived from objective maneuver-oriented evaluation procedures such as the PPDR fail to provide a basis for determining the operational acceptability of a given error score. An error rate of 40 percent indicates that twice as many errors are made, relatively, as with an error rate of 20 percent. However it cannot be assumed that the latter score represents performance that is twice as safe as the former, or, more importantly, that one is minimally safe and acceptable from an operational standpoint while the other is not. Attempts to derive such criteria of acceptable performance are the subject of the following subsection. Nevertheless, error scores can be used as a basis for discriminating whether some factor (e.g., EFIS) affects the performance of groups of pilots favorably, unfavorably, or not at all.

In the evaluation of EFIS, error scores will be generated from the use of PPDRs for each of the flight maneuvers that are selected from those listed in Table 3 and Appendix E. Error rates will be computed for each of the maneuvers performed by pilot subjects using either EFIS displays or conventional displays under each of three levels of flight control. An overall error rate for each subject also will be computed. Mean error rates will be computed for each treatment group by totaling the error rates for all subjects in a group and dividing the total by the number of subjects in the group.

Develop Performance Quality Index. Another level of scoring consists of assigning some cutoff or criterion for minimally acceptable (i.e., passing) performance. Such criteria enable performance discriminations to be made and ultimately permit or disallow general FAA aviation pilots and equipment to operate in the National Airspace System. FAA flight tests for pilot and equipment certification purposes employ such criteria, although, necessarily, they are often not explicitly stated. The point to be made is that criteria of acceptable performance are needed for making reliable operational judgments.

In the planned exploratory evaluations, a Performance Quality Index (PQI) will be derived for each maneuver that is assessed and over all maneuvers. The index will be generated on the basis of a numerical rating assigned by the evaluator that reflects the severity or criticality of errors recorded on the PPDR. If an accident occurs as a result of one or more Type B (i.e., critical) errors, a rating of "4" will be assigned to the maneuver performance. The occurrence of one or more Type B errors within the maneuver without a resultant accident will be given a rating of "3". If the maneuver contains only Type A errors (i.e., tolerance deviations that are not serious enough to place the aircraft at risk), a rating of "2" will be assigned. Finally, if all of the measured variables on the PPDR maneuver are within prescribed tolerances, the maneuver performance will receive a rating of "1". Maneuver ratings of "1" or "2" will be considered acceptable performance (i.e., passing), while ratings of "3" or "4" will constitute unacceptable performance (i.e., failing). Since maneuver ratings are multidimensional, it may be inadvisable to attempt to combine them arithmetically to achieve an overall PQI rating. However, a profile of maneuver ratings will be constructed, and profile analysis techniques (Nunnally, 1967) will be used to make meaningful comparisons of maneuver PQI ratings.

To summarize the conceptual approach for maneuver scoring, PPDR error rates and PQI ratings will be generated for each maneuver and over all maneuvers. Additionally, an overall maneuver failure rate will be computed on the basis of the ratio between the number of maneuvers passed and the number of maneuvers failed.

DATA COLLECTION. There is no substitute for thorough planning and coordination prior to the onset of data collection. General activities to be described for maneuver data collection are (1) developing the data collection systems, (2) selecting and training evaluators, (3) developing the test schedule, and (4) developing procedures for maintaining quality control.

Develop Data Collection Instruments. An important initial consideration relates to whether data will be collected manually or by automated means in the simulator. A fairly common misconception is that automatic or computer-controlled performance evaluation is more objective, reliable, and valid than other evaluation methods. Objective data collection involves explicitly stating indices of desired performance, providing evaluation guidelines such that reliable comparisons between actual and desired performance values can be made, and making the comparisons public by recording. Automating the comparison is not a prerequisite for objectivity. In addition, precisely specifying the nature of all Type B situation-related errors in a manner that would allow automated assessment would be extremely difficult, if not impossible; the experienced pilot can make such real-time assessments probably more validly than can the computer. Further, automation of performance measurement has the disadvantage of requiring extensive analyses to define measurement algorithms precisely and also extensive resources for programming the automated system. Thus, given the objectives of the planned evaluation, data are to be recorded manually by thoroughly trained evaluators.¹

The recording forms for the planned evaluation will be PPDRs specially adapted for EFIS applications. Care will be taken to include performance

¹Collection of data may be facilitated by displays at the operator station that provide performance information. Such displays are discussed in Chapter V.

measures that offer potential for identifying safety differences associated with the use of EFIS and conventional displays. Each PPDR will provide for the recording of Performance Quality Indices as well as the observed performance deviations that will be used to derive error rates. Examples of such recording forms are shown in Appendix F. The PPDR format has been developed through extensive research and is designed to facilitate the recording of data and prevent the occurrence of recording errors by the evaluator (Greer et al., 1962).

Select and Train Evaluators. Provisions should be made for securing and training personnel capable of evaluating performance and collecting the data. Such personnel should have substantial flight experience as well as experience in assessing pilot performance--e.g., certified flight instructors and designated examiners. Performance evaluators must be trained and practiced to ensure their familiarization with both the methodology and use of the forms employed for data collection. Information concerning difficulties in the use of the forms (e.g., questions concerning data recording or misinterpretations of measured variables) should be freely exchanged with the researchers participating in the study. Preliminary trials should be conducted in the simulator (or aircraft) to detect and correct any problems that the evaluators may have with the recording forms. Such indoctrination is necessary to ensure evaluator familiarization with the content and format of the forms prior to use for actual data collection purposes.

A single evaluator will be employed for the planned evaluation. Use of only one evaluator is feasible in this situation because the PPDR recording form is designed to facilitate the efficient collection of data. In addition to the evaluators, an experienced flight simulator instructor will be responsible for operating the simulator, manipulating conditions associated with the performance of each maneuver, and simulating air traffic control communications.

Develop Testing Schedule. Table 3 and Appendix E, which were discussed earlier in this section, list a large number of maneuvers and conditions that could be employed in the exploratory evaluations. It is clear that not all of these flight situations could be assessed in one check. However, the number of checks that are conducted and the maneuvers/conditions that are employed need to be determined with respect to the operational requirements and constraints (e.g., the amount of research funds available, the type of simulator). Thus, it is impossible to specify, a priori, the detailed content of such checks.

Certain general recommendations concerning the nature of the checks can be made, however. It is highly likely, for example, that an excessively long test session (particularly given the use of difficult conditions) would confound the evaluation of pilot performance effects due to display variables with those due to the fatigue that the subjects would probably experience.¹ Short sessions, on the other hand, waste valuable simulator (or aircraft) time due to the need for certain fixed amounts of preparation time by the subjects and evaluators before each session. Under recognition of these constraints, it is recommended that the data collection sessions typically be approximately two hours in length, 30

¹It should be recognized, however, that differential pilot fatigue resulting from use of various displays (and the resultant pilot performance decrement) is a factor of interest in the evaluation.

minutes of which will be used for briefing and debriefing subjects. Such a schedule would allow four sessions to be scheduled in each eight hour workday.

Further, each of the checks that are conducted should be composed of a mix of maneuvers and conditions from Table 3 and Appendix E (e.g., basic and advanced maneuvers, favorable and unfavorable conditions). Such a mix is required to keep the pilots from anticipating specific favorable or unfavorable conditions, as would be the case if individual checks were constructed using only one of the sets. Additionally, the mixture of basic and advanced maneuvers prevents the pilot from encountering high (or low) task demands continually throughout a check.

One note of caution needs to be mentioned. Great care should be taken to assure that the pilots who serve as subjects are given sufficient time to adjust or "warmup" to each test situation (each combination of maneuver and condition that is presented during a check). The pilot should not be presented with new maneuvers in a way that prevents him from understanding what is required and from focusing his concentration on the new maneuver. Further, the pilot should be allowed to prepare before the test session for the more advanced maneuvers that are to be tested (e.g., allowed to perform the required preflight planning). Each pilot's preflight plans would be checked to assure that they are correct, since preflight planning skills are not of interest in the exploratory evaluation.

Develop Quality Control Procedures. Data collection is often constrained by operational factors that affect the quality of the data that are collected. For example, record forms may sometimes contain incomplete or inaccurate entries because published recording procedures are not carefully followed. Additionally, forms may even be misplaced due to confusion in the system used to manage this information. Such practices may diminish the validity of the data acquired and therefore restrict the interpretations and conclusions that may be drawn from the data. Thus, procedures must be developed to maintain the desired level of quality control over all incoming data and to ensure that such data are secured and organized once they have been gathered.

The tasks of monitoring data recording forms and collating data should be assumed by conscientious, well-motivated, and thoroughly briefed personnel. Incomplete or inaccurate data that are not detected until the project has been completed are generally of little use. Because such data usually cannot be reconstructed accurately by evaluators, who likely have long since forgotten what actually transpired on a specific flight, it is necessary that performance data be inspected frequently and as soon after actual data collection as possible.

In the planned evaluation, the evaluator will have the responsibility of maintaining quality control for all incoming data. At the completion of each data collection session, that evaluator will review the PPDR forms in their entirety to ensure that each form is complete and that its data are accurate. Incomplete or inaccurate data will be corrected immediately. All completed PPDR data forms will be filed in one central location and will be regularly inspected and reviewed by research personnel. Discrepancies in recording procedures or in the data resulting from the use of those procedures will be discussed with the evaluator, and immediate steps will be taken to correct such discrepancies.

DATA ANALYSIS. The final step in maneuver-oriented evaluation consists of descriptive and comparative statistical analyses performed on the error data acquired. While some of the performance measurement complexity can be addressed at the experimental design and measure development phases, it is inevitable that much of it will have to be treated later during data analysis. The analysis should be planned thoroughly and carefully in conjunction with the design. Part of this planning involves a careful consideration of the questions to be addressed by the design as well as the analysis. Because of the influence of the experimental design on the data analysis process, general considerations related to both are discussed in Chapter III. The following discussion focuses upon data analysis factors to be addressed in the exploratory evaluations. Included in the discussion are activities related to determining how to (1) analyze group comparisons, (2) identify critical maneuvers and conditions, and (3) identify assessment procedures that are useful for other applications.

Analyze Group Comparisons. The initial consideration in analyzing maneuver data is that of determining whether observed differences between evaluation groups' performance error can be attributed to the differences in experimental conditions. Conventional univariate statistical methods such as one-way and factorial analysis of variance (ANOVA) are generally employed in such statistical comparisons. In addition, tests of differences in error frequency can be useful. The purpose of statistical comparisons between groups is to determine whether performance differences are of sufficient magnitude that such differences may be reliably attributed to variance resulting from the treatment (as opposed to random or systematic error variance). The reader is referred to Chapter III for a more detailed discussion of between-groups statistical comparisons of maneuver performance.

In the planned exploratory evaluations, statistical comparisons will be made for main effects between evaluation groups using EFIS and those using conventional displays to perform a subset of the maneuvers listed in Table 4. The comparisons also will provide for identifying main effects for the three levels of flight control depicted in the experimental design (Chapter III). Finally, the comparisons will permit significant interactions among display and control levels to be revealed. All comparisons will be made for both PPDR error rates and for Performance Quality Index ratings via repeated measures factorial ANOVA. Descriptive statistics (means and standard deviations) also will be presented for each cell of the design.

Identify Critical Maneuvers and Conditions. Statistical analyses, whether univariate or multivariate, are useful for identifying error patterns and trends in the performance of flight maneuvers. Such patterns may provide specific information concerning the types of errors made as well as the conditions under which they were made. Shipley, Gerlach, and Brecke (1974), for example, reported significant increases in error probabilities at critical control transition points of flight maneuvers. Prophet and Jolley (1969) found that errors decreased significantly for some maneuvers during early training, but did not decrease for others. Childs (1979c) reported higher error rates for heading control than airspeed or altitude during intermediate segments of basic instrument maneuvers. Many of the previously cited studies have reported performance problems associated with the execution of certain maneuver/condition combinations. Such diagnostic information can result from analyses designed to isolate and identify those flight maneuvers and conditions that are closely related to performance error.

In the planned evaluations, data analyses will be designed to identify critical maneuvers and conditions associated with the use of EFIS. Since three-way interaction effects (Display Type X Control Level X Maneuver) are possible with the factorial ANOVA to be employed, various post hoc exploratory techniques (e.g., Tukey's Honestly Significant Difference test) are likely to be necessary. Such tests help to isolate combinations of maneuvers and conditions that tend to account for the majority of overall performance variance.

Identify Useful Performance Assessment Procedures. In the planned evaluations, an attempt will be made in the analysis to refine the Performance Quality Index by identifying specific error patterns for PQI ratings of "2" or "3". Such error patterns will provide the basis for developing objective performance standards or criteria that may be used to evaluate the safety and proficiency of flight operations employing not only EFIS, but other new advanced avionics systems. Such standards may be derived from post hoc exploratory techniques such as those mentioned for identifying critical maneuvers and conditions.

B. DEVELOPMENT OF OPERATIONS-ORIENTED PROFICIENCY CHECKS.

The steps to be discussed in carrying out operations-oriented evaluations are (1) Scenario Development; (2) Measure Development; (3) Scoring; (4) Data Collection; and (5) Data Analysis. As with maneuver-oriented evaluation, each step contains two or more component activities as shown in Figure 6. Each of the following subsections contains conceptual guidance for the conduct of these activities as well as a recommended approach for the planned exploratory evaluation. The conceptual guidance was derived from a review of procedures employed by air carriers to develop Line Oriented Flight Training (LOFT) (Lauber and Foushee, 1981a; 1981b), and of the few flight simulation studies that have sought to assess pilot performance in the context of an entire operational mission (e.g., Rockwell and Giffin, 1981; Smith, 1979).

SCENARIO DEVELOPMENT. The development of realistic scenarios requires considerable knowledge of the skills to be evaluated and how those skills are used in executing a selected flight operation. Skill requirements for executing general aviation operations vary considerably in both number and type. It is desirable to require a wide range of flight tasks to be performed in the scenarios to allow such variance to be addressed. Scenario tasks should not be so standardized that spontaneity is lost, nor should the consequences of pilot decisions and judgments be ignored. The following discussion presents two aspects of the scenario development process that should be considered in attempts to achieve this balance--Flight Operations Analysis and Scenario Structure.

Analyze Flight Operations. To provide realism, scenarios should be based on actual flight operations. Tasks and operating contingencies for insertion into the scenarios can best be identified from review and analysis of typical general aviation flight operations. Determinations of tasks and conditions recommended for a selected flight operation should be based upon analyses and discussions with experienced pilots as well as upon observations of actual flights. Analyses should include the required activities that are performed by the pilot during each phase of the flight, as well as the problems that may be encountered in carrying out these activities.

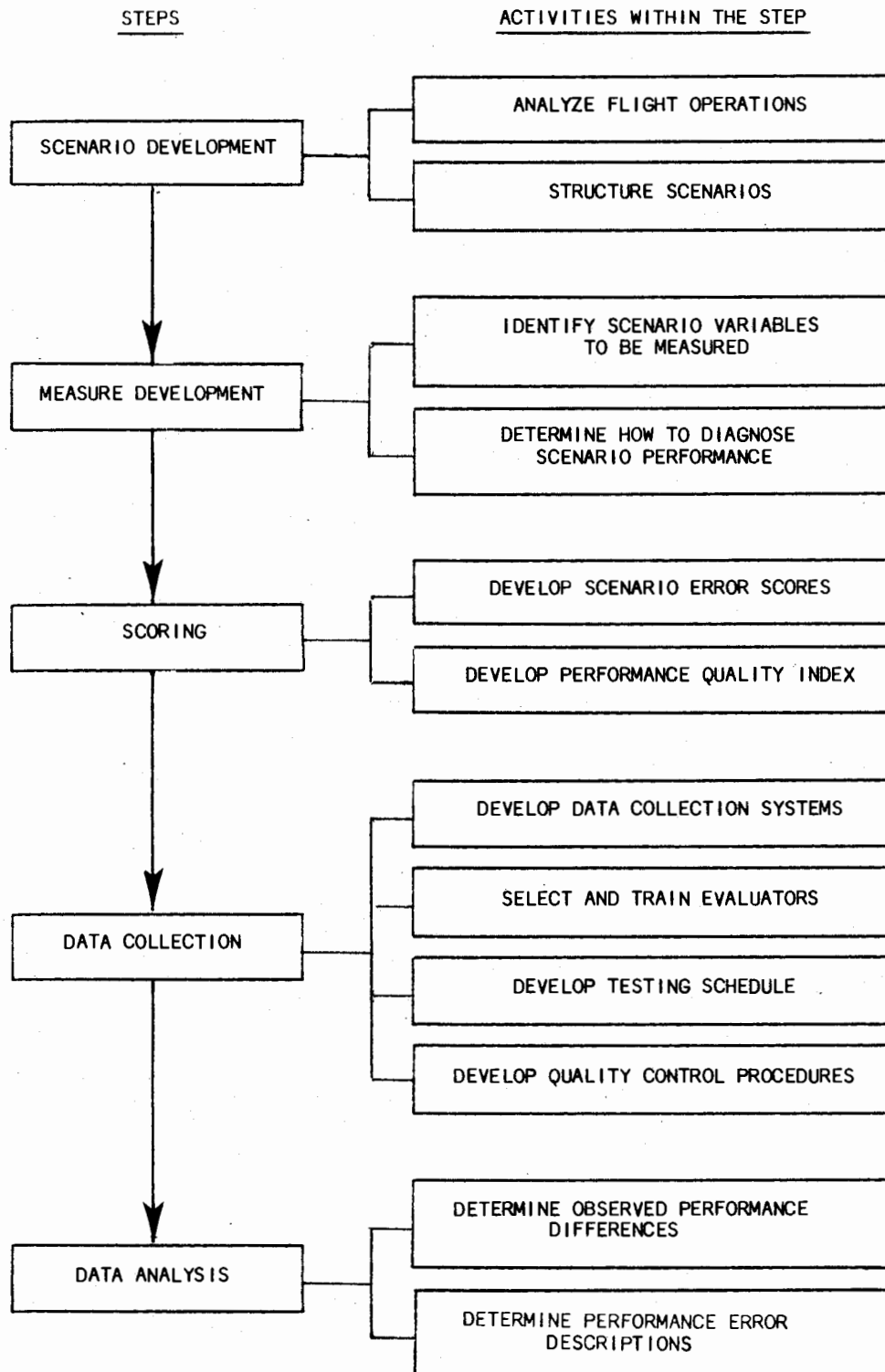


FIGURE 6.--MAJOR STEPS AND COMPONENT ACTIVITIES INVOLVED IN PLANNING OPERATIONS-ORIENTED EVALUATIONS.

To assist in the analysis of flight operations during the present effort, a number of discussions were held with pilots who fly or have flown corporate aircraft on a routine basis. Information derived from these discussions was used to define two typical corporate aircraft missions. These missions are described in Appendix D. Following a detailed review of these missions, one of them was chosen as the model scenario to be used in the operations-oriented proficiency check.

Structure Scenarios. After the flight operations that are to be modeled have been selected, test scenarios should be structured such that the sequence of activities and the problems encountered are reasonably analogous to those that would be encountered in the actual flight operation. Much of the desired realism can be lost, for example, if an excessive number of low probability events are combined in a single scenario. Thus, low frequency events should be inserted with great care and their use supported by accident or incident analyses or analyses (in the case of new equipment) of probable malfunctions. The scenarios to be used in the evaluation should be structured much like the LOFT scenarios used by the airlines. As such, guidance for structuring these scenarios is applicable here. Such guidance (taken from Lauber and Foushee [1981a]) is provided below, adapted as necessary to the general aviation context and to the needs of the planned evaluation.

Origin, routing, and destination. Consideration must be made of where the scenario will commence, proceed, and terminate. These factors must be planned in view of available routes, pre-flight preparations, navigation constraints, weather, alternate airports, fuel requirements, and ATC exigencies. Pilots should have access to the full range of information necessary to plan and conduct the flight. The choice of origin, routing, and destination should be made on the basis of a consideration of the nature of the general aviation operation to be evaluated. For example, an operation involving a turbojet aircraft equipped with RNAV, DME, weather radar, a two-axis autopilot, and other advanced equipment realistically could be routed directly through moderately adverse weather conditions with the expectation that the pilot would fully exploit such equipment to achieve fuel and time savings. Such routing would be unrealistic for a lower-performance, lesser-equipped aircraft, however. Similarly, it would not be advisable to construct a scenario in which the destination airport included a runway of insufficient length to accommodate a large business jet, unless one wished to determine whether or not the pilot would attempt to operate into such an airport.

Abnormal and emergency conditions. Problems to be inserted into the scenario should be selected on the basis of requirements and objectives identified in the operations analysis. Problems may range from very simple, short-duration events to intricate occurrences that continue throughout the flight. It is generally desirable to employ a wide variety of abnormal conditions, but to do so without detracting from the operational realism of the scenario. Problems should not be unnecessarily complex, nor should too many problems occur simultaneously. However, multiple problems should be allowed to accrue as a result of inappropriate pilot responses to initial adverse conditions. Scenarios should not be designed to "load" pilots such that the occurrence of an accident inevitably becomes the dependent measure. However, the occurrence of accidents should not be prevented, since experience with LOFT has shown that such occurrences may provide valuable diagnostic information. Additionally, the introduction of adverse conditions (such as inoperative equipment) for which

there is no solution may be desirable depending upon the evaluation objectives. Such conditions can increase realism by forcing the pilot to continue an operation as would be done in the real world, and often require the pilot to make judgments and decisions that are not otherwise made. In this sense, irreversible adverse conditions are useful for evaluation purposes. Examples of test conditions that can be loaded into scenarios to increase task demands are shown in Table 6.

Scenario problems can be drawn for such sources as Pilots Operating Handbooks, Flight Operations Manuals, NASA ASRS reports and other flight incident reports, NTSB special studies and accident reports, and reports of research in which pilot performance problems were identified and studied.

Pacing and tempo. Such factors as the departure time and phase of flight should be considered relative to the pacing and tempo of a scenario, and such factors must be consistent with the requirements and objectives of the flight operation. The continual insertion of problems or tasks decreases the realism of a scenario by removing the periods of the flight during which pilots remain relatively idle. Thus, depending on the length of a given scenario, pilots' attention spans should be given the opportunity to lapse by carefully scheduling problem and task insertions. It is also beneficial to incorporate scenario segments that induce stress via the sequencing, pacing, and tempo of problems and tasks. Pilots' ability to cope with this stress while attending to other cockpit resource management responsibilities is a useful index of system performance integrity.

Scenario detail. The airlines' experience with LOFT indicates that scenarios should be as detailed as possible. Not only does the absence of detail detract from operational realism, it also results in a less standardized evaluation procedure, since, without such detailed guidance, the evaluator must decide when and how to structure the scenario for each pilot subject. This sacrifice of standardization obscures valid comparisons of performance occurring among and within scenarios. The pacing and timing of scenario events should be explicitly stated so that the evaluator knows when and how they are to be introduced and evaluated. It is, therefore, useful to include in the scenario script a statement of the expected actions of the pilot under each adverse condition. Such a script is illustrated in Appendix G.

It is often necessary to plan and generate "contingency" scenarios in anticipation of pilot decisions and judgments that occur unexpectedly. In many cases, the exercise of "reasonable judgment" in an approach to a problem would permit a variety of acceptable actions. For example, diversion to an alternate airport, although not required, could be considered an acceptable response to some adverse condition introduced within the scenario. A contingency scenario might then be used to evaluate performance throughout such a diversion leg. Alternate routes and destinations can be used to modify scenario timing and thereby stay within simulator scheduling constraints. Evaluators need the flexibility to omit or extend parts of a scenario when pilot actions dictate a contingency. However, it should be understood that it is not possible to anticipate all pilot actions and contingencies thereof.

The evaluator should never routinely modify a scenario script. If, however, a scenario is observed to be overloaded to the extent that pilots are unable to continue the operation, the evaluator should be allowed to exercise

TABLE 6.--EXAMPLES OF TEST CONDITIONS THAT WILL
INCREASE THE DIFFICULTY OF TASK DEMANDS

Weather

- Wind (e.g., crosswind, gusts)
- Density altitude (e.g., unusually high)
- Barometric pressure (e.g., shifting during the flight to unusually low)
- Turbulence (e.g., clear air, associated with thunderstorms)
- Wind shear
- Wake vortex
- Precipitation (e.g., heavy rain, snow)
- Icing conditions
- Clouds, smog, smoke, fog (e.g., low ceiling, poor visibility)

Air Traffic Control

- Clearances (e.g., incorrect, demanding requirements, poorly timed)
- Communications (e.g., excessive frequency changes, frequent traffic calls, nonstandard phraseology)

Aircraft and Equipment

- Weight and balance (e.g., heavily loaded, aft center of gravity)
- Flight instruments (e.g., subtle, partial failures or complete failures)
- Autopilots/autothrottles (e.g., subtle, partial failures or complete failures)
- Landing gear (e.g., failure to extend)
- Radios (e.g., static, failure)
- Engines (e.g., rough running, failure)
- Electrical system (e.g., loss of power)

Airport

- Facilities (e.g., no visual or instrument landing aids)
 - Runway surface (e.g., slick, sloping)
 - Runway marking and lighting (e.g., limited visual cues for judgment of distance)
 - Surrounding environment (e.g., high obstacles, distracting lights at night)
 - Runway length (e.g., short)
-

reasonable judgment to prevent further compounding of the situation. This can be accomplished by deleting planned problems or through aid rendered within the context of the scenario (e.g., via ATC).

Scenario length. The length of a given scenario should be determined in accordance with two sets of objectives: (1) those of the flight operation on which the scenario is modeled, and (2) those of the evaluation. The increase in the number of general aviation business operations conducted in high performance aircraft equipped with sophisticated avionics likely has resulted in longer routes and a greater number of long distance operations than in the past. A range of trip lengths that are representative of those used by general aviation should nevertheless be employed to generate the set of scenarios. Adequate representation of trip lengths may be governed by the number of scenarios employed and by simulator scheduling parameters.

The scenario to be used for the EFIS exploratory evaluation is shown in Appendix G. This scenario depicts an origin at Teterboro, New Jersey and a destination of Punxsutawney, Pennsylvania, with a diversion to Pittsburgh. The scenario was structured according to the general guidance presented in this subsection. It was designed to include the operational requirements and problems considered to be realistic of those encountered by general aviation pilots who, on a regular basis, operate corporate aircraft equipped with advanced avionics.¹ The operational complexity of the scenario presented in Appendix G was increased by introducing adverse weather conditions and an engine shutdown necessitated by unacceptably low oil pressure during instrument flight in adverse weather. The diversion to an alternate airport (Pittsburgh) is to be accomplished under such conditions (single engine out and adverse weather).

MEASURE DEVELOPMENT. Considerations of measures to be employed during operations-oriented evaluations relate to the determination of the variables that are to be measured and evaluated and how diagnoses are to be made concerning underlying causes for inadequate scenario performance. Following is a brief discussion of (1) identifying scenario variables to be measured, and (2) determining how to diagnose scenario performance.

Identify Scenario Variables to be Measured. One of the goals of operations-oriented evaluation is to assess various decision-making and resource management skills when confronted with unexpected problems. The emphasis upon pilot behavior in the loop is therefore greater than in the evaluation of maneuvers. Often, pilot behavior can be inferred from careful observation of aircraft state throughout the scenario. However, pilot actions and decisions that are considered to be dangerous may not result in the aircraft deviating from the assigned flight path or airspace, but would prove fatal (or potentially so) in combination with other events and conditions. Therefore, the list of candidate variables to be measured should include those related to the pilot as well as the aircraft. One of the advantages of this practice is that the consequences of a given pilot response can be examined relative to the alternatives and information confronting the pilot at the time the response occurred. One of

¹The scenario in Appendix G is predicated on the use of a Cessna 421, a light twin-engine aircraft. However, the use of higher performance aircraft (e.g., turboprops and turbojets) is not precluded.

its disadvantages is that the evaluator cannot make a valid assessment of the efficacy of the response without enabling information pertaining to the rationale for the response at the time of its occurrence and to the acceptability of performance subsequent to the response. Such information necessarily must be developed in post-flight debriefing sessions. The need for such information may create an evaluation bias attributable to hindsight.

Both pilot- and aircraft-referenced variables will be used in scenarios employed for the exploratory evaluation of EFIS. Pilot variables will be limited to observable aspects of control and data entry behavior that comprise the necessary interface between pilot and aircraft. No measures of pilot eye movement, physiological state, or flight control displacement will be taken, for example. However, if a pilot enters an incorrect RNAV waypoint, resulting in the aircraft deviating from a desired course, that data entry error will become part of the overall evaluation of the scenario performance (see Develop Scenario Error Scores).

Determine How to Diagnose Scenario Performance. When properly constructed, scenarios may yield measures that permit meaningful diagnoses of pilot performance. Such measures help to identify specific sources of performance problems associated with the use of EFIS. While the evaluator should not intrude during the scenario, it is helpful to take note of those actions and events that appear to influence the overall success of completion of a scenario. Since correct solutions cannot be specified a priori for many of the problems and contingencies, the evaluator should reflect on the range of potential solutions to such problems and contingencies during the debriefing. After the test session, pilots should be encouraged to present a rationale for their responses based upon the information they possessed at the time of the response. Often the pilot will have more insight into the appropriateness of a given response than will the evaluator.

In the planned evaluation, diagnostic measures will be recorded manually using a standard recording form. The measures will consist primarily of actions and decisions taken by the pilot that appreciably degrade the safe outcome of the scenario as indicated by observable system state deviations (e.g., airspace excursions) during the scenario.¹ Examples of such pilot-related diagnostic measures are: failed to respond to ATC instructions, entered an incorrect RNAV waypoint, or mismanaged the autopilot.

SCORING. After scenarios have been produced and the general domain of flight variables to be evaluated has been identified, the next evaluation step is to generate procedures for scoring scenarios. Because scenarios are designed to provide for behavioral and decisional flexibility, some degree of measurement and scoring uniformity is sacrificed relative to maneuver-oriented flight checks. However, it is feasible to provide a structure for scenario assessment that is consistent with that described for maneuver-oriented checks in Section A. As with flight maneuvers, scenario performances may be assigned error scores as well as Performance Quality Index (PQI) ratings. The following subsections

¹The reader is referred to the Scoring and Data Collection subsections for respective discussions of scenario performance scoring, and the selection and training of evaluators.

describe the development of (1) error scores and (2) Performance Quality Index ratings, both of which will be used for scoring scenario performance.

Develop Scenario Error Scores. Scenario error scores may be derived as for maneuvers described in Section A of this chapter. However, because not all possible alternatives for performing a scenario correctly or incorrectly can be specified beforehand, it is difficult to anticipate and list all of the variables to be measured within a scenario. Thus, the forms for scoring scenario performance cannot be standardized to the extent of the PPDR.

It is possible to provide a sufficient degree of structure to gain valuable insight into performance error by providing the evaluators with a structured form for recording errors. Such a form is illustrated in Figure 7. This form provides the evaluators with spaces to describe unacceptable pilot actions during a given flight segment as well as system state deviations. System state deviations and unacceptable pilot actions may be defined by using desired values and tolerances published in Pilots' Operating Handbooks, Flight Test Guides, and other sources of operational data. It is sometimes necessary, however, to define these values analytically.

SEGMENT	PERFORMANCE ERRORS			PQI RATING
	UNACCEPTABLE PILOT ACTIONS	SYSTEM STATE DEVIATIONS		
		TYPE A	TYPE B	
CLIMB	● SET UP AUTO-PILOT INCORRECTLY ● FAILED TO ANSWER ATC	● AIRSPEED 5 KTS LOW ● HEADING 10° OFF	● INTERCEPTED R 122 (SID SPECIFIED 132)	3

FIGURE 7.--EXAMPLE OF ONE SEGMENT OF THE SCORING FORM FOR SCENARIO PERFORMANCE EVALUATION.

To assess performance on the scenario shown in Appendix G, error scores will be derived by recording pilot actions and decisions that result in system state deviations for each segment of the scenario. These unacceptable pilot actions will be tabulated for each segment and for the entire scenario, and their sum will represent one error score. Additionally, the system state deviations will be classified as Type A or Type B errors depending on their severity, and tabulations of each error type will be made for each segment. These tabulations will constitute a second error score.

Develop Performance Quality Index. Like maneuver-oriented evaluations, minimum performance criteria are needed to determine whether overall scenario performance is acceptable (passing) or unacceptable (failing). To this end, a Performance Quality Index (PQI) rating will be assigned to observed performance within each scenario segment. A scenario segment will receive a rating of "4"

if it contains an accident; "3" if an incident occurs (i.e., Type B system state deviation); "2" if a deviation from desired system state (i.e., Type A system state deviation) is observed; and "1" if no system state deviations occur. The overall PQI for the scenario will be driven by the highest (i.e., poorest) segment PQI rating contained therein. For example, any segment PQI rating of "3" would result in an overall PQI rating of "3" for the scenario, assuming that no segment PQI rating of "4" was assigned to a subsequent segment. Like maneuver-oriented PQIs, acceptable (passing) scenario performance will be defined by an overall PQI of "1" or "2", and unacceptable (failing) performance will result from an overall PQI of "3" or "4". Where PQI ratings of "3" or "4" signify critical system state deviations within a segment, unacceptable pilot actions related to those states will be analyzed for diagnostic purposes. Additionally, profile analyses (Nunnally, 1967) will be performed on all segment PQI ratings. Figure 7 shows how a PQI rating would result from system state deviations. In this example, a Type B (airspace) deviation has resulted in a segment PQI rating of "3" (failing). To summarize, pass/fail scores will be derived from overall scenario PQI ratings which, in turn, will result from segment PQI ratings. Any PQI segment rating of "3" or "4" will constitute a failing scenario performance.

DATA COLLECTION. As with maneuver-oriented data gathering, four general considerations will be addressed relative to operations-oriented evaluations. These consist of (1) developing data collection systems, (2) selecting and training evaluators, (3) developing a testing schedule, and (4) developing and using quality control procedures.

Develop Data Collection Systems. As earlier noted for the scoring performance error within scenarios, some measurement uniformity is sacrificed when attempts are made to assess scenario performance. This is due to the fact that a major objective in the scenario evaluation process is to allow flexibility and spontaneity of pilot response. In this sense, scenario evaluation is somewhat more "open-ended" than maneuver evaluation, and the forms that are developed and used to collect data generally reflect this. However, if adequate parameters regarding performance error are furnished to evaluators, appreciable structure and objectivity in the recorded data may be achieved.

An example of one segment of the scoring form to be used in the evaluation of scenarios is shown in Figure 7. As previously discussed, two types of performance error information will be derived--error attributable to unacceptable pilot actions, and that reflecting system state deviations. Each of these errors will be taken across all scenario segments, and each will influence the PQI rating as described in the previous subsection. The form will be comprised of fifteen scenario segments with provisions for additional segments as pilot decisions and responses dictate. Recordings of unacceptable pilot actions will be made by two evaluators while Type A or B system state deviations and PQI ratings will be assigned by a third evaluator.

Select and Train Evaluators. The evaluator has two roles in the operations-oriented flight check. First, he is responsible for administering the script. This means that he must decide spontaneously whether to permit a script digression to occur. If the digression is permitted, he must furnish necessary enabling information. As script administrator, the evaluator must be thoroughly familiar with the simulator's characteristics and capabilities. The second role of the evaluator is to assess the safety and proficiency of ongoing

scenario performance relative to the evaluation guidance with which he is provided and on which he is thoroughly trained.

In the planned EFIS evaluation, three evaluators will be used to observe and record performance. Evaluators will have an air transport pilot certificate. They will undergo two weeks of familiarization training designed to enhance their use of the script and scoring form. During this training, they will be provided with guidelines for evaluating scenario performance. Included in these guidelines will be performance measures and error parameter definitions. This indoctrination is to promote evaluator standardization so that observed performance differences can be ascribed reliably to differences in aircraft equipment rather than to interpretational and recording errors by evaluators. Recordings of unacceptable pilot actions will be made by two evaluators. One of these evaluators also will be responsible for administering the script. Type A and B system state deviations and PQI ratings will be assigned by a third evaluator. In addition to the three evaluators, an experienced flight simulator instructor will be responsible for equipment operation including the standard introduction of adverse conditions into the scenario and the simulation of ATC communications.

Develop Testing Schedule. In the planned evaluation, each data collection session will be approximately four hours in length based upon the scenario presented in Appendix G. Approximately one hour of that time will be used for briefing and debriefing subjects as well as for evaluator debriefing concerning performance recordings. Two sessions will be scheduled daily. All scheduling revisions will have to be approved by one of the evaluators.

Develop Quality Control Procedures. One of the evaluators will be assigned the responsibility of maintaining quality control for all incoming data. That evaluator will review all recording forms at the completion of each scenario run to ensure that each form is complete and that its data are accurate. Incomplete or inaccurate data acquired by any evaluator will be discussed promptly and corrected as necessary. All completed data forms will be filed in one standard location and will be regularly inspected and reviewed by research personnel.

DATA ANALYSIS. The final step in operations-oriented evaluation consists of analyzing the scenario data acquired. As with maneuver-oriented evaluation, questions to be addressed by the analysis should be considered early during the experimental design phase (Chapter III). In the planned evaluation, data analyses will consist of descriptive rather than evaluative performance comparisons. The general activities to be discussed relative to scenario data analysis are (1) describing observed differences, and (2) generating performance error descriptions.

Determine Observed Performance Differences. Performance error may arise from multiple factors in the operating environment which create a mismatch between pilot capabilities and task demands (Shelnutt et al., 1980). Often it is not possible to determine the exact nature of this relationship. Reports of accidents and incidents, for example, rely primarily on inferences and deductions drawn from observational data. While it is not possible to identify functional relationships between errors and antecedent conditions on the basis of accident and incident data, such information can be very useful for identifying problem areas and error-producing conditions in the pilot-aircraft-ATC interface. For example, analyses of profile descents revealed observed differences

among several major problem areas related to the use of charts and procedures, and to ATC communications (Cheaney and Billings, 1980). Empirical data gathered during full mission simulations (Smith, 1979) indicated observed differences in overall crew performance under low and high workload conditions. Such differences provide a foundation for generating hypotheses concerning specific relationships between accidents or incidents and their antecedent conditions. This type of analysis, which long has been used in accident investigations, would seem to be best suited to the evaluation of scenario performance.

In the planned evaluation, a major descriptive comparison of interest will be the incidence and nature of system state deviations associated with PQI ratings of "3" or "4" for the two major evaluation groups. Such a comparison will be made for each segment of the scenario and should provide useful information for generating a taxonomy of system errors that appear to be unique to the use of EFIS. Additionally, unacceptable pilot actions leading to critical (i.e., Type B) system state deviations will be of interest. The analysis will be conducted much like an accident investigation in that inferences will be made about causal and contributing factors surrounding critical system outcomes. Thus, the frequency and pattern of system state deviations will be of interest relative to a particular outcome (e.g., accident or incident). The identification of system state deviations and unacceptable pilot actions that appear to relate strongly to such deviations are considered to be a crucial prerequisite for identifying performance evaluation standards for EFIS and conventional displays. Such an approach also would appear to offer the potential for yielding useful data within other types of aviation system evaluations.

Determine Performance Error Descriptions. Smith (1979) described errors that occurred during scenario performances and assigned them to one of nine error categories. These categories and the error frequencies contained within each category are shown in Table 7. It can be seen that errors in tactical decisions (Category 5) occurred more frequently than those of the other categories. Some errors considered to be detrimental to the safe outcome of the scenario were termed "significant" errors. Such errors mainly occurred in Categories 1, 3, 4, and 5. Examples of these significant errors were: tuned wrong outer marker; used wrong VOR to identify intersection; missed turning point/fix by 10 miles; started climb before clearance from ATC; inserted wrong waypoint and deduced wrong position; used wrong flight director computer; overboosted engines; and activated ground proximity warning system during approach. The comparability of these errors to those observed during European flight operations (Smith, 1979) several years prior supports the use of error taxonomies, especially those for identifying and describing significant (i.e., critical) error.

In the planned evaluations, performance data will be arrayed to describe both system state and pilot behavioral categories of error. System state deviations that do not result in excessive risk to the pilot and aircraft will be identified as Type A deviations. Deviations that do result in such risk (e.g., airspace excursions) will be designated as Type B (i.e., critical) deviations.

Unacceptable pilot actions that are associated with Type A or B errors also will be described. These performance errors will be described for both EFIS and conventional display evaluation groups across each segment of the scenario.

TABLE 7.--ERROR FREQUENCIES BY CATEGORY IN THE SMITH (1979) STUDY

ERROR CATEGORY	FREQUENCY	DESCRIPTION/EXAMPLES
1. Navigation	54	selected wrong frequency, radial, or heading; selected new facility at wrong time; misread charts
2. Communication	40	selected wrong frequency; failed to reply to ATC; misunderstood ATC message; used wrong call sign; forgot to comply with message
3. Systems Operation	64	mishandled engines, hydraulic, or fuel systems; misset instruments; failed to use ice protection
4. Flying	52	used incorrect parameters; neglected speed limits; flew at wrong altitude
5. Tactical Decisions	124	fuel dumping (wrong amount or time); miscalculated values of gross weight, correct flap setting, and automatic braking
6. Crew Integration	13	failure to use onboard equipment (e.g., autopilot) to optimize workload
7. Flying Skill	51	unable to control aircraft to desired parameters (e.g., failed to maintain altitude within 250 feet)
8. Autopilot	25	autopilots incorrectly sequenced or otherwise misused
9. Other	27	failure to brief passengers concerning turbulence; poorly organized charts

C. CONCLUSIONS.

The following conclusions were derived from the information that has been presented in this chapter. The first set of conclusions pertains to the conduct of maneuver-oriented evaluations, while the second set relates to operations-oriented evaluations.

GENERAL CONCLUSIONS FOR CONDUCTING MANEUVER-ORIENTED EVALUATIONS. The following general conclusions were drawn concerning the conduct of maneuver-oriented evaluations.

1. Maneuvers to be evaluated should be selected on the basis of the extent to which they require skills that are deemed critical for operating corporate aircraft. These skills can be assessed by testing the pilot in a wide range of basic and advanced maneuvers under various favorable and adverse test conditions.

2. Maneuvers should be segmented for evaluation purposes. Segmentation increases the manageability of evaluation by reducing the maneuvers into elements that can more readily be observed and recorded.

3. Maneuver-oriented evaluations should be focused upon aircraft state rather than pilot behavior. An appreciable range of pilot responses may lead to the same acceptable (or unacceptable) system outcome as indicated by measurable states of the aircraft. With few exceptions, aircraft state represents a high-fidelity measure of pilot control inputs, procedures, and decisions.

4. Each flight variable to be sampled within a maneuver should have a desired value (or state) and tolerance level specified for each sampling point. Such explicit evaluation criteria are required if comparisons based on valid performance measures are to be made.

5. Maneuver scores should reflect both the frequency and criticality of performance errors. Error rates resulting from the use of objective measurement techniques are useful for rendering performance discriminations, but their relationship to operational criteria such as accidents and incidents is largely unknown. To achieve operational significance, pass/fail scores based on error criticality are needed as well.

6. The efficient collection of maneuver data requires thorough and careful pre-experimental planning and coordination. Specifically, scoring forms must be developed and produced, performance evaluators must be selected and trained in the use of the forms, data collection sessions must be carefully scheduled and adhered to, equipment must be procured and prepared, and quality control must be maintained for all incoming data.

7. In addition to statistical comparisons of treatment groups, maneuver data analyses should identify those flight variables and conditions that are critical to the successful outcome of a maneuver performance. The identification of such variables and conditions can be used to guide future performance measurement.

GENERAL CONCLUSIONS FOR CONDUCTING OPERATIONS-ORIENTED EVALUATIONS. The following general conclusions were drawn concerning the conduct of operations-oriented evaluations.

1. Efficient scenario development requires a knowledge of the skills necessary for conducting an entire flight operation. Scenario realism and detail are achieved through a recognition of, and provision for, such factors as aircraft systems operations and procedures, pilot capabilities, ATC variables, and constraints related to routes, weather, traffic, navigation facilities, and airport conditions.

2. Scenarios should be sufficiently flexible to permit the assessment of pilot decisions and actions when they are confronted with emergencies and contingencies. While scenarios must be structured, performance evaluators should have the prerogative of omitting or extending scenario segments to accommodate such contingencies.

3. Variables to be measured in operations-oriented evaluations should pertain to both the pilot and the aircraft. The measurement of pilot variables is desirable in that the consequences of a response or decision can be assessed relative to the alternatives confronting the pilot when the response or decision occurred. Aircraft measures provide a clear indication of the outcome of those pilot decisions and responses.

4. Scenario scores primarily should reflect system performance error criticality. Such scores should indicate whether minimum operational performance criteria for system outcome have been met. Criteria should be specified for each scenario segment, and pass/fail scores based on those criteria should be assigned. Of interest for diagnostic purposes are pilot actions and decisions that accompany unacceptable system outcomes.

5. Scenario data collection involves substantial attention to detail to create the illusion of reality. ATC communications must be credible and realistic, evaluators must be carefully trained in both the administration and evaluation roles, script digressions and simulator malfunctions must be anticipated, subjects must be thoroughly briefed and provided all necessary flight planning information, recording forms must be readily available, and quality control over incoming data must be maintained.

6. Scenario data analysis should primarily be descriptive rather than evaluative. Because of the lack of rigid control over scenario performances, it is recommended that the data analysis be limited largely to descriptions of observed differences in group performance error and of error patterns within groups.

V. DETERMINATION OF REQUIREMENTS FOR TEST FACILITIES AND EQUIPMENT

Previous chapters have outlined some of the advantages that would accrue from use of a simulator as the vehicle for the planned exploratory evaluations. Its advantages in terms of the range of situations and conditions that can be presented and the degree of experimental control it affords are obvious. The use of an aircraft in such evaluations, however, should not be precluded from consideration. Indeed, use of both an aircraft and a simulator, while not included in the design of the planned evaluations as presented here, would provide data that could not be obtained if only one type of test vehicle were employed. Such aircraft studies, though, are viewed as more appropriate for later efforts than for the immediate evaluation plan.

The relative cost of simulator and aircraft test vehicles is not a simple matter. There is substantial expense associated with the use of either an aircraft or a simulator. Given the cost constraints inherent in general aviation research, a thorough examination of requirements for the test vehicle and their cost implications is in order. Therefore, in the following two sections certain aspects of these requirements are addressed. The first section (Section A) contains a review of the potential advantages and disadvantages associated with the use of simulators as vehicles for assessing pilot proficiency. It also contains a discussion of issues in the design of such simulators as well as recommendations for simulators that could be employed in the planned exploratory evaluations. Section B discusses the benefits and problems associated with the use of aircraft for proficiency testing and considerations related to the design of aircraft that could be employed in the planned evaluation.

A. USE OF SIMULATORS AS TEST VEHICLES.

Recent advances in simulation technology have enabled the development of aircraft simulators that provide high fidelity reproductions of the pilot's environment.¹ Such advances also have enabled the development of simulator control features--referred to as instructional support features--that facilitate the use of simulators both for training and for assessing pilot performance.² Use of these advanced fidelity and instructional support features will facilitate presentation of the wide variety of flight conditions that have been recommended for use in the maneuver- and operations-oriented checks during the evaluations.

¹A detailed discussion of advanced simulation technology that has enabled increased simulator fidelity can be found in Semple, Hennessy, Sanders, Cross, Beith, and McCauley (1981).

²A detailed discussion of such features and their use in training and proficiency assessment can be found in Caro, Pohlmann, and Isley (1979); Semple, Cotton, and Sullivan (1981); and Caro, Shelnutt, and Spears (1981). While the use of such control features is discussed in this chapter with reference to the assessment of pilot performance, the term "instructional support features" will be used since it is the most widely accepted label for such equipment.

Such devices and features will enable evaluators to set up the specific conditions that are desired for each maneuver or scenario segment. Further, they will be able to control the evolution of such conditions during simulated flight. Such control over test conditions is crucial to the evaluation design, since any unwanted variance in these conditions would confound the determination of differences in pilot performance due to flight instrument and control systems. Such precise experimental control would be very difficult to attain if aircraft were employed in the evaluation.

Moreover, the use of an aircraft would prevent, or at least complicate, the testing of pilots in many of the potentially dangerous conditions described in Appendices E and G. Since the creation of situations in which pilot performance problems are likely to arise is crucial to the objectives of the evaluation, the capability to create such conditions in a safe environment constitutes a decided advantage for simulators.

Simulators also provide several other advantages, in comparison with aircraft, with respect to the assessment of pilot performance. For example, observation of pilot performance in aircraft often is hindered by the need for the observers to act as copilots and assure safe flight, particularly during simulated IFR flight when the pilot being tested is fitted with a device to restrict his view outside the cockpit. Safety of flight and other distractions attendant to use of the actual aircraft (e.g., a cramped, noisy cockpit) are problems, even if a third individual serves as evaluator.

In contrast, evaluators in well-designed simulators generally are not subjected to such distractions. Furthermore, the presence of instructional support features in simulators facilitates the assessment of pilot performance. Such features include displays at the operator station that enhance the ability of the evaluator to observe and measure system performance. Such displays and other useful features will be discussed later in this section. The point to be made here is that the evaluator receives assistance in the simulator that is unavailable or very expensive to provide in the aircraft.

The simulator also enables the evaluator to observe the ultimate consequences of a pilot's error. In many instances in actual flight operations, the pilot makes an error and corrects the error before any serious consequences occur. In other instances, such errors may not lead to serious consequences, even if uncorrected, because they are of noncritical nature--at least with respect to the current flight situation. In yet other instances, however, pilot errors may result in system deviations that are sufficiently severe to be classified as incidents or accidents (as discussed in Chapter IV with respect to Type B errors and the Performance Quality Index).

During the conduct of flight checks in aircraft, the evaluator usually must correct the errors of the pilot being tested or even take control of the aircraft when an error has the potential to put the aircraft at an unacceptable level of risk. In the simulator, however, simulated flight may be allowed to continue to determine the actual consequences of an error.¹ The

¹Substantial disagreement exists concerning whether pilots should be allowed to "crash" simulators during training, particularly during LOFT sessions (Lauber and Foushee, 1981a). Such crashes may have potentially detrimental effects on the pilot undergoing instruction (e.g., loss of confidence). Care should be taken to identify and prevent any such undesirable effects during the conduct of the planned evaluations.

determination of such consequences allows the practical significance of an error to be analyzed.

Finally, the use of simulators can provide certain cost advantages relative to the use of aircraft. However, as noted, such relative cost advantage is not a simple matter. In air carrier and military aviation the substantial expense associated with acquiring, operating, and maintaining air transport and military aircraft usually provides a clear cost advantage to the use of simulator over aircraft. Since such costs are much lower in general aviation, though, the relative cost advantage of simulators over aircraft can be less substantial. Nevertheless, there are other expenses associated with the use of even general aviation simulators that are much lower than analogous costs associated with the use of aircraft. For example, simulators can be utilized on a schedule designed to optimize the efficient use of research resources; simulator test schedules are not interrupted by the many factors that frequently interfere with aircraft operations--such as bad weather or runway repairs; and the simulator can be utilized more efficiently than an aircraft during the conduct of the proficiency checks. With respect to maneuver-oriented checks, for example, increased efficiency can be attained by eliminating the time between maneuvers when the aircraft is flown to the proper altitude and geographic location for the next test situation--more testing can be done in less time. Such efficiency reduces personnel and other costs associated with the evaluation.

Such advantages of simulators have resulted in their increased use in pilot training and proficiency assessment, both in general aviation, and in the rest of civil and military aviation. The use of simulation in research and development efforts also is increasing. Simulators, for example, played a major role in the development of the air transport EFIS and other advanced air transport displays such as heads-up displays (HUDs). There is also growing interest in expanding the use of simulators in the certification of air transport aircraft (McLucas, Drinkwater, and Leaf, 1981).

Such advantages make the simulator the primary choice as a test vehicle in the planned exploratory evaluations. Several issues, however, are raised by this selection. These issues relate to requirements for fidelity and instructional support features for simulators that could be used in the evaluation.

FIDELITY REQUIREMENTS. As discussed above, advances in simulation technology have enabled the development of simulators that provide quite complete and high fidelity reproductions of the pilot's airborne environment. Such technology can be very expensive, however, and given the limited resources available for general aviation research, cost is a matter of particular concern. Thus, the determination of fidelity requirements necessary to the evaluation and their cost feasibility is a major issue in the selection of simulators for use in the planned research.

Such a determination must be based on requirements that are implied by the principal goal of the planned evaluations, which is to identify major benefits and problems that may accrue from use of the EFIS in the diverse flight operations common in corporate aviation.¹ To attain this goal, the evaluation

¹As discussed in Section E of Chapter II, programmatic research is needed to address a wide range of research questions associated with the use of EFIS as well as other advanced cockpit technology. As such, selection of a research vehicle should reflect the more general goals of such a program of research, as well as the specific goals of planned exploratory evaluation.

must cover a fairly wide sampling of maneuvers and flight conditions. Further, it is necessary to the evaluation that pilots respond to the task demands created by these simulated flight situations in substantially the same manner as they would in an aircraft.

Thus, for each of the flight situations that are tested, the simulator must present cues that are the major determinants of pilot behavior in those situations in the aircraft. On a simple level, this means that the pilot should be presented with cues in the simulator that would be available and are effective in the aircraft. If a visual landing is required, for example, the pilot needs to be presented with a visually simulated runway. If acceleration cues are important, as in the response to externally caused deviations in aircraft attitude, then the pilot should be given those cues. The broader the range of flight situations that are simulated, the greater the need for diverse fidelity features that simulate the wide variety of cues needed by the pilot in the aircraft. If all of the maneuvers and conditions described in Table 3 and Appendices E and F are to be tested, the simulator used in the evaluation must be capable of providing the full range of salient cues used by the pilot in those flight situations.

Simulation systems that produce such cues, however, vary considerably with respect to the fidelity with which they replicate the real world cues. Simulation of certain acceleration cues, for example, may be provided by relatively low cost, two-axis systems that simply tilt the simulator during turns or climbs and descents. More sophisticated motion simulation devices, such as the so-called "six-degree-of-freedom" motion platforms used in many air transport aircraft simulators, provide a greater variety of acceleration cues, and through the use of sophisticated software programs, they are able to provide much more realistic cues.¹

The fidelity with which acceleration (and other) cues are simulated does have an impact on the way the pilot responds to the situation being simulated. Differences in such responses between the aircraft and a simulator have the potential to confound the analysis of the influence of EFIS and other flight instruments on pilot performance. Work at the University of Illinois, for example, revealed that the presence or absence of motion cues, as well as the type of motion cues that are provided, has a significant impact on the pilot's ability to use different types of attitude indicators (Ince, Williges and Roscoe, 1975; Jacobs, Williges, and Roscoe, 1973; Roscoe and Williges, 1975).

Simply stated, the performance of pilots in simulators that did not have motion systems or that provided distorted acceleration cues differed significantly from the performance of the same pilots in aircraft or in simulators with more sophisticated motion systems. The specific source of this difference is, at present, unknown. Relevant to the present context, however, the important point is that such differences confound the analysis of variations in pilot performance that may be attributed to the flight instruments that are being studied.

¹Discussion of the different types of motion simulation devices can be found in Semple, Hennessy, Sanders, Cross, Beith, and McCauley (1981).

It should be noted that the Illinois research studied the ability of the pilot to restore an aircraft to a level attitude following externally-caused deviations in the roll axis. The maneuver in which the pilot performs this specific task appears to be influenced substantially by the presence of whole-body acceleration cues that enable the pilot to detect such deviations rapidly and efficiently. In contrast, the performance of other significant piloting functions, such as certain navigation tasks, would appear to be less influenced by acceleration cues. Thus, requirements for the fidelity with which cues are simulated depend, to a great extent, on the particular set of tasks that the pilot is asked to perform.

In summary to this point, the definition of fidelity requirements necessitates (1) the identification, for each task that is to be tested, of cues that are major determinants of pilot behavior, and (2) the determination of the level of fidelity necessary to assure that the pilot performs in substantially the same way in the simulator as he does in the aircraft. Unfortunately, such determinations are difficult to make since there are no comprehensive empirical data bases or analytical models that can be used to support decisions concerning fidelity requirements (Semple, Hennessy, Sanders, Cross, Beith, and McCauley, 1981).

The lack of such information has long plagued personnel responsible for the design and use of simulators. To address this problem, various military and civilian research organizations have sponsored and continue to support extensive investigations of fidelity requirements for simulators that can be used in research and development or in pilot training (such research is reviewed in Baron, Pew, and Zacharias, 1980; Prophet, Shelnutt, and Spears, 1981; Semple, Hennessy, Sanders, Cross, Beith, and McCauley, 1981).¹ Precise, objective methods of determining fidelity requirements, however, will not be available for a considerable time.

Given the lack of precise methods, determination of simulator fidelity requirements for the EFIS evaluations must be based on a more general, subjective analysis of cue requirements and, to be practical, of potential resources for the planned evaluations. Such an analysis was conducted during the present project, and two basic approaches to specifying fidelity requirements were developed, both of which are described below. In the first approach, requirements for a high fidelity, general aviation simulator were developed. The second approach was to define the subset of flight situations that could be assessed in lower fidelity simulators and to determine if the limitations imposed by the lower fidelity would vitiate any possible benefits that could be obtained from the evaluation.

Use of A High Fidelity Simulator. It is well within the current state of the art in simulation technology to produce a simulator with sufficient fidelity to enable the assessment of all of the flight situations specified in this report for the maneuver- and operations-oriented proficiency checks. In general, such a device should have the following characteristics. (1) The device should simulate a common, twin-engine corporate aircraft in which first

¹Fidelity requirements for simulators used in research on pilot performance can be, and often are, greatly different from requirements for simulators used in pilot training (Shelnutt, Smillie, and Bercos, 1977).

generation EFIS are likely to be installed. (2) The simulator should be capable of having both EFIS and conventional flight instruments installed in it.¹ (3) It also should be capable of having the different automated flight control systems installed in it.² (4) The EFIS system that is simulated should have the same quality display that is possible in the aircraft. (5) The simulator should have a visual system, a motion system, handling characteristics, and other fidelity features that meet FAA Phase III requirements (as specified in FAR, Part 121.407, Appendix H). (6) The simulator should have the capability of being connected to the ATC Simulator at the FAA Technical Center. Such a linkage would enable problems arising from pilot-controller interactions to be studied that perhaps would not be detected if ATC communications are simulated by the simulator operator.

The government does not own a general aviation simulator that completely meets these requirements. Such a simulator, while expensive, would constitute a national resource that could be used by government and industry to address many of the research questions identified in this report and numerous other airman research questions associated with pilot training, operating procedures, and other factors influencing pilot performance (as identified in Shelnutt et al., 1980).

Such a simulator could be acquired for research in two ways. The government could purchase such a simulator and install it in one of their research laboratories. The government also could lease simulators that meet most of the above requirements from commercial pilot training organizations. Some of these organizations plan to acquire high fidelity simulators for selected corporate aircraft in the next five years or so. It is highly likely that one or more of these devices will simulate an EFIS-equipped aircraft. While leasing such a simulator would reduce capital expenditures associated with purchasing and maintaining a government-owned device, use of commercial simulators presents several problems. Such devices, for example, will probably be more difficult to modify to enable EFIS and conventional flight instruments to be tested. Additionally, since high fidelity simulators are relatively rare in general aviation and the demand for their use is predicted to be high, it may be difficult to find an organization willing to lease such devices for research for a substantial amount of time. Further, the use of such devices for research would have to be coordinated with, and perhaps even subordinated to, scheduled use of such devices for training (which, after all, is the main source of revenue for the commercial organizations).³ Although these and other less

¹The most feasible method of comparing performance across these instrument systems would be to install one system in a simulator and complete all the training and testing that is required, then install the second system. A less desirable approach would be to install one system in front of the left seat and the other in front of the right seat in a simulator capable of being flown from either seat. A third approach, of course, would be to employ two simulators.

²Another approach would be to degrade the capabilities of the most advanced system so that it simulated the basic autopilot.

³An alternate source for an EFIS-equipped simulator may be the avionics manufacturers who are building these systems or airframe manufacturers who are building EFIS-equipped aircraft. At present, none of these organizations has plans for a high fidelity device, but many do plan to build lower fidelity devices for use in their own development projects and in marketing.

major problems exist, they can be circumvented in part by modifying the design of the evaluation.

In conclusion, a high fidelity simulator is recommended primarily because such a device would enable a wide range of maneuvers and conditions to be tested. Use of such a simulator would also maximize the probability that a wider range of performance problems that have the potential to arise in aircraft are identified during the evaluation. Further, the fidelity of the simulator used in the production probably will influence the acceptance of the results of the evaluation by the general aviation community.

Use of Lower Fidelity Research Simulators. Both the FAA and NASA have general aviation simulators which, although they do not meet all of the fidelity requirements specified in the preceding subsection, could be used in the planned exploratory evaluation. General aviation simulators located at the FAA Technical Center (i.e., the "B" system of the Advanced Concepts Cockpit Facility) and NASA's Langley Research Center, for example, already have advanced pilot-aircraft interfaces (e.g., cathode ray tube displays) installed in them. Thus, they could be employed, with some modifications and other preparations, for research much sooner than would be possible if the government purchased or leased a new simulator.

The existing FAA and NASA simulators have roughly comparable levels of fidelity. As stated above, they both employ cathode ray tube displays, symbol generators, and digital computers that could present display formats similar in nature to those that will be presented by the first generation EFIS. At present, however, these display systems employ out-of-date technology that does not enable high resolution, full color EFIS displays to be reproduced exactly. Plans currently exist at both the FAA and NASA facilities to install new display systems.

The FAA simulator does not, at present, have a system capable of simulating a full range of external visual cues. The NASA simulator, on the other hand, does have a terrain model board visual system (although this system does not meet Phase III requirements). Some of the tasks and conditions that are recommended for use in the planned evaluation could be conducted in a simulator without a visual system--i.e., the maneuvers that require no external visual cues. The addition of even a minimal system (e.g., a system such as the one that may be used with the NASA simulator) adds considerable capability to these simulators. For this reason, the FAA is, at present, considering the addition of a visual system to its simulator.

The NASA and FAA general aviation simulators have relatively low fidelity motion systems (i.e., two degrees of freedom). However, extensive and expensive facility modifications are required to add or upgrade the capabilities of motion systems. As a result, such modifications are not planned by the research organizations.

Both the FAA and NASA simulators, since they are currently being utilized for diverse projects, are continually undergoing modifications to alter their fidelity features--e.g., changes in aerodynamic equations to alter simulator handling qualities. Since such modifications usually improve the fidelity of the devices, they enhance the utility of the simulators for the planned evaluation. Unfortunately, such modifications can also create problems if they continue during the planned evaluations.

In conclusion, existing general aviation simulators at the FAA Technical Center and NASA Langley Research Center could be employed advantageously for the planned evaluations. Use of these devices, as they now exist, would be less expensive than constructing a new simulator since acquisition costs associated with the new simulator are eliminated, and the government already has support facilities and staffs required for their operation and maintenance. Further, research could commence in the near future, a decided advantage given the nearing introduction of EFIS into the general aviation fleet.

It must also be noted, however, that the existing simulators do not, at present, have the capability to reproduce the first generation EFIS displays exactly. Nor do they have the sophisticated visual or motion systems needed to produce the cues required for several of the flight situations that are recommended to be tested. Thus, the set of flight situations to be tested would be smaller if these devices were used than if more sophisticated devices were employed. Reduction in the number of the flight situations sampled decreases the probability that major pilot performance problems will be identified.

Such limitations, however, do not prevent a number of important benefits to be derived from an evaluation conducted in these simulators. The changes in the pilot's role due to the introduction of EFIS and advanced automated flight control systems are very general and wide ranging. As a consequence, it is highly likely that many of the pilot performance problems that may be identified also will be very general and wide ranging. For example, the previously cited research by NASA on the use of advanced autopilots revealed several fundamental pilot performance problems that may represent serious safety problems (Bergeron, 1980a).

Since the results of the NASA work are preliminary, these problems need to be subjected to further investigations. However, the NASA research, which was conducted in the simulator described above, did serve as a screening mechanism to detect such problems. Similarly, conduct of the planned exploratory evaluations in lower fidelity simulators would enable many flight situations to be screened and potentially critical problems to be detected. Given the urgency for studies to determine whether advanced cockpit technology creates new problems for pilots, such screening represents an efficient method of getting such research underway.

REQUIREMENTS FOR INSTRUCTIONAL SUPPORT FEATURES. The fidelity of a simulator is a principal factor in determining the size and nature of the sample of flight situations that can be tested. Its instructional support features, on the other hand, influence how efficiently and effectively pilot performance can be assessed in the situations that are sampled. More specifically, these features influence the ability of the evaluator to set up and control the conditions under which pilots are tested, and to monitor and evaluate pilot performance. The next two subsections discuss the instructional support features of the simulator and their utility in the planned evaluations. Additionally, as will be discussed in Chapter VI, the simulator used in the evaluations also will be used to train the pilots who serve as subjects. Thus, the final subsection briefly reviews additional instructional support features that should be available for use during this training.

Features That Aid in the Control of Test Conditions. To facilitate the evaluator's (and simulator operator's) ability to control test conditions, the

simulator used in the planned evaluations should have the following features: (1) manual and programmable sets of initial conditions; (2) manual and programmable malfunction control; (3) simulator "freeze" control; (4) "fast-time" capabilities; and (5) manual and automated control of other air traffic.

Manually inserted or programmed initial condition sets enable the evaluator to select conditions and set up the simulator for the scenario or for each of the maneuvers to be tested. These features, for example, increase the efficiency with which the evaluator is able to set up initial aircraft characteristics (such as aircraft weight, fuel status, speed, altitude, and geographic location) and environmental conditions (such as the weather at destination airports or in which the aircraft is flying). Programmed control of initial condition sets is useful because it automatically sets diverse aircraft and environmental parameters to predetermined specifications. Manual control of condition sets also is useful since this feature allows the evaluator or operator to make desired changes in conditions while a simulated flight is in progress--e.g., to simulate the sudden loss of visibility. Considerations in the design of these features (e.g., the use of computer driven displays to present menus of test conditions) are discussed in Semple, Cotton, and Sullivan (1981).

Similar to initial condition control, manual and programmable malfunction control aids the evaluator by enabling him to modify test conditions to simulate the failure of airborne equipment or other types of malfunctions (e.g., runway lights or navaid failures). Automated malfunction control is particularly useful, since this feature can create malfunctions at a predetermined time after the start of a flight or at predetermined locations in the flight profile. Such automation reduces the demands placed on the simulator operator and facilitates standardization of the test conditions.

Simulator "freeze" controls enable the evaluator to stop simulated flight at any point desired. This feature can be used during the maneuver-oriented checks to stop the simulator when the pilot has completed a desired portion of the flight profile (such as indicated by the end points described in Appendix F). The freeze control also can be used at the start of each maneuver while the pilot is being briefed. By using freeze, the evaluator will be able to show the pilot the aircraft performance parameters (e.g., airspeed, altitude) that exist at the beginning of the maneuver.

The "fast-time" feature enables portions of the simulated flight to be condensed in time. That is, the simulated aircraft can be advanced more rapidly along the flight path than would be possible in the actual aircraft (with fuel remaining and aircraft weight changing accordingly). This feature is used by some airlines during LOFT to reduce the "dead time" spent enroute when the pilot is simply tracking a desired course. If this feature is used in the operations-oriented evaluation, care should be taken that it does not disrupt the pacing and timing of the scenario.

Some of the flight situations described in Appendix E require the simulation of other air or ground (on the runway) traffic. To simulate such traffic, the evaluator may need the capability to be able to control the movement of these other aircraft. Such control can be accomplished manually through the use of a joy stick or other control devices at the operator station. It may also be

accomplished automatically through the use of algorithms that enable the computation of the flight profile of the other traffic. Finally, it may be accomplished through a link-up with the FAA's ATC simulation facility located at the FAA Technical Center.

Features That Facilitate Monitoring and Assessing Pilot Performance. At a minimum, the recording forms that will be used to collect data during both the maneuver- and operations-oriented checks require that the evaluator be able to view the actions of the pilot; observe flight instruments and the settings of other cockpit displays and controls; and view the external visual scenes that are provided to the pilot. These requirements may be met by placing evaluators in the copilot seat or in a jumpseat behind the pilot. To better simulate single pilot flight, however, the evaluator and simulator operator may be placed to the rear of, or outside of, the simulator cab. If the evaluator is located away from the pilot, the following instructional support features are needed at the remote location: (1) a closed circuit television to observe pilot actions; (2) replicas of flight instruments and other displays, and annunciators that show switch and control settings; and (3) a reproduction, which can be low fidelity, of external visual scenes.

In addition, the simulator should have several other features that facilitate monitoring and assessing pilot performance. Such features include (1) performance monitoring displays; (2) automated performance alerts; (3) record and playback capabilities; (4) hardcopy printouts; and (5) automated performance measurement.

Performance monitoring displays provide the evaluator with real time information concerning pilot and aircraft performance. In their simplest form, they are the replicas of aircraft displays. However, displays can be designed that will present the evaluator with information that is unavailable to the pilot. Further, such displays can be formatted to enhance the ability of evaluators and simulator operators to use them. Map displays, for example, can be provided that show the aircraft's track (past and projected future) over the ground. Additionally, a "side-view" display can be used to show the aircraft's vertical flight path in relation to ground-referenced locations. These displays will aid the evaluator in detecting when errors have occurred and determining the criticality of the errors. Performance variables that are presented in these displays should be related to those measured during the maneuver-oriented proficiency checks. Additionally, units of measurement that are specified in the recording forms should also be used in the displays.

To aid the evaluator in detecting errors, automated performance alerts also should be provided. Such alerts would indicate when any given system parameter (or combination of parameters) achieved an unacceptable or error status. These alerts would serve to assure that errors are detected, especially during the operations-oriented evaluation. As such, they tend to increase the reliability of data collection.

Record and playback capabilities furnish the evaluator with the ability to record portions of the simulated flight (as represented in flight instrument indications and presentations on the performance monitoring displays). The recorded flight can then be played back (at normal or fast time) for review after a check is completed. While this capacity will be useful in both types of checks that will be conducted, it will be especially useful during the

debriefings following operations-oriented checks. The evaluators and the pilots who serve as subjects can use the playback as a reference while discussing errors that were made during the test session.

Such post test session reviews can also be aided through the use of hard-copy printouts. Such printouts may contain "snapshots" of system performance parameters at selected points during the test. They may also contain graphical depictions of horizontal and vertical components of the simulated aircraft's path. These printouts can also be used to review pilot performance. As with the recorded playbacks, they will be particularly useful in detecting and diagnosing pilot performance problems following operations-oriented checks. In both types of checks, however, the "snapshots" can be used to document Type A, and, more importantly, Type B errors.

Finally, the tremendous computational power of modern digital computers enables sophisticated, automated performance measurement systems to be developed for these devices. Such systems can automatically record pilot actions and aircraft performance on almost any parameter that is desired. Further, algorithms can be developed that will guide the collection (e.g., the determination of when performance is to be sampled), reduction, and analysis of performance data. As discussed in Chapter IV, however, automated performance measurement capabilities will not be employed in the planned evaluations. The use of manual recording and analysis methods was deemed sufficient to accomplish desired evaluation objectives. Given the extensive effort required to develop a fully automated system, a manual system was judged to be the most cost-effective method that could be used.

If a high fidelity simulator is acquired for the planned evaluation, however, it also will be used for a variety of other research. As a consequence, some of the advantages afforded by the use of an automated performance measurement system--e.g., greater precision, the capability to compute complex measures--provide impetus for the inclusion of this feature. Guidance for the design of automated performance measurement systems can be found in Semple, Cotton, and Sullivan (1981).

Features That Aid in Instruction. As will be discussed in Chapter VI, the quality of the training that the pilots receive is critical to the conduct of the planned evaluations. Further, such training, especially for the use of EFIS and the advanced autopilot, will require a significant portion of the funding allocated to the project. Therefore, to assure effective and efficient training, the simulator should be designed to function as a training device as well as a test vehicle.

All of the features that have been discussed thus far in this subsection can be used in the training that will be conducted. In addition, the following instructional support features also should be provided.

- (1) Flight system freeze--i.e., the capability to freeze flight control and propulsion system parameters together with aircraft attitude and position; this feature enables the pilot to focus on subsystem operations.

- (2) Parameter freeze--i.e., the capability to hold one or more parameters constant; this feature enables the instructor to reduce the total level of task demands placed on the pilot.

(3) Store/reset current conditions--i.e., the capability to store system parameters at any point in a simulated flight and return to that point later; this feature enables the pilot to practice a designated maneuver repeatedly.

(4) Automatic demonstration--i.e., the capability to show a pilot how to perform a maneuver using a programmed demonstration that "flies" the simulated aircraft.

(5) Cockpit mounted, audio-visual media--i.e., a slide-sound device (perhaps with CRT display) will be placed in the cockpit during training to enable the pilot to receive instruction using the device while he is using the simulator. (Such instruction will be discussed in Chapter VI.)

Use of the above features, and the others discussed in this subsection, for instruction is discussed at length in Caro, Pohlmann, and Isley (1979); Caro, Shelnutt, and Spears (1981); and Semple, Cotton, and Sullivan (1981). These references also contain guidance for the design of these features.

All of the instructional support features discussed in this subsection, except for automated performance measurement systems, are well within the current state of the art in simulation technology. If a new high fidelity simulator is constructed for use in the planned evaluation, the addition of these features would represent a relatively small and well-justified expense. If a simulator is leased, it is highly likely that it will have many of the above features since they are commonly available in most modern state-of-the-art simulators. The availability of such features should be considered in the selection of a simulator for leasing. Finally, if an existing research simulator is used, it should be modified to include as many of the specified features as practical.

B. USE OF AIRCRAFT AS TEST VEHICLES.

As discussed in Section A, use of an aircraft would limit the sample of flight situations that could be tested in the planned evaluations. The use of an aircraft is not precluded, however, since a considerable portion of the maneuvers and conditions, both favorable and adverse, could still be tested. The obvious advantage associated with use of an aircraft, relative to the use of even high fidelity simulators, is that the pilot has most, if not all, of the cues available to him during the checkride that are present in actual flight operations. Thus, unlike pilot performance data obtained in simulators, data obtained in aircraft are less likely to be questioned by the general aviation community with respect to their relation to actual flight operations.

It should be noted, however, that pilot performance in the aircraft during the checkride reflects the somewhat artificial conditions under which proficiency checks are conducted. The pilot being tested, for example, knows that he is being observed by the evaluator and that the evaluator is serving as a safety pilot. The pilot also knows that some conditions probably will not occur because they are prohibited in the aircraft for reasons of safety.

Nevertheless, properly conducted checks in the aircraft will provide data that cannot be obtained in simulators due to the greater fidelity of many test

situations that can be created in the aircraft. Indeed, use of an aircraft and a simulator would provide much better screening of possible pilot performance problems than use of either alone, particularly if simulators without motion and visual systems are employed. Further, use of both types of test vehicles would enable examination of the extent to which performance in the simulator corresponds to performance in the aircraft. Such information would aid in developing guidance for the use of simulators (and aircraft) in future research.

This guidance is needed due to the lack of information concerning the extent to which performance in simulators predicts performance in aircraft. While numerous studies have compared performance in simulators and aircraft, they have focused on transfer of training--i.e., the degree to which training in the simulator reduces the need for training in the aircraft. Very few studies (e.g., American Airlines, 1969; Koonce, 1974) have obtained data that treat the relation between performance in aircraft and simulators. Thus, there are no comprehensive empirical data bases or analytical models that can be used to guide the use of simulators in research of the sort discussed here.

In the absence of such data, judgments concerning the utility of simulator data must be based on the "face" validity of the specific test situations--i.e., on the judgment of experienced pilots and aviation researchers concerning the extent to which pilot performance in the simulator corresponds to performance in the aircraft. It should be emphasized, however, that such judgments are supported by the generalization of results of the extensive research on transfer of training. The vast majority of these research studies have revealed positive relationships between performance in the simulator and aircraft.¹

Given that an aircraft is used in the planned evaluations, either alone or in conjunction with a simulator, it should be capable of being instrumented with both conventional flight displays and EFIS, and with the automated flight control systems that are of interest. Several avenues exist for meeting this fundamental requirement. First generation EFIS, for example will be available in 1982 for installation into test aircraft. Additionally, new EFIS-equipped aircraft will also be available and can be purchased or leased from the airframe manufacturers.²

The availability of these production EFIS affords an unprecedented opportunity for the acquisition of relatively low cost (compared to one-of-a-kind research aircraft used in past research on flight displays) aircraft for research. Since the performance measurement system does not require special instrumentation, production aircraft could be used without modifications. It would be beneficial, however, to add some instrumentation (i.e., a Discrete Addressed Beacon System) to enable the use of instrumented test ranges at NASA's Wallops Station

¹Transfer of training studies are reviewed in Semple, Hennessy, Sanders, Cross, Beith, and McCauley (1981).

²Two almost identical aircraft, differing only in their flight instrument and autopilot systems, could be used in the planned evaluation. Or, one conventionally-equipped aircraft could be used with the EFIS being retrofitted into it after testing on conventional instruments is completed. One aircraft could also be used if conventional instruments and EFIS are installed on the left and right sides of the instrument panel.

and at the FAA Technical Center. Use of these ranges would facilitate the measurement and assessment of aircraft performance parameters.

"Airborne simulation" equipment could also be added to the production aircraft (such equipment is described in Strauch, 1981). This equipment would enable phantom navigation aids (e.g., ILS) to be established in remote test areas. Thus, approaches and other instrument maneuvers could be flown away from the crowded airspaces around major airports. Further, by inserting simulated altimeter readings, such maneuvers could be performed at the higher altitudes necessary for safety during some test conditions (e.g., during engine-out performance).

In addition to production aircraft, the government also has or has access to research aircraft that could be employed in the planned study. NASA, for example, has a Cessna twin-engine aircraft equipped with the Demonstration Advanced Avionics System, which has certain advanced flight displays that are of interest (e.g., an electronic horizontal situation indicator). NASA researchers have also used Princeton University's Avionic Research Aircraft for display research (Downing, Bryant, and Yenni, 1981). This aircraft (a single-engine NAVION) has a modular instrument panel in which advanced displays can be installed. For purposes of the planned evaluations, however, production aircraft with first generation EFIS and conventional instruments represent the most logical and cost-efficient alternative.

C. CONCLUSIONS.

This chapter is devoted to the analysis of requirements for a test vehicle for the planned evaluation. The following conclusions and recommendations summarize major aspects of this analysis.

1. Aircraft simulators are better suited than are aircraft for use as test vehicles in evaluations of the type planned. Simulators afford several advantages with respect to the use of potentially dangerous test conditions and scenarios in which pilot performance problems are more likely to occur; the control of test conditions; and the observation, measurement, and assessment of pilot performance. Further, simulation provides certain cost advantages that can reduce the amount of funding required for the planned research.

2. The preferred test vehicle for the planned evaluation is a high fidelity simulator with advanced motion and visual systems specifically configured for use in research. While building such a device would be expensive, it would constitute a national resource that could be used by the FAA and NASA, as well as industry. The planned EFIS evaluation is just one of many critical projects that could best be performed in this type of simulator.

3. If available, a high fidelity simulator leased from a general aviation training organization could also serve as a test vehicle for the planned evaluations. Some of the larger general aviation training organizations are planning to build high fidelity training devices that will simulate EFIS-equipped aircraft. These simulators could be used in the planned evaluations. However, their use for other research, particularly where aspects of the EFIS displays are modified, might be limited.

4. General aviation simulators at the FAA Technical Center and NASA Langley Research Center could be employed as test vehicles for the planned evaluations. While these devices currently lack sophisticated motion and visual systems, they provide an efficient means for screening a number of flight situations for potential pilot performance problems. Some relatively low cost (compared to building a new simulator) modifications and additions would increase their capability substantially--e.g., the addition of more advanced display systems, and, in the case of the FAA's simulator, the addition of a visual system.

5. The simulator used as a test vehicle should be equipped with state-of-the-art instructional support features that will facilitate use of the device during the evaluations and during the training of pilots who will serve as subjects in the evaluations. Such features include (1) manual and programmable sets of initial conditions, (2) manual and programmable malfunction control, (3) simulator freeze, (4) fast-time capabilities, (5) manual and automated control of air traffic, (6) performance monitoring displays, (7) automated performance alerts, (8) record and playback capabilities, (9) hard-copy printouts, (10) automated performance measurement capabilities (although such capabilities are not critical to the planned evaluation), (11) flight system freeze, (12) parameter freeze, (13) store/reset current conditions, (14) automatic demonstration, and (15) cockpit mounted, audio-visual media.

6. If an aircraft is used in the planned evaluations, first generation EFIS and other avionics that will be available commercially can be used to configure it for the comparisons that need to be made. The availability of the first generation EFIS affords an opportunity for relatively low cost (compared to the cost of past research aircraft) in-flight research on advanced flight displays.

VI. DEVELOPMENT OF PROCEDURES FOR SELECTING AND TRAINING EVALUATION SUBJECTS

As discussed in Chapter II, the planned evaluations should employ as subjects pilots with skill levels that best represent the capabilities of pilots who normally will fly EFIS-equipped aircraft in general aviation flight operations. The use of such pilots, rather than experienced test pilots, will facilitate the examination of performance problems that may be attributable to factors influencing pilot capabilities (e.g., training) as well as task demands (e.g., the type of flight instrument or control system that is used).

The capabilities of general aviation pilots who will fly EFIS-equipped aircraft will be determined, in part, by the FAA pilot certificates and ratings that will be required for such aircraft and the operations in which they are employed. Such certificates and ratings, in turn, define requirements for the training that these pilots will receive--both for the certificates and ratings and for the maintenance of proficiency afterwards. The purpose of this chapter is to discuss considerations related to the selection of pilots who will serve as subjects in the planned evaluations, and the development of the training that these pilots will receive to prepare them for their proficiency checks.

A. SELECTION OF SUBJECTS.

The first generation EFIS initially will be installed in corporate aircraft and other relatively large and expensive general aviation aircraft. The pilots who fly these aircraft generally represent the best trained and most experienced pilots in general aviation. They are usually professional pilots who have commercial and often airline transport pilot certificates. They also usually have multiple aircraft class and type ratings, and, of course, the instrument rating. Many of these pilots fly frequently under a variety of conditions, and, in some cases, in a variety of aircraft. Further, they often receive support in the performance of flight-related duties (e.g., flight planning) from company flight departments and other organizations. In general, they have a better safety record than other general aviation pilots. Nevertheless, the majority of the corporate and business aircraft accidents that occur are attributed to pilot performance problems (as is the case in the rest of general aviation.)

Thus, the first group of pilots who will fly EFIS-equipped aircraft, with some exceptions that will be discussed later, are a rather elite group in the general aviation pilot community. In some ways, their characteristics make them good candidates for use in planned research. They will require, for example, less training than less experienced pilots to prepare them for the wide range of flight situations on which they are to be tested. Further, they are more likely (relative to other general aviation pilots) to have operated aircraft of the type that will be used or simulated in the exploratory evaluation--i.e., multiengine aircraft with sophisticated flight instruments, weather radars, complex autopilots, and other advanced avionics.

In addition to these professional pilots, however, some EFIS-equipped aircraft will be flown by pilots who are employed in other occupations (e.g., businessmen, lawyers, and physicians) and who fly for business and personal

reasons. These pilots tend to fly aircraft that are somewhat smaller, slower, and less expensive (e.g., twin-engine, piston-powered aircraft) than top-of-the-line corporate aircraft. Such aircraft still have the potential to be a major market for EFIS, especially the less expensive versions of these systems.¹ These pilots tend to be less experienced than the professional pilots who were discussed in this section, and to fly less frequently. They also have been the subject of some concern due to their being involved in a higher proportion of certain types of accidents than other general aviation pilots (NTSB, 1974).

Pilots of this type also have characteristics that make them interesting candidates to be subjects in the planned evaluations. Their lack of extensive flight experience, for example, provides a contrast with the professional pilots who fly corporate aircraft. Moreover, since they fly less frequently than the professional pilots, their overall flight skills may tend to be less keen, especially with respect to the skills needed to perform some of the less common maneuvers and to perform under the adverse conditions that will be tested.

As presently configured, the design of the exploratory evaluations is optimized for a homogenous subject sample--i.e., for a sample of pilots whose capabilities are relatively alike. Such a sample will provide conditions that will be most sensitive (given the present experimental design) to the detection of differences due to aircraft equipment. For this reason, it is recommended that only one type of pilot, the experienced professionals, be used in the evaluation. These pilots are selected because they will represent the largest group of EFIS users, at least of the first generation systems. The final selection of subjects, however, must take into consideration the requirements and constraints of the research setting that is selected (e.g., the availability of pilots near the location at which the planned study is performed).

Another equally feasible, but more complex, approach to selecting subjects would be to have a wide range of skills represented in the planned evaluations. If such a range is used, then it would be beneficial to analyze data with respect to factors related to pilot skill level as well as aircraft equipment. While the experimental design presented in Chapter III does not make provisions for such analyses, it could easily be adapted to enable pilot capability factors to be included. An analysis of covariance, for example, could be conducted using factors related to pilot skill level as a concomitant variable--e.g., total number of flight hours, amount of experience with flight directors, autopilots and other advanced avionics.²

B. DEVELOPMENT OF TRAINING FOR THE SUBJECTS.

The development of instruction for the use of advanced avionics is a major source of concern in air carrier and military aviation, where such equipment has already become quite common. Although no formal studies have been conducted, insight into the problem has been gained as a result of the

¹The various levels of EFIS are described in Appendix A.

²Analysis of covariance designs are discussed in most texts on experimental design and statistical analysis (e.g., Meyers, 1966; Winer, 1962).

observations of personnel who are responsible for airline and military aircrew training.¹ These personnel have reported that some pilots had difficulty learning to use advanced avionics systems when these systems were first introduced. Examples of such systems include flight management systems used in certain wide body air transport aircraft and sophisticated fire control systems on military fighter and attack aircraft.

As a consequence of such training problems, many of these pilots never learned to make full use of the extensive capabilities of the new systems. Less frequently, but more critically, some of these pilots also erred on the use of the systems during actual flight operations (such as in the American DC-10 accident discussed in Chapter II). In response to these problems, several airlines have reviewed their training programs for such systems and have concluded those programs underestimated the training requirements associated with such systems. As a result, those programs have been revised and further instruction devoted to the operation of these systems has been provided.

Further, the airlines who are buying the new, highly automated generation of air transport aircraft are devoting considerable resources (in conjunction with airframe manufacturers) to the development of operating procedures and training programs for the pilots of these highly innovative aircraft.

The experience of the airlines is instructive, since it may foreshadow training problems that could arise as the EFIS and other advanced cockpit systems become more common in general aviation. As discussed in Chapter II, research is needed that will support the development of effective and efficient instruction to teach pilots how to use EFIS and other advanced systems. The manipulations required for such research (e.g., the development of alternative techniques and courses) is beyond the scope of the present project. However, the development of training for the subjects during this project and an assessment of problems that arise during this training will provide valuable information that will permit a better understanding of the training problem.

The training that is developed and the procedures for developing the training will depend on the specific research vehicle and EFIS that are selected for use in the evaluations. One approach would be to employ training that has been developed by the avionics or airframe manufacturers (or other commercial sources) for the EFIS that is simulated (or actually used) in the study. This approach is preferred since such instruction would be typical of that received by most general aviation pilots who will fly EFIS-equipped aircraft.

Another approach would be to develop training specifically for the planned evaluations using personnel who have extensive experience in the development of pilot training programs. As part of this approach, selected airline and military training programs could be reviewed to identify innovative techniques

¹Such observations have been reported in a variety of contexts--e.g., a conference on flight-deck automation (Boehm-Davis et al., 1981), a survey of aircrew training practices and problems (Caro, Shelnut, and Spears, 1981), and in documents related to the two-man versus three-man crew controversy in air carrier aviation (McLucas, Drinkwater, and Leaf, 1981).

(related to teaching the use of advanced cockpit systems) that could be employed, if economically feasible, in general aviation training. Further, various training programs regimes also could be reviewed that have been developed to teach general aviation pilots how to use EFIS and other advanced systems. Following these reviews, standard instructional system development techniques could be used to develop instruction for the subjects. The training requirements, objectives, techniques, and other aspects of the training program that are developed would be documented and published as part of the final report.

Regardless of how instruction is developed, the progress of the subjects through training should be measured and assessed. Problems that appear during training should be identified and compared with problems that are detected in the assessment phase of the study. Such training problems, and approaches to their solution, also should be published as part of the final report.

C. CONCLUSIONS.

In summary, the planned exploratory evaluations provide an excellent opportunity to examine factors affecting the capabilities of pilots to use the EFIS and other advanced cockpit technology. The following conclusions and recommendations summarize how the examination of such factors can be pursued.

1. The recommended evaluation design does not allow for distinctions to be made in pilot skill level, and, consequently, the subjects should have capabilities that are approximately alike. A homogeneous sample of subjects is needed to reduce variance due to individual differences that would decrease the sensitivity of the statistical analyses that are planned. If only one "category" of pilot is used, then professional pilots who regularly fly corporate aircraft should be employed as subjects. Given operational constraints, a second approach would be to employ nonprofessional pilots who have less experience, but still have the appropriate certificates and ratings required for instrument flight in the aircraft (simulator) used as a test vehicle.

2. If research resources are available, the design of the exploratory evaluations should be modified to allow a wider range of pilots to be employed as subjects. Factors related to pilot capability could be identified and used to classify the pilots participating in the study. Such information could then be used to support the conduct of statistical analyses designed to investigate differences in pilot performance due to factors that influence pilot capabilities. While this approach would require more subjects and entail increased cost, the results could be generalized to a broader segment of the pilot population.

3. If a specific production EFIS is used (or simulated) in the exploratory evaluations, the commercially-produced training that is available to pilots who buy that system should be used to prepare the subjects for their proficiency checks. Such training will be more representative of the instruction that most general aviation pilots actually will receive than would training developed specifically for the planned evaluations.

4. If training is developed specifically for the exploratory evaluations, then it should be based on a review of other training programs, and, additionally, it should be developed using commonly accepted procedures for instructional system development. Documentation of the review of relevant aspects of other airline, military, and general aviation training programs, as well as of the training program that is developed, would aid personnel in the general aviation community who are faced with developing instruction to teach pilots to use EFIS and other advanced systems.

5. The progress and problems experienced by the subjects during training should be measured, assessed and documented. Such information also will be of use to training personnel in the general aviation community.

REFERENCES

- Advisory Group for Aerospace Research and Development. Problems of the cockpit (AGARD-CP-55). Neuilly sur Seine, France: Author, November 1968. (NTIS No. AD-685 268)
- American Airlines, Inc. Optimized flight crew training: A step toward safer operations. Fort Worth, TX: Author, April 1969.
- Baker, C. H. Review of selected aspects of the ANIP program. El Segundo, CA: Douglas Aircraft Company, November 1961. (NTIS No. AD-814 404)
- Baker, C. A., & Grether, W. F. Visual presentation of information (WADC Tech. Rep. 54-160). Wright-Patterson AFB, OH: Wright Air Development Center, August 1954. (NTIS No. AD-043 064)
- Baron, S., & Levison, W. H. Display analysis with the optimal control model of the human operator. Human Factors, 1977, 19(5), 437-458.
- Baron, S., Pew, R., & Zacharias, G. Performance measurement for simulator evaluation (BBN Report No. 4315). Cambridge, MA: Bolt, Beranek, & Newman, Inc., February 1980.
- Bergeron, H. P. Single pilot IFR autopilot complexity/benefit tradeoff study (AIAA Paper No. 80-1869). Paper presented at the AIAA Aircraft Systems and Technology Meeting, Anaheim, August 1980a.
- Bergeron, H. P. Analysis of general aviation single pilot IFR incident data obtained from the National Aeronautics and Space Administration Aviation Safety Reporting System (NASA-TM-80206). Washington, DC: National Aeronautics and Space Administration, October 1980b.
- Berlin, J., & Holmes, C. Developing a civil aviation pilot judgment training and evaluation manual. Paper presented at the First Symposium on Aviation Psychology, Columbus, April 1981.
- Biberman, L. M. (Ed.) Perception of displayed information. New York: Plenum Press, 1973.
- Boehm-Davis, D. A., Curry, R. E., Wiener, E. L., & Harrison, R. L. Human factors of flight-deck automation - NASA/Industry workshop (NASA-TM-81260). Washington, DC: National Aeronautics and Space Administration, January 1981.
- Bolz, E. H., & Eisele, J. E. General aviation IFR operational problems (NASA-CR-159022). Washington, DC: National Aeronautics and Space Administration, April 1979. (NTIS No. N79-22068)
- Boucek, G. P., Veitergruber, J. E., & Smith W. D. Aircraft alerting systems criterion study: Vol. II Human factors guidelines for aircraft alerting systems (FAA-RD-76-222-II). Washington, DC: Federal Aviation Administration, May 1977. (NTIS No. AD-A043 383)

- Brecke, F. H., Gerlach, V. S., & Schmid, R. F. The role of verbal prescriptive rules in cognitive pretraining for a flying task (TR No. 60201). Arlington, VA: Air Force Office of Scientific Research, 1976.
- Buckler, A. T. A review of the literature on the legibility of alphanumerics on electronic displays (Tech. Memo. 16-77). Aberdeen Proving Grounds, MD: U.S. Army Human Engineering Laboratory, May 1977. (NTIS No. AD-A040 625)
- Cakir, A., Hart, D. J., & Stewart, T. F. M. Visual display terminals. New York: John Wiley & Sons, 1980.
- Caro, P. W. Flight evaluation procedures and quality control of training (TR-68-3). Alexandria, VA: Human Resources Research Organization, March 1968.
- Caro, P. W., Pohlmann, L. D., & Isley, R. N. Development of simulator instructional feature design guides (Tech. Rep. TR 79-12). Pensacola, FL: Seville Research Corporation, October 1979.
- Caro, P. W., Shelnut, J. B., & Spears, W. D. Aircrew training devices: Utilization (AFHRL-TR-80-35). Wright-Patterson AFB, OH: Air Force Human Resources Laboratory, January 1981.
- Carter, V. E. Development of automated performance measures for introductory air combat maneuvers. In Proceedings of the 21st Annual Meeting of The Human Factors Society, Santa Monica, CA: The Human Factors Society, 1977.
- Carter, V. E., & Semple, C. A. Specific behavioral objectives for VF-121 training in basic air combat maneuvering (Contract N62269-74-C-0314). Hawthorne, CA: Northrop Corporation, October 1974.
- Cheaney, E. S., & Billings, C. Applications of the epidemiological model in studying human behavior. Paper presented at the 1980 Aircraft Safety and Operating Problems Conference, Washington, November 1980.
- Childs, J. M. Development of an objective grading system along with procedures and aids for its effective implementation in flight (ARI-RN-79-18). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences, July 1979a.
- Childs, J. M. The identification and measurement of critical IERW performance variables (Contract No. DAHC19-77-C-0008). Westlake Village, CA: Canyon Research Group, Inc., April 1979b.
- Childs, J. M. The development of objective inflight performance assessment procedures. In Proceedings of the 23rd Annual Meeting of the Human Factors Society, Santa Monica, CA: The Human Factors Society, October 1979c.
- Childs, J. M., Prophet, W. W., & Spears, W. D. The effects of pilot experience on acquiring instrument flight skills-phase I (FAA-CT-81-38). Washington, DC: Federal Aviation Administration, March 1981.
- Climb procedures cited in incident. Aviation Week & Space Technology, 1981, 114, 65-71.

- Cochran, W. G., & Cox, G. M. Experimental designs (2nd Edition). New York: John Wiley & Sons, 1957.
- Connor, T. M., & Hamilton, C. W. Evaluation of safety programs with respect to the causes of general aviation accidents. Volume I: Technical report. Columbus, OH: Battelle Columbus Laboratories, 1979.
- Covault, C. Heavy rain danger called greater than wind shear. Aviation Week & Space Technology, 1981, 114, 50-51.
- Cundari, F. L. Bibliography of technical reports of the Joint Army Navy Aircraft Instrument Research (JANAIR) Program. Washington, DC: Office of Naval Research, April 1968.
- Dalton, G. W., Lawrence, P. R., & Greiner, L. E. Organizational change and development. Homewood, IL: Richard D. Irwin, 1970.
- DeBellis, W. B. A dynamic evaluation of the integrated avionics control system (IACS) (HEL-TM-2-80). Aberdeen Proving Ground, MD: Human Engineering Laboratories, February 1980. (NTIS No. AD-A082 203)
- Del Balzo, J. M. Keynote speech. Paper presented at the IEEE/AESS Seminar on The Human-Machine Interface in Airborne Systems, Dayton, December 1980.
- Denisov, V. G., & Onishchenko, V. F. Aerospace human factors engineering. Arlington, VA: Joint Publications Research Service, October, 1973.
- Department of the Air Force. AFSC design handbook 1-3, human factors engineering (Third Edition). Andrews AFB, DC: Headquarters, Air Force Systems Command, January 1977.
- Department of the Army. Human factors engineering design for Army material (MIL-HDBK-759). Redstone Arsenal, AL: U.S. Army Missile Command, March 1975.
- Department of Defense. Human engineering design criteria for military systems, equipment, and facilities (MIL-STD-1472C). Washington, DC: Author, July 1981.
- Downing, D. R., Bryant, W. H., & Yenni, K. R. Flight test evaluation of advanced symbology for general aviation approach to landing displays (AIAA-81-1643). Paper presented at the AIAA Aircraft Systems and Technology Conference, August 1981.
- Duning, K. E., Hemesath, N. B., Hickok, C. W., Lammers, D. G., & Goemaat, M. L. Curved approach path study (FAA-RD-72-143). Washington, DC: Federal Aviation Administration, March 1973. (NTIS No. AD-763 603)
- Editors of Flying Magazine. Pilot error. New York: Van Nostrand Reinhold Company, 1977.
- Egan, D. E., & Goodson, J. E. Human factors engineering for head-up displays: A review of military specifications and recommendations for research (NAMRL Monograph-23). Pensacola, FL: Naval Aerospace Medical Research Laboratory, April 1978. (NTIS No. AD-A056 944)

- Eggspuehler, J. J., & Weislogel, G. S. Study to determine the flight profile and mission of the certified private pilot (FAA-DS-68-15). Washington, DC: Federal Aviation Administration, July 1968. (NTIS No. AD-675 818)
- Eldredge, D., Crook, W. G., & Crimbring, W. R. Simulation tests of flight technical error in 2D/3D area navigation (RNAV) using a multiple waypoint RNAV system with and without a flight director system (FAA-RD-77-112). Washington, DC: Federal Aviation Administration, October 1977. (NTIS No. AD-A047 246)
- Elke, D. R., Malone, T. B., Fleger, S. A., & Johnson, J. H. Human engineering-design criteria for modern control/display components and standard parts (Tech. Rep. RS-CR-80-1). Redstone Arsenal, AL: U.S. Army Missile Command, May 1980.
- Elson, B. M. Navy expands simpler cockpit displays. Aviation Week & Space Technology, 1977, 107, 59-64.
- Fadden, D. M., & Weener, E. F. Computer generated displays as primary flight instruments. Seattle, WA: The Boeing Company, no date.
- Federal Aviation Administration. Instrument flying handbook (AC61-27A). Washington, DC: Author, 1968.
- Federal Aviation Administration. United States standards for terminal instrument procedures. Washington, DC: Author, July 1976.
- Federal Aviation Administration. General aviation pilot stall awareness training syllabus. Washington, DC: Author, February 1979.
- Fink, D. E. GAMA expects 1981 sales of \$3 billion. Aviation Week & Space Technology, 1980, 112, 64-66.
- Fitts, P. M., & Jones, R. E. Psychological aspects of instrument display--I. Analysis of 270 "pilot-error" experiences in reading and interpreting aircraft instruments (AMC Memo. Rep. TSEAA-694-12A). Wright-Patterson AFB, OH: Aerospace Medical Research Laboratories, October 1947.
- Flathers, G. W., Giffin, W. C., & Rockwell, T. H. A study of decision-making behavior of aircraft pilots deviating from a planned flight. Paper presented at the First Symposium on Aviation Psychology, Columbus, April 1981.
- Forrest, F. G. Develop an objective flight test for the certification of a private pilot (DS-70-17). Washington, DC: Federal Aviation Administration, May 1970. (NTIS No. AD-708 293)
- Forsyth, D. L., & Shaughnessy, J. D. Single pilot IFR operating problems determined from accident data analysis (NASA-TM-78773). Washington, DC: National Aeronautics and Space Administration, September 1978. (NTIS No. N79-11013)
- General Accounting Office. How to improve the Federal Aviation Administration's ability to deal with safety hazards (CED-80-66). Washington, DC: Author, February 1980.

- Gorrell, E. L. A human engineering specification for legibility of alpha-numeric symbology on video monitor displays (revised) (DCIEM-TR-80-R-26). Downsview, Ontario (Canada): Defence and Civil Institute of Environmental Medicine, June 1980. (NTIS No. AD-A088 470)
- Gould, J. D. Visual factors in the design of computer-controlled CRT displays. Human Factors, 1968, 10, 359-376.
- Grandjean, E., & Vigliani, E. (Eds.) Ergonomic aspects of visual display terminals. London: Taylor & Francis, 1980.
- Greer, G. D., Smith, W. D., & Hatfield, J. L. Improving flight proficiency evaluation in Army helicopter pilot training (TR-77). Alexandria, VA: Human Resources Research Organization, May 1962.
- Greer, P. E., & Hanking, J. R. Application of AIDS to the A-7E and a projected future tactical aircraft (NADC-78032-060). Warminster, PA: Naval Air Development Center, December 1977. (NTIS No. AD-A053 775)
- Hagin, W. V., Herrington, S. S., & Haygood, R. C. Measuring pilot proficiency on an instrument training maneuver (TR No. 70820). Arlington, VA: Air Force Office of Scientific Research, August 1977.
- Haines, R. F. Head-up transition behavior of pilots during simulated low visibility approaches (NASA-TP-1618). Washington, DC: National Aeronautics and Space Administration, 1980.
- Haines, R. F., Fischer, E., & Price, T. A. Head-up transition behavior of pilots with and without head-up displays in simulated low visibility approaches (NASA-TP-1720). Washington, DC: National Aeronautics and Space Administration, 1980.
- Hatfield, J. J., Robertson, J. B., & Batson, V. M. Advanced crew station concepts, displays, and input/output technology for civil aircraft of the future. Paper presented at the IEEE/AIAA 3rd Digital Avionics Systems Conference, Fort Worth, 1979.
- Hill, J. H., & Chernikoff, R. Altimeter display evaluation (NRL 6242). Washington, DC: U.S. Naval Research Laboratory, January 1965.
- Hinton, D. A., & Shaughnessy, J. D. Adaption of the time line analysis program to single pilot instrument flight research (NASA-TM-78748). Washington, DC: National Aeronautics and Space Administration, August 1978.
- Hoekstra, H. D., Perry, E. B., & Huang, S. Altimetry display study: Part one - analysis of altitude accidents. Arlington, VA: Flight Safety Foundation, February 1972.
- Holmes, C. W., & Childs, J. M. The effects of pilot experience on acquiring instrument flight skills - phase II (DOT/FAA/CT-82/35). Washington, DC: Federal Aviation Administration, January 1982.
- Hudock, P. F., & Hudock, R. P. The operational profile and mission of the certified non-instrument rated commercial pilot (FAA-RD-70-50). Washington, DC: Federal Aviation Administration, July 1970. (NTIS No. AD-710 822)

- Ince, F., Williges, R. C., & Roscoe, S. N. Aircraft simulator motion and the order of merit of flight attitude and steering guidance displays. Human Factors, 1975, 17, 388-400.
- Instruments on a CRT. Avionics, January 1981, 8-11.
- Jacobs, R. S., Williges, R. C., & Roscoe, S. N. Simulator motion as a factor in flight director display evaluation. Human Factors, 1973, 15, 569-582.
- Jensen, R. S. Prediction and quickening in perspective flight displays for curved landing approaches (Doctoral dissertation, University of Illinois at Urbana-Champaign). Ann Arbor, MI: University Microfilm International, May 1979. (University Microfilms No. 80-04198)
- Jensen, R. S., & Benel, R. A. Judgment evaluation and instruction in civil pilot training (FAA-RD-78-24). Washington, DC: Federal Aviation Administration, December 1977. (NTIS No. AD-A057 440)
- Jensen, R. S., Vanderkolk, R. J., FitzHenry, P., Rose, D. J., & Roscoe, S. N. Pilotage error in area navigation: Performance of instrument pilots using symbolic displays (FAA-RD-71-31). Washington, DC: Federal Aviation Administration, May 1971. (NTIS No. AD-739 309)
- Kelly, M. J., Hennessy, R. T., Vreuls, D., Barneby, S. F., Wooldridge, L., & Cotton, J. C. Air combat maneuvering performance measurement study (AFHRL-TR-79-3). Luke AFB, AZ: Air Force Human Resources Laboratory, November 1978.
- Kershner, W. K. The instrument flight manual (3rd Edition). Ames: Iowa State University Press, 1977.
- Ketchel, J. M., & Jenney, L. L. Electronic and optically generated aircraft displays: A study of standardization requirements (JANAIR Rep. No. 680505). Washington, DC: Office of Naval Research, May 1968. (NTIS No. AD-684 849)
- Kirk, R. E. Experimental design: Procedures for the behavioral sciences. New York: Brooks/Cole, 1968.
- Koonce, J. M. Effects of ground-based aircraft simulator motion conditions upon prediction of pilot proficiency (TR ARL-74-5). Savoy, IL: University of Illinois at Urbana-Champaign, 1974.
- Kowalsky, N. B., Masters, R. L., Stone, R. B., Babcock, G. L., & Rypka, E. W. An analysis of pilot error-related aircraft accidents (NASA CR-2444). Washington, DC: National Aeronautics and Space Administration, June 1974.
- Kraus, E. F., & Roscoe, S. N. Reorganization of airplane manual flight control dynamics. In Proceedings of the 16th Annual Meeting of the Human Factors Society, Santa Monica, CA: The Human Factors Society, 1972.
- Krebs, M., Wolf, J., & Sandrig, J. Color display design guide (ONR-CR123-136-2F). Arlington, VA: Office of Naval Research, October 1978. (NTIS No. AD-A066 630)

- Larson, G. C. Update on EFIS. Business and Commercial Aviation, October 1981, 76-80.
- Lauber, J. K., & Foushee, H. C. Guidelines for line-oriented flight training. Volume I (NASA-CP-2184-I). Washington, DC: National Aeronautics and Space Administration, August 1981a.
- Lauber, J. K., & Foushee, H. C. (Eds) Guidelines for line-oriented flight training. Volume II (NASA-CP-2184-II). Washington, DC: National Aeronautics and Space Administration, 1981b.
- Lee, W. Experimental design and analysis. San Francisco: W. H. Freeman, 1975.
- Long, G. M., Shannon, R. H., & Waag, W. L. The isolation of critical elements within selected maneuvers during primary flight training. In Proceedings of the 16th Annual Meeting of the Human Factors Society, Santa Monica, CA: The Human Factors Society, 1972.
- Loomis, J. P., & Porter, R. F. The performance of warning systems in avoiding controlled-flight-into-terrain (CFIT) accidents. Paper presented at the First Symposium on Aviation Psychology, Columbus, April 1981.
- Lyons, J. D. Factors influencing utilization of research findings in institutional change (PP 2-66). Alexandria, VA: Human Resources Research Office, March 1966.
- Mason, R. C., Price, T. R., Rich, B. A., Slightam, R. J., Stautbery, J. A., Whalen, W. P., & Wilent, C. E. Digital avionics information system (DIAS): Development and demonstration (AFAL-TR-79-1027). Wright-Patterson AFB, OH: Air Force Avionics Laboratory, March 1979. (NTIS No. AD-A068 438)
- Matula, R. A. Effects of visual display units on the eyes: A bibliography (1972-1980). Human Factors, 1981, 23(5), October 1981.
- McClelland, J. M. The era of electronic flight instruments draws near. Business and Commercial Aviation, February 1981a, 52-55.
- McClelland, J. M. TV screens as way of life in the cockpit. Flying, 1981b, 108(3), 102-104.
- McClelland, W. A. The process of effecting change (PP 32-68). Alexandria, VA: Human Resources Research Office, October 1968.
- McCourt, F. P., & Hewin, L. M. A study of key problems in general aviation safety. Washington, DC: Aircraft Owners and Pilots Association Air Safety Foundation, March 1979.
- McGrath, J. J. (Ed.). Geographic orientation in air operations (a JANAIR symposium). Santa Barbara, CA: Anacapa Sciences, Inc., November 1969. (NTIS No. AD-709 124)
- McIver, D., & Hatfield, J. J. Coming cockpit avionics. Astronautics & Aeronautics, 1978, 54-64.

McLucas, J. L., Drinkwater, F. J., & Leaf, H. W. Report of the President's Task Force on Aircraft Crew Complement. Washington, DC: The President's Task Force on Aircraft Crew Complement, July 1981.

Meister, D. Human factors: Theory and practice. New York: Wiley-Interscience, 1971.

Meister, D., & Farr, D. E. The utilization of human factors information by designers. Washington, DC: Office of Naval Research, September 1966. (NTIS No. AD-642 057)

Meister, D., & Sullivan, D. J. A further study of the use of human factors information by designers. Washington, DC: Office of Naval Research, March 1967. (NTIS No. AD-651 076)

Meister, D., & Sullivan, D. J. Guide to human engineering design for visual displays. Washington, DC: Office of Naval Research, August 1969. (NTIS No. AD-693 237)

Meyers, J. L. Fundamentals of experimental design. Boston: Allyn and Bacon, 1966.

Mitchell, T. R. Altimetry display study: Part one - summary report (FAA-RD-72-46, 1). Washington, DC: Federal Aviation Administration, May 1972.

Mixon, T. R. A model to measure bombardier/navigator performance during radar navigation in Device 2F114, A-6E Weapon System Trainer. Monterey, CA: Naval Postgraduate School, March 1981.

Mixon, T. R., & Moroney, W. F. Annotated bibliography of objective pilot performance (NAVTRAEQUIPCEN IH-330). Orlando, FL: Naval Training Equipment Center, In Press.

Moll, N. Jet set refresher. Flying, 1981, 108(10), 24-25.

National Aeronautics and Space Administration. NASA Aviation Safety Reporting System: Third quarterly report (NASA-TM-X-3546). Washington, DC: Author, May 1977.

National Aeronautics and Space Administration. NASA Aviation Safety Reporting System: Fifth quarterly report (NASA-TM-78476). Washington, DC: Author, April 1978.

National Aeronautics and Space Administration. Altimeter reading and setting errors as factors in aviation safety. In National Aeronautics and Space Administration. NASA Aviation Safety Reporting System: Twelfth quarterly report. Washington, DC: Author, 1980.

National Transportation Safety Board. Carburetor ice in general aviation (NTSB-AAS-72-1). Washington, DC: Author, January 1972a. (NTIS No. PB-208 463)

- National Transportation Safety Board. Special study - general aviation stall spin accidents, 1967 - 1969 (NTSB-AAS-72-8). Washington, DC: Author, September 1972b. (NTIS No. PB-213 614)
- National Transportation Safety Board. Special study - accidents involving engine failure/malfunction: U.S. general aviation, 1965-1969 (NTSB-AAS-72-10). Washington, DC: Author, November, 1972c. (NTIS No. PB-217 115)
- National Transportation Safety Board. Special study of fatal, weather-involved, general aviation accidents (NTSB-AAS-74-2). Washington, DC: Author, August 1974.
- National Transportation Safety Board. Flightcrew coordination procedures in air carrier instrument landing system approach accidents (NTSB AAS-76-5). Washington, DC: Author, August 1976. (NTIS No. PB-258 720)
- National Transportation Safety Board. Annual review of aircraft accident data U.S. general aviation, calendar year 1977 (NTSB-ARG-78-2). Washington, DC: Author, November 1978. (NTIS No. PB-291 627)
- National Transportation Safety Board. Special study - single-engine, fixed-wing general aviation accidents, 1972-1976 (NTSB-AAS-79-1). Washington, DC: Author, May 1979a.
- National Transportation Safety Board. Special study--light twin-engine aircraft accidents following engine failures, 1972-1976 (NTSB-AAS-79-2). Washington, DC: Author, December 1979b.
- Nicklas, D. R. A history of aircraft cockpit instrumentation 1903-1946 (WADC-TR-57-301). Wright-Patterson AFB, OH: Wright Air Development Center, April 1958. (NTIS No. AD-118 299)
- North, D. M. Upturn seen in general aviation sales. Aviation Week & Space Technology, 1981, 114, 55-56.
- Nunnally, J. Psychometric theory. New York: McGraw-Hill, 1967.
- Ontiveros, R. J. General aviation cockpit display and control simulation (FAA-NA-68-48). Washington, DC: Federal Aviation Administration, October 1968. (NTIS No. AD-680 054)
- Ontiveros, R. J., Spangler, R. M., & Sulzer, R. L. General aviation (FAR 23) cockpit standardization analysis (FAA-RD-77-192). Washington, DC: Federal Aviation Administration, March 1978. (NTIS No. AD-A052 803)
- Parker, J. F., & West, V. R. Bioastronautics data book (NASA-SP-3006). Washington, DC: National Aeronautics and Space Administration, 1973.
- Parsons, H. M. Man-machine system experiments. Baltimore: The John Hopkins Press, 1972.

- Prophet, W. W., & Jolley, O. B. Evaluation of the integrated contact-instrument concept for Army fixed wing flight instruction (Tech. Rep. 69-26). Alexandria, VA: Human Resources Research Organization, December 1969. (NTIS No. AD-703 161)
- Prophet, W. W., Shelnutt, J. B., & Spears, W. D. Simulator training requirements and effectiveness study (STRES): Future research plans (AFHRL-TR-80-37). Wright-Patterson AFB, OH: Air Force Human Resources Laboratory, January 1981.
- Quinby, G. F. An assessment of general aviation utilization of advanced avionics technology (NASA-CR-159328). Washington, DC: National Aeronautics and Space Administration, September 1980. (NTIS No. N81-13941)
- Radio Technical Commission for Aeronautics. Minimum operational performance standards-airborne weather and ground mapping pulsed radars (DO-173). Washington, DC: Author, 1981.
- Ramsey, H. R., & Atwood, M. E. Human factors in computer systems: A review of the literature (Tech. Rep. SAI-79-111-DEN). Englewood, CO: Science Applications, Inc., September 1979. (NTIS No. AD-A075 679)
- Ramsey, H. R., Atwood, M. E., & Kirshbaum, P. J. A critically annotated bibliography of the literature on human factors in computer systems (SAI-78-070-DEN). Englewood, CO: Science Applications, Inc., May 1978. (NTIS No. AD-A058 081)
- Rehmann, J. T. Cockpit display of traffic information and the measurement of pilot workload: An annotated bibliography (DOT/FAA/EM-81/9). Washington, DC: Federal Aviation Administration, February 1982.
- Rockwell, T. H., & Giffen, W. C. An investigation into pilot and system response to critical in-flight events. Volume I (Grant No. NAS2-10047). Columbus, OH: The Ohio State University Research Foundation, June 1981.
- Rogers, J. G., & Armstrong, R. Use of human engineering standards in design. Human Factors, 1977, 19, 15-24.
- Rogers, J. G., & Pegden, C. D. Formatting and organization of a human engineering standard, Human Factors, 1977, 19, 55-62.
- Roscoe, S. N. Airborne displays for flight and navigation. Human Factors, 1968, 10, 321-332.
- Roscoe, S. N. Aviation psychology. Ames: Iowa State University Press, 1980.
- Roscoe, S. N., & Bergman, C. A. Flight performance control. In Roscoe, S. N. Aviation Psychology. Ames: Iowa State University Press, 1980.
- Roscoe, S. N., & Childs, J. M. Reliable, objective flight checks. In Roscoe, S. N. Aviation Psychology. Ames: Iowa State University Press, 1980.
- Roscoe, S. N., Corl, L., & Jensen, R. S. Flight display dynamics revisited. Human Factors, 1981, 23(3), 341-354.

- Roscoe, S. N., Smith, J. F., Johnson, B. E., Dittman, P. E., & Williams, A. C. Comparative evaluation of pictorial and symbolic VOR navigation displays in the 1-CA-2 Link trainer. Washington, DC: Civil Aeronautics Administration, 1950.
- Roscoe, S. N., & Williges, R. C. Motion relationships in aircraft attitude and guidance displays in a flight experiment. Human Factors, 1975, 17, 374-387.
- Rosenburg, A., Stein, E., & Rehmann, J. Development of measures of pilot workload (Draft) (DOT/FAA/EM-81/13). Washington, DC: Federal Aviation Administration, In Preparation.
- Schiff, B. The proficient pilot. Washington, DC: Aircraft Owners and Pilots Association, 1980.
- Schofield, J. E., & Giffen, W. C. An analysis of aircrew procedural compliance. Paper presented at the First Symposium on Aviation Psychology, Columbus, April 1981.
- Scott, W. B. New electronic instruments displayed. Aviation Week & Space Technology, 1981, 115, 77-80.
- Semple, C. A., Cotton, J. C., & Sullivan, D. J. Air training devices: instructional support features (AFHRL-TR-80-58). Wright-Patterson AFB, OH: Air Force Human Resources Laboratory, January 1981.
- Semple, C., Heapy, R., Conway, E., & Burnette, K. Analysis of human factors data for electronic flight display systems. Northridge, CA: Manned System Sciences, Inc., April 1971. (NTIS No. AD-884 770)
- Semple, C. A., Hennessy, R. T., Sanders, M. S., Cross, B. K., Beith, B. H., & McCauley, M. E. Aircrew training devices: Fidelity features (AFHRL-TR-80-3). Wright-Patterson AFB, OH: Air Force Human Resources Laboratory, January 1981.
- Shelnutt, J. B., Childs, J. M., Prophet, W. W., & Spears, W. D. Human factors problems in general aviation (FAA-CT-80-194). Washington, DC: Federal Aviation Administration, July 1980.
- Shelnutt, J. B., Spears, W. D., & Prophet, W. W. Effects of different distributions of training time on the acquisition of private pilot flying skills (FAA-CT-81/76). Washington, DC: Federal Aviation Administration, July 1981.
- Shelnutt, J. B., Smillie, R. J., & Bercos, J. A consideration of Army training device proficiency assessment capabilities (ARI-TR-78-A20). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences, June 1978. (NTIS No. AD-A056 191)
- Sherr, S. Fundamentals of display systems. New York: Wiley, 1970.
- Shipley, B. D., Gerlach, V. S., & Brecke, F. H. Measurement of flight performance in a flight simulator (TR No. 40830). Washington, DC: Air Force Office of Scientific Research, 1974.

- Shrager, J. J. Altimetry display study. Part 3 - review of R & D on display readability (FAA-RD-72-46, II). Washington, DC: Federal Aviation Administration, May 1972.
- Shurtleff, D. A. How to make displays legible. La Mirada, CA: Human Interface Design, 1980.
- Siering, G. D., Ruffner, J. W., & Childs, J. M. Identification of key elements for inflight performance assessment (ARI-WP-80-4). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences, July 1980.
- Simon, C. W. New research paradigm for applied experimental psychology: A system approach (CWS-04-77A/AFOSR-TR-78-0117). Westlake Village, CA: Canyon Research Group, Inc., October 1977. (NTIS No. AD-A056 984)
- Smith, D., & Dieterly, D. L. Automation literature: A brief review and analysis (NASA-TM-81245). Washington, DC: National Aeronautics and Space Administration, October 1980.
- Smith, H. P. R. A simulator study of the interaction of pilot workload with errors, vigilance and decisions (NASA-TM-78872). Washington, DC: National Aeronautics and Space Administration, January 1979.
- Smith, J. F., Flexman, R. E., & Houston, R. C. Development of an objective method of recording flight performance (Tech. Rep. 52-15). Lackland AFB, TX: Air Training Command Human Resources Research Center, December 1952.
- Society of Automotive Engineers. Flight deck instrumentation and display design objectives for transport aircraft (ARP 1068). Warrendale, PA: Author, 1981a.
- Society of Automotive Engineers. Flight deck visual, audible and tactile signals (ARP 4500). Warrendale, PA: Author, 1981b.
- Society of Automotive Engineers. Airborne electronic displays (draft). Warrendale, PA: Author, 1981c.
- Spady, A. A. How pilots look at altitude. Paper presented at the 1980 Aircraft Safety and Operating Problems Conference. Langley, VA, November 1980.
- Strauch, B. Measures of effectiveness in evaluating a prototype general aviation in-flight simulator. Paper presented at the First Symposium on Aviation Psychology, Columbus, April 1981.
- Taylor, R. L., & Guinther, W. M. Positive flying. New York: Delacorte Press, 1978.
- Thomas, J. M., & Bennis, W. G., (Eds) Management of change and conflict. Baltimore: Penquin Books, 1972.
- Toffler, A. Future Shock. New York: Random House, 1970.
- Trammell, A. Cause and circumstance. New York: Ziff-Davis Publishing Co., 1980.

- Van Cott, H. P., & Kinkade, R. G. (Eds.). Human engineering guide to equipment design. Washington, DC: U.S. Government Printing Office, 1972.
- Vreuls, D., & Wooldridge, L. Aircrew performance measurement. In Pope, L. T. and Meister, D. (Eds) Symposium proceedings. Productivity enhancement: Personnel performance assessment in Navy systems. San Diego: Navy Personnel Research and Development Center, October 1977.
- Vreuls, D., Wooldridge, A. L., Obermayer, R. W., Johnson, R. M., Norman, D. A., & Goldstein, I. Development and evaluation of trainee performance measures in an automated instrument flight maneuvers trainer (NAVTRAEQUIPCEN 74-C-0063-1). Orlando, FL: Naval Training Equipment Center, October 1975.
- Waag, W., & Knoop, P. Planning for aircrew performance measurement R & D: U.S. Air Force. In Pope, L. T., & Meister, D. (Eds) Symposium proceedings. Productivity enhancement: Personnel performance assessment in Navy systems. San Diego: Navy Personnel Research and Development Center, October 1977.
- Weislogel, G. S., & Miller, J. M. Study to determine the operational profile and mission of the certificated instrument-rated private and commercial pilot (FAA-RD-70-51). Washington, DC: Federal Aviation Administration, July 1970.
- Wiener, E. L., & Curry, R. E. Flight-deck automation: Promises and problems (NASA-TM-81206). Washington, DC: National Aeronautics and Space Administration, June 1980.
- Wierwille, W. W., & Williges, B. H. An annotated bibliography on operator mental workload assessment (SY-27R-80). Patuxent River, MD: Naval Air Test Center, March 1980.
- Williams, A. C. Preliminary analysis of information required by pilots for instrument flight. Port Washington, NY: Office of Naval Research, Special Devices Center, 1947.
- Winer, B. J. Statistical principles in experimental design. New York: McGraw-Hill, 1962.
- Winkler, R. E. Readability of electronic displays (AFIT-CT-79-237T). Wright-Patterson AFB, OH: Air Force Institute of Technology, 1979. (NTIS No. AD-A091 411)
- Woodson, W. E. Human factors design handbook. New York: McGraw-Hill, 1981.
- Woodson, W. E., & Coburn, C. Human engineering design criteria for modern control/display components and standard parts (Tech. Rep. RS-CR-80-2). Redstone Arsenal, AL: U.S. Army Missile Command, May 1980.
- Zeller, A. F. Three decades of USAF efforts to reduce human error accidents 1947-1977. In Proceedings of the 35th Specialists Aerospace Medical Panel Meeting. Neuilly sur Seine, France: Advisory Group for Aerospace Research and Development, November 1978.

APPENDIX A

DESCRIPTION OF ELECTRONIC FLIGHT INSTRUMENT SYSTEMS THAT WILL BE INSTALLED ON GENERAL AVIATION AIRCRAFT

Several avionics manufacturers are developing electronic flight instrument systems (EFIS) for general aviation aircraft. While sharing some general characteristics, these new systems, like other avionic systems, will differ in certain respects across manufacturers. Further, some of the manufacturers are also planning to produce series of systems that differ in capability and cost to match the needs of their varied general aviation customers.

This appendix describes some of the general characteristics that these systems will share, as well as differences that will exist across systems. In line with the focus of this report on pilot performance, emphasis has been placed on describing the display formats that will be generated by the various EFIS. These descriptions were derived from interviews with personnel who are developing the EFIS,¹ and from articles describing the EFIS that have been published in aviation magazines and journals (e.g., Instruments on a CRT, 1981; Larson, 1981; McClellan, 1981a; 1981b; Scott, 1981). The reader is referred to these articles for additional information concerning general aviation EFIS, particularly with respect to system architecture and other equipment-related characteristics. These articles also contain color photographs of prototype EFIS displays. The black and white illustrations included in this appendix were necessitated by printing constraints and do not adequately depict the total impact of the full color EFIS displays.

The most expensive general aviation EFIS will have five cathode ray tube displays. Two of the displays, an electronic attitude director indicator (EADI) and electronic horizontal situation indicator (EHSI), will be located directly in front of the pilot. An EADI and EHSI also will be located in front of the copilot. The fifth display, which will be used for multiple purposes, usually will be located between the pilot and copilot in the center of the instrument panel.

An example of a prototype EADI display is presented in Figure A-1. In general, the formats of all of the EADI displays will be similar to those of the electromechanical attitude director indicators (ADI) that the EADIs will replace. Information concerning aircraft roll and pitch, for example, will be presented on the EADI using the same fixed aircraft, moving horizon display format of conventional ADIs, although some of the "earth, horizon line, sky" displays will be square (as shown in Figure A-1), instead of the conventional round shape. Yaw information usually will be presented using the "ball" display found on ADIs. Command symbols will be presented using conventional "V-bars" or crosspointers, with some manufacturers providing pilots with a switch that will enable them to choose the type of command cue they prefer. Other information that may be presented on different EADIs includes localizer

¹These interviews are described in Section B of Chapter I. Organizations that were visited are listed in Appendix B.

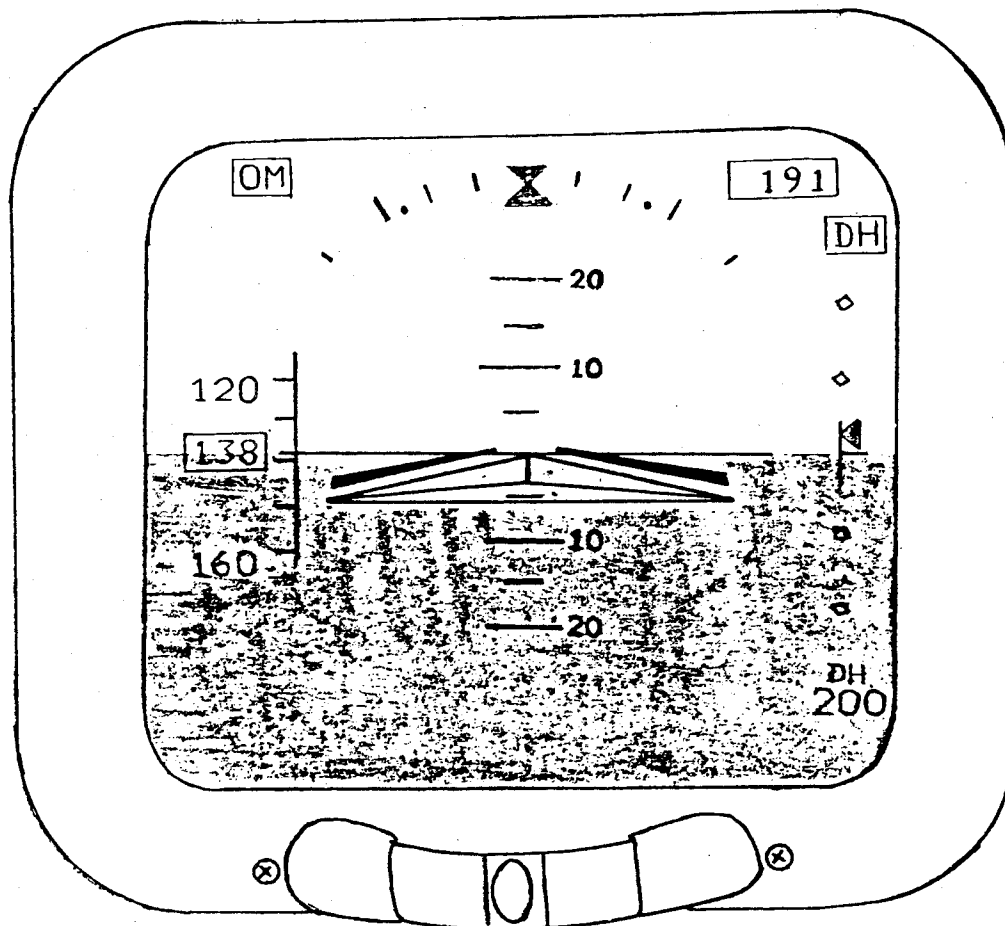


FIGURE A-1.--EXAMPLE OF AN ELECTRONIC ATTITUDE DIRECTOR INDICATOR (EADI) DISPLAY.

and glideslope deviation, airspeed, V speeds (which can be calculated by the computer), deviation from desired airspeed (e.g., fast/slow scales), decision height, ground speed, barometric altitude, radio altitude, and autopilot/ autothrottle or navigation modes. The specific parameters that are presented and the formats that are used (e.g., colors, location, and type of symbols) will differ across systems. Further, pilots will be given the ability to select parameters that are appropriate for particular flight phases (e.g., symbols used only during approaches can be eliminated during cruise).

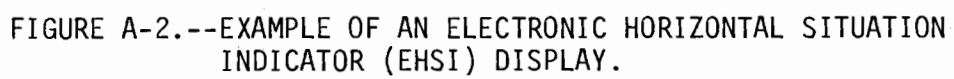
The EHSI displays usually will have several modes for the pilot to select. Some of the display modes will be similar to the formats of conventional, electromechanical navigational displays. Figure A-2, for example, illustrates an EHSI display that resembles a conventional horizontal situation indicator (HSI). Other modes will present full or partial compass rose formats. Yet other modes, however, will be completely different from existing electromechanical displays--such as the map mode illustrated in Figure A-3. Map modes typically will present aircraft flight path and geographic data superimposed over a color-coded (for precipitation severity) weather radar display. Additional data that may be displayed on map or other EHSI displays include the selected navigation radio frequency, Distance Measuring Equipment (DME) readouts, heading, track, wind vector and speed, glideslope and localizer deviation, and navigation modes.

The multiple purpose displays located in the center of the panel will present a wide variety of information to the pilots. The exact content of the displays will depend on the capabilities of the EFIS of which it is a part. In some systems, pilots will be able to call up displays that contain checklists and procedures, aircraft performance data (normally found in Pilot Operating Handbooks), navigation information (e.g., radio frequencies, latitudes and longitudes of waypoints, waypoint and navaid identifiers), engine status data, and fuel status information. In some cases, these displays will also serve as master warning displays. Some of the EFIS will also contain displays that provide reproductions of conventional airspeed displays and altimeters.

An example of a multiple purpose display is provided in Figure A-4. In this illustration, navigation waypoint information for a selected flight plan is displayed. The various pushbuttons around the display allow the pilot to create and edit the flight plan, as well as call up other displays.

Should any of the cathode ray tubes (or associated symbol generators) malfunction, the pilots can call up the display formats that normally would be presented at the failed location on other cathode ray tubes--e.g., they could call up an EADI on the cathode ray tube normally used to present the EHSI. Some manufacturers also are planning combined displays (e.g., split screen displays) that also could be used when one cathode ray tube fails.

Less expensive versions of the EFIS will have fewer cathode ray tubes and less redundancy with respect to the black boxes used to process signals and generate displays. In some versions, for example, only two displays--an EADI and EHSI for the pilot--will be available. Other less expensive versions will have only one cathode ray tube. This single display typically will contain certain EHSI display formats as well as some of the formats presented in multiple purpose displays in larger systems.



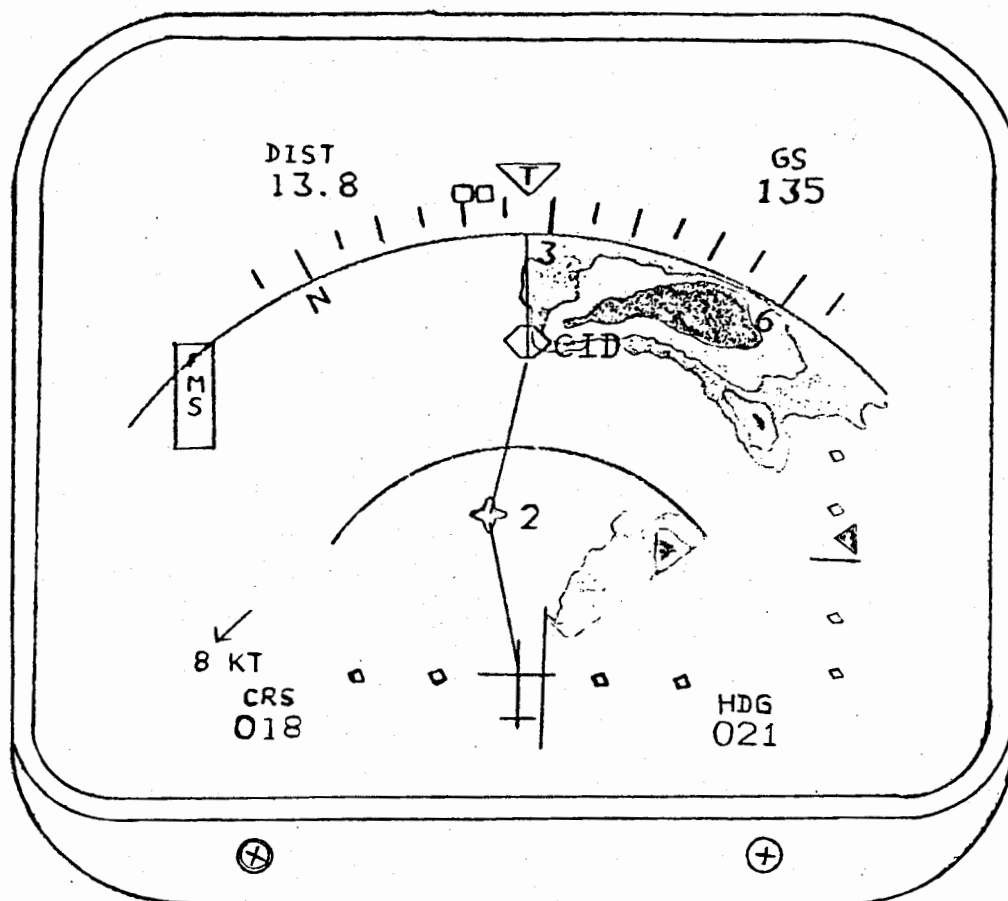


FIGURE A-3.--EXAMPLE OF A MAP DISPLAY (EHSI).

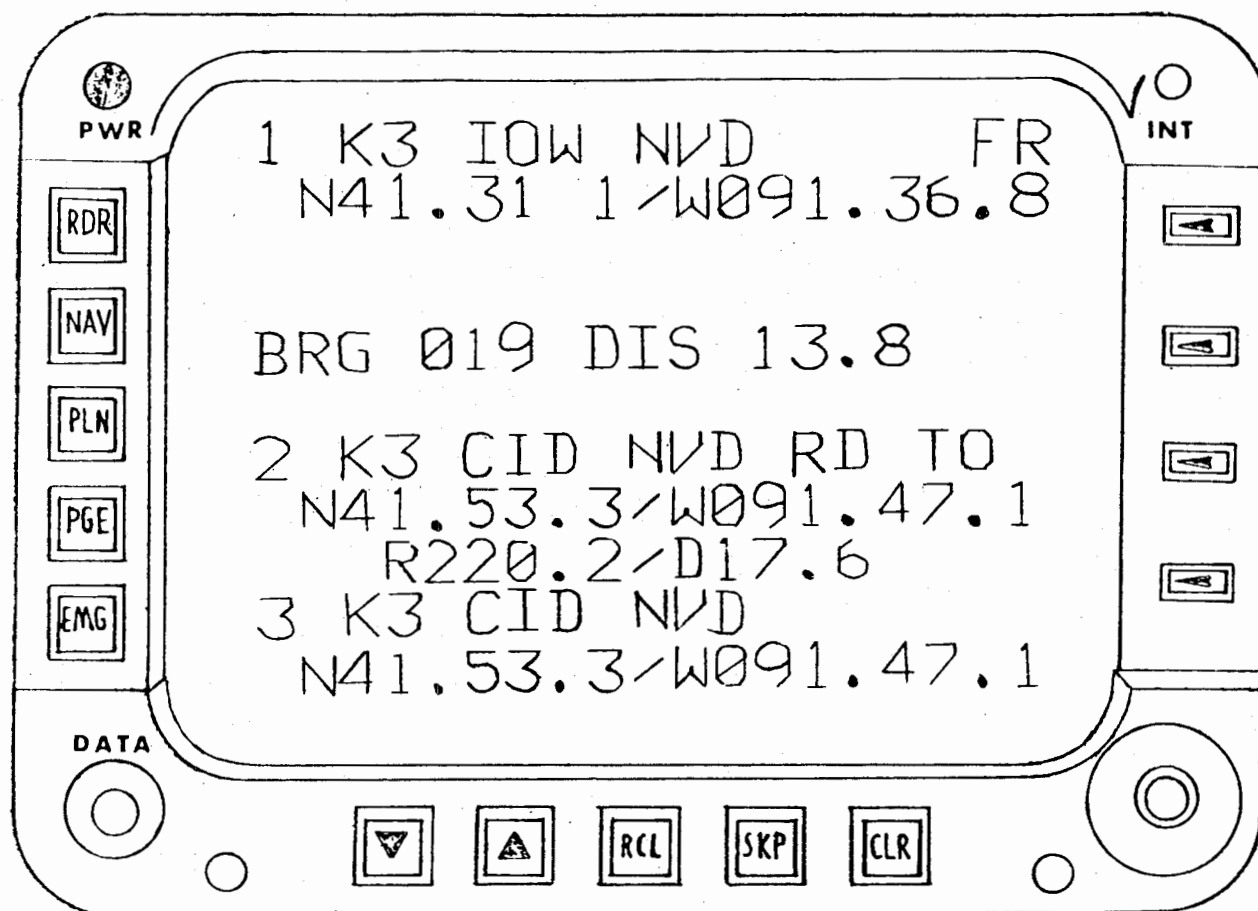


FIGURE A-4.--EXAMPLE OF A MULTIPLE PURPOSE DISPLAY.

APPENDIX B

LIST OF ORGANIZATIONS CONTACTED

Following is a list of organizations that were visited or contacted by telephone during the present study.

Site Visits

- Rockwell International (Collins Air Transport Division; Collins General Aviation Division; Avionics Division, Collins Radio Group)
- Sperry Flight Systems (Avionics and Commercial Divisions)
- Boeing Commercial Airplane Company (Systems Technology, Flight Deck; 757/767 Flight Deck Integration; Crew Systems Technology)
- Gates Learjet Corporation
- FAA Northwest Region
- FAA Technical Center
- FAA Headquarters (Office of Aviation Policy; Office of Airworthiness; Office of Aviation Safety; Office of Systems Engineering Management; Systems Research and Development Service)

Telephone Interviews

- FAA Central Region
- FAA Western Region
- NASA Langley Research Center
- NASA Ames Research Center
- Radio Technical Commission for Aeronautics (Special Committees SC-133--Airborne Weather and Ground Mapping Pulsed Radios--and SC-145--Digital Avionics Software)
- Society of Automotive Engineers (A4 Committee on Aircraft Displays)
- US Air Force Flight Dynamics Laboratory
- US Air Force Aeromedical Research Laboratory
- US Army Human Engineering Laboratory
- National Bureau of Standards (Human Factors Section; Standards Impact Program, Office of Engineering Standards)
- Naval Post Graduate School
- Naval Air Development Center

APPENDIX C

A BIBLIOGRAPHY OF EMPIRICAL STUDIES OF ELECTRONIC FLIGHT INSTRUMENT SYSTEMS

As discussed in Chapter II, a review was conducted of past research on electronic flight instrument systems (EFIS) to aid in the identification of experimental techniques that could be employed to evaluate such systems. This appendix contains references for the research studies that were reviewed and a subject index that catalogs the studies with respect to general research issues.

Several criteria were used as a basis for selecting these studies. (1) The research focused on primary flight displays--i.e., the display of information related to navigation and control of aircraft attitude, flight path, and velocity. (2) The research was concerned with flight operations that are characteristic of fixed-wing, general aviation aircraft. (3) The flight instruments that were studied employed advanced electronic display technology (although a few other types of studies were selected for review when it was felt that they contained information relevant to the design of EFIS displays). (4) Use of the flight displays was evaluated with certificated pilots during actual or simulated flight operations in an aircraft or simulator (some analytical studies were included, however, to broaden the scope of topics that were covered).

While the studies selected through the use of these criteria were sufficient for the purpose cited above, the reports referenced in this appendix constitute only a small portion of the literature concerned with the design of flight displays. To aid the reader in identifying additional literature that may be of interest, several major reviews of the flight display research literature have been included in the reference list. They are identified under the heading "bibliographies and reviews" in the Subject Index. Further, since the articles in this appendix focus on flight displays, research on other types of visual displays is not referenced, even though it may have concerned issues relevant to the design of EFIS displays--e.g., studies investigating parameters associated with the legibility of cathode ray tube displays. References to such research can be found in the design guides cited in Table 2 in Chapter II.

SUBJECT INDEX

Altitude information

Hill & Chernikoff, 1965
Matheny, 1964
Mitchell, 1972
Spady, 1980
Spady, 1981
Triggs, 1960

Angle of attack information

Forrest, 1969
Gandleman, 1968
Gee, Gaidsick, & Enevoldson, 1971

Area of navigation (RNAV) information (2-D, 3-D, and 4-D)

Adams, 1975
Bolz & McConkey, 1972
Bruckner, Benson, McCormick, & Sharpe, 1977
Edmonds, Pursel, & Gallagher, 1977
Edmonds, Gallagher, & Pursel, 1980
Eldredge, Crook, & Crimbring, 1977
Eldredge, Crook, DeBaryshe, & Crimbring, 1979
Eldredge, Goldberg, & Crimbring, 1978
Goldberg & Eldredge, 1978
Goldberg, Eldredge, & Crimbring, 1979
Jensen, FitzHenry, Vanderkolk, Rose, & Roscoe, 1971
Jensen & Marsh, 1976
Jensen & Roscoe, 1973
Jensen, Vanderkolk, & Roscoe, 1979
Knox, 1976
Neuman & Hardy, 1981

Attitude information (also see pictorial displays, integrated displays display dynamics, and vertical situation displays)

Beringer, Williges, & Roscoe, 1975
Bernberg, 1960
Besco, 1964
Fogel, 1959
Gardner, 1954
Gardner & Lacey, 1954
Gartner & Holzhansen, 1978
Hasbrook, & Rasmussen, 1973
Ince, Williges, & Roscoe, 1975
Jacobs, Williges, & Roscoe, 1973
Jensen, 1979
Jensen, 1981
Johnson & Roscoe, 1972
Pangburn, Metzler, & Kline, 1972
Roscoe, Corl, & Jensen, 1981
Roscoe & Williges, 1975
Rud & Michas, 1980
Weir, Klein, & McRuer, 1971

SUBJECT INDEX (cont'd)

Bibliographies and reviews

Baker, 1961
Chatelier & Hemingway, 1977
Cundari, 1968
Defense Documentation Center, 1974
Fox, Ferguson, & Andrew, 1960
Johnson, Rover, Medlinski, Ritchie, & Schmier, 1979
Kappauf, 1949
Ketchel & Jenney, 1968
Matheny, 1964
Nicklas, 1958
Roscoe, 1980
Semple, Heapy, Conway, & Burnette, 1971
Shrager, 1972
Shrager, 1978

Curved and other complex trajectory approaches (display requirements)

Dieudonne, Grove, & Steinmetz, 1976
Duning, Hemesath, Hickok, Lammers, & Goemaat, 1973
Erkelens, 1978
Harris & Mixon, 1981
Jensen, 1979
Jensen, 1981
Johnson, Rover, Medlinski, Ritchie, & Schmier, 1979
Steinmetz, 1979
Wyatt & Eastman, 1976

Control of displayed information

Crawford, Pearson, & Hoffman, 1978
Gartner & Holzhansen, 1978
Graham, 1973

Display dynamics (also see HUDs, pictorial displays, integrated displays)

Baron & Levison, 1977
Clement, Jex, & Graham, 1970
Ince, Williges, & Roscoe, 1975
Jacobs, Williges, & Roscoe, 1973
Jensen, 1979
Jensen, 1981
Johnson & Roscoe, 1972
Ketchel & Jenney, 1968
Roscoe, Corl, & Jensen, 1981
Roscoe, Johnson, & Williges, 1980
Roscoe & Williges, 1975
Weir, Klein, & McRuer, 1971

Display size (discussed independent of specific information content)

Abbott & Moen, 1981
Barnes, 1978
Semple, Heapy, Conway, & Burnette, 1971

SUBJECT INDEX (cont'd)

Flight path angle (also see HUDs)

Cronn & Palmer, 1975
Downing, Bryant, & Yenni, 1981
Hanisch, Ernst, & Johnston, 1981
Kelley, 1978
Steinmetz, 1980

Head-up displays (HUDs)

Bourquin, Palmer, Cooper, & Gerdes, 1973
Bray, 1980
Bray & Scott, 1980
Dowes-Dekker, 1970
Dwyer & Palmer, 1975
Fgan & Goodson, 1978
Fischer, Haines, & Price, 1980
Frank, 1979
Gee, Gaidsick, & Enevoldson, 1971
Haines, 1980
Haines, Fischer, & Price, 1980
Harris, Goode, & Yenni, 1978
Harris & Hewes, 1973
Jenney, Malone, & Schweickert, 1971
Lauber, Brag, & Scott, 1980
Leitner & Haines, 1981
Naish, 1980
Naish & Miller, 1980
Orrick & York, 1975
Palmer, 1972
Skelton & Sulzer, 1971

Horizontal situation displays (also see moving map displays, other air traffic, pictorial displays, predictor displays)

Abbott, Moen, Person, Keyser, Yenni, & Garren, 1980
Baty, 1976
Crook & Sulzer, 1968

Integrated displays (also see pictorial displays, horizontal situation displays, and vertical situation displays)

Bamford & Ritchie, 1957
Braid, 1975
Clement, Allen, & Graham, 1971
Clement, Best, & Stapleford, 1967
Clement, Jex, & Graham, 1970
Jensen, FitzHenry, Vanderkolk, Rose, & Roscoe, 1971
Johnson, Rover, Medlinski, Ritchie, & Schmier, 1979
Levison, 1978
Loschke, Barber, Enevoldson, & McMurty, 1974
Ritchie, 1955

SUBJECT INDEX (cont'd)

Legibility (discussed independently of specific information content)

Ketchel & Jenney, 1968
Semple, Heapy, Conway, & Burnette, 1971

Low visibility approaches and landings (display requirements)

Gartner, 1969
Hanes & Ritchie, 1965
Karmarker & Sovensen, 1976
Waller, Harris, & Slamirs, 1979
Weir & Klein, 1970

Methods of coding symbols (discussed independent of specific information content)

Beyer, 1971
Ketchel & Jenney, 1968
Neil, 1979
Semple, Heapy, Conway, & Burnette, 1971

Moving map displays

Burton, Clay, Croce, Gore, & Tetrev, 1975
Clement, 1976
Harris & Mixon, 1981
McGrath, 1971
Ontiveros, 1968
Roscoe, Smith, Johnson, Dittman, & Williams, 1950

Other air traffic (cockpit displays)

Abbott & Moen, 1981
Abbott, Moen, Person, Keyser, Yenni, & Garren, 1980
Ace, 1981
Boeing Commercial Airplane Company, 1977
Connelly, 1977
Curry, 1974
Curry & Young, 1970
Hart, 1979
Hart & Loomis, 1980
Hart & Wempe, 1979
Howell, 1972
Kelley, 1980
Kreifeldt, 1980
Kreifeldt, Parkin, Rothschild, & Wempe, 1976
O'Connor, Jago, Baty, & Palmer, 1980
Palmer, Jago, Baty, & O'Connor, 1980
Stark, 1975
Steinmetz, 1979

Over-ocean separation assurance (display requirements)

Crook & Sulzer, 1968

SUBJECT INDEX (cont'd)

Peripheral presentation of information

Hasbrook, 1968
Hasbrook & Young, 1968
Hasbrook, Rasmussen, & Willis, 1975
Rud & Michas, 1980
Swartzendruber & Roscoe, 1980
Vallerie, 1967

Pictorial displays

Adams & Lallman, 1978
Carel, 1965
Cross & Cavallero, 1971
Downing, Bryant, & Yenni, 1981
Gartner & Baldwin, 1970
Grether, 1947
Jensen, 1979
Knox & Leavitt, 1977
LaFranchi, 1966
Lewis & Wolling, 1971
Lincoln, Palmer, & Wempe, 1972
McKinloy, 1975
Morello, Knox, & Steinmetz, 1977
Parks, Jonsen, & Niwa, 1969
Parks & Tubb, 1970
Roscoe, 1976
Roscoe, Corl, & Jensen, 1981
Roscoe, Smith, Johnson, Dittmann, & Williams, 1950
Simonelli, 1978
Steinmetz, Morello, Knox, & Person, 1976
Wilckens & Schattenmann, 1970

Pilot information requirements

Caldwell & Jones, 1981
Havron, 1961
Jensen, 1979
Johnson, Rover, Medlinski, Ritchie, & Schmier, 1979
Matheny, 1964
Ritchie, 1960
Weir, Klein, & McRuer, 1971
Westland, Weingarten, & Kelley, 1962
Williams, 1971
Zipoy, Premelaar, Gargett, Belyea, & Holl, 1970

Predictor displays

Jensen, 1979
Kreifeldt & Wempe, 1973
Roscoe, 1976
Smith & Kennedy, 1975

Sensitivity of vertical and horizontal displacement indicators

Adams, 1980
Erkelens, 1978

SUBJECT INDEX (cont'd)

Side vertical situation display
Baty, 1976

Standby flight instrument systems
Barnette, 1978

Track information
Downing, Bryant, & Yenni, 1981
Morello, Knox, & Steinmetz, 1977
Steinmetz, Morello, Knox, & Person, 1976

Velocity vector (see also HUDs, vertical situation displays)
Dwyer & Palmer, 1975
Harris, Goode, & Yenni, 1978

Vertical situation displays (also see attitude indicators, flight path angle,
pictorial displays, peripheral presentation of
information, predictor display, velocity vector)
Baron & Levison, 1973
Baty, 1976
Clement, Allen, & Graham, 1971
Reeder & Kolnick, 1964

Weather conditions
Connolly, 1968

Wind shear (information requirements)
Gartner & Baldwin, 1970
Gartner & McTee, 1977
Levison, 1978
Ostroff, Hueschen, Hellbaum, & Creedon, 1981

REFERENCES CITED IN THE SUBJECT INDEX

- Abbott, T. S., & Moen, G. C. Effects of display size on utilization of traffic situation displays for self-pacing task (NASA-TP-1885). Washington, DC: National Aeronautics and Space Administration, August 1981.
- Abbott, T. S., Moen, G. C., Person, L. H., Keyser, G. I., Yenni, K. R., & Garren, J. F. Flight investigation of cockpit-displayed traffic information utilizing coded symbology in an advanced operational environment (NASA-TP-1684). Washington, DC: National Aeronautics and Space Administration, July 1980.
- Ace, R. E. Candidate CDTI procedures study (NASA-CR-165673). Washington, DC: National Aeronautics and Space Administration, January 1981.
- Adams, J. J. Simulator study of conventional general aviation instrument displays in path following tasks with emphasis on pilot-induced oscillations (NASA-TP-1776). Washington, DC: National Aeronautics and Space Administration, 1980.
- Adams, J. J. & Lallman, F. J. Description and preliminary studies of a computer drawn instrument landing approach display (NASA-TM-78771). Washington, DC: National Aeronautics and Space Administration, 1978.
- Adams, R. J. An operational evaluation of flight technical error (DOT-FAA-RD-76-33). Washington, DC: United States Department of Transportation, July 1975.
- Baker, C. H. Review of selected aspects of the ANIP program. El Segundo, CA: Douglas Aircraft Company, November 1961.
- Bamford, Jr., H. E. & Ritchie, M. L. Integrated instruments: A roll and turn indicator (TR-57-205). Wright Patterson AFB, OH: Wright Air Development Center, May 1957.
- Barnes, M. J. Factors that affect display size criteria in a cockpit display system. In Proceedings of the 22nd Annual Meeting of the Human Factors Society, Santa Monica, CA: The Human Factors Society, 1978, 218-221.
- Barnette, J. F. Evaluation of a "Jet 2" standby flight instrument system (USAFIFC-TR-78-1). Randolph AFB, TX: Air Force Instrument Flight Center, January 1978.
- Baron, S., & Levison, W. H. A manual control theory analysis of vertical situation displays for STOL aircraft (NASA-CR-2-6652). Washington, DC: National Aeronautics and Space Administration, April 1973.
- Baron, S., & Levison, W. H. Display analysis with the optimal control model of the human operator. Human Factors, 1977, 19, 437-458.
- Baty, D. L. Introduction to a coordinated cockpit display concept (NASA-TM-X-73). Washington, DC: National Aeronautics and Space Administration, May 1976.

- Beringer, D. B., Williges, R. C., & Roscoe, S. N. The transition of experienced pilots to a frequency-separated aircraft attitude display. Human Factors, 1975, 17, 401-414.
- Bernberg, R. E. A comparison of three flight attitude displays. Human Factors, 1960, 2, 14-17.
- Besco, R. O. Manual attitude control systems: Vol. II. Display format considerations. Culver City, CA: Hughes Aircraft Company, 1964.
- Beyer, R. A. A limited study of the trade-off between luminance and color coding in electronic displays (AGARD-CP-96). Neuilly sur Seine, France: Advisory Group for Aerospace Research and Development, October 1971.
- Boeing Commercial Airplane Company. Cockpit displayed traffic information study (FAA-EM-77-18). Washington, DC: Federal Aviation Administration, September 1977.
- Bolz, E. H., & McConkey, E. E. Vertical area navigation system analysis (FAA-RD-72-125). Washington, DC: Federal Aviation Administration, September 1972.
- Bourquin, K., Palmer, E., Cooper, G., & Gerdes, R. Initial flight and simulation evaluation of a head up display for standard and noise abatement visual approaches (NASA-TMX-62, 187). Washington, DC: National Aeronautics and Space Administration, 1973.
- Braid, J. M. Integrated multifunction cockpit display systems (AGARD-CP-167). Neuilly sur Seine, France: Advisory Group for Aerospace Research and Development, December 1975.
- Bray, R. S. A head-up display format for application to transport aircraft approach and landing (NASA TM-81199). Washington, DC: National Aeronautics and Space Administration, July 1980.
- Bray, R. S., & Scott, B. C. A head-up display format for transport aircraft approach and landing. In Stickley, J. W. 1980 Aircraft Safety and Operating Problems (NASA-CP-2170). Washington, DC: National Aeronautics and Space Administration, November 1980.
- Bruckner, J. M. H., Benson, F. B., McCormick, L. J., & Sharpe, T. G. Area navigation system design, development, and implementation (FAA-RP-77-79). Washington, DC: Federal Aviation Administration, June 1977.
- Burton, G. T., Clay, B. R., Croce, R. F., Gore, D. A., & Tetrev, R. E. Holographic horizontal situation display extension (NADC-75343-30). Warminster, PA: Naval Air Development Center, November 1975.
- Caldwell, J. D., & Jones, T. G. Analytical study of cockpit information requirements (FAA/RD-81/4). Washington, DC: Federal Aviation Administration, April 1981.
- Carel, W. L. Pictorial displays for flight (JANAI TR-2732.01/45). Washington, DC: Office of Naval Research, 1965.

- Chatelier, P. R., & Hemingway, J. C. Abstracts of control and display related human factors engineering research and development efforts. Washington, DC: Naval Air Systems Command, June 1977.
- Clement, W. F. Investigating the use of a moving map display and a horizontal situation indicator in simulated power lift, short haul operations (NASA-TM-X-73). Washington, DC: National Aeronautics and Space Administration, May 1976.
- Clement, W. F., Allen, R. W., & Graham, D. Pilot experiments for a theory of integrated display format (STI-TR-183-2). Hawthorne, CA: Systems Technology, Inc., October 1971.
- Clement, W. F., Best, J. J., & Stapleford, R. L. Analysis of display - pilot vehicle dynamics for ILS approach of a large jet aircraft (STI-TM-163-C). Princeton, NJ: Systems Technology, Inc., May 1967.
- Clement, W. F., Jex, H. R., & Graham, D. Jet transport instrument approach application of a theory for manual control display systems (AGARD-CP-55). Neuilly sur Seine, France: Advisory Group for Aerospace Research and Development, March 1970.
- Connelly, M. E. Simulation studies of airborne traffic situation display applications-final report (ESL-R-751). Cambridge, MA: Massachusetts Institute of Technology, May 1977.
- Connolly, D. W. Display of weather conditions (FAA-68-29). Washington, DC: Federal Aviation Administration, August 1968.
- Crawford, B. M., Pearson, W. H., & Hoffman, M. S. Multipurpose digital switching and flight control workload (AMRL-TR-78-43). Wright-Patterson AFB, OH: Aerospace Medical Research Laboratory, December 1978.
- Cronn, F., & Palmer, E. Comparison of two head-up displays in simulated standard and noise abatement night visual approaches (NASA-RM-3264). Washington, DC: National Aeronautics and Space Administration, July 1975.
- Crook, W. G., & Sulzer, R. L. Simulation and analysis of over-ocean separation assurance procedures and displays (FAA-RD-67-43). Washington, DC: Federal Aviation Administration, February 1968.
- Cross, K. D., & Cavallero, F. R. Utility of the vertical contact display for carrier landings - a diagnostic evaluation (AGARD-CP-96). Neuilly sur Seine, France: Advisory Group for Aerospace Research and Development, October 1971.
- Cundari, F. L. Bibliography of technical reports of the Joint Army Navy Aircraft Instrumentation Research (JANAIR) Program. Washington, DC: Office of Naval Research, April 1968.
- Curry, R. E. Investigation of pilot's role and display requirements in automatic landing (NASA Grant 22-009-733). Cambridge, MA: Massachusetts Institute of Technology, August 1974.

- Curry, R. E., & Young, L. R. Display research: Collision warning systems (NASA Grant 22-009-444). Cambridge, MA: Massachusetts Institute of Technology, July 1970.
- Defense Documentation Center. Human factors in design and control of aircraft (DDC-TAS-74-28). Alexandria, VA: Author, July 1974.
- Dieudonne, J. E., Grove, R. D., & Steinmetz, G. G. A simulation study of curved, decending, decelerating, landing approaches for transport aircraft (NASA-TN-D-8190). Washington, DC: National Aeronautics and Space Administration, April 1976.
- Dowes-Dekker, F. E. Head-up display symbology (AGARD-CP-55). Neuilly sur Seine, France: Advisory Group for Aerospace Research and Development, March 1970.
- Downing, D. R., Bryant, W. H., & Yenni, K. R. Flight test evaluation of advanced symbology for general aviation approach to landing displays (AIAA-81-1643). Dayton, OH: American Institute of Aeronautics and Astronautics, August 1981.
- Duning, K. E., Hemesath, N. B., Hickok, C. W., Lammers, D. G., & Goemaat, M. L. A curved approach path study (FAA-RD-72-143). Washington, DC: Federal Aviation Administration, April 1973.
- Dwyer, J. H., & Palmer, E. A. Three methods of presenting flight vector information in a head-up display during simulated STOL approaches (NASA TM-X-3273). Washington, DC: National Aeronautics and Space Administration, July 1975.
- Edmonds, J., Gallagher, J., & Pursel, R. A flight investigation of system accuracies and operational capabilities of a general aviation/air transport area navigation system (RNAV) (FAA-RD-79-120). Washington, DC: Federal Aviation Administration, February 1980.
- Edmonds, J. D., Pursel, R. H., & Gallagher, J. A flight investigation of system accuracies and operational capabilities of a general aviation area navigation system (RNAV) (FAA-RD-77-43). Washington, DC: Federal Aviation Administration, June 1977.
- Egan, D. E., & Goodson, J. E. Human factors engineering for head-up displays: a review of military specifications and recommendations for research (NAMRL Monograph-23). Pensacola, FL: Naval Aerospace Medical Research Laboratory, April 1978.
- Eldredge, D., Crook, W. G., & Crimbring, W. R. Simulation tests of flight technical error in 2D/3D area navigation (RNAV) using a multiple waypoint RNAV system with and without a flight director system (FAA-RD-77-112). Washington, DC: Federal Aviation Administration, October 1977.
- Eldredge, D., Crook, W. G., DeBaryshe, B. D., & Crimbring, W. R. Simulation study of the operational characteristics of a two/three - dimensional multiwaypoint area navigation (RNAV) system (FAA-RD-29-31). Washington, DC: Federal Aviation Administration, August 1979.

- Eldredge, D., Goldberg, B., & Crimbring, W. An evaluation of modified RNAV terminal procedures using a single-waypoint RNAV system (FAA-RD-78-27). Washington, DC: Federal Aviation Administration, April 1978.
- Erkelens, L. J. J. A simulation investigation on the feasibility of curved approaches under MLS guidance (Revised edition). Amsterdam: National Aerospace Laboratory, September 1978.
- Fischer, E., Haines, R. F., & Price, T. A. Cognitive issues in head-up displays (NASA-TP-1711). Washington, DC: National Aeronautics and Space Administration, December 1980.
- Forrest, F. G. Angle of attack presentation in pilot training (Report No. DS-69-6). Washington, DC: Federal Aviation Administration, March 1969.
- Fox, J. G., Ferguson, I., & Andrew, I.D.C. An annotated bibliography of presentation of information in aircraft cockpits. London: Ministry of Aviation, May 1966. (NTIS No. Ad 634 575)
- Frank, L. H. Comparison of specifications for head-up displays in the Navy A-4M, A-7E, AV-8A, and F-14A aircraft (Special Report 79-6). Pensacola, FL: Naval Aerospace Medical Research Laboratory, November 1979.
- Gandelman, J. H. Evaluation of angle of attack instrumentation in the training of student pilots to private pilot certification (FAA-DS-68-19). Washington, DC: Federal Aviation Administration, August 1968.
- Gardner, J. F. Speed and accuracy of response to five different attitude indicators (TR-J4-236). Wright-Patterson AFB, OH: Wright Air Development Center, December 1954.
- Gardner, J. F., & Lacey, R. J. An experimental comparison of five different attitude indicators (TR-54-32). Wright-Patterson AFB, OH: Wright Air Development Center, May 1954.
- Gartner, K. P., & Holzhausen, K. P. Human engineering evaluation of a cockpit display/input device using a touch sensitive screen (AGARD-CP-240). Neuilly sur Seine, France: Advisory Group for Aerospace Research and Development, 1978.
- Gartner, W. B. A simulator study of flight management task performance during low visibility approach and landing using baseline Category II flight instrumentation (NASZ-4406). Sherman Oaks, CA: Serendipity, Inc., December 1969.
- Gartner, W. B., & Baldwin, K. M. Improved display support for flight management during low visibility approach and landing: A simulator evaluation of an ILS-independent runway perspective display. Palo Alto, CA: Serendipity, Inc., October 1970.
- Gartner, W. B., & McTee, A. C. Piloted flight simulator study of low level wind shear - phase I (FAA-RD-77-166). Washington, DC: Federal Aviation Administration, May 1977.

- Gee, S. W., Gaidick, H. G., & Enevoldson, E. K. Flight evaluation of angle of attack as a control parameter (NASA TN-D-6210). Washington, DC: National Aeronautics & Space Administration, March 1971.
- Goldberg, B., & Eldredge, D. RNAV procedural turn anticipation techniques experiment No. 2, GAT-2A. Phase III - 2 and 4 NMI offset tracking procedures (FAA-RD-78-110). Washington, DC: Federal Aviation Administration, September 1978.
- Goldberg, B., Eldredge, D., & Crimbring, W. An evaluation of turn anticipation techniques and offset flying procedures using a single waypoint RNAV system (FAA-RD-78-114). Washington, DC: Federal Aviation Administration, January, 1979.
- Graham, D. K. Cockpit switching study: Logic and design procedure development for multifunction mode switching controls. Seattle, WA: Boeing Aerospace Co., May 1973.
- Grether, W. F. Discussion of pictorial versus symbolic instrument displays. Wright-Patterson AFB, OH: Engineering Division, Air Material Command, August 1947.
- Haines, R. F. Head-up transition behavior of pilots during simulated low visibility approaches (NASA-TP-1618). Washington, DC: National Aeronautics and Space Administration, 1980.
- Haines, R. F., Fischer, E., & Price, T. A. Headup transition behavior of pilots with and without headup display in simulated low visibility approaches (NASA-TP-1720). Washington, DC: National Aeronautics and Space Administration, 1980.
- Hanes, L. F., & Ritchie, M. L. Display problems in instrument approach and landing (RTD-TDR-TP-63-4000). Wright-Patterson AFB, OH: Air Force Systems Command, June 1965.
- Hanisch, B., Ernst, H., & Johnston, R. Cockpit simulation study of use of flight path angles for instrument approaches (NASA-CR-165708). Washington, DC: National Aeronautics and Space Administration, May 1981.
- Harris, R. L., Goode, M. W., & Yenni, K. R. Simulation and flight evaluation of a head-up landing aid for general aviation (NASA-TP-1276). Washington, DC: National Aeronautics and Space Administration, September 1978.
- Harris, R. L., & Hewes, D. E. An exploratory simulation study of a head-up display for general aviation light planes (NASA-TN-D-7456). Washington, DC: National Aeronautics and Space Administration, 1973.
- Harris, Sr., R. L., & Mixon, R. W. Effects of curved approach paths and advanced displays on pilot scan patterns (NASA-TP-1846). Washington, DC: National Aeronautics and Space Administration, 1981.
- Hart, S. G. Content, symbology, and format of cockpit display of traffic information: General aviation pilot opinion. Paper presented at the 15th Annual Meeting on Manual Control Behavior, Dayton, March 1979.

- Hart, S. G., & Loomis, L. L. Evaluation of the potential format and content of a cockpit display of traffic information. Human Factors, 1980, 22, 591-604.
- Hart, S. G. & Wempe, T. E. Cockpit displays of traffic information: Airline pilots' opinions about content, symbology, and format (NASA TM-78601). Washington, DC: National Aeronautics and Space Administration, August 1979.
- Hasbrook, A. H. A comparison of effects of peripheral vision cues on pilot performance during instrument flight in dissimilar aircraft simulators (FAA-AM-68-22). Washington, DC: Federal Aviation Administration, September 1968.
- Hasbrook, A. H. & Rasmussen, P. G. In-flight performance of civilian pilots using moving-aircraft and moving horizon indicators. Washington, DC: Federal Aviation Administration, June, 1973.
- Hasbrook, A. H., Rasmussen, P. G., & Willis, D. M. Pilot performance and heart rate during inflight use of a compact instrument display (FAA-AM-75-12). Washington, DC: Federal Aviation Administration, November 1975.
- Hasbrook, A. H., & Young, P. E. Pilot response to peripheral vision cues during instrument flying tasks (FAA-AM-68-11). Washington, DC: Federal Aviation Administration, February 1968.
- Havron, M. D. Information requirements methods as applied to development of displays and controls (HSR-RR-61/4-SM). Human Sciences Research, Inc., March 1961.
- Howell, J. D. Simulator evaluation of pilot assurance derived from an airborne traffic situation display (FAA-EM-72-3). Washington, DC: Federal Aviation Administration, February 1972.
- Ince, F., Williges, R. C., & Roscoe, S. N. Aircraft simulator motion and the order of merit of flight attitude and steering guidance displays. Human Factors, 1975, 17, 388-400.
- Jacobs, R. S., Williges, R. C., & Roscoe, S. N. Simulator motion as a factor in flight director display evaluation. Human Factors, 1973, 15, 569-582.
- Jenney, L. L., Malone, T. B., & Schweickert, G. A. Head-up displays: A study of their applicability in civil aviation. Falls Church, VA: The Matrix Research Corporation, January 1971.
- Jensen, R. S. Prediction and quickening in perspective flight displays for curved landing approaches (Doctoral Thesis). Urbana-Champaign, IL: University of Illinois, 1979.
- Jensen, R. S. Prediction and quickening in perspective flight displays for curved landing approaches. Human Factors, 1981, 23, 355-364.

- Jensen, R. S., FitzHenry, P., Vanderkolk, R. J., Rose, D. S., & Roscoe, S. N. Pilotage error in area navigation performance of instrument pilots using symbolic displays (FAA-RD-71-31). Washington, DC: Federal Aviation Administration, May 1971.
- Jensen, R. S., & Marsh, R. W. Simulator tests of pilot performance in terminal area navigation operations: Effects of various airborne system characteristics (FAA-RD-76-99). Washington, DC: Federal Aviation Administration, May 1976.
- Jensen, R. S., & Roscoe, S. N. Flight tests of pilotage error in area navigation with vertical guidance (FAA-RD-72-126). Washington, DC: Federal Aviation Administration, August 1973.
- Jensen, R. S., Vanderkolk, R. J., & Roscoe, S. N. Pilotage error in area navigation: Effects of symbolic display variables (FAA-RD-72-29). Washington, DC: Federal Aviation Administration, January 1979.
- Johnson, R., Rover, R., Medlinski, W., Ritchie, M., & Schmier, H. Control-display investigation of complex trajectory flight using the microwave landing system. Analysis phase. (AFFDL-TR-79-3139). Wright-Patterson AFB, OH: Air Force Flight Dynamics Laboratory, December 1979.
- Johnson, S. L., & Roscoe, S. N. What moves, the aircraft or the world? Human Factors, 1972, 14, 107-129.
- Kappauf, W. E. Studies pertaining to the design of visual displays for aircraft instruments, computers, maps, charts, tables and graphs-a review of the literature. Wright-Patterson AFB, OH: Air Material Command, April 1949.
- Karmarker, J. S. & Sovensen, J. A. Information and display requirements for independent landing monitors (NASA-CR-2687). Washington, DC: National Aeronautics and Space Administration, August 1976.
- Kelly, J. R. Preliminary evaluation of time and distance spacing cues using a cockpit displayed target (NASA-TM-81794). Washington, DC: National Aeronautics and Space Administration, August 1980.
- Kelley, W. W. Results of a simulator test comparing two display concepts for piloted flight path angle control (NASA-TM-78692). Washington, DC: National Aeronautics and Space Administration, March 1978.
- Ketchel, J. M., & Jenney, L. L. Electronic and optically generated aircraft displays. A study of standardization requirements (JANAIIR Report No. 680505). Washington, DC: Office of Naval Research, May 1968.
- Knox, C. E. A comparison of two commercial and the Terminal Configured Vehicle area navigation systems (NASA-TM-72683). Washington, DC: National Aeronautics and Space Administration, June 1976.
- Knox, C. E., & Leavitt, J. Description of path-in-the-sky contact analog piloting display (NASA-TM-74057). Washington, DC: National Aeronautics and Space Administration, 1977.

- Kreifeldt, J. G. Cockpit displayed traffic information and distributed management in air traffic control. Human Factors, 1980, 22, 671-692.
- Kreifeldt, J., Parkin, L., Rothschild, P., & Wempe, T. Implications of a mixture of aircraft with and without traffic information displays for air traffic management (NASA-TM-X73, 170). Washington, DC: National Aeronautics and Space Administration, May 1976.
- Kreifeldt, J. G., & Wempe, T. Pilot performance during a simulated standard instrument procedure turn with and without a predictor display (NASA-TM-62201). Washington, DC: National Aeronautics and Space Administration, January 1973.
- LaFranchi, V. E. Experimental results of a simulated flight test using various contact analog texture formats (NADC-AM-6645). U.S. Naval Development Center, August 1966.
- Lauber, J. K., Bray, R. S., & Scott, B. C. An evaluation of head-up displays in civil transportation. In Stickle, J. W. 1980 Aircraft Safety and Operating Problems (NASA-CP-2170). Washington, DC: National Aeronautics and Space Administration, November 1980.
- Leitner, E. F., & Haines, R. F. Magnitude of visual accommodation to a head-up display (NASA TP-1796). Washington, DC: National Aeronautics and Space Administration, February 1981.
- Levison, W. H. Analysis and in-simulator evaluation of display and control concepts for a Terminal Configured Vehicle in a final approach windshear environment (NASA-CR-3034). Washington, DC: National Aeronautics and Space Administration, 1978.
- Lewis, J. D., & Wolling, G. P. A true 3-D or 2-D flat display (AGARD-CP-96). Neuilly sur Seine, France: Advisory Group for Aerospace Research and Development, October 1971.
- Lincoln, R., Palmer, E., & Wempe, T. Effect of pictorial display configuration on the frequency of control reversals during aircraft landing approaches (NASA TM-X-62, 191). Washington, DC: National Aeronautics and Space Administration, October 1972.
- Loschke, P. C., Barber, M. R., Enevoldson, E. K., & McMurry, T. C. Flight evaluation of advanced control systems and displays on a general aviation airplane (NASA-TR-D-7703). Washington, DC: National Aeronautics and Space Administration, June 1974.
- Matheny, W. G. Altimeter display study. Part 1 - summary and review of data requirements (ASD-TDR-63-621). Wright-Patterson AFB, OH: Air Force Flight Dynamics Laboratory, May 1964.
- McGath, J. J. Contemporary map displays in guidance and control displays (AGARD-CP-96). Neuilly sur Seine, France: Advisory Group for Aerospace Research and Development, October 1971.

- McKinloy, W. H. The application of electronic and combined displays to ground mapping and navigation (AGARD-CP-167). Neuilly sur Seine, France: Advisory Group for Aerospace Research and Development, December 1975.
- Mitchell, T. R. Altimetry display study: Part one - summary report (FAA-RD-72-46, 1). Washington, DC: Federal Aviation Administration, May 1972.
- Morello, S. A., Knox, C. E., & Steinmetz, G. G. Flight test evaluation of two electronic display formats for approach to landing under instrument conditions (NASA-TP-1085). Washington, DC: National Aeronautics and Space Administration, December 1977.
- Naish, J. M. Head-up display in the non-precision approach (NASA-TM-81167). Washington, DC: National Aeronautics and Space Administration, May 1980.
- Naish, J. M., & Miller, D. L. An experimental evaluation of head-up display formats (NASA TP-1550). Washington, DC: National Aeronautics and Space Administration, 1980.
- Neil, D. E. Design parameters and color CRT display design (NPS55-79-05). Monterey, CA: Naval Postgraduate School, May 1979.
- Neuman, F., & Hardy, G. Flight investigation of a four dimensional terminal area guidance system for STOL aircraft (NASA-TM-81271). Washington, DC: National Aeronautics and Space Administration, March 1981.
- Nicklas, D. R. A history of aircraft cockpit instrumentation 1903 - 1946 (NADC-TR-57-301). Wright-Patterson AFB, OH: Wright Air Development Center, April 1958.
- O'Connor, S., Jago, S., Baty, D., & Palmer, E. Perception of aircraft separation with pilot-preferred symbology on a cockpit display of traffic information (NASA-TM-81172). Washington, DC: National Aeronautics and Space Administration, September 1980.
- Ontiveros, R. J. General aviation cockpit display and control simulation (Report No. NA-68-46). Washington, DC: Federal Aviation Administration, October 1968.
- Orrick, W. P., & York, P. E. Head-up display symbology (NADC-75267040). Warminster, PA: Naval Air Development Center, December 1975.
- Ostroff, A. J., Hueschen, R. M., Hellbaum, R. F., & Creedon, J. F. Flight evaluation of a simple total energy-rate system with potential wind-shear application (NASA-TP-1854). Washington, DC: National Aeronautics and Space Administration, May 1981.
- Palmer, E. A. Night visual approaches - pilot performance with and without a head-up display (NASA-TM-62, 188). Washington, DC: National Aeronautics and Space Administration, October 1972.
- Palmer, E. A., Jago, S. J., Baty, D. L., & O'Connor, S. L. Perception of horizontal aircraft separation on a cockpit display of traffic information. Human Factors, 1980, 22, 605-620.

- Pangburn, R. C., Metzler, T. R., & Kline, J. M. Pilot performance as a function of three types of altitude displays (FAA-RD-72-130). Washington, DC: Federal Aviation Administration, August 1972.
- Parks, D. L., Jensen, G. L., & Niwa, J. S. Use of perspective displays and aiding symbology in simulated IFR landings (D6-55002). Seattle, WA: Boeing Commercial Aircraft Company, August 1969.
- Parks, D. L., & Tubb, D. G. Simulator development and flight validation of perspective display as an independent landing monitor (AIAA Paper No. 70-924). New York: American Institute of Aeronautics and Astronautics, July 1970.
- Reeder, J. P., & Kolnick, J. J. A brief study of closed circuit television for aircraft landing (NASATND-2185). Washington, DC: National Aeronautics and Space Administration, February 1964.
- Ritchie, M. L. Integrated instruments: A drag indicator (TR-55-423). Wright-Patterson AFB, OH: Wright Air Development Center, December 1955.
- Ritchie, M. L. Preliminary studies of cockpit information content and equivalence of information in cockpit standby instrumentation (Lear Advance Engineering Report #32). Grand Rapids, MI: Lear Incorporated, November 1960.
- Roscoe, S. Advanced integrated aircraft displays and augmented flight control (ARL-76-17/ONR-76-4). Urbana-Champaign, IL: University of Illinois, November 1976.
- Roscoe, S. N. Aviation Psychology. Ames: Iowa State University Press, 1980.
- Roscoe, S. N., Corl, L., & Jensen, R. S. Flight display dynamics revisited. Human Factors, 1981, 23, 341-354.
- Roscoe, S. N., Johnson, S. L., & Williges, R. C. Display motion relationships. In Roscoe, S. N. Aviation Psychology. Ames: Iowa State University Press, 1980.
- Roscoe, S. N., Smith, J. F., Johnson, B. E., Dittman, P. E., & Williams, A. C. Comparative evaluation of pictorial and symbolic VOR navigation displays in the I-CA-2 Link training. Washington, DC: Civil Aeronautics Administration, 1950.
- Roscoe, S. N., & Williges, R. C. Motion relationships in aircraft attitude and guidance displays: A flight experiment. Human Factors, 1975, 17, 374-387.
- Rud, R. C., & Michas, R. D. Flight evaluation of the concept of the State A Peripheral Vision Horizon Device (PVHD) using the CH135 aircraft. Ontario, Canada: Defense and Civil Institute of Environmental Medicine, December 1980.
- Semple, C. A., Heapy, R., Conway, E., & Burnette, K. Analysis of human factors data for electronic flight display systems. Northridge, CA: Manned Systems Sciences, April 1971.

- Shrager, J. J. Altimetry display study. Part 3-review of R&D on display readability (FAA-RD-72-46, II). Washington, DC: Federal Aviation Administration, May 1972.
- Shrager, J. J. Head-up displays: A literature review and analysis with an annotated bibliography (FAA-RD-78-31). Washington, DC: Federal Aviation Administration, April 1978.
- Simonelli, N. M. An investigation of pictorial and symbolic aircraft displays for landing. In Proceedings of the 22nd Annual Meeting of the Human Factors Society, Santa Monica, CA: The Human Factors Society, 1978, 213-217.
- Skelton, G. L., & Sulzer, R. L. Prevention of aircraft loss of control using a simple head-up display (FAA-RD-71-28). Washington, DC: Federal Aviation Administration, June 1971.
- Smith, R. L., & Kennedy, R. S. Predictor displays: History, research, and operations. Inglewood, CA: Dunlap and Associates, 1975.
- Spady, A. A. How pilots look at altitude. Paper presented at the 1980 Aircraft Safety and Operating Problems Conference, Langley, November 1980.
- Spady, A. A., & Harris, R. L. How a pilot looks at altitude (NASA-TM-81967). Washington, DC: National Aeronautics and Space Administration, April 1981.
- Stark, R. Will the future electronic display be stereoscopic? (AGARD-CP-167). Neuilly sur Seine, France: Advisory Group for Aerospace Research and Development, December 1975.
- Steinmetz, G. G. A simulation investigation of cockpit display of aircraft traffic during curved, descending, decelerating approaches (NASA-TM-80098). Washington, DC: National Aeronautics and Space Administration, May 1979.
- Steinmetz, G. G. Simulation development and evaluation of an improved longitudinal velocity vector control wheel steering mode and electronic display format (NASA-TP-1564). Washington, DC: National Aeronautics and Space Administration, 1980.
- Steinmetz, G. G., Morello, S. A., Knox, C. E., & Person, L. H. A piloted simulation evaluation of two electronic display formats for approach and landing (NASA-TN-D-8183). Washington, DC: National Aeronautics and Space Administration, April 1976.
- Swartzendruber, L., & Roscoe, S. N. Rate-field displays. In Roscoe, S. N. Aviation Psychology. Ames: Iowa State University Press, 1980.
- Triggs, T. J. An experimental evaluation of digital altimeters (HE Note-21). Melbourne, Australia: Aeronautical Research Laboratories, August 1960.
- Vallerie, L. L. Peripheral vision displays (NASA-CR-808). Washington, DC: National Aeronautics and Space Administration, 1967.

- Waller, M. C., Harris, R. L., & Slamirs, S. A study of parameters affecting a display for aircraft instrument landings. In Proceedings of the 23rd Annual Meeting of the Human Factors Society, Santa Monica, CA: The Human Factors Society, 1979, 345-346.
- Weir, D. H., & Klein, R. H. The measurement and analysis of pilot scanning and control behavior during simulated instrument approaches (NASA-CR-1535). Washington, DC: National Aeronautics and Space Administration, June 1970.
- Weir, D. H., Klein, R. H., & McRuer, D. T. Principles for the design of advanced flight director systems based on the theory of manual control displays (NASA CR-1748). Washington, DC: National Aeronautics and Space Administration, March 1971.
- Westland, R. A., Weingarten, L. B., & Kelley, R. B. An examination of pilot information requirements. Santa Monica, CA: Dunlap and Associates, November 1962. (NTIS No. AD 401 662).
- Wilckens, V., & Schattenmann, W. Test results with new analog displays for all-weather landings (AGARD-CP-55). Neuilly sur Seine, France: Advisory Group for Aerospace Research and Development, March 1970.
- Williams, Jr., A. C. Preliminary analysis of information required by pilots for instrument flight. Aviation Research Monographs, 1971, 1(1), 1-17.
- Wyatt, J., & Eastman, D. Flight test demonstration of selected curved segment approach paths based on microwave landing system guidance (AFFDL-TR-76-43). Wright-Patterson AFB, OH: Air Force Flight Dynamic Laboratory, January 1976.
- Zipoy, D. R., Premseelaar, S. J., Gargett, R. E., Belyea, I. C., & Holl, Jr., H. J. Integrated information presentation and control system study (AFFDL-TR-70-79). Seattle, WA: Boeing Military Airplane Systems Division, August 1970.

APPENDIX D

GENERAL AVIATION PILOT TASKS AND INFORMATION NEEDS¹

INTRODUCTION.

The history of aviation contains many technological advances that have had a profound impact on pilot performance. The electronic flight instrument systems (EFIS), which will soon be introduced into general aviation aircraft, represent such an advance. To provide a basis for understanding the substantial impact that these new systems will have, several analyses were conducted during the initial part of the present project. These analyses focused on several different aspects of contemporary general aviation--i.e., general aviation aircraft, flight operations, pilots, and avionics--and examined their influence on the development of general aviation EFIS. In addition, representative general aviation missions were analyzed to support the identification of tasks that general aviation pilots might perform when they fly EFIS-equipped aircraft. These mission analyses were used to support the development of the proficiency checks discussed in Chapter IV.

CONTEMPORARY GENERAL AVIATION.

General aviation is defined, in this report, as including all segments of aviation other than the military and air carrier segments. As such it encompasses a substantial portion of the spectrum of the aircraft produced and utilized in the United States. Major categories of use of general aviation (Vahovitch, 1978) include personal, business, instructional, and air taxi. In addition, such use categories as recreational (e.g., sky diving), industrial (e.g., pipeline inspection), aerial application (e.g., crop dusting), and emergency (e.g., air ambulance) are significant aspects of general aviation.

Reflecting this diversity of uses, general aviation aircraft vary from simple single-engine models with limited capabilities to highly sophisticated, multiengine turbojet aircraft capable of crossing the North Atlantic nonstop. Similarly, general aviation pilots differ widely in experience, skill, and the frequency with which they fly. They range from weekend recreational pilots to active professional pilots with thousands of hours of experience in complex aircraft. General aviation missions also vary from point-to-point flying, originating or terminating at very crowded airports, to flights to or from unpaved airstrips in very remote areas.

This variation in general aviation aircraft, pilots, and missions directly affects the types of tasks that the pilots perform and the nature of information that they require during flight. To understand the kinds of tasks that general aviation pilots perform, a familiarity with the nature of general

¹This report was produced during the early phases of the present project. It was written by Dr. Barry Strauch of the Aviation Research Center, Embry-Riddle Aeronautical University. It is included here to provide the interested reader with more information about general aviation flight operations and aircraft.

aviation today, as well as some of the influences that may affect it in the near future, is helpful. The following subsections discuss aspects of general aviation, aircraft avionics, flight operations, and pilots in both the contemporary and near future settings.

GENERAL AVIATION AIRCRAFT. There are estimated to be in excess of 20,000 active fixed-wing, general aviation aircraft in domestic use today (FAA, 1980a). Single-engine aircraft with reciprocating engines comprise the bulk of that fleet with over 167,000 aircraft, or 83 percent, of the general aviation total. There are also more than 24,500 active multiengine aircraft with reciprocating engines, over 12 percent of the fleet. Multiengine aircraft with turbine engines (turboprops) account for over 2 percent of the total fleet, there being approximately 3,400 such aircraft. Finally, turbojet aircraft--around 3,000 active aircraft--comprise slightly less than 2 percent of the total general aviation fleet.

By contrast, the domestic air carrier fleet totals only 2,745 aircraft, i.e., only about 2 percent of all U.S. registered civil aircraft. The air carrier fleet, with its high aircraft utilization rate, does account, however, for a higher proportion of total aircraft hours flown than would be predicted by the fleet size. For 1980, the FAA (1980b) estimated that, while general aviation aircraft, fixed- and rotary-wing, flew a total of 42.1 million hours, or 89 percent of the total hours flown, domestic air carriers flew approximately 5.1 million hours, or 11 percent of all hours flown by U.S. civil aircraft.

General aviation aircraft range in price from about \$5,000 for a used, single-engine aircraft, to about \$10 million for top-of-the-line turbojet equipment. A new multiengine aircraft sells for at least \$140 thousand, a turboprop aircraft for \$750 thousand, and a turbojet aircraft for at least \$1.5 million (Aviation Week and Space Technology, 1981a). In addition, optional avionics such as color radar, flight directors, VLF/Omega, and 3-axis autopilots can increase the initial aircraft purchase price substantially. As might be expected, maintenance and operating expenses are generally proportional to the initial purchase price of the aircraft. These costs can range from approximately \$35 per hour for a single-engine aircraft to hundreds of dollars per hour for turboprop and turbojet equipment.

In the United States today, there are five principal aircraft powerplant and thirteen airframe manufacturers involved in manufacturing general aviation aircraft (Table D-1). The list of airframe manufacturers does not include foreign manufacturers nor those domestic manufacturers who produce agricultural and rotary-wing models exclusively. This diversity of general aviation domestic manufacturers contrasts with the relatively small number of domestic air carrier airframe and powerplant manufacturers. In this latter case, essentially, two powerplant and three airframe manufacturers supply all U.S. made turbojet equipment.

TABLE D-1.--1981 DOMESTIC GENERAL AVIATION AIRFRAME
AND POWERPLANT MANUFACTURERS

<u>AIRCRAFT TYPE</u>	<u>AIRFRAME MANUFACTURERS</u>
Non-agricultural aircraft with reciprocating engines	Lake Aircraft Mooney Aircraft Maule Aircraft
Aircraft with reciprocating and/or turboprop engines	Beech Aircraft Fairchild Swearingen Aviation Omac, Inc. Piper Aircraft
Aircraft with turboprop and/or turbojet engines	Gates Learjet Corporation Learfan Limited Foxjet International Sabreliner Division Rockwell International
Aircraft with reciprocating, turboprop, and turbojet engines	Cessna Aircraft Gulfstream American Aircraft
	<u>POWERPLANT MANUFACTURERS</u>
	The Garrett Corporation Avco-Lycoming Division of Avco General Electric Company Continental Division of Teledyne Pratt and Whitney Division of United Technologies

Given the diversity of available models, the purchaser of new general aviation aircraft can select models of similar capabilities from several manufacturers. The customer selecting an aircraft for personal use, or for use by a relatively small corporation, would probably closely examine available single-engine aircraft. (Such aircraft also comprise the bulk of trainers used by general aviation pilots.) Other customers might require more operational capabilities than that afforded by the single-engine aircraft. Multiengine aircraft with reciprocating engines generally provide a higher cruising speed and level of performance, but at considerably greater expense. Turboprop aircraft provide still higher levels of performance, at greater cost, than do reciprocating-engine aircraft, and they generally provide a higher level of safety because of their more reliable engines.

Several divisions exist within the turboprop line, with the lower end of the market typified by, for example, the Cessna Corsair series, and the higher end typified by the Piper Cheyenne 3, Beech King Air, Fairchild Swearingen, and Lear Fan. The price for a basic model of these aircraft is well over \$1 million. Among the general aviation turbojets, the lower end of the product line would be represented by the Cessna Citation 1, the middle level by the Learjet 35 series, and the top of the line by the Gulfstream American G3. The

price for a basic model at each level of the product line is about \$1.7 million for the lower end, \$3.25 million for the middle level, and \$10 million for the upper end.

GENERAL AVIATION OPERATIONS. Pilots fly general aviation aircraft at their own convenience to a far greater number of airfields than do their commercial counterparts. In 1980, for example, there were 14,744 airports in operation in the United States, 8,087 private and 6,657 public (FAA, 1980b). Of these, approximately 2,800 have paved and lighted runways, and 494 have control towers (Beardsley, 1978). There were 698 instrument landing systems (ILS) at these airports, although several major airports have more than one ILS. While general aviation operates at virtually all U.S. airports, most major air carrier operations are at terminals equipped with control towers or ILS facilities. Less than 450 airports, in fact, are served by regularly scheduled large air carrier aircraft. Further, the carriers concentrate most of their operations at a relatively few airports. According to the FAA (1980b), the 25 busiest airports account for about two-thirds of all air carrier passenger enplanements and the busiest 100 airports account for over 90 percent of the enplanements.

For those communities located near the remaining airports, general aviation offers a highly suitable method of aviation service. Many of these airports (4,549) have instrument approaches, further enhancing their attractiveness to the general aviation community. The general aviation pilot, thus, has a wide array of airports available, varying from the major hubs with the most sophisticated landing aids to remote fields with no air traffic control services or instrument approach procedures.

GENERAL AVIATION PILOTS. There are currently over 814,000 licensed pilots in the United States (FAA, 1980a). Of these, about 63,000 hold airline transport ratings, the license held extensively by professional pilots and required for air carrier pilots. There are over 182,000 pilots with commercial licenses, 343,000 private pilots, and 210,000 student pilots, all licensed to fly fixed-wing aircraft. These pilots differ markedly in experience, type of aircraft flown, and proficiency in piloting the aircraft they are rated to fly.

General aviation pilots are subject to somewhat less restrictive Federal Aviation Regulations (FARs) than are their commercial or professional counterparts. In addition to Federal restrictions, these latter pilots are often subject to their own company regulations. For example, Federal Aviation Regulations specify minimal flight experience and recency requirements for visual and instrument meteorological flight for all pilots. Most general aviation pilots, however, are governed by regulations that require them to complete only three takeoffs and landings every 90 days in order to be able to carry passengers. If they are flying solo, that is, with no one else in the aircraft, there is no recency of experience requirement, other than the Biennial Flight Review. In contrast, pilots who fly for major air carriers are required by Federal and company regulations to undergo intensive proficiency training sessions at least twice a year and extensive proficiency checks at least once a year.

Another factor of concern in this regard is the number of different aircraft the general aviation pilot may fly. General aviation pilots, as others, can fly any aircraft within the category and class of aircraft to which their

licenses apply. Thus, a pilot with multiengine land ratings can legally fly both light twins with reciprocating engines, as well as top-of-the-line turboprop equipment, so long as the aircraft gross weight is less than 12,500 pounds. Although most aviation insurance policies require more extensive flight experience to ensure pilots flying top-of-the-line equipment, there is no legal requirement for that experience.

The regulations are somewhat different for larger general aviation aircraft. Pilots of aircraft with gross weights exceeding 12,500 pounds and turbojet aircraft are legally required to be rated for each type of heavy aircraft flown. Thus, a general aviation pilot licensed to fly a Learjet 25 is not licensed to fly a Cessna Citation 1. However, a pilot licensed to fly a Cessna 310 light twin aircraft can legally fly a Beech turboprop King Air, an aircraft with very different capabilities. Thus, because type ratings are required for only a few aircraft models in the fleet, general aviation pilots can and often do transition across a wide variety of aircraft.

Air carrier pilots, on the other hand, are required to have type ratings for those aircraft in their company fleet that they are likely to fly. In addition, because there are only a few models that are used by each air carrier, large-scale pilot transitioning across models is rare among the carriers. Indeed, air carrier pilots often fly only one model of aircraft during a given period of time. In general aviation, operators change the composition of their fleets more frequently than do the air carriers. Further, general aviation pilots change companies, with their different fleet compositions, far more often than do their air carrier counterparts. This leads to still greater general aviation pilot transitioning across models.

GENERAL AVIATION AVIONICS. The avionics requirements of general aviation are as diverse as the aircraft and pilots that interact with them. Avionics generally refers to those radio-based, information display units that involve air-to-ground communications, navigation, and weather detection. The following discussion also includes EFIS within the category of avionics, since many of these systems will incorporate traditional avionics components into more sophisticated information processing and flight control capabilities.

Vahovitch (1978) examined the relative influence of several factors on the acquisition of selected avionics, such as DME (distance measuring equipment), ADF (automatic direction finder), and weather radar, according to general type aircraft use, personal or corporate. He states that aircraft speed, more than any other factor, consistently differentiated aircraft that incorporated specific avionics components from those that did not. The faster aircraft tended to include those avionic components more frequently than did the slower aircraft.

Apart from its relationship to avionics acquisitions, aircraft speed is closely related to the costs of purchasing and maintaining the basic aircraft, i.e., the higher the cost, the faster the aircraft can be expected to fly (at least up to a point). Since much of the cost of aircraft acquisition is directed toward the powerplant and related systems, there is, as a result, a close relationship between aircraft cost and powerplant capabilities.

A subsequent FAA survey (Avionics, 1981) examined other factors in the acquisition of highly specialized avionics components. The acquisition of

components such as RNAV (area navigation), long range navigational units (e.g., VLF/Omega), and radar altimeters varied markedly according to specific category of use, e.g., executive/corporate, personal use and the like. The survey indicated that aircraft engaged in executive and corporate use tended to have the highest proportion of the more expensive avionics. For example, 81 percent of the surveyed aircraft which engaged in executive transport had autopilots, compared to 18.3 percent of personal use aircraft. Over half of the executive-use aircraft had weather radar, while less than 1 percent of the personal-use aircraft were so equipped.

Avionics equipment also varies as a function of aircraft utilization rate. Quinby (1980) noted that air carriers who operate the most expensive civil aircraft have a higher aircraft utilization rate than is found in general aviation and stand to lose more from aircraft down time than do general aviation operators. As a result, they pay for avionics whose cost is "an order of magnitude higher" than those acquired by general aviation owners so as to ensure high component reliability. As the costs of the general aviation aircraft increase, it can be assumed that the concerns of the aircraft operators approach those of the air carriers. That is, down time becomes more expensive, and, as a result, operators should be willing to allocate more capital to purchase equipment with high component reliability. In addition, the more expensive avionics enhance overall mission reliability by increasing aircraft ability to complete the mission regardless of the weather. For example, radar altimeters allow aircraft to land in low ceiling conditions, and weather radar enables aircraft to "sight," and therefore circumnavigate, areas of adverse weather, thus enhancing likelihood of accomplishing the mission.

Quinby also noted that general aviation operators are likely to retrofit aircraft avionics systems several times during the useful life of the airframe. Thus, as new avionics and display capabilities become available, the general aviation operator can be expected to incorporate them in an aircraft. As EFIS become available in general aviation, it seems likely that they will first appear in executive transport, top-of-the-line aircraft. As display costs decrease, they will probably appear in aircraft in the lower levels of the general aviation product line.

GENERAL AVIATION IN THE NEAR FUTURE. For the last several years, the general aviation market, along with the entire civil aviation community, has been changing. General aviation total dollar sales have been growing each year for the last several years, at ever increasing rates. In 1979, for example, the dollar value of all general aviation aircraft shipped exceeded \$2.2 billion, up from \$1.82 billion shipped the previous year (Aerospace Facts and Figures, 1980). The 21 percent increase that is represented was considerably beyond that year's rate of inflation. This percentage increase value was itself up from the previous year's 17 percent dollar increase in sales. Moreover, such increases show little sign of abating, despite a recessionary economy and increasing fuel costs. In the first third of 1981, there was a 17.7 percent increase in orders over the same period in 1980.

Yet, the increase in general aviation sales has not been uniform across the board. The total number of aircraft shipped actually decreased from the 1978 level of 17,817 to 17,055 in 1979, and continues to decrease as of this writing. As Business Aviation (1981) notes:

Latest figures show a continuation of the trend that has been evident for the past few years--sharply reduced shipments of single and multi-engine aircraft and agricultural planes and increased deliveries of higher-priced turboprop and jet models--resulting in lower overall deliveries but increased billings. For the first four months of 1981, jet deliveries were up 25.3% to 124 units and turboprops were up 9.1% to 289. Single engine shipments were off 30.4% to 2,236, multi-engine deliveries fell 27.5% to 578 and agricultural aircraft were down 7.6% to 122 (p. 153).

FAA projections show an increase in all of the general aviation product lines, but a much higher rate of increase for the top-of-the-line equipment (Table D-2). The FAA forecasts (FAA, 1980a) a 94 percent increase in turbojet and a 95 percent increase in turboprop deliveries over the next ten years. By contrast, only a 40 percent increase in single-engine and a 37 percent increase in reciprocating, multiengine aircraft are predicted over the same time period.

TABLE D-2.--FAA PROJECTED GROWTH OF GENERAL AVIATION AIRCRAFT SALES
1981 - 1982^a

	<u>Reciprocating</u>		<u>Turboprop</u>	<u>Turbojet</u>
	<u>Single engine</u>	<u>Multiengine</u>		
1981	175,800	25,800	3,800	3,200
1992	246,800	35,400	7,400	6,200
Percent Increase	40	37	95	94

^aFAA, 1980a.

Several factors can account for both the growing general aviation market and the change in the nature of that market. Since World War II, there has been a basic shift in both the industrial base and overall demography of the United States. The industrial plants of the Northeast and Great Lakes states, once the major focus of industrial activity in this country, have been increasingly replaced by more modern and efficient units in the South and West, the so-called "Sunbelt." This demographic shift has been accompanied by the dispersion and relocation of industrial units among small communities with little or no scheduled air service, away from major industrial centers with previously excellent service (Helms, 1980). In addition, new corporations have been formed and additional units of more established corporations set up at various locations. As a result, individuals requiring access to several of their company's plants, or visiting units of other corporations, have increasingly relied on general aviation as an economical method of providing that access.

Given that inflation has driven the salaries of all employees, and particularly executives, to ever higher levels, the translation of an employee's time

into dollar amounts often justifies the corporate investment in aircraft. As Helms (1980) notes, this trend has been further enhanced by the reduction of the national speed limit to 55 miles per hour. Thus, the time involved in driving from one location to another is an often expensive burden for corporate executives to bear, particularly in comparison to the cost of operating a general aviation aircraft. Combined with the dispersion of the nation's industrial base, general aviation has offered an increasingly attractive method of inter-city travel.

At the same time, commercial aviation has been markedly affected by the Airline Deregulation Act of 1978. This Act reduced the control of air carriers on their routes and opened their previously guarded routes to any carrier. Among the effects of the act, which are still being felt at this time, has been a reduction in scheduled air carrier service to those communities which had been part of revenue losing routes for the carriers. Smaller communities, many of which had poor scheduled air service to begin with, have witnessed a marked reduction or complete loss of major air carrier service. Cities as large as Charleston, West Virginia have lost a substantial portion of their major air carrier service, while even cities such as Cincinnati, Ohio, and Chattanooga, Tennessee have seen a reduction in their scheduled service. For many travelers, the trend to substitute general aviation service for scheduled air service was accelerated by airline deregulation. An additional result of the Airline Deregulation Act was to give air carriers unprecedented authority to modify and increase their fares. Almost simultaneously with the deregulation legislation, the fuel crisis of early 1979 occurred and fuel costs doubled. Air carriers were affected by the fuel price increases, as were all forms of transportation. As a result of these factors and with their new ability to set their own fares, air carrier ticket prices increased during 1979 and 1980 to roughly double what they had been previously. The result for passengers was a combination of decreased service to smaller communities and increased ticket prices for nearly all routes.

These phenomena occurred during a downturn in the U.S. economy that reduced air carrier load factors and led to substantial losses for all but a few carriers. At the present time, while losses have been diminishing for several major carriers (Aviation Week and Space Technology, 1981b), some still remain in severe financial difficulty. It is clear that in the next few years air carrier service will be more expensive and less frequent. Additionally, they will serve fewer localities than at present.

As a result of these phenomena and despite the recent downturn in the overall domestic economy, general aviation aircraft manufacturers' profits have been increasing at a greater rate than have most other sectors of the economy. The next few years, however, although projected to be profitable for the industry (FAA, 1980a; Helms, 1980), contain several uncertainties that can dramatically affect its long term profitability.

First and foremost is the availability and cost of aviation fuel. The rapid increase in aviation fuel prices of the last three years has not led to reduced profits from general aviation aircraft sales, but it has helped to alter the nature of the general aviation market. Fuel prices have influenced the reduction in sales of models at the lower end of the general aviation product line, which include many aircraft sold primarily for training and personal use (North, 1981). To most general aviation aircraft owners and operators, the availability of fuel is a more critical factor than its price.

This is particularly true in newer models which have incorporated such advances as performance and flight management systems to yield improved aircraft fuel efficiency. Those owners and operators with more substantial capital investment in their aircraft generally will distribute a smaller proportion of the aircraft operating expenses to fuel costs than will operators of less expensive models. Further, since aircraft used for executive transport are generally amortized as business investments, the major way this investment can be written off is through increased aircraft utilization. If fuel supplies are available intermittently or in limited supply, corporate aircraft ownership will be less profitable or advantageous. Although as of this writing the short term availability of aviation fuel is sufficient to meet market demands, the long term supply remains uncertain.

A second factor, directly related to the first, is the status of business tax legislation. Present tax laws permit business depreciation of aircraft over a period of years and a credit for new equipment acquisition. This allows corporations to pay a portion of the acquisition costs of the aircraft by deferring or saving part of their corporate tax expenses. Should legislation be enacted to restrict this, then the expense of owning these aircraft will be substantially increased to corporate users; sales and aircraft utilization can then be expected to decrease.

Finally, the availability and utilization of viable alternatives to air transportation is uncertain (NASA-ASEE, Engineering System Design Fellows, 1979). For example, there has been extensive use of two-way audio and visual teleconferencing through communication satellites in the last few years. The effect of this and other technology on in-person communication, the kind that has relied heavily on air transportation in the past, remains unclear.

Thus, general aviation can be expected to undergo changes in the nature of its sales and operations in the near future. These changes can alter the proportion of missions flown in favor of those emphasizing fuel efficiency, corporate applications, and point-to-point flying in higher priced aircraft. This phenomenon will come about at the expense of training and personal use missions that are generally carried out in lower priced aircraft. The next section discusses the nature of the point-to-point missions, and the tasks performed by the pilot during these missions.

GENERAL AVIATION MISSIONS.

The executive/corporate transport missions, i.e., flying from point to point, usually are flown in top-of-the-line aircraft, the product line that is projected to utilize the EFIS first. In many respects, this type of mission is similar to air carrier missions. While both involve transporting people from a predetermined origin to a destination, the two also differ. In general aviation, as contrasted with air carrier aviation,

- the type of aircraft flown is almost always less complex;
- the schedule flown is more flexible;
- there are generally fewer air traffic control amenities and navigational aids at the origin and/or destination;

- the pilot and/or copilot is/are generally less experienced;
- the pilot and/or copilot transitions more often across aircraft models;
- there is often only one pilot on non-turbojet aircraft; and
- there is less assistance available to the pilot in pre-flight planning and aircraft dispatch.

Each of these differences influences the conduct of general aviation missions and the tasks performed by the pilot. This section will focus on the pilot tasks that are performed during each of the various phases of a typical general aviation mission.

These flight phases can be categorized into the following:

- Pre-flight planning
- Engine start
- Taxi
- Takeoff
- Climb
- Cruise
- Descent
- Land
- Taxi
- Engine shutdown

PRE-FLIGHT. The pre-flight phase is perhaps the most critical of the flight phases since the tasks performed at this time influence the conduct of all subsequent phases. In this phase, the pilot collects and analyzes information affecting almost all aspects of the aircraft, the point of origin, the route, and the intended destination.

In the pre-flight phase, the pilot will obtain some of this information by determining if any Notices to Airmen (NOTAMs) exist. This is generally done by communicating with the Flight Service Station (FSS) or by carefully reading the appropriate sections of the current Airmen's Information Manual (AIM). The AIM will inform the pilot if there are restrictions along the intended route or at the destination and alternate airports. The pilot will ascertain the status of the aircraft itself by a pre-flight examination to ensure the structural integrity of the airframe and all aircraft components. During pre-flight, the pilot will determine appropriate aircraft takeoff speeds, weight and balance, and other relevant data from information contained in the aircraft operating manual.

General aviation pilots must also gather weather information for all route segments, generally by communicating with either FSS or National Weather Service (NWS) briefers. Based on weather and aircraft data, the pilot will synthesize all information required for a flight plan. The pilot will then file the flight plan with the FSS or appropriate ATC facility.

Air carrier pilots do not themselves carry out many of these determinations. For example, flight plan data are generally computer-stored in the flight

service stations and automatically filed before the flight is scheduled to depart. In addition, aircraft weight and balance and takeoff speeds are generally determined by air carrier dispatchers or flight engineers, and weather information by company meteorologists.

ENGINE START. Aircraft engine and systems start procedures are delineated in the operating manual of the aircraft or in a separate checklist. The checklist describes each procedure and the correct order to be followed to initiate operation of all aircraft systems and ensure that all controls are functioning properly before the aircraft becomes airborne. In commercial aviation or general aviation turbojet operations, the copilot helps to ensure that the pilot has followed each checklist item, since in complex aircraft there are often many steps included within the checklist. In the single pilot operations, which are predominant in general aviation operations, this is not the case.

TAXI. Pilot tasks during taxi are affected by whether or not there is a control tower operating on the field. If there is an operating tower or an FSS on the field, the pilot will obtain the enroute clearance for an IFR flight from them, by radio, prior to taxiing the aircraft. At airports without an operating tower or FSS, the pilot will obtain the IFR clearance by telephone from the appropriate air traffic control facility prior to starting the engine. If operating VFR, no enroute clearance is needed.

At airports with operating control towers, the tower will clear the aircraft to the active runway along designated taxiways. At airports without towers, the pilot will taxi the aircraft after determining himself the active runway and the best ground route to that runway. In addition, the pilot exclusively must see and avoid any ground traffic during the taxi; at controlled airports, the tower shares this responsibility with the pilot.

TAKEOFF. Prior to takeoff, the pilot will complete the pre-takeoff checklist as a final check before the aircraft becomes airborne to determine that all aircraft powerplants and systems are operating normally. As with the engine start checklist, each procedure is stated in the proper order in the aircraft operating manual or in a separate checklist.

Following completion of the pre-takeoff checklist, at a towered airport the pilot will request and obtain takeoff clearance from the tower controller; at an uncontrolled field, the pilot is responsible for seeing and avoiding traffic on or near the active runway prior to initiating takeoff.

CLIMB. The pilot will fly the aircraft, during climb, at the rate determined during pre-flight for best speed of climb, best ground speed, most economical speed, or a combination of any of several speeds. If IFR, the course will be established by air traffic control during the climb, prior to takeoff in the enroute clearance, or by the pilot during pre-flight. The altitude to which the aircraft will climb will likewise be established in the clearance by ATC, or, if VFR, by the pilot prior to takeoff.

If the visibility during the climb is VMC (Visual Meteorological Conditions), the pilot will be responsible for seeing and avoiding other aircraft while performing the aircraft climb procedures. If conditions are IMC (Instrument Meteorological Conditions), this responsibility is exclusively that of air traffic control.

CRUISE. After reaching cruise altitude, the aircraft is generally in an environment that minimizes the out-of-cockpit responsibilities for the pilot of seeing and avoiding other aircraft. The pilot is, however, still responsible for see-and-avoid duties in VMC. Pilot responsibilities during cruise primarily concern navigation and guidance; aircraft control; and flight management and planning. The pilot must ensure that the aircraft is on the proper course, either that established during the pre-flight or established enroute by air traffic control, and that the aircraft is cruising at the airspeed previously established for economy and speed. During cruise the pilot also monitors information on the status of aircraft powerplant and systems.

DESCENT. As in the climb, pilot tasks during descent are a function of the current meteorological conditions and the type of air traffic control facilities available to the pilot. Since many general aviation operations involve remote airfields, locating the airfield may require extensive pilot activity, while at the same time the pilot is managing and controlling the aircraft and seeing and avoiding others.

If there is an instrument approach to the destination field, and more airports are being provided with such capabilities, locating the field will be relatively simple as the pilot adheres to the approach requirements. These are available to all pilots in published form, with clear instructions as to the required aircraft navigation and guidance parameters required for the approach.

If the airport is in a major terminal environment, air traffic control will provide the pilot with vectors or headings to the field, thereby somewhat simplifying the pilot tasks. However, since the airspace in those environments is often quite crowded, air traffic control communications may be very rapid and ATC instructions somewhat restrictive.

LANDINGS. Pilots will have determined the landing distance, approach speeds, and other required information during the pre-flight phase of the mission. If an instrument approach is flown, the pilot will fly the aircraft according to the approach requirements, while scanning the horizon for the runway environment. In a two-pilot aircraft, one pilot usually flies according to the instruments while the other scans the horizon to sight the field. The second pilot can also provide assistance in maintaining communications with ATC, calling out critical altitudes and airspeeds, and calling out descent and landing checklist items.

If the approach is a visual one, then the pilot will control the aircraft primarily through visual cues. If the airport is controlled, the pilot will obtain landing clearance and active runway information from the tower controller. If the field is uncontrolled, the pilot determines all runway information (unless there is an FSS on the field) while seeing and avoiding all runway traffic.

TAXI. Taxi procedures and pilot tasks after landing closely parallel those in effect for the pre-takeoff taxi. If the airport is controlled, the ground controller will assist the pilot in locating other ground traffic and providing the best route to the ramp. At uncontrolled fields, the pilot has exclusive responsibility for seeing and avoiding traffic and determining the best taxiways from the runway to the ramp.

ENGINE SHUTDOWN. Pilot activities closely parallel the activities carried out during engine start procedures. Each activity is noted in the checklist in the correct order to be performed. Finally, if the flight was operated under visual flight rules, the pilot will cancel the VFR flight plan through the nearest FSS. If operated under IFR, the tower automatically closes the flight plan after the aircraft has landed.

REPRESENTATIVE GENERAL AVIATION MISSIONS.

This section presents pilot tasks and information requirements for two missions representative of the flight operations usually performed by middle-of-the-line general aviation aircraft. The aircraft utilized in both missions is a twin, reciprocating-engine aircraft of the Cessna 400 series. For purposes of the present analysis, it is assumed that the aircraft is flown by a single pilot with several thousand total flight hours and several hundred instrument hours experience.

In the first mission, the aircraft will depart from an uncontrolled field and land at a major hub airport. In the second mission, it will depart from a hub satellite airport and land at an uncontrolled field. The missions will be portrayed as realistically as possible to illustrate the tasks that general aviation pilots perform and how they use the flight-related information in actual flight operations.

MISSION I. This mission originates in Ormond Beach, Florida, with a planned destination at Atlanta-Hartsfield International Airport, Georgia. Ormond Beach (OMN) is an uncontrolled field approximately 10 miles north of Daytona Beach, Florida; Atlanta-Hartsfield (ATL) is a hub airport, one of the busiest in the world. The Cessna 421 is scheduled to depart OMN at 10:00 a.m. local time, with one pilot and four passengers.

Pre-Flight. At 9:30 a.m., the pilot performs the pre-flight calculations. After consulting the Airmen's Information Manual (AIM), the pilot selects the most direct low altitude route to ATL. This route will take the aircraft from OMN via V51 and V179 to ATL, a distance of 321 nautical miles. At the selected cruise altitude of 16,000 feet, the true air speed is planned to be 197 knots. As a result, the trip should take 1 hour and 46 minutes, including time to climb, assuming that there will be no strong headwinds. In case an alternate airport is needed, the pilot determines that Augusta, Georgia (AGS), 116 miles east of ATL, would be suitable. The time from ATL to AGS is calculated to take 39 minutes. The Cessna 421, with an approximate fuel consumption rate of 34 gallons per hour, will burn an estimated 60 gallons enroute to ATL. The trip to the alternate, AGS, 116 miles east of ATL, should take 38 minutes and will require an additional 20 gallons of fuel. Since the FARs require that aircraft on IFR flights carry an additional 45 minutes of fuel, 25 gallons for the Cessna, the aircraft must be loaded with a minimum of 105 gallons; but to be safe, the aircraft will be loaded with 125 gallons of usable fuel, adequate for a 3-1/2 hour flight.

Before filing the flight plan, the pilot must determine the weather and winds along the route. A local telephone call to the nearest flight service station in Orlando indicates that a frontal system is extending along western Georgia and eastern Alabama, and that ATL is forecast to have 500 foot ceilings with visibility less than 3 miles. Although OMN is VFR and takeoff

will not be affected by the weather, the approach to ATL will require an IFR flight plan for that leg of the trip, and an alternate airport in case a landing could not be made there. FSS informs the pilot that around the time the aircraft is due at ATL, Augusta should have 1,000 foot ceilings, scheduled to deteriorate to 500 feet by the end of the day. AGS will, therefore, be an acceptable alternate; however, delays in takeoff or along the route may preclude using AGS as an alternate.

The winds, at 16,000 feet, are from the west, and will not appreciably affect the flight. The temperature at OMN is 80° F, Daytona altimeter is 30.00, the wind is easterly and light to moderate in velocity, so adequate runway distance should be available on OMN's runway 8, given these meteorological conditions. The pilot performs the weight and balance computations and then files the flight plan 45 minutes before the scheduled departure.

Flight Service did not indicate, in response to the pilot's request, the presence of any NOTAMs, nor did the AIM. No pilot reports of weather adverse enough to disrupt the flight are evident and reports of cloud tops indicate that the aircraft should be above the clouds that are present in Georgia by a comfortable 6,000 feet.

He next conducts the pre-flight inspection of the aircraft. The airframe, skin, cowlings, tires, brakes, and landing gear all appear satisfactory. All nav-comm antennas are in place, stall warning and pitot-static ports are clear, and fuel, oil, and hydraulic fluid levels appear adequate.

Engine Start. At 10:05 the passengers arrive at the terminal and board the aircraft. The pilot completed all pre-flight activities at 9:50 and has been waiting for the passengers to arrive so he may begin the next flight phase. Once they are boarded, the pilot briefly informs them of the route, cruising altitude, and expected arrival time in Atlanta. He then ensures that they have fastened their seat belts before he starts the engines.

At 10:08 he begins the engine start procedures by following each procedure in the engine start checklist. These procedures take less than a minute to complete. The pilot next tunes the navigation radios to the OMN VOR on the frequency 112.6 MHz, the unicom frequency of uncontrolled airports, and the second communication radio to 118.8 MHz, the Daytona Beach departure control frequency. Finally, he sets the transponder code to 1200, the VFR aircraft code, and turns the transponder to the standby mode.

Taxi. The pilot taxis the aircraft shortly thereafter. He determines from the windsock that the wind is easterly and, as a result, runway 8 would be the desired runway for takeoff. A slight left crosswind is evident but it will be no factor on takeoff. The pilot scans the airport diagram and follows the best ground route to runway 8. While taxiing, he scans the gyroscopic and pitot static instruments to ensure that they are presenting all information correctly. Adjustments to any instruments are made as needed. At the same time, the pilot adjusts the control wheel as needed to counter wind effects while taxiing.

Takeoff. After reaching the active runway, the pilot performs the engine runup procedure as outlined in the pre-takeoff checklist, to ensure that the aircraft engines and systems are operating normally and instruments are giving

appropriate readings. This takes no more than two minutes to carry out, and, upon completion, he is ready for takeoff. The pilot checks that all radios are set to the proper frequency, and gyro instruments and altimeters are adjusted as needed. Before entering the active runway, he announces on the unicom frequency, 122.8 MHz, his intentions to enter the runway. Since there are no other aircraft about to land, he enters the runway. At 10:13, with the propellers in high RPM and mixtures in the full rich positions, the pilot moves the throttles to takeoff power, being careful not to exceed the maximum allowable manifold pressure of 39.5 inches of mercury, as noted in the aircraft operating handbook. He raises the nose of the aircraft at the recommended speed of 106 knots indicated airspeed and begins the climb. He then retracts the flaps, raises the gear after passing the end of the runway, and adjusts power and propeller RPM. Since OMN is VMC, there is no need to request an IFR clearance before departing. However, since ATL is in IMC, he will request the clearance while enroute from the Jacksonville Center. His route and cruising altitude are the same as filed in the flight plan.

Climb. Climb is carried out at an airspeed of 125 knots, the rate of climb suggested in the operating manual; the climb rate is about 1,000 feet per minute. The pilot proceeds directly to Jacksonville and climbs to 16,000 feet. In 16 minutes, the cruising altitude is reached, at which point the pilot readjusts engine power and propeller RPM to conform to 70 percent horsepower for the trip to ATL; the RPM is 1900, and the manifold pressure 31.0 inches of mercury.

Cruise. Upon reaching cruise altitude, the pilot couples the aircraft controls to the autopilot, on a course to Jacksonville on the first leg to ATL. The pilot notes the times of both departure and of reaching cruise altitude. The pilot continually scans the VOR Course Deviation Indicator (CDI) to ensure that the aircraft is on course and that the appropriate wind correction angle, determined by noting the extent of course deviation from the CDI, is added to the aircraft heading, which he sets into the autopilot. After several adjustments, the pilot notes that only a 5 degree correction is needed to maintain the desired course. The pilot trims the pitch and elevator controls and maintains the aircraft at the assigned altitude of 16,000 feet. While enroute, the pilot notes that the estimated time from the first fix noted, Astor intersection, to Jacksonville, a distance of 44 miles, was 15 minutes, 5 minutes more than expected. This gives the aircraft a ground speed of 176 knots, not 196 as anticipated, a fact confirmed by the DME ground speed readout. The trip will, as a result, take about 11 minutes longer than expected, provided there are no delays enroute. The additional time will entail an additional fuel burn of six gallons which the pilot determines from his aviation calculator after entering time and fuel consumption rate.

The pilot contacts Jacksonville Center on frequency 118.0 MHz, as noted in the low altitude enroute chart, and is given the enroute IFR clearance. The aircraft is identified and tracked on air route traffic control center radar. About one hour into the trip, the pilot is told to contact Atlanta Center which will control the aircraft until shortly before it approaches Atlanta. He contacts them on the frequency 127.9 MHz, as assigned by Jacksonville Center. Atlanta Center acknowledges the contact and the handoff is complete. Over Georgia, the pilot notices a solid layer of clouds obscuring the ground, as was forecast.

In navigating and guiding the aircraft during cruise, the pilot requires information on the aircraft and its actual and planned location. Based on the information, the pilot determines the relationship of the actual aircraft course, speed, and attitude to the desired parameters. Depending on the variance of the actual from the desired parameters, the pilot will make the necessary changes in aircraft power or flight controls to return the aircraft to the desired course, speed and/or altitude.

As Bolz and Eisele (1979) observed, during this phase of flight the information needed to support the pilot decision making and tasks necessary during flight can be grouped into the following categories:

- Powerplant operation and monitoring;
- Aircraft flight controls operation;
- IFR flight instrumentation;
- Communications information;
- Weather information;
- Route and approach information; and
- ATC, navigation and guidance.

Course information, which many of these categories concern, accounts for a majority of pilot information needs during cruise. This information, on contemporary information display systems, is shown primarily on the following flight instruments:

- Magnetic compass;
- Directional gyro;
- VOR;
- ADF (Automatic Direction Finder);
- DME (Distance Measuring Equipment);
- RNAV (Area Navigation);
- HSI (Horizontal Situation Indicator);
- RMI (Radio Magnetic Indicator); and
- Weather radar.

The pilot monitors these instruments to ensure that they are tuned to the correct station, and that, in the case of VOR and RNAV, the appropriate headings and required course deviations are displayed. Courses, although established in the flight clearance that the pilot accepts, may be changed at any point during the flight by air traffic control. As a result, the pilot should scan the charts to determine where the new courses, if assigned, will place the aircraft in relation to the planned course and desired destination. Any major change in the planned course, such as course deviation or holding, necessitates recomputation of the basic flight parameters, especially as they pertain to fuel consumption. If fuel reserves become insufficient, a refueling stop is required. On this mission, neither Jacksonville nor Atlanta Center sufficiently changes the aircraft course enroute to ATL to warrant this.

To determine aircraft attitude, speed, and altitude, the pilot will be monitoring the following instruments:

- Air speed indicator;
- Altimeter;
- Turn and bank indicator or turn coordinator;
- Vertical speed indicator; and
- Artificial horizon-attitude indicator (or flight director if available).

If the aircraft is equipped with an autopilot, it will generally guide the aircraft along the course selected by the pilot. The pilot, in that instance, will be monitoring those instruments to determine aircraft adherence to the selected course, most often the directional gyro, VOR, and DME. Control inputs will be directed to aircraft pitch and/or power to maintain selected altitude.

If the aircraft has a three-axis autopilot, the autopilot will maintain the selected altitude. Flight under IFR requires precise navigation and aircraft control since aircraft are allowed to deviate no more than 100 feet above or below their assigned altitude and one mile off their airway center-line while enroute. Without an autopilot, much of the pilot's activities are directed toward minimizing these course and altitude deviations.

The pilot also monitors information on the status of aircraft powerplant and systems throughout the flight. On current models of multiengine aircraft, such as the Cessna 400 series, there are at least two sets of powerplant instruments, one for each engine, as well as other system instruments. These include the following:

POWERPLANT

- Manifold pressure
- Tachometers
- Exhaust gas temperature
- Cylinder head temperature
- Oil temperature
- Oil pressure
- Vacuum
- Propeller synchronization

SYSTEMS

OXYGEN

- Flow
- Pressure
- Quantity

FUEL

- Fuel
- Pressure
- Quantity

ELECTRICAL

- Ammeter
- Generator

AIRCRAFT CONTROL

- Flaps
- Gear

The trip has been, and continues to be, uneventful as the aircraft is handed off by Atlanta Center to Atlanta approach control, and the pilot is told to begin the descent. The pilot tunes in the ATL automatic terminal information service (ATIS) on frequency 125.55 MHz as noted on the ATL charts, and learns that the Atlanta weather has deteriorated to a ceiling of 300 feet overcast and a visibility of 1-1/2 miles in fog and rain. Approaches to the ILS runways 27L and 26 are in use. The ATL controller informs the pilot that an estimated 20 minute delay is expected on approach to the Atlanta-Hartsfield airport.

Descent. The pilot sets the autopilot to the assigned heading and trims the aircraft for a 500 feet per minute descent at cruise speed into the ATL area. All aircraft landing at ATL are told to expect to hold approximately 20 minutes before they can begin the approach to the airport. The pilot is given holding instructions and told to expect approach clearance to runway 27L in 20 minutes.

As the aircraft is vectored to the holding fix, Anval intersection, the pilot notes that the aircraft has been aloft for 1 hour and 45 minutes, with 1-3/4 hours of fuel remaining, based on the fuel consumption rate. The pilot can, if necessary, safely hold, execute the approach, and fly the aircraft to the alternate. The pilot determines the proper entry to the holding pattern, based on the aircraft heading, and throttles back to the holding speed, 140 knots, in order to conserve fuel. The VOR radials that comprise Anval are listed on the terminal area chart and set into the OBS of the VOR receivers. The pilot enters the hold at 12,000 feet, and is told to expect approach clearance to 27L in 20 minutes, or 10 minutes after noon, local time. Once established in the hold, he informs the controller of the aircraft location and altitude.

During the hold, the pilot informs the passengers of the delay and the possible diversion to Augusta. The pilot monitors the appropriate instruments and ensures that all pressure, oxygen, oil, fuel flow and pressure, and electrical systems are operating normally. Powerplant instruments, exhaust gas, and cylinder head temperatures are adequate and manifold pressure and propeller RPM are set for each engine.

The pilot examines the ILS 27L approach procedure and notes that the decision height is 1,199 feet sea level, or 200 feet above the airport elevation. Decision height is the height at which, during a precision approach, the pilot must decide whether to continue to approach or execute a missed approach. If conditions remain the same, a landing should be possible. If not, he decides that rather than try a second approach, particularly with the delays into ATL, he will divert to Augusta. After 15 minutes, the pilot is cleared to descend to approach altitude, given vectors to establish the aircraft on course to intercept the localizer, and then to execute the ILS 27L approach. The propeller RPM and mixture controls are in the full forward position, the fuel pumps are turned on, and the cabin depressurized in accordance with the landing checklist. In carrying out an instrument approach, regardless of the type of approach, the following information, available on the appropriate chart, is needed:

- Course headings for all approach phases;
- Holding pattern or procedure turn requirements;
- Frequencies - communication and navigation;
- Altitudes - minimum descent altitude or decision height;
- Time at which to execute a missed approach (if non-precision approach);
- Rate of descent - if precision approach; and
- Missed approach procedure - heading, altitude, and reporting point.

In addition, the pilot must still control the aircraft and monitor the appropriate aircraft and flight displays while performing the approach. The pilot will adjust power and propeller settings, flaps, and landing gear according to directions on the aircraft descent and landing checklist. This will be carried out regardless of whether or not an autopilot controls the aircraft approach. If the aircraft is equipped with a sophisticated autopilot, that system can, at the pilot's discretion, guide the aircraft during the approach while the pilot monitors the aircraft instruments.

In this mission, the pilot changes one of the VOR receivers to the ILS 27L frequency, and notices that the localizer course will be intercepted shortly. After turning to intercept the localizer, the pilot establishes a 580 feet per minute descent, with an approach speed of 110 knots. His attention is divided between the ILS display which indicates how to maneuver the aircraft vertically and horizontally to remain on course, the attitude display, directional gyro, barometric pressure, vertical velocity indicator, airspeed indicator, and altimeter, which was set to the ATL just before leaving the holding fix.

Upon reaching the outer marker, the pilot is told to contact the ATL tower and, after doing so, is cleared to land. As listed on the descent and landing checklist, he lowers the landing gear and ensures that the gear is down and locked, after which he lowers the flaps. He checks the engine power and propeller RPM one last time to ensure that they are set properly. Just 2-1/2 minutes after passing the outer marker, the aircraft has passed the middle marker. The pilot observes that the aircraft is on course, at just over 1400 feet sea level, or 200 feet above the decision height; the pilot must shortly either have the runway environment in sight or execute a missed approach, which means a diversion to AGS. At 1500 feet the pilot, who is rapidly shifting attention from outside the windscreen to the altimeter, airspeed indicator, and ILS display, notices the 27L approach lights and executes the landing. After landing, the control tower cancels the aircraft IFR flight plan for that mission.

Landing. The aircraft touches down on 27L at 12:14 p.m.; the airspeed is 85 knots. After landing, the pilot is told by the tower to contact the ground controller when clear of 27L and to expedite the rollout. He is aware that an air carrier transport is behind him and that he must exit the runway quickly.

Taxi. He leaves the runway after rolling about 3,000 feet from the runway threshold and informs the ground controller on the assigned frequency of 121.9 MHz of his intentions to proceed to the fixed base operator (FBO) at which he will tie the aircraft down. The ground controller clears him to the FBO via specific taxiways. He scans the ATL taxi diagram and follows the

route the controller has assigned him. Since he is familiar with ATL, the assigned taxiways present no difficulty.

Engine Shutdown. Upon arriving at the FBO, the pilot follows the directions of ground personnel to the tie-down spot. He then begins the engine and systems shutdown checklist procedures. The flight, except for the hold, was uneventful.

MISSION II. In this mission, a Cessna 421 departs from Teterboro, New Jersey on a flight to Punxsutawney, Pennsylvania (N35). Teterboro (TEB) is a satellite airport in the New York City hub area, located approximately 10 miles northeast of Newark International Airport. It is a controlled field with several instrument approaches including an ILS, full air traffic control services, and a flight service station on the field. Punxsutawney is an uncontrolled field located 65 miles northeast of Pittsburgh and 13 miles south of DuBois, Pennsylvania (DUJ). There are no approved instrument approach procedures and no ground-based navigational aids on or near the field. It has one 3,000 foot paved runway, a rotating beacon, and runway lights. As in the previous mission, the pilot is experienced, with several thousand flight hours and several hundred instrument hours.

Pre-Flight. The flight to Punxsutawney is scheduled to depart TEB around 7:30 p.m. local time, depending on when the passengers arrive at the fixed base operator. The first step in the pre-flight phase is selection of a flight route. The pilot finds, from his charts, that there is a standard instrument departure (SID) from TEB. He therefore selects the Clinton Eight Departure from TEB with a transition to the Philipsburg VOR, from which he will attempt the approach to Punxsutawney or, if unsuccessful, DUJ. The route to Punxsutawney is 187 miles long; assuming a cruising speed of 197 knots, the trip should take about an hour, including time to taxi and climb.

Before filing the flight plan, the pilot visits the TEB flight service station to learn the current weather in western Pennsylvania, and if there are any NOTAMs. DuBois, the nearest reporting station, is currently under a 500 foot ceiling, and, as a result, a VFR landing in Punxsutawney looks doubtful, as does the use of DUJ as an alternate. If DUJ is not available, the pilot can either return to TEB or use Pittsburgh as an alternate. The return flight is scheduled to depart TEB around 7:30 p.m. local time, depending on when the passengers return to the fixed base operator. The pilot files an IFR flight plan to Punxsutawney, with the hope that the destination will be VFR by the time of arrival, although conditions are not scheduled to improve. He requests DUJ as an alternate airport, but decides to carry enough fuel to continue for a landing at Pittsburgh should that become necessary. The distance from Punxsutawney to DUJ is 13 miles, and from DuBois to Pittsburgh, 77 miles, or 90 additional miles in all.

The pilot quickly determines, based on the fuel consumption rate, that the fuel necessary for the trip to Punxsutawney is 34 gallons, but a diversion to Pittsburgh will add an additional requirement of 16 gallons. This is determined from the time and fuel consumption data entered into his aviation calculator. The 45 minute IFR fuel reserve requirement adds another 25 gallons to the fuel required. The pilot decides that no additional fuel should be added to the remaining fuel on board the aircraft, four hours worth, since the aircraft departed Punxsutawney with full tanks in the morning and used only

1-1/4 hour's fuel on the trip from N35 to TEB. Similarly, he will not re-determine the aircraft weight and balance since that will not have changed appreciably from the morning's calculation.

While at the flight service station, the pilot reads the AIM and asks the personnel for information on NOTAMs. He further asks if there are any advisories for an significant adverse weather along the route. He is informed that there are none and that the only deterrents to the flight as planned are the low ceilings reported in western Pennsylvania. The pilot files the flight plan with an estimated time of departure at 7:30 p.m.

The weather at TEB is also poor, with a 1,000 foot ceiling reported, but winds and visibility are adequate for takeoff. The pilot then performs the pre-flight inspection of the aircraft. All exterior aircraft controls are free and correct, the propellers are in good condition, as are the tires, brakes, and landing gear. All nav-comm antennas are in place, and the stall warning and pitot-static ports are unobstructed. All fuel, oil, and fluid levels are satisfactory and all lights necessary for night landings are operating normally. The aircraft is ready for flight.

The pilot calls the flight service station and learns that the weather in western Pennsylvania has deteriorated. Since DuBois is reporting 300 foot ceilings, a return to Teterboro may be likely if neither DuBois nor Pittsburgh are available as alternates. The pilot determines that there is sufficient fuel to return to TEB.

At 9:05 p.m., the pilot turns on the communication radios. By listening to the ATIS (Automatic Terminal Information Service), he learns that runway 1 is in use at Teterboro, ceilings are 1,500 feet overcast, the temperature is 68° F, and winds are 030 degrees at 8 knots. The slight crosswind will not be a factor in the takeoff and, with a 7,000 foot runway and a low density altitude, the takeoff should be uneventful.

He then contacts Teterboro ground control on the frequency 121.9 MHz for enroute clearance. Since the weather at DuBois has deteriorated, the pilot cannot use DuBois as an alternate. He requests clearance direct to DuBois with Pittsburgh as an alternate. The ground controller cannot give him an immediate clearance to DUJ with Pittsburgh as an alternate, but informs him that such clearance should be available shortly. In five minutes, ground control calls the aircraft and the enroute clearance to DuBois is given as filed, with Pittsburgh as an alternate. The altitude requested is 12,000 feet, the expected altitude 10 minutes after departure, after first following the Clinton Eight departure to the Solberg VOR. At 9:12 p.m., the pilot starts the engines and at 9:14 is ready to taxi to runway 1.

Taxi. The pilot recontacts Teterboro ground control and is cleared to taxi south to runway 1 via taxiway Charlie to Echo to 1. The controller informs the pilot that there will be a single-engine Cherokee taxiing to his right on Charlie and the pilot confirms sighting the Cherokee. At 9:17 the pilot begins the engine runup.

Takeoff. During the runup, the pilot checks the power and propeller RPM headings at various power settings; all appear normal. Suction is satisfactory and the pilot sets the gyro and pitot-static instruments as necessary.

Navigation radios are set with Colts Neck and Solberg VOR and Newark departure frequencies all tuned in. At 9:19 he calls the tower and informs the controller that he is ready for takeoff on runway 1. He is told to taxi into position and hold. At 9:20 he is cleared for takeoff.

The pilot advances the throttles and at rotation speed, about 106 knots, he raises the aircraft nose and shortly thereafter begins the climb, maintaining 120 knots indicated air speed. He raises the flaps, adjusts manifold pressure and propeller RPM, and raises the gear when beyond the end of the runway.

Climb. Shortly after takeoff, the pilot is cleared to Solberg via the Clinton Eight departure and is told to contact Newark departure. The pilot, while monitoring his rate of climb and airspeed, throttles back to climb power and RPM and contacts Newark departure control as directed by the tower. The Clinton Eight departure is specific as to the particular headings, altitudes, and fixes to follow. Because the aircraft is now in IMC, the pilot's workload is somewhat decreased since responsibility for seeing and avoiding other aircraft is the air traffic controller's. He need only follow air traffic control directions, while guiding the aircraft along the specified altitude and course parameters of flight, to ensure separation from other air traffic. The pilot, during the climb, is shifting his attention from the SID requirements to the navigational displays and to the engine and system displays. His major navigational concern will be the course, altitude, vertical velocity, and airspeed. Engine parameters of major concern are manifold pressure and propeller RPM. Before reaching Solberg, the pilot is told to climb to and maintain 12,000 feet, to proceed on course via V6, and to contact New York Center (air route traffic control) on a specified frequency. He increases the airspeed to 150 knots and decreases the rate of climb for the cruise climb to 12,000 feet.

Cruise. During cruise, the pilot's major concern is maintaining the appropriate heading and altitude. At 12,000 feet the autopilot is engaged; it will guide the aircraft along specific headings while the pilot monitors the directional gyro, magnetic compass, VOR, and CDI to ensure that the correct course is being maintained. He trims the aircraft pitch to maintain the assigned altitude of 12,000 feet. At this altitude other aircraft will be a minor factor; being in the clouds, aircraft separation is still the exclusive responsibility of the air traffic controller. During cruise, the pilot also scans the instrument panel periodically to ensure that all powerplant and engine instruments are operating normally, which they are. The DME is indicating a ground speed of 192 knots, very close to what the pilot had estimated before takeoff. At the initial approach fix to either Punxsutawney or DuBois, approximately 3 hours of fuel should be remaining.

During cruise, the pilot has been scanning the approach charts to DUJ; he is almost certain that a landing at Punxsutawney, requiring a visual approach, will not be feasible. With the ILS in operation at DuBois, a descent to 250 feet above the airport should be possible, thereby allowing a landing there. Shortly after passing the Philipsburg VOR, the aircraft is handed off from New York Center to Cleveland Center. After being informed by Cleveland Center that the aircraft is in radar contact, the pilot is told to descend to and maintain 6,000 feet. He requests the destination weather at DuBois and, after

a short wait, is told that DUJ is reporting a 300 foot overcast, with visibility one mile in light rain and fog. Winds at DuBois are reported to be light and variable.

The pilot has reduced the power, as indicated by the manifold pressure, for a 1,000 feet per minute descent and adjusted propeller RPM accordingly. Fuel mixture is readjusted during the descent and airspeed is maintained at the desired indicated cruise airspeed of 197 knots. The autopilot is still maintaining the proper heading which the pilot notes by scanning the directional gyro, magnetic compass, and VOR course deviation indicator.

During the descent, the pilot determines that the weather at DuBois, only 13 miles from Punxsutawney, will preclude the deviation from and descent off the airway which is required for the approach to Punxsutawney. Since the minimum altitude on the airway is 4,000 feet, the low ceiling at DuBois, which almost certainly extends to Punxsutawney, will prevent a descent below that altitude required for the visual approach to Punxsutawney. The pilot elects to proceed directly to DuBois.

The DUJ airport has both an ILS approach and a flight service station on the field, which can give the pilot current surface weather conditions. The pilot scans the approach charts and selects the ILS approach to runway 25. Since winds are light and variable, no runway is favored. The ILS approach will allow the pilot to descend closer to the runway, with lower visibility requirements than either of the other two approaches to DuBois's only runway.

Before reaching 6,000 feet, the pilot is told to descend to 4,000, is vectored to the intersection, is cleared for the ILS approach to runway 25 at DuBois, and is told to contact DuBois radio on the frequency 123.6 MHz. The pilot has the approach and the aircraft descent and landing checklists in front of him. From the approach chart, he tunes in the communication frequency and the localizer frequency for runway 25, as well as the DUJ outer marker frequency. From the descent and landing checklist, he adjusts all power settings and airspeed for the approach to DuBois. Flaps will be lowered as needed during the approach and the gear will be lowered upon interception of the localizer. Lastly, he disengages the autopilot and manually controls the aircraft for the approach.

Upon contacting DuBois radio, the pilot is told that conditions in DuBois have worsened from the last known report; there is now a 300 foot ceiling with visibility about one mile, just above the minimum requirements for the ILS approach. In response to his request, the DuBois briefer informs him that Pittsburgh is reporting an 800 foot ceiling with one mile visibility.

The pilot is now primarily scanning the displays for three items of information: the airspeed, the altitude, and the localizer/glideslope deviations. The scan also includes the vertical velocity, the artificial horizon reading, and the engine power settings. Upon interception of the runway 25 localizer, he lowers the gear and ensures that they are locked in place. Flaps are lowered, airspeed is established, and the fuel mixture is enriched. At 400 feet above ground level, 2,217 feet above sea level, the pilot cannot identify the runway or the approach lights. The pilot is now rapidly shifting his scan from the three primary displays to outside the windscreen to locate the runway. At 250 feet above the airport, the decision

height is reached; since the runway is still not visible, the pilot must execute a missed approach. He immediately opens the throttle to climb power and raises the flaps, and the landing gear. He informs DuBois radio of the missed approach and follows the DuBois ILS 25 missed approach procedure: He climbs to 4,000 feet sea level, about 2,200 feet above the airport, and enters a holding pattern around the DuBois outer marker. DuBois radio then directs him to contact Cleveland Center.

Upon contacting Cleveland Center, just after entering the holding pattern, the pilot is asked to state his intentions as to the type of approach to be executed or alternate destination. The pilot requests clearance to Pittsburgh where he will attempt to land. The pilot is told to climb to 8,000 feet and is vectored on a heading to intercept V226 for the trip to Pittsburgh. The pilot now reconfigures the aircraft for the climb by adjusting throttle, propeller RPM, and elevator trim. In addition, he establishes the headings and frequencies required to fly via V226. Once reaching the assigned altitude, he reconfigures the aircraft for cruise and selects the approach charts to the Greater Pittsburgh International Airport. He then computes the estimated fuel remaining onboard the aircraft for the trip to Pittsburgh. As less than 2-1/2 hours of fuel have been consumed since the morning departure from Punxsutawney to the present climb to 8,000 feet, the aircraft still has 2-1/2 hours of fuel remaining, more than adequate reserves with which to hold, if necessary, and then execute the approach to Pittsburgh.

Descent. About 30 miles north of Pittsburgh, the aircraft is handed off to Pittsburgh approach control for the descent. The pilot is told to descend to 5,000 feet and to expect an ILS runway 28R approach into the airport, which he anticipated from monitoring the Pittsburgh ATIS. He selects the chart for that approach and notices that this will permit a descent to within 200 feet over the runway. Conditions at Pittsburgh have deteriorated to a 400 foot ceiling with one mile visibility. The pilot again readjusts the aircraft controls for the descent, monitoring all power and systems gauges.

The pilot is vectored to the ILS approach and repeats the actions performed during the approach to DuBois. All nav-comm frequencies are set, aircraft system displays noted, airspeed, heading, and rate of descent are monitored. After reaching the outer marker, the pilot is told to contact the Pittsburgh tower and, on doing so, is cleared to land. He lowers the gear, readjusts the airspeed and, at 400 feet above the airport, 1,600 feet sea level, he identifies the approach lights to runway 28R.

Landing. Since the pilot has identified the approach lights, he shifts his scan primarily to outside the windscreen, although noting airspeed and glideslope throughout the descent to landing. He then lands the aircraft at the touchdown speed of 85 knots. Shortly thereafter, he is told to contact the Pittsburgh ground controller on the frequency 121.9 MHz. At this point in time, the Pittsburgh tower controller has cancelled the aircraft IFR flight plan.

Taxi. Pittsburgh International Airport, being a major hub, has a discrete taxi chart which the pilot consults once safely off the runway. Ground control clears him to the general aviation terminal along specified taxiways. Although he has the taxiway chart, he still requests progressive clearances to the ramp. Since it is almost 11:00 p.m. and few other aircraft

are on the ground, the ground controller offers progressive clearances to the ramp rather than advising him to follow a particular aircraft.

Engine Shutdown. Upon reaching the ramp, the pilot follows the signals of the ramp agent who assigns him to a particular tie down location. Since the aircraft was expected, a fuel truck quickly drives to the area to await the engine shutdown and passenger exit before servicing the aircraft. The pilot follows the engine shutdown checklist and ends the flight at 10:53 p.m.

REFERENCES

- Aerospace Facts and Figures 1980/81. Washington, DC: Aerospace Industries Association of America, 1980.
- Aviation Week and Space Technology. Air transport: 1980 traffic survey, 1981a, 114(2), 24-27.
- Aviation Week and Space Technology. Aerospace inventory, 1981b, 114(10), 116-137.
- Avionics. Avionics equipment by primary use, 1981, 4(3), 20-21.
- Beardsley, P. FAA statistical handbook of aviation. Washington, DC: Federal Aviation Administration, December 1978.
- Bolz, E. H., & Eisele, J. E. General aviation IFR operational problems (NASA CR 159022). Washington, DC: National Aeronautics and Space Administration, 1979.
- Federal Aviation Administration. FAA aviation forecasts fiscal years 1981-1992. Washington, DC: Author, September 1980a.
- Federal Aviation Administration. National aviation system development and capital needs for the decade 1982-1991. Washington, DC: Author, December 1980b.
- Helms, J. L. General aviation--a look at the eighties. Paper presented at the annual meeting of the Society of Experimental Test Pilots, Beverly Hills, CA, September 1980.
- NASA-ASEE 1979 Engineering System Design Fellows. Avionics: Projections for civil aviation 1995-2000 (NASA CR 159035). Washington, DC: National Aeronautics and Space Administration, September 1979.
- North, D. M. Manufacturers project 1981 billings of \$3 billion. Aviation Week and Space Technology, 1981, 114(5), 50-51.
- Quinby, G. F. An assessment of general aviation utilization of advanced avionics technology (NASA CR 159328). Washington, DC: National Aeronautics and Space Administration, September 1980.
- The Weekly of Business Aviation, 1981, 32, 153.
- Vahovitch, S. G. General aviation: Hours flown and avionics purchase decisions (FAA-AVP-78-9). Washington, DC: Federal Aviation Administration, May 1978.

APPENDIX E

LIST OF CANDIDATE MANEUVERS AND ADVERSE CONDITIONS FOR THEIR PERFORMANCE

This appendix contains examples of candidate maneuvers and adverse conditions that can create flight situations in which the likelihood of pilot error may increase.¹ General procedures and criteria for selecting the maneuvers and conditions are discussed in Chapter IV. Comments provided with each example briefly describe the rationale for selecting the maneuver and conditions that are listed, as well as references that are pertinent thereto. Readers are referred to those references for additional information concerning the maneuvers and conditions, and the pilot performance problems that are believed to be associated with those flight situations.

Conditions for the performance of the maneuvers are described in terms of only the key conditions that were selected to increase the difficulty of the maneuver. Conditions that are not explicitly stated for each listing are assumed to be those that might normally occur with the key conditions. Further, maneuvers are described using generic terms--e.g., a VOR approach instead of a specific type of VOR approach. The difficulty of each of the maneuver/condition listings may be varied by changing the characteristics of the maneuver--e.g., varying the type of initial approach segments in a VOR approach or where the VOR is located (on or off of the airport).

Such variations, as well as variations in the key conditions, will be examined during preliminary testing prior to the conduct of the exploratory evaluation. Such testing will enable researchers to determine if the situations can be simulated realistically in the assessment vehicle selected for the evaluation. Additionally, different maneuvers and conditions can be examined with respect to their actual influence on pilot performance. Such information will facilitate the selection of actual maneuver/conditions for the planned exploratory evaluation. A glossary of the terms that are abbreviated in this appendix is included at the end of the list of examples. Definitions for such terms can be found in FAA publications on instrument flight (e.g., FAA, 1968).

¹As discussed in Chapters III, IV, and V, it is recommended that the exploratory evaluation be conducted in a high fidelity simulator (for a twin-engine corporate aircraft). As such, the conditions specified here are optimized for such a test vehicle. Many of the maneuvers and conditions listed in this appendix, however, can be adapted to be performed in a low fidelity simulator or in an aircraft.

<u>MANEUVER</u>	<u>KEY ADVERSE CONDITIONS</u>	<u>COMMENTS</u>
1. ILS approach	● Ceiling and RVR at published minimums for the approach (Category IIA) ● Visibility above the ceiling is intermittent due to scattered clouds and fog. ● Moderate wind shear between 150' to 50' (DH at 150') ● Night	Designed to analyze the pilots' ability to transition between "head down" (on instruments) and "head-up" (viewing the runway). Intermittent visibility increases the number of times that such transitions may occur. Night and wind shear add to general level of task demands and to the need to monitor instruments (Haines, 1980). Maneuver ends after landing or missed approach.
2. LOC backcourse approach	● Ceiling below published minimums ● Strong headwind on final approach segment	The strong headwind can affect the timing of the inbound leg and thus the time of the execution of the missed approach (Bergeron, 1980a). Maneuver ends after missed approach.
3. NDB approach	● Ceiling below published minimums ● Strong crosswind on final approach segment	Wind can cause problems with respect to tracking the NDB (Bergeron, 1980a). Maneuver ends after missed approach.
4. VOR approach	● Ceiling just above published minimums ● Strong tailwind on final approach segment	If the pilot does not compensate for the strong tailwind, the aircraft will descend too slowly and breakout beyond the airport (Bergeron, 1980a). Maneuver ends after aircraft is lined up on final or at start of missed approach.
5. Maximum performance takeoff	● Ceiling and visibility at departure minimums (e.g., 150') ● Engine failure during climbout after entering IMC (e.g., 200' AGL); aircraft can climb if properly configured	Loss of control after single engine failure is a major safety problem (NTSB, 1979b). Maneuver ends after aircraft is established on downwind for landing.

<u>MANEUVER</u>	<u>KEY ADVERSE CONDITIONS</u>	<u>COMMENTS</u>
6. VOR track, enroute cruise; ATC vectors to new heading	● Cruise altitude several thousand feet above single engine absolute ceiling. ● Engine failure ● Moderate turbulence ● IMC	Requires pilot to maintain control of the aircraft during single engine "drift down." Turbulence and turn to new heading adds to task demands (Schiff, 1980). Maneuver ends when aircraft is established on new heading and at an altitude that can be maintained.
7. VOR/DME approach	● Ceiling just above published minimums ● Engine failure just before visual breakout ● Moderate turbulence and crosswind on the final segment (from the side of the failed engine)	Creates problem that may result in loss of control of the aircraft (NTSB, 1979b). Maneuver ends after landing.
8. Climbout, execution of SID	● ATC clearance to a specified altitude (e.g., 6000') ● Ceiling is above designated altitude (e.g., 8000') ● Frequent ATC communications reporting possible conflicting traffic ● Failure of autopilot altitude capture mode (if aircraft has one)	Distractions have been associated with altitude overshoots. Such overshoots have also been associated with subtle autopilot failures (NASA, 1977). Maneuver ends when aircraft levels out at designated altitude or altitude is exceeded by more than 100 ft.
9. LOC backcourse approach	● Ceiling and visibility at published minimums ● Moderate turbulence with occasional severe gusts ● ATC asks pilot to expedite approach due to other traffic	Localizer backcourse approach cause problems because of reverse indications on conventional displays (Bergeron, 1980a). Moderate turbulence and ATC request add to workload. Maneuver ends at breakout or missed approach.

<u>MANEUVER</u>	<u>KEY ADVERSE CONDITIONS</u>	<u>COMMENTS</u>
10. LOC approach	● Ceiling at MDA along course of final approach, with higher ceiling closer to the field ● Visual breakout occurs at a position that is before MAP, but too late to establish a satisfactory approach angle to the desired runway	If pilot attempts to land, he may set up an approach angle that will result in an excessive sink rate (Trammel, 1980). Maneuver ends with landing or missed approach.
11. STAR interrupted by ATC vector	● Mountainous terrain ● Execution of STAR is interrupted by ATC vector ● ATC vector is in error and will take aircraft below MSA for area ● Moderate turbulence	Detection of ATC error will require awareness of actual altitude and MSA in an unexpected situation (Trammel, 1980). Maneuver ends when pilot detects error or descends below MSA.
12. ATC vector to ILS final approach course, and ILS approach	● After initial vector to ILS, ATC delays before giving the second vector. Delay is designed to assure that the aircraft intercepts the ILS at a larger than desired angle (e.g., 45°), and is high and fast on the glide-slope ● Ceiling and visibility at published minimums	Delay in vector disrupts pacing and timing of approach. Pilot is forced to fly final approach from abnormal starting position (Trammel, 1980). Maneuver ends with landing or missed approach.
13. ILS approach	● Ceiling and visibility at published minimums ● Severe wind shear at DH	Severe wind shear makes landing very difficult. Pilot needs to detect and compensate for problem. Maneuver ends with landing or missed approach.

<u>MANEUVER</u>	<u>KEY ADVERSE CONDITIONS</u>	<u>COMMENTS</u>
14. VOR/DME approach (circling final approach)	● Short-field landing is required ● Moderate crosswind (with occasional gusts) relative to active runway	Circling and landing tasks are composite flight operations (both external cues and instruments are used). Crosswind makes short-field landing more difficult (Trammel, 1980). Maneuver ends with landing.
15. ILS approach	● Ceiling below published minimums ● Nav radio tuned to ILS fails at the outer marker	Requires detection of failure and decision to execute a missed approach (Trammel, 1980). Maneuver ends after missed approach.
16. STAR, ATC vectors	● CAVU ● ATC clearance requires new heading, and descent to different altitude than planned profile ● Unreported, conflicting VFR traffic that will require aircraft to maneuver to avoid	ATC clearance requires pilot to compute and execute new profile. Associated task demands can distract from collision avoidance duties. IFR-VFR conflicts are frequently reported as incidents (Bergeron, 1980b). Maneuver ends with successful avoidance maneuver or near miss/midair.
17. Profile descent (RNAV), ATC vectors and new RNAV profile	● IMC ● Frequent requirements to change navaid and communication radio frequencies ● Moderate turbulence ● Planned profile will take aircraft through excessive precipitation (as indicated by airborne weather radar)	High workload is often associated with problems in profile descents (NASA, 1977). Pilot also is required to detect need for course change, request change, and program in new waypoints. Maneuver ends when aircraft reaches desired altitude.

<u>MANEUVER</u>	<u>KEY ADVERSE CONDITIONS</u>	<u>COMMENTS</u>
18. ADF enroute, ATC vectors to new heading and altitude	● IMC ● Failure of primary flight instruments due to flight reference system/sensor failure	Will require flight using back-up instruments. Need to assure approximate equivalency of information content for aircraft with EFIS and conventional flight instruments. Maneuver ends when aircraft is on the new heading at designated altitude. ¹
19. ILS approach	● Ceiling and visibility just above published minimums (Category II) ● Obstacle on runway ● Moderate turbulence	Assesses transition from head down to head up and ability to detect obstacle (Haines, Fisher, & Price, 1980). Maneuver ends with missed approach.
20. VOR approach and landing	● Ceiling at published minimums ● Landing gear unsafe indication, gear capable of being extended manually ● Night	Assesses ability of pilot to handle distraction. Maneuver ends with landing or missed approach.
21. NDB approach	● Ceiling at published minimums ● Structural icing simulated by need for more power to maintain airspeed; excessive ice will accumulate if pilot does not exit icing conditions	Assesses ability of pilot to detect icing problem while performing difficult approach. (NTSB, 1974). Maneuver ends when aircraft climbs out or aircraft loses flying speed.

¹EFIS displays may have failure modes that are not possible with conventional instruments--e.g., normally separate displays are presented on the same cathode ray tube when one cathode ray tube fails. Such failures could be assessed for information value, but could not be used in the formal comparisons among evaluation groups.

<u>MANEUVER</u>	<u>KEY ADVERSE CONDITIONS</u>	<u>COMMENTS</u>
22. ILS approach	● Ceiling at published minimums (Category IIA) ● Lateral ILS offset ● Crosswind from side opposite of lateral offset	Pilot must detect offset at breakout (Fischer, Haines & Price, 1980). Maneuver ends after landing or missed approach.
23. ILS approach	● Ceiling and visibility at published minimums ● Heavy rain on final segment simulated by increased drag and loss of momentum ● Mild wind shear	Pilot needs to react to altered aircraft performance characteristics. Heavy rain and wind shear thought to be associated with several severe aircraft accidents (Covault, 1981). Maneuver ends with landing or missed approach.
24. LOC approach	● While in IMC, moderate turbulence from a wake vortex is simulated by roll rate disturbance ● Ceiling below published minimums ● Mild turbulence	Roll disturbance provides context for assessment of control reversal (input opposite of response needed to restore correct attitude). Maneuver ends after return to level flight.
25. Noise abatement takeoff and climbout (including steep turn and maximum angle of climb)	● While engaged in turn and power reductions, pilot is asked to perform distracting, but realistic activity (e.g., urgent traffic call from ATC)	Distractions in such a maneuver can result in inadvertent stalls (FAA, 1979). Maneuver ends when enroute climb commenced.
26. VOR/DME approach	● Ceiling at published minimums, but there is intermittent ground fog. Visual breakout occurs before MAP, but visual contact is lost before landing	Loss of visual cues during low visibility landings has been associated with several weather-related accidents (NTSB, 1976). Maneuver ends with missed approach.

<u>MANEUVER</u>	<u>KEY ADVERSE CONDITIONS</u>	<u>COMMENTS</u>
27. RNAV, profile climb (3-D)	● ATC clearance requires impromptu change of waypoints and crossing altitudes ● IMC ● Moderate turbulence ● Thunderstorms in area (on airborne weather radar), but not in path of aircraft	Impromptu change of waypoints can induce high task demands which, in turn, can lead to pilot error (Eldredge, Crook, & Crimbring, 1977). Maneuver ends when pilot completes climb.

GLOSSARY

ADF	Automatic Direction Finder
AGL	Above Ground Level
ATC	Air Traffic Control
CAVU	Ceiling and Visibility Unlimited
DH	Decision Height
DME	Distance-Measuring Equipment
EFIS	Electronic Flight Instrument System
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
ILS	Instrument Landing System
LOC	Localizer
MAP	Missed Approach Point
MDA	Minimum Descent Altitude
MSA	Minimum Safe Altitude
NDB	Non-Directional Beacon
RVR	Runway Visual Range
SID	Standard Instrument Departure
STAR	Standard Terminal Arrival Route
VFR	Visual Flight Rules
2-D	Two dimensional (horizontal navigation)
3-D	Three dimensional (horizontal plus vertical navigation)

APPENDIX F

EXAMPLES OF RECORDING FORMS FOR THE MANEUVER-ORIENTED PROFICIENCY CHECKS

This appendix presents a candidate set of Pilot Performance Description Records (PPDR) for use in maneuver-oriented proficiency checks that were discussed in Chapter IV. The maneuvers range in complexity from basic control-oriented tasks to those that are more highly mediated by the use of procedural, cognitive, and decisional skills. Segmentation and measurement logic for these maneuvers was developed as a result of a review of FAA and Embry-Riddle Aeronautical University (E-RAU) documentation on training and evaluation as well as the general literature concerning pilot performance measurement.

INSTRUMENT TAKEOFF & DEPARTURE

GROUND RUN

FULL THROTTLE

(NO)

(YES)

TAKEOFF HEADING

LEFT

-5

0

+5

RIGHT

LIFTOFF

AIRSPEED

LOW

-5

0

+5

HIGH

ACCEPTABLE ROTATION

(NO)

(YES)

CLIMBOUT

AIRSPEED

LOW

-5

0

+5

HIGH

HEADING

LEFT

-5

0

+5

RIGHT

BANK

SHALLOW

-5

0

+5

STEEP

PROPER USE OF POWER

(NO)

(YES)

TRIM (FOR CLIMB)

(NO)

(YES)

PROPER ATC COMMUNICATIONS

(NO)

(YES)

LEVEL OFF

ALTITUDE

LOW

-5

0

+5

HIGH

HEADING

LEFT

-5

0

+5

RIGHT

TRIM (LEVEL FLIGHT)

(NO)

(YES)

SMOOTH CONTROL

(NO)

(YES)

AIRSPED CHANGE

NORMAL CRUISE

ALTITUDE	-100	-50	0	+50	+100
HEADING	-10	-5	0	+5	+10
AIRSPED	-10	-5	0	+5	+10

ACCELERATION

ALTITUDE	-100	-50	0	+50	+100
HEADING	-10	-5	0	+5	+10

TARGET AIRSPEED
 ATTAINED (+ 5 KTS) (NO) (YES)
 TRIM (+ 1 BALL WIDTH) (NO) (YES)

DECELERATION

ALTITUDE	-100	-50	0	+50	+100
HEADING	-10	-5	0	+5	+10

TARGET AIRSPEED
 ATTAINED (+ 5 KTS) (NO) (YES)
 TRIM (+ 1 BALL WIDTH) (NO) (YES)

SMOOTH CONTROL

(NO) (YES)

CONSTANT AIRSPEED CLIMB

INITIATE

PROPER POWER INCREASE
(+ 50 RPM)

(NO) (YES)

HEADING -10 -5 0 +5 +10

AIRSPEED -10 -5 0 +5 +10

TRIM (NO) (YES)

MAINTAIN

HEADING -10 -5 0 +5 +10

AIRSPEED -10 -5 0 +5 +10

PROPER POWER CONTROL (NO) (YES)

TRIM (NO) (YES)

LEVEL OFF

PROPER POWER DECREASE
(+ 50 RPM)

(NO) (YES)

ASSIGNED ALTITUDE -100 -50 0 +50 +100

HEADING -10 -5 0 +5 +10

AIRSPEED -10 -5 0 +5 +10

TRIM (NO) (YES)

SMOOTH CONTROL

(NO) (YES)

CLIMBING TURN

INITIATE

CLIMB & TURN STARTED
SIMULTANEOUSLY

(NO)

(YES)

PROPER BANK (+ 1°)

(NO)

(YES)

PROPER POWER INCREASE
(+ 50 RPM)

(NO)

(YES)

AIRSPEED

-10

-5

0

+5

+10

MAINTAIN

STANDARD RATE TURN (+ 1°)

(NO)

(YES)

PROPER POWER (+ 50 RPM)

(NO)

(YES)

AIRSPEED

-10

-5

0

+5

+10

TERMINATE

COORDINATED LEVEL OFF
AND ROLLOUT

(NO)

(YES)

AIRSPEED

-10

-5

0

+5

+10

ASSIGNED ALTITUDE

-100

-50

0

+50

+100

ASSIGNED HEADING

-100

-50

0

+50

+100

SMOOTH CONTROL

(NO)

(YES)

STEEP TURN

ROLL IN

PROPER BANK (+ 1°)

(NO)

(YES)

AIRSPED

-10

-5

0

+5

+10

ALTITUDE

-100

-50

0

+50

+100

MAINTAIN

PROPER BANK

(NO)

(YES)

AIRSPED

-10

-5

0

+5

+10

ALTITUDE

-100

-50

0

+50

+100

ROLLOUT

ASSIGNED HEADING

-10

-5

0

+5

+10

AIRSPED

-10

-5

0

+5

+10

ALTITUDE

-100

-50

0

+50

+100

SMOOTH CONTROL

(NO)

(YES)

SLOW FLIGHT (FLAPS UP)

ENTRY

PROPER ENTRY

(NO)

(YES)

STRAIGHT AND LEVEL

AIRSPED

-10

-5

0

+5

+10

ALTITUDE

-100

-50

0

+50

+100

HEADING

-10

-5

0

+5

+10

TURN

AIRSPED

-10

-5

0

+5

+10

ALTITUDE

-100

-50

0

+50

+100

SHALLOW BANKS

(NO)

(YES)

RECOVERY

PROPER RECOVERY

(NO)

(YES)

SMOOTH CONTROL

(NO)

(YES)

TRAFFIC PATTERN (UNCONTROLLED AIRPORT)

ENTRY

PROPER PREPARATION	(<u>NO</u>)	(<u>YES</u>)
ACKNOWLEDGE INTENTIONS	(<u>NO</u>)	(<u>YES</u>)
PROPER ENTRY	(<u>NO</u>)	(<u>YES</u>)

ALTITUDE	-100	-50	0	+50	+100
----------	------	-----	---	-----	------

RPM	-100	-50	0	+50	+100
-----	------	-----	---	-----	------

DISTANCE OUT FROM RUNWAY	TOO CLOSE	0	TOO FAR
--------------------------	-----------	---	---------

DOWNWIND

ALTITUDE	-100	-50	0	+50	+100
----------	------	-----	---	-----	------

ACKNOWLEDGE INTENTIONS	(<u>NO</u>)	(<u>YES</u>)
------------------------	---------------	----------------

COCKPIT CHECK	(<u>NO</u>)	(<u>YES</u>)
---------------	---------------	----------------

REDUCE POWER	EARLY	0	LATE
--------------	-------	---	------

GEAR DOWN	(<u>NO</u>)	(<u>YES</u>)
-----------	---------------	----------------

AIRSPEED	-10	-5	0	+5	+10
----------	-----	----	---	----	-----

PROPER FLAPS	(<u>NO</u>)	(<u>YES</u>)
--------------	---------------	----------------

PROPER GROUND TRACK	(<u>NO</u>)	(<u>YES</u>)
---------------------	---------------	----------------

TURN STARTED BASE	EARLY	0	LATE
-------------------	-------	---	------

(TRAFFIC PATTERN)

BASE

AIRSPEED	-10	-5	0	+5	+10
PROPER GROUND TRACK		(NO)	(YES)		
PROPER FLAPS		(NO)	(YES)		
TURN STARTED (FINAL)	EARLY		0		LATE
ACKNOWLEDGE INTENTIONS		(NO)	(YES)		

FINAL

TRACK FROM EXTENDED RUNWAY	LEFT		0		RIGHT
AIRSPEED	-10	-5	0	+5	+10
DESCENT RATE	SLOW		0		FAST
APPROACH ANGLE	SHALLOW		0		STEEP
PROPER FLAPS		(NO)	(YES)		
MAINTAIN EXTERNAL SCAN		(NO)	(YES)		
TRIM		(NO)	(YES)		

SHORT FIELD LANDING

FINAL APPROACH

AIRSPEED	-10	-5	0	+5	+10
APPROACH ANGLE FOR OBSTACLE CLEARANCE	(NO)		(YES)		
RUNWAY CENTERLINE TRACK	LEFT		0		RIGHT

TRANSITION (FLARE)

ALTITUDE	-10	-5	0	+5	+10
PROPER FLARE RATE	(NO)		(YES)		
PROPER FLARE ATTITUDE	(NO)		(YES)		

TOUCHDOWN

TOUCHDOWN POINT	SHORT		0		LONG
PROPER POWER	(NO)		(YES)		
PROPER NOSE ATTITUDE	(NO)		(YES)		
CONTACT	DROP		0		BOUNCE
RUNWAY CENTERLINE TRACK	LEFT		0		RIGHT

SMOOTH CONTROL	(NO)	(YES)
----------------	------	-------

MAX PERFORMANCE TAKEOFF (OBSTACLE CLEARANCE)

GROUND RUN

PROPER FLAPS (NO) (YES)

FULL THROTTLE (NO) (YES)

RUNWAY CENTERLINE TRACK LEFT 0 RIGHT

LIFTOFF

AIRSPPEED LOW -5 Vx +5 HIGH

ACCEPTABLE ROTATION (NO) (YES)

CLIMBOUT

AIRSPPEED (BEFORE OBSTACLE CLEARED) LOW -5 Vx +5 HIGH

TRACK FROM EXTENDED RUNWAY LEFT Vx RIGHT

AIRSPPEED (AFTER OBSTACLE CLEARED) LOW -5 +5 HIGH

PROPER PATTERN EXIT (NO) (YES)

TRIM (FOR CLIMB) (NO) (YES)

LEVEL OFF

ASSIGNED ALTITUDE LOW -50 0 +50 HIGH

TRIM (LEVEL FLIGHT) (NO) (YES)

SMOOTH CONTROL (NO) (YES)

NOISE ABATEMENT TAKEOFF AND CLIMBOUT

GROUND RUN

PROPER FLAPS	(<u>NO</u>)	(<u>YES</u>)	
FULL THROTTLE	(<u>NO</u>)	(<u>YES</u>)	
RUNWAY CENTERLINE TRACK	LEFT	0	RIGHT

LIFTOFF

AIRSPEED	LOW	-3	V1	+3	HIGH
ACCEPTABLE ROTATION	(<u>NO</u>)	(<u>YES</u>)			

CLIMBOUT (TO 1500' AFL)

AIRSPEED (V2+10)	LOW	-5	(V2+10)	+5	HIGH
TRACK FROM EXTENDED RUNWAY	LEFT	0	RIGHT		

CLIMBOUT (1500' to 3000' AFL)

AIRSPEED (VFS)	LOW	-5	VFS	+5	HIGH
RETRACT FLAPS	(<u>NO</u>)	(<u>YES</u>)			
VERTICAL SPEED (FPM)	LOW	-50	1000	+50	HIGH
TRIM (FOR CLIMB)	(<u>NO</u>)	(<u>YES</u>)			

CLIMBOUT (3000' AFL)

AIRSPEED	LOW	-50	0	+50	HIGH
NORMAL CLIMB	(<u>NO</u>)	(<u>YES</u>)			

HOLDING PATTERN (NDB FIX)

PROPER ENTRY	(<u>NO</u>)	(<u>YES</u>)
--------------	---------------	----------------

TRACK	(<u>NO</u>)	(<u>YES</u>)
-------	---------------	----------------

PROPER TIMING	(<u>NO</u>)	(<u>YES</u>)
---------------	---------------	----------------

PROPER TURN RATE	(<u>NO</u>)	(<u>YES</u>)
------------------	---------------	----------------

ALTITUDE	-100	-50	0	+50	+100
----------	------	-----	---	-----	------

AIRSPEED	-10	-5	0	+5	+10
----------	-----	----	---	----	-----

COMPLIANCE WITH ALL ATC INSTRUCTIONS	(<u>NO</u>)	(<u>YES</u>)
---	---------------	----------------

HOLDING PATTERN (VOR FIX)

PROPER ENTRY	(<u>NO</u>)	(<u>YES</u>)
TRACK	(<u>NO</u>)	(<u>YES</u>)
PROPER TIMING	(<u>NO</u>)	(<u>YES</u>)
PROPER TURN RATE	(<u>NO</u>)	(<u>YES</u>)
ALTITUDE	-100 -50 0 +50 +100	
AIRSPEED	-10 -5 0 +5 +10	
COMPLIANCE WITH ALL ATC INSTRUCTIONS	(<u>NO</u>)	(<u>YES</u>)

HOLDING PATTERN (RNAV FIX)

PROPER ENTRY	(<u>NO</u>)	(<u>YES</u>)
TRACK	(<u>NO</u>)	(<u>YES</u>)
PROPER TIMING	(<u>NO</u>)	(<u>YES</u>)
PROPER TURN RATE	(<u>NO</u>)	(<u>YES</u>)
ALTITUDE	-100 -50 0 +50 +100	
AIRSPEED	-10 -5 0 +5 +10	
COMPLIANCE WITH ALL ATC INSTRUCTIONS	(<u>NO</u>)	(<u>YES</u>)

PROCEDURE TURN (VOR)

PROPER ENTRY (NO) (YES)

TRACK (NO) (YES)

PROPER TIMING (NO) (YES)

ALTITUDE -100 -50 0 +50 +100

AIRSPEED -10 -5 0 +5 +10

COMPLIANCE WITH ALL
ATC INSTRUCTIONS (NO) (YES)

PROCEDURE TURN (ADF)

PROPER ENTRY	(<u>NO</u>)	(<u>YES</u>)
--------------	---------------	----------------

TRACK	(<u>NO</u>)	(<u>YES</u>)
-------	---------------	----------------

PROPER TIMING	(<u>NO</u>)	(<u>YES</u>)
---------------	---------------	----------------

ALTITUDE	-100	-50	0	+50	+100
----------	------	-----	---	-----	------

AIRSPEED	-10	-5	0	+5	+10
----------	-----	----	---	----	-----

COMPLIANCE WITH ALL ATC INSTRUCTIONS	(<u>NO</u>)	(<u>YES</u>)
---	---------------	----------------

VOR ENROUTE NAVIGATION

TRACK INTERCEPT

STATION TUNED/IDENTIFIED (NO) (YES)

PROPER INTERCEPT ANGLE (+ 5°) (NO) (YES)

DESIRED RADIAL SELECTED (NO) (YES)

INTERCEPT HEADING -10 -5 0 +5 +10

CENTERED CDI NEEDLE (+ 1 Dot) (NO) (YES)

COURSE HEADING -10 -5 0 +5 +10

ALTITUDE -100 -50 0 +50 +100

TRACK INBOUND

CENTERED CDI NEEDLE ("TO") (+ 1 Dot) (NO) (YES)

ALTITUDE -100 -50 0 +50 +100

AIRSPEED -10 -5 0 +5 +10

RECOGNIZE STATION PASSAGE (NO) (YES)

TRACK OUTBOUND

CENTERED CDI NEEDLE ("FROM") (+ 1 Dot) (NO) (YES)

ALTITUDE -100 -50 0 +50 +100

AIRSPEED -10 -5 0 +5 +10

ADF ENROUTE NAVIGATION

INTERCEPT BEARING

STATION TUNED/IDENTIFIED (NO) (YES)

TRACK BEARING (+ 5°) (NO) (YES)

ALTITUDE -100 -50 0 +50 +100

AIRSPEED -10 -5 0 +5 +10

TRACK INBOUND BEARING

TRACK BEARING (+ 5°) (NO) (YES)

ALTITUDE -100 -50 0 +50 +100

AIRSPEED -10 -5 0 +5 +10

RECOGNIZE STATION PASSAGE (NO) (YES)

TRACK OUTBOUND BEARING

TRACK BEARING (+ 5°) (NO) (YES)

ALTITUDE -100 -50 0 +50 +100

AIRSPEED -10 -5 0 +5 +10

RNAV ENROUTE NAVIGATION (WITH COURSE LINE COMPUTER)

DIRECT COURSE

PROPER WAYPOINTS SELECTED (NO) (YES)

PROPER WAYPOINTS ENTRY (NO) (YES)

COURSE TRACK (+ 5°) (NO) (YES)

ALTITUDE -100 -50 0 +50 +100

AIRSPEED -10 -5 0 +5 +10

PARALLEL TRACK

PROPER WAYPOINTS SELECTED (NO) (YES)

PROPER WAYPOINT ENTRY (NO) (YES)

COURSE TRACK (+ 5°) (NO) (YES)

ALTITUDE -100 -50 0 +50 +100

AIRSPEED -10 -5 0 +5 +10

NDB APPROACH/MISSED APPROACH

STATION TUNED, IDENTIFIED	(<u>NO</u>)	(<u>YES</u>)
---------------------------	---------------	----------------

COURSE INTERCEPTED (+ 10°)	(<u>NO</u>)	(<u>YES</u>)
----------------------------	---------------	----------------

ROLLED OUT ON COURSE (+5°)	(<u>NO</u>)	(<u>YES</u>)
----------------------------	---------------	----------------

PROPER TRACK (+5°)	(<u>NO</u>)	(<u>YES</u>)
--------------------	---------------	----------------

MDA (+100 FT)	(<u>NO</u>)	(<u>YES</u>)
---------------	---------------	----------------

AIRSPED	-10	-5	0	+5	+10
---------	-----	----	---	----	-----

MISSED APPROACH

TIMELY COMPLIANCE WITH ALL ORGANIZATIONS	(<u>NO</u>)	(<u>YES</u>)
---	---------------	----------------

REPORT	(<u>NO</u>)	(<u>YES</u>)
--------	---------------	----------------

AIRCRAFT CONTROL	(<u>NO</u>)	(<u>YES</u>)
------------------	---------------	----------------

COMPLIANCE WITH ALL ATC INSTRUCTIONS	(<u>NO</u>)	(<u>YES</u>)
---	---------------	----------------

ILS APPROACH/MISSED APPROACH

TRACK TO OM

STATION TUNED, IDENTIFIED (NO) (YES)

COURSE INTERCEPTED (NO) (YES)

ROLLED OUT ON COURSE (+5°) (NO) (YES)

PROPER TRACK (+ 1 Dot) (NO) (YES)

ALTITUDE

-100	-50	0	+50	+100
------	-----	---	-----	------

GLIDESLOPE INTERCEPTED (+1 Dot) (NO) (YES)

APPROACH

ALTITUDE

-100	-50	0	+50	+100
------	-----	---	-----	------

REPORT (NO) (YES)

AIRSPEED

-10	-5	0	+5	+10
-----	----	---	----	-----

COURSE TRACKING (+2°) (NO) (YES)

GLIDE SLOPE (+1 Dot) (NO) (YES)

PROPER TIME (NO) (YES)

ALTITUDE-DH (+100 FT) (NO) (YES)

MISSED APPROACH

TIMELY COMPLIANCE WITH ALL PROCEDURES (NO) (YES)

REPORT (NO) (YES)

AIRCRAFT CONTROL (NO) (YES)

COMPLIANCE WITH ALL ATC INSTRUCTIONS

(NO) (YES)

LOC APPROACH/MISSED APPROACH

TRACK TO OM

STATION TUNED, IDENTIFIED (NO) (YES)

COURSE INTERCEPTED (NO) (YES)

ROLLED OUT ON COURSE (+5°) (NO) (YES)

PROPER TRACK (+ 1 Dot) (NO) (YES)

ALTITUDE

-100	-50	0	+50	+100
------	-----	---	-----	------

RECOGNIZE OM PASSAGE (NO) (YES)

APPROACH

START DESCENT (NO) (YES)

VERTICAL SPEED (FPM)

-100	-50	0	+50	+100
------	-----	---	-----	------

REPORT (NO) (YES)

AIRSPEED

-10	-5	0	+5	+10
-----	----	---	----	-----

COURSE TRACKING (+ 1 Dot) (NO) (YES)

PROPER TIME (NO) (YES)

ALTITUDE-MDA(+100 FT) (NO) (YES)

MISSED APPROACH

TIMELY COMPLIANCE WITH ALL PROCEDURES (NO) (YES)

REPORT (NO) (YES)

AIRCRAFT CONTROL (NO) (YES)

COMPLIANCE WITH ALL ATC INSTRUCTIONS (NO) (YES)

VOR/DME APPROACH/MISSED APPROACH

ORIENTATION

VOR STATION TUNED,
IDENTIFIED (NO) (YES)

DME STATION TUNED,
IDENTIFIED (NO) (YES)

CDI NEEDLE CENTERED (NO) (YES)

ASSIGNED ALTITUDE -100 -50 0 +50 +100

ASSIGNED HEADING -10 -5 0 +5 +10

APPROACH

ROLLED OUT ON COURSE (+5°) (NO) (YES)

KNOWS DISTANCE FROM STATION (NO) (YES)

TRACK (+ 1 Dot) (NO) (YES)

MDA (+100 FT) (NO) (YES)

AIRSPEED -10 -5 0 +5 +10

MISSED APPROACH

TIMELY COMPLIANCE
WITH ALL PROCEDURES (NO) (YES)

REPORT (NO) (YES)

AIRCRAFT CONTROL (NO) (YES)

COMPLIANCE WITH ALL
ATC INSTRUCTIONS (NO) (YES)

RNAV APPROACH

ORIENTATION

VOR STATION TUNED,
IDENTIFIED (NO) (YES)

DME STATION TUNED,
IDENTIFIED (NO) (YES)

CDI NEEDLE CENTERED (NO) (YES)

ASSIGNED ALTITUDE -100 -50 0 +50 +100

ASSIGNED HEADING -10 -5 0 +5 +10

APPROACH

ROLLED OUT ON COURSE (+5°) (NO) (YES)

KNOWS DISTANCE FROM STATION (NO) (YES)

TRACK (+ 1 Dot) (NO) (YES)

MDA (+100 FT) (NO) (YES)

AIRSPEED -10 -5 0 +5 +10

MISSED APPROACH

TIMELY COMPLIANCE
WITH ALL PROCEDURES (NO) (YES)

REPORT (NO) (YES)

AIRCRAFT CONTROL (NO) (YES)

COMPLIANCE WITH ALL
ATC INSTRUCTIONS (NO) (YES)

PAR APPROACH/MISSED APPROACH

TRACKING TO OM

STATION TUNED,
IDENTIFIED (NO) (YES)

COURSE INTERCEPTED (NO) (YES)

ROLL OUT ON COURSE (+5°) (NO) (YES)

PROPER TRACK (NO) (YES)

ALTITUDE -100 -50 0 +50 +100

GLIDESLOPE INTERCEPTED
(+ 1 Dot) (NO) (YES)

APPROACH

ALTITUDE -100 -50 0 +50 +100

REPORT (NO) (YES)

AIRSPEED -10 -5 0 +5 +10

COURSE TRACKING (+1 Dot) (NO) (YES)

GLIDE SLOPE (+1 Dot) (NO) (YES)

PROPER TIME (NO) (YES)

ALTITUDE-DH (+100 FT) (NO) (YES)

MISSED APPROACH

TIMELY COMPLIANCE
WITH ALL PROCEDURES (NO) (YES)

REPORT (NO) (YES)

AIRCRAFT CONTROL (NO) (YES)

COMPLIANCE WITH
ALL ATC INSTRUCTIONS (NO) (YES)

ENERGY EFFICIENT CLIMB/DESCENT (RNAV)

INITIATE

PROPER WAYPOINT SELECTED (NO) (YES)

PROPER WAYPOINT ENTRY (NO) (YES)

CLIMB/DESCENT

HEADING -10 -5 0 +5 +10

PROPER CLIMB RATE (+50FPM) (NO) (YES)

AIRSPEED -10 -5 0 +5 +10

LEVEL OFF

LEVELOFF ALTITUDE -100 -50 0 +50 +100

HEADING -10 -5 0 +5 +10

COMPLIANCE WITH
ATC INSTRUCTIONS (NO) (YES)

APPENDIX G

DESCRIPTION OF A SCENARIO FOR AN OPERATIONS-ORIENTED PROFICIENCY CHECK

The scenario depicted in this appendix is an adaptation of a flight mission described in Appendix D. The origin for the flight is Teterboro, New Jersey and the destination is Punxsutawney, Pennsylvania. Teterboro is a satellite airport in the New York City hub area. It is a controlled field with several instrument approaches, full ATC services and a flight service station on the field. Punxsutawney is an uncontrolled field with no instrument approach facilities and no ground based navigational aids on or near the field. The scenario was written for a twin-engine/piston-powered aircraft.

In the scenario, adverse weather prevents the approach and landing at Punxsutawney, so the probable response of the pilot is to continue on to DuBois, the alternate airport listed on the flight plan. During the diversion and approach to DuBois, the weather degrades to the extent that a missed approach is required. At this point, the pilot will be required to select another alternate. If the pilot chooses an alternate other than Pittsburgh, he will be informed through the simulation of ATC communication that Pittsburgh is the closest airport that is open. The pilot will then be given vectors to intercept V226 to Pittsburgh.

Once the aircraft has intercepted the radial, a rough running engine accompanied by very low oil pressure and high cylinder head temperature indications will be introduced. The probable response for the pilot will be to shut down the engine and declare an emergency. The aircraft will then be given vectors for an ILS approach to runway 28R at Pittsburgh. The scenario ends when the pilot lands at Pittsburgh.

The scenario is presented in this appendix in a script format similar to the type used by some airlines to guide the conduct of Line Oriented Flight Training sessions. Detailed discussion of the script format can be found in Lauber and Foushee (1981a). In brief, the scenario script provides the evaluator/simulator operator with (1) key communication information (e.g., radio frequencies, clearances), (2) weather conditions (for configuring the simulator and communications with the pilot), (3) problem descriptions, and (4) the probable response of the pilot.

ORIGIN Teterboro, NJ

DESTINATION Punxsutawney, PA

TIME COUNT	ATC COMMUNICATIONS TO PILOT	WEATHER	SEGMENT	PROBLEM INPUT	PROBLEM INDICATION	PROBABLE RESPONSE
2105	121.9: CLRD to N35 as filed. Clinton 8 DEP. V30 to PSB. Direct to N35. Expect 12000 10 min. after DEP.	15 OVC 2F 68/62 0308 999	Preflight			
	121.9: CLRD to RW 01. Contact DEP 119.2		Taxi			
	119.2: Proceed via Clinton 8. Climb and maintain 12000. Contact NY Center on 132.5		Climb			
	132.5: Contact Cleveland Center on 133.4		Cruise			

TIME COUNT	ATC COMMUNICATIONS TO PILOT	ORIGIN <u>Teterboro</u>		DESTINATION <u>Diversion to DUJ</u>		
		WEATHER	SEGMENT	PROBLEM INPUT	PROBLEM INDICATION	PROBABLE RESPONSE
	133.4: Descend and maintain 6000. DUJ is reporting 300', OVC, visibility 1 mile in LF, winds are variable and light		Descent	Wx prevents deviation off airway for landing at N35 (low ceiling, does not permit non-precision approach)	ATC communication	Proceed direct to DUJ where precision approach is available
	133.4: Contact DUJ on 123.6					
	123.6: CLRD ILS RW 25 approach	200, OVC	Approach DUJ	Wx prevents landing at DUJ	Visual contact not made (if pilot attempts to land again, DUJ radio will report Wx below minimums)	Execute missed approach Select alternate airport

TIME COUNT	ATC COMMUNICATIONS TO PILOT	ORIGIN <u>Teterboro</u>		DESTINATION <u>Diversion to PIT</u>		
		WEATHER	SEGMENT	PROBLEM INPUT	PROBLEM INDICATION	PROBABLE RESPONSE
	123.6: Understand you wish to divert to PIT. Follow DUJ missed approach. Contact Cleveland Center on 133.4. (If the pilot chooses any other airport besides PIT, he will be told PIT is the only airport that is open).		Missed approach			
	133.4: Turn left hdg 280. Intercept V226.		Climb			

TIME COUNT	ATC COMMUNICATIONS TO PILOT	ORIGIN <u>Teterboro</u>		DESTINATION <u>PIT</u>		PROBABLE RESPONSE
		WEATHER	SEGMENT	PROBLEM INPUT	PROBLEM INDICATION	
	133.4: Proceed direct to PIT. Maintain 6000. Con- tact PIT APP on 127.65.		Cruise (Inter- ception of V226)	Rapid loss of oil pressure	Rough running engine, oil pressure indica- tion descending to zero, high cylinder head temp. Engine will fall if not feathered.	Perform rough running engine checklist, diagnose loss of oil pressure, shut down engine, declare emergency
	127.65: CLRD ILS RW 28R APP. Descend and maintain 4000		Descent			
	127.65: Turn right, hdg 280. Contact tower on 119.3		Approach			
	119.3: CLRD to land	400, OVC, IF	Landing			