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HUMAN FACTORS PROBLEMS
IN
GENERAL AVIATION

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16. Abstract

Approximately 80% of general aviation accidents in the past decade have been attributed to errors made by pilots. For this reason, the most promising approach to making substantial improvements in general aviation safety is through the systematic study of factors affecting the performance of general aviation pilots (i.e., human factors) and use of the resultant information to enhance pilot performance. In recognition of the need for comprehensive information to aid in the planning of such studies, the major objective of the work reported here was to identify and analyze human factors design issues related to the major performance problems of general aviation pilots. Thirty-five such issues were identified, primarily through the review of the human factors, aircraft accident, and general aviation literature. The analysis and discussion of these issues was structured through the use of a conceptual model of the components of the general aviation system. Six such components were identified--(1) aircraft, (2) airports, (3) aeronautical information systems, (4) the pilot certification and rating structure, (5) training and proficiency assessments for certificates and ratings, and (6) continuation training and recurrent proficiency assessments.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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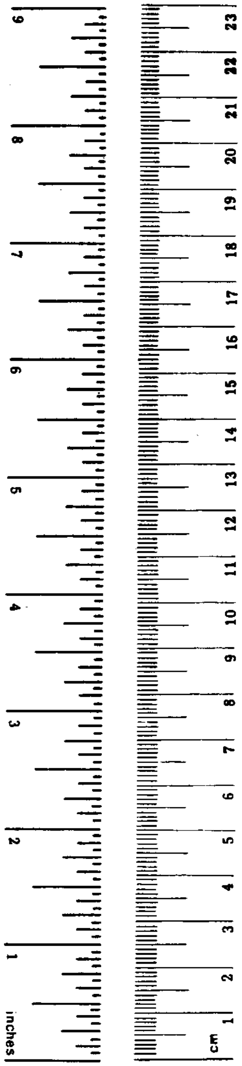
*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
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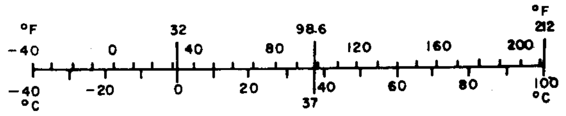

EXECUTIVE SUMMARY

Approximately 80% of general aviation accidents in the past decade have been attributed to errors made by pilots. For this reason, the most promising approach to making substantial improvements in general aviation safety is through the study of factors affecting the performance of general aviation pilots (i.e., human factors) and use of the resultant information to enhance pilot performance. In recognition of the need for such studies, the Office of Systems Engineering and Management of the Federal Aviation Administration (FAA) and the FAA Technical Center have begun a systematic program of research on human factors in general aviation. This program has two parts--(1) a systematic review of human factors problems in general aviation, and (2) the subsequent conduct of a series of human factors research activities aimed at the development of direct solutions to the most critical problems. This report presents the findings of the first of these activities.

OBJECTIVES.

The objectives of the present effort were:

- to identify major problems affecting the performance of general aviation pilots,
- to determine the types of human factors data required to identify and support actions to solve such problems, and
- to analyze the implications of these requirements for planning and managing future human factors research activities in support of general aviation.

APPROACH.

To accomplish these objectives, a wide variety of documental information was collected concerning the performance problems of general aviation pilots, and, when relevant, pilots in general. This information was acquired through the use of both automated and manual searches of a broad range of sources, including the scientific and engineering research literature, regulatory reports of various government agencies, and aviation publications. In addition, personnel in various private and government organizations involved with general aviation and aviation safety were interviewed to provide an overall perspective for organizing the information derived from the published sources, as well as to identify problems that might not have been adequately addressed in the literature.

The analysis of this information was structured through the use of a conceptual model of the complex of factors affecting pilot performance in general aviation. The central premise of this model is that pilot performance problems result from incongruities between task or performance demands made on the pilot and his physical, physiological, and psychological capabilities to meet those demands. Thus, individual actions that can be taken to reduce pilot performance problems must increase pilot capabilities and/or reduce task demands. The identification, management, and modification of those factors that affect task demands and/or pilots capabilities is the key to improved safety. Such factors that affect task demands and pilot capabilities are referred to as system components in this model.

In the development of the model, six such components were identified. Three of these interact to influence task demands, while the other three interact to influence pilot capabilities. Those components that influence task demands are (examples of aspects of the components that influence pilot performance are included in parentheses after each component):

(1) aircraft (e.g., controls and displays, handling characteristics, extracockpit visibility, environmental support);

(2) airports (e.g., runways and approach aids); and

(3) aeronautical information systems (e.g., documental information concerning operation of the aircraft and use of the National Airspace System, as well as real time communications with air traffic service facilities).

The components that influence pilot capabilities are:

(1) the pilot certification and rating structure (e.g., entry level requirements and task subsets for certificates and ratings);

(2) training and proficiency assessments for pilot certificates and ratings (e.g., training requirements, training methodologies, design of training devices, certificated flight instructors, and proficiency tests); and

(3) continuation training and recurrent proficiency assessments (e.g., continuation training requirements and methods, and the structure of proficiency reviews).

In application of this model, the key to the solution of pilot performance problems lies in the design of each of these components. That is, each component must be designed so as to interact with other components to attain or maintain congruency between task demands and pilot capabilities. Because of the diverse nature of general aviation, however, each of these components typically is designed by different personnel working independently of one another. Since there is not a single system designer responsible for integrating all the components, each of these independent component designers has the responsibility, wittingly or unwittingly, for selecting from among the design alternatives pertinent to his component, and, as a consequence, for aiding or hindering the achievement of the overall system goal of harmony between task demands and pilot capabilities.

Such determinations require that these component design personnel have information about system interrelationships and the effects of design alternatives on pilot performance. When such information is incomplete or absent, a human factors design issue exists and research is needed to generate the needed data required to support design decisions. Thus, the human factors design issues serve as the basic units for describing research needs. Some 35 such issues were identified in the present study through analysis of the documental and interview information collected.

HUMAN FACTORS DESIGN ISSUES.

The human factors design issues that were identified are listed below and are discussed in detail in Chapters II through VII. (The number beside each issue corresponds to its position in the sequence of issues in those chapters.)

1. Identification of Requirements for Human Factors Engineering Standards and Guidance for Aircraft Controls and Displays

2. Development of Objective Assessment Methods for Aircraft Handling Qualities

3. Identification of Requirements for Extracockpit Visibility Criteria and Guidelines

4. Identification of Requirements for Human Factors Guidelines and Standards Concerning Intracockpit Noise and Vibration

5. Identification of Requirements for Integrated Flight Management Systems

6. Generation of Runway Surface, Marking, and Lighting Requirements

7. Identification of Requirements for Airport Approach Aids

8. Identification of Requirements for Normal and Emergency Aircraft Operating Procedures

9. Determination of Information Dissemination Methods for Aircraft and Subsystem Operating Procedures

10. Determination of Requirements for Aircraft and Subsystem Performance Data

11. Specification of Formats for Presentation of Aircraft and Subsystem Performance Data

12. Assessment of Impact of Different Airspace Assignments on Pilot Performance

13. Identification of Requirements for Modification of Minimum Visibility and Cloud Clearance Standards for VFR Flight

14. Development of Guidance for the Design of Instrument Flight Procedures

15. Identification of Requirements for Communications Between General Aviation Pilots and Air Traffic Control Personnel

16. Identification of Requirements for Communications Between General Aviation Pilots and Flight Service Personnel

17. Determination of Flight Experience Requirements for Certificates and Ratings

18. Determination of Medical/Psychophysiological Requirements for Certificates and Ratings

19. Identification of Task Subsets for Current Certificates and Ratings

20. Identification of Needs for New Certificates

21. Identification of Needs for New Ratings

22. Identification of Training Requirements for Certificates and Ratings

23. Determination of Training Techniques for Use in the Aircraft

24. Determination of Training Methods for Use in Pilot Training Devices

25. Determination of Training Device Fidelity Requirements

26. Design of Instructional Support Features for Pilot Training Devices

27. Determination of Instructor Training Requirements

28. Development of Guidance for Recurrent Instructor Training

29. Development of Guidance for the Modification of Written Proficiency Tests

30. Development of Objective Flight Checks

31. Identification of Techniques for Using Alternative Test Media

32. Determination of Requirements for Continuation Training

33. Identification of Methods for Encouraging Continuation Training

34. Determination of Requirements for the Recurrent Assessment of Pilot Proficiency

35. Determination of Guidance for Structuring the BFR

While all of these 35 issues were deemed to be important, they were grouped into these categories with respect to their relative research priorities to aid research managers in the use of the results of this effort. The procedures and criteria employed to make this judgement are described in Chapter I, and the category to which each issue was assigned is listed in Appendix C. The nine issues assigned to the category with the highest priority were 1, 5, 15, 19, 22, 27, 32, 34, and 35.

CONCLUSIONS AND RECOMMENDATIONS.

Great strides have been made in general aviation safety in spite of increases in its size and the complexity of its equipment and operations. Thus, the fact that the emphasis in this report has been on pilot performance problems should not obscure the achievements and progress that have been made. The 35 issues that have been identified, however, indicate that there is much yet to be done to alleviate pilot performance problems. As noted previously, research programs to settle these various issues may differ in terms of their priorities, but all are important to an effective general aviation system.

Finally, the conceptual model developed during this study and the 35 issues that were identified represent an initial attempt to develop the use of the systems approach as an organizing framework for planning human factors research and for determining how to implement the results of such research in the general aviation context. Full development of such an approach, however, will require the establishment of a human factors research management system. Therefore, it is recommended that research be conducted that would define the functional requirements for such a system.

PREFACE

That portion of the aviation community referred to as "general aviation" is an important and growing segment of aviation. General aviation, which includes all civil aviation except for air carriers, involves over 190,000 aircraft of varying types and approximately 800,000 persons who hold pilot certificates. Not only is it the largest segment of civil aviation, it is a segment that is becoming increasingly vital to the business community as well as to society in general.

General aviation is undergoing significant changes, and clearly it faces a number of significant challenges in the 1980s and 1990s. Some of these changes are technological--e.g., the advent of the computer into the cockpit--while others relate to patterns of aircraft usage--e.g., the increasing market for business jet and turboprop aircraft. Perhaps the most critical area of change--and challenge--is that relating to the availability and cost of aircraft fuels. All of these changes, as well as many others, present significant challenges to general aviation, indeed to all of aviation, in the immediate future.

There are, however, other types of challenges that general aviation must meet in order to play its role in American commerce and society in the most beneficial fashion. One such challenge, in fact a pervasive concern, is that of enhancing flight safety. Safety drives the engineering design activities of the manufacturers of aircraft and associated systems, as well as the activities of the weekend pleasure pilot. Safety is also the major concern of the Federal Aviation Administration (FAA), the agency responsible for the regulation of the civil aviation system.

There are many factors that influence the safety of general aviation. Aircraft and aircraft system manufacturers have produced equipment for general aviation that is highly reliable, and they are constantly seeking to improve their products. But, reliable equipment must be operated by pilots who can perform the tasks required for them if the overall system of man and aircraft is to function safely and effectively. It is in this area of human performance enhancement that one of the major challenges for general aviation lies.

In recognition of the criticality of pilot performance factors to general aviation, the Office of Systems Engineering and Management of the FAA and the FAA Technical Center have initiated a program of human factors research in general aviation. The goals of the program relate to enhancing pilot performance, improving the compatibility of the pilot and the equipment and system with which he interacts, increasing the overall effectiveness with which general aviation fulfills its various roles, and, as a consequence, increasing safety in general aviation operations.

The present report presents results of one aspect of that program, specifically, a systematic review of human factors problems in general aviation. The objective was to conduct a comprehensive review of the scientific, technical, and other literature relevant to such problems. The review focused on those items relevant to pilot performance problems in general aviation, particularly as they relate to flight safety concerns, and identified human factors research issues underlying such problems and assigned research priorities to them. The identification and prioritization of such issues can serve as one input into determination of subsequent general aviation human factors research activities to be conducted by the FAA.

The present effort was carried out by the Seville Research Corporation under subcontract to Embry-Riddle Aeronautical University (E-RAU). The efforts of E-RAU were conducted under prime contract DOT-FA79NA-6040. Mr. Douglas Harvey is the Contracting Officer's Technical Representative for the FAA Technical Center. The present effort is Task No. 1 of several tasks projected under the prime contract. A second task, currently underway, involves an experimental investigation of the current 200-hour experience requirement for the FAA instrument rating. Task No. 2 is being conducted jointly by E-RAU and Seville personnel.

The work reported here was conducted by a team of Seville personnel under the direction of Dr. Jack B. Shelnutt. The literature review and interviews were conducted principally by Dr. Shelnutt and Dr. Jerry M. Childs, with additional assistance provided by Dr. William D. Spears. The overall effort was conducted under the cognizance of Dr. Wallace W. Prophet, Program Manager for Seville. Able assistance to the effort was provided by personnel of the E-RAU Library. Mr. Julius H. Gandelman was Principal Investigator for E-RAU.

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I. INTRODUCTION

General aviation currently fulfills a variety of important roles in American society. It provides public, business, and personal transportation for many persons, as well as providing a means of satisfying numerous other industrial, public service, agricultural, and commercial needs. Its services vary from emergency medical evacuation to aerial survey of wildlife populations. In meeting these needs, general aviation also furnishes jobs to a large number of citizens and provides opportunities for investment in aviation and aviation-related industries. Finally, it provides pleasure and recreation to numerous private citizens who simply like to fly.

General aviation's past growth has been steady and substantial, and it is expected that it will continue to expand its role in future years, thus increasing the already substantial social and economic benefits it provides. It should be noted, though, that general aviation faces problems that must be solved if it is to continue to grow and provide increased benefits over the last two decades of the century. Such problems include fuel availability, rising capital and operating costs, environmental concerns, and a variety of others. However, paramount among general aviation's problems is the matter of flight safety. Stated succinctly, general aviation must meet the challenge of reducing its accident rate significantly if it is to realize its full potential in years to come.

Many individuals, both inside and outside of general aviation, believe the present accident rate is one of general aviation's major problems, one that threatens its acceptance, support, and use by the public. A number of persons have written persuasively on this subject; e.g., see Collins (1980), Rudolph (1974), Silver (1976), Connor and Hamilton (1979), and McCourt and Hewin (1979). Such writings illustrate the substantial demand that exists for actions that will improve the safety of general aviation without reducing the benefits that can be derived from it. The present report represents a systematic attempt to examine this problem from a particular perspective, that of the discipline of human factors, in order to identify appropriate approaches to solutions.

In excess of 80 percent of general aviation accidents in the past decade have been attributed to errors made by pilots. For this reason, perhaps the most promising approach to making substantial improvements in general aviation safety will be through the study of factors affecting the performance of general aviation pilots (i.e., human factors) and through use of the resultant information to devise actions to enhance pilot performance. There are, however, several complicating concerns in such study. First, the study of human factors in general aviation is complicated by the large number of variables that can affect pilot performance. Not only is the number of variables large, they are related in complex ways such that their effects cannot be studied in isolation. Moreover, the extent to which human factors studies can be conducted is necessarily restricted by the expense of performing aviation research and the practical limitations on research funds. Priorities, therefore, must be established. For human factors studies to be efficient, research topics must be addressed on a programmatic basis that systematically focuses investigations on the most critical needs for human factors data.

In recognition of this need, the Office of Systems Engineering and Management of the Federal Aviation Administration (FAA) and the FAA Technical Center have initiated a systematic integrated program of research on human factors in general aviation. This program has two parts: (1) a systematic review of human factors problems in general aviation, including a determination of what is presently known about their nature and an assessment of their relative magnitude and criticality; and (2) subsequent conduct of a coordinated series of human factors research activities aimed at the development of direct solutions to those problems and development of the data base underlying the solutions. The present report presents the results of the first of these activities, a systematic survey of the research and technical literature relevant to identification and assessment of human factors problems in general aviation.

OBJECTIVES.

In seeking to review the body of literature and other information that would allow the identification and description of human factors problems in general aviation, a relatively broad conception of human factors problems has been utilized. Specifically, in order that the survey have the greatest probability of detecting all significant human factors problems, particularly those related to flight safety, the effort has sought to access any information relating to "pilot performance problems." Whether or not a pilot performance problem was formally identified in a source document as a "human factors" problem, it was felt that the fact of the problem's having been categorized as dealing with pilot performance made it an appropriate object of this search.[1] With this orientation in mind, the objectives of the present effort were:

- to identify major problems affecting the performance of general aviation pilots,
- to determine the types of human factors data required to identify and support actions to solve such problems, and
- to analyze the implications of these requirements for planning and managing future human factors research activities in support of general aviation.

The approach followed in this effort to achieve these objectives is described in greater detail in the last section of this chapter. Generally, it consisted of: (a) the acquisition and review of a wide variety of documentary and interview information concerning general aviation pilot performance problems; (b) development of a system-design, action-oriented human factors conceptual structure for organizing that information; (c) systematic review and analysis of the information base with reference to that structure; (d) identification of pilot performance problems and system design issues; and (e) assessments of priorities to provide a basis for future research management.

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[1] There are additional aspects of pilot performance and safety that may be of concern for human factors research and that are not treated here--e.g., crash survivability considerations in the design of aircraft, and the efficiency of pilot performance with respect to the accomplishment of mission goals. Similarly, individuals such as air traffic controllers and maintenance personnel influence general aviation safety, and their performance should also be the subject of human factors investigations. The goal of the present study, however, was to focus on factors affecting the effectiveness of pilot performance.

BACKGROUND.

Two basic considerations governed the approach taken in this study. They will be discussed briefly in order to provide the reader with appropriate background for understanding the approach. These considerations deal with: (1) the diversity of general aviation in terms of its missions, its pilots, the aircraft of concern, and the various organizations that play a significant role in general aviation; and (2) the nature of pilot performance problems and their relationship to the human factors discipline and to system design solutions.

GENERAL AVIATION DIVERSITY. General aviation has no legal definition, but the term is commonly used in reference to all civil aviation except air carriers (Smith, 1977). This comprises a rather substantial segment of the aviation community; it includes (1) a wide variety of different aviation missions, (2) almost 200,000 aircraft of greatly different size, cost and sophistication, (3) approximately 800,000 pilots with varying skills and motivations, and (4) a number of different government agencies and private organizations involved in the design of general aviation aircraft, the training of pilots, and other related activities. This varied composition complicates the study of human factors in general aviation and must be considered in the planning of research to identify and solve pilot performance problems.

General Aviation Missions. The missions of general aviation may be classified as shown in Table 1. These missions, when considered along with the other factors, determine performance requirements for aircraft and pilots. For example, transportation missions require mostly point-to-point navigation, while agricultural missions frequently entail extensive maneuvering with respect to terrain and selected points on the ground. Effective performance of these diverse tasks requires different pilot and aircraft capabilities. Thus, the categories in Table 1 represent not only the diversity of general aviation missions, but also the variations in requirements for aircraft and pilots associated with them.

TABLE 1.--CATEGORIES OF GENERAL AVIATION.

Transportation

- Public
- Business
- Personal

Special Applications

- Industry
- Agriculture
- Security/Emergency Services
- Recreation/Sport
- Instruction

The first major category, Transportation, includes travel for public, business, and personal reasons. Public transportation, furnished by both commuter airlines[1] and air taxi operations, represents a major segment of general aviation. Commuter airlines are small, regularly scheduled airlines that are employed for travel among (1) small communities not serviced by air carriers, (2) small and large communities for the purpose of connecting with air carriers, and (3) large communities to supplement air carrier service. Air taxi operations fill the gaps left by all scheduled services by offering flexible, on-demand charter services to every airport in the country. While there is a tendency to think of the major air carriers as servicing most of our cities, it is estimated that approximately 98.9 percent of the communities in the United States are dependent solely on general aviation for air access (Smith, 1977). Indeed, general aviation is the only form of public carrier transportation for some small communities.

General aviation increasingly provides a means for business and personal travel. Private business travel is accomplished in aircraft owned, leased, or rented by corporations and other businesses who employ their own pilots; by individual businessmen and professionals who serve as their own pilots; and by local, state or federal nonmilitary government agencies who employ their own pilots. Private travel is also accomplished in aircraft owned, leased or rented by numerous individual pilots for their own personal purposes. The volume of general aviation operations for personal travel has been decreasing, however, due to national economic trends and energy problems. As a result, most current general aviation travel is for business purposes (Fink, 1980).

The second major category in Table 1, Special Applications, includes general aviation activities in support of industry, agriculture, security and emergency services, recreation and sport, and flight instruction. In industry, many advanced industrial technologies and commercial practices have been enabled or facilitated through the use of general aviation aircraft. Such applications of general aviation include aircraft use in construction, geological exploration, surveying, aerial photography and mapping, pipeline and powerline patrol, off-shore oil operations support, advertising, flight testing, and fish spotting. In agriculture, the implementation of many modern agricultural techniques depends on the unique capabilities provided by general aviation aircraft. Examples include use of aircraft for, or in support of, aerial seeding, spraying, and dusting of crops; monitoring the growth and assisting in the harvesting of certain crops; managing livestock and wildlife; modifying the weather to aid in crop growth; and conducting ecological research.

A number of security and emergency services also use general aviation in the performance of their missions. Many law enforcement agencies regularly employ aircraft, particularly helicopters, for crime prevention and control as well as for traffic regulation and safety purposes. Aircraft also serve firefighting, search and rescue, emergency medical transportation, and other public health and safety needs. Their role is especially important during disasters where the capability for rapid action is essential.

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[1] Due to their recent growth, and to other economic and regulatory factors, commuter airlines are sometimes no longer included as part of general aviation in civil aviation classification systems. They are included here, however, because their human factors problems, and their resources for addressing those problems, are similar to those of other general aviation segments.

In addition to their use for industrial, agricultural, and public service missions, general aviation aircraft are employed by a large number of private individuals who fly for recreation and sport. Flying itself may be the desired activity, as in aerobatics or racing, or use of the aircraft may be to enable or facilitate the conduct of other activities, such as skydiving, sight-seeing, or hunting.

Finally, general aviation aircraft are employed to train pilots who may, in turn, fly general aviation, commercial, and even military aircraft. This use has long represented the largest special application of general aviation aircraft (Aviation Advisory Commission, 1972), though the relative balance is changing as other special applications increase in frequency. Aircraft are used for dual instruction, supervised solo training flights, and flight checks by pilots training for different pilot certificates or ratings. Additionally, pilots fly general aviation aircraft periodically to maintain proficiency in skills not normally performed on routine missions.

While the preceding review of uses of general aviation is not exhaustive, it illustrates the wide variety of missions flown by general aviation pilots and, thus, the wide variety of contexts for the occurrence of different pilot performance problems.[1] As will be discussed later, the necessary first step in the solution of many of these problems lies in the analysis of the missions and the contexts in which they occur.

General Aviation Aircraft. Because of the diversity of its missions, a number of different airframes, powerplants, and avionic systems are employed in general aviation. Table 2 shows the different types of airplanes, along with estimates of the total numbers of each type active in 1979. The aircraft represented in this list cover a broad range of aircraft procurement costs, sizes, performance capabilities, handling qualities, and operational complexities. The diversity among general aviation aircraft is considerable, both across and within these various dimensions.[2]

TABLE 2.--NUMBER OF ACTIVE GENERAL AVIATION AIRCRAFT.
(1979 estimate, in thousands)[a]

Piston						
Single Engine	Multi Engine	Turboprop	Turbojet	Rotorcraft	Other	TOTAL
155.2	23.0	3.3	2.6	5.1	3.8	193

[a] FAA Aviation Forecasts, Fiscal Years 1980-1991 (FAA, 1979d).

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[1] Comprehensive reviews of the uses of general aviation that can be consulted for further reference include AOPA (1968), Aviation Advisory Commission (1972), Helms (1975), Henry and Froehlich (1975), Kitely (1976), LaFoy (1977), Sincoff and Dajani (1975), and Smith (1977). Additionally, data describing the extent of the different uses can be found in the FAA Statistical Handbook of Aviation, which is published annually.

[2] Additional information concerning the composition and utilization of the general aviation fleet can be found in Smith (1977), Schwenk (1979), and the FAA Statistical Handbook of Aviation.

The diversity of the various types of general aviation aircraft is further increased by the large number of different systems with which they can be equipped to facilitate navigation, communication, and operation of the aircraft. These systems, some of which are described in Chapter II, range from relatively simple mechanical devices that have been in aircraft for many years to complex microprocessors and displays that incorporate the latest electronics technology. The inclusion of these more modern systems often dramatically changes the tasks to be performed by the pilot and, thus, the nature of the pilot performance problems that occur. The rather dramatic changes in electronics and computer technologies that have occurred represent a major area of concern for future human factors research, as will be seen from later discussions. Because of the extremely rapid rate with which these technologies are changing and the revolutionary nature of the changes, the problems related to this area are among the more pressing for general aviation.

General Aviation Pilots. General aviation pilots are a very heterogeneous group. They vary with respect to training, total flight experience, recency of experience, motivation, flight skills, basic abilities, amount of supervision they receive, and on a variety of other parameters. The certificate and rating structure delineated in the Federal Aviation Regulations (Part 61) is the basic mechanism for matching the wide ranging capabilities of these pilots with the varying demands of different general (and air carrier) aviation missions and aircraft. Table 3 shows the numbers of pilots holding various of these certificates. In some degree, the certificate the pilot holds bears some relationship to the types and levels of capabilities he or she possesses.

TABLE 3.--NUMBER OF GENERAL AVIATION PILOTS BY CERTIFICATE TYPE.
(1979 estimate, in thousands)[a]

Students	Private	Commercial	Airline Transport	Helicopter	Glider	Other	TOTAL
204.9	337.6	185.8	55.9	4.9	6.5	3.2	798.8

[a] FAA Aviation Forecasts, Fiscal Years 1980-1991 (FAA, 1979d).

As with the diversity of missions and aircraft, the wide range of characteristics and capabilities of general aviation pilots complicates the study of human factors in general aviation. While some problems may be common to all pilots, others may be unique to certain types of pilots. Moreover, actions that may solve a problem for one type of pilot may not solve the same problem for another type; indeed, they may even create problems for other pilots.

Organizations Involved In General Aviation. There are a number of different private and government organizations involved in general aviation. While they do not have the direct impact on human factors and pilot performance problems attributable to the diversity of missions, types of aircraft, and pilot characteristics, various aspects of organizational roles and purposes must be considered in issues regarding aviation safety. As previously discussed, a number of different businesses own, lease or rent general aviation aircraft for a variety of uses. For some, aircraft are instruments for facilitating the conduct of business. For others, aircraft are their business, as is the case with fixed base operators, commuter airlines, and aviation training institutions. These organizations represent a separate force acting to shape general aviation. They develop their own missions, "design" aircraft to fit those missions through their selection of aircraft and optional equipment, and manage their own flight operations.

Additionally, some of these businesses and the individuals involved belong to associations or other types of organizations concerned with general aviation, such as the Aircraft Owners and Pilots Association, the National Business Aircraft Association, the National Association of Flight Instructors, and others. These organizations serve as sources of information (often safety related) to general aviation pilots; they represent general aviation interests in political affairs; and they perform various other functions for the benefit of their members. Such organizations may be more than just vocational or avocational interest groups; they often represent major dynamic forces in the shaping of general aviation.

The manufacturers of general aviation airframes, power plants, and avionics represent yet another major force in general aviation. These manufacturers are, necessarily, concerned with profits, so they are sensitive to market pressures, product liability problems, and a variety of other economic factors. They are also directly concerned with the welfare of the general aviation community and, hence, are major advocates of safety in general aviation. As individual businesses, and as collective organizations (e.g., the General Aviation Manufacturers Association), they sponsor a variety of programs and projects to promote safe use of general aviation aircraft.

In addition to these private organizations, a number of government agencies affect general aviation through regulation and in other ways (e.g., allocation of fuel, taxation, design and operation of airports).[1] A major government agency, the Federal Aviation Administration (FAA), is responsible for the airworthiness of aircraft and the proficiency of pilots, as well as for the operation of the National Airspace System (see Chapter IV). As with all regulatory agencies, however, the FAA is constrained by the desire and necessity to protect individual freedoms, as well as by its desire to assure public safety.

Implications. The diversity of general aviation missions, aircraft, pilots, and organizations complicates both the identification and resolution of pilot performance problems. Any attempt to identify these problems must take into consideration the numerous possible combinations--and interactions--of these variables. Any attempt to solve problems must be implemented through the many agencies and forces that are operative in general aviation. The difficulties of identifying pilot performance problems in general aviation should not, however, inhibit attempts to study and solve them. The heterogeneity of variables that complicates study of human factors is also a manifestation of the breadth of the economic and social contributions of general aviation to American

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[1] Review of all of the government organizations involved in general aviation can be found in Fraser (1971); Sincoff and Dajani (1975); and Department of Transportation/ National Aeronautics and Space Administration (1971a, 1971b).

society. This same diversity and breadth also underscores the need to solve such problems and to do so through a research program that recognizes the interrelationships among all parts of general aviation.

PILOT PERFORMANCE PROBLEMS IN GENERAL AVIATION. The clearest indication of pilot performance problems in general aviation is the high percentage of accidents that are attributed to errors made by pilots (see Figure 1). Analyses of general aviation accidents have frequently concluded that action should be taken to enhance the performance of general aviation pilots (Bolz and Eisele, 1979; Hoekstra and Huang, 1971; Lederer, 1973; McCourt and Hewin, 1979; Post, 1970; Roskam and Kohlman, 1974; and Strickler and Eggspuehler, 1975). Despite numerous efforts toward this end, these problems persist. Fresh approaches to human factors research on pilot performance problems are needed, and the research should derive from an informed overview of the nature of the problems and the interrelatedness of each with the others. Thus, the research should be programmatic in nature rather than reactive.

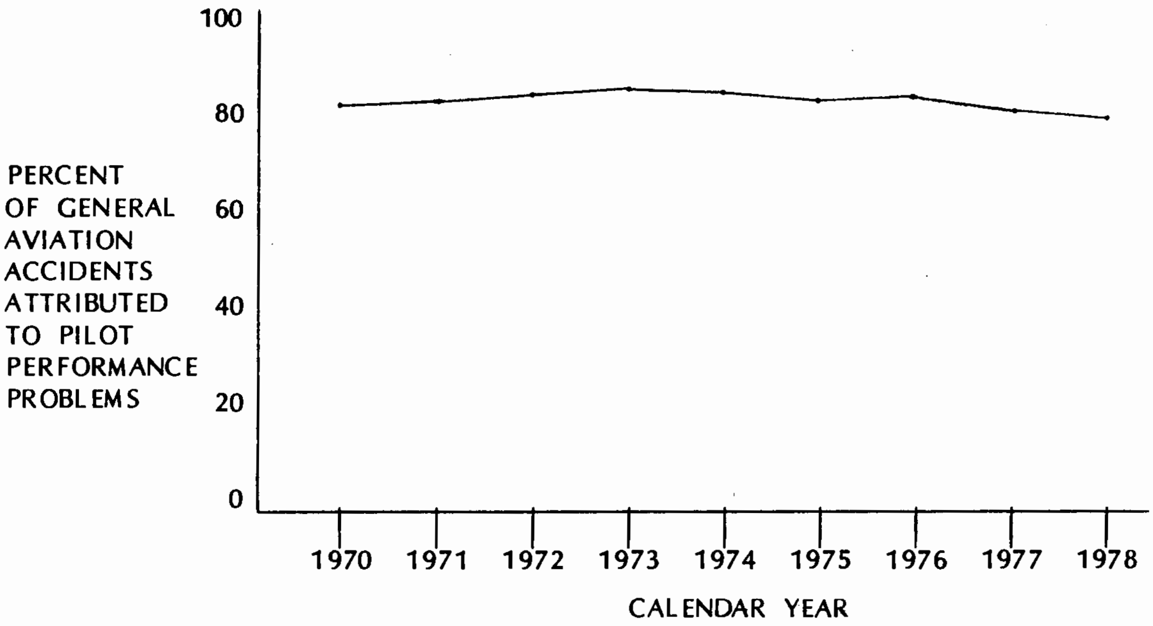

FIGURE 1.--GENERAL AVIATION ACCIDENTS ATTRIBUTED TO PILOT PERFORMANCE PROBLEMS IN THE PAST DECADE.[a]

[a] National Transportation Safety Board.

The initiation of such research is a matter of some urgency. The National Transportation Safety Board (NTSB) data shown in Figure 1 indicate the need for solutions to current pilot performance problems. But, there is an even greater sense of urgency that derives from the potential development of a number of new performance problems as general aviation continues to grow and evolve in future years. Indeed, reviews of projections of future changes within general aviation reveal that general aviation pilots will have to cope with increasingly complex aircraft and avionics, as well as with an increasingly crowded and sophisticated National Airspace System (Bergey, 1978; Bolz and Eisele, 1979; FAA, 1979b; Smyth, 1980).

These changes will result from a number of forces that are acting in concert to speed up the once rather slow evolution of general aviation. Some of these changes relate to direct attempts to improve safety, while others derive from the rapidly changing state of certain aviation-related technologies. Still others are planned in response to the wide variety of pressures affecting individual pilots and the private and government organizations involved in general aviation. Examples include needs for (1) expansion of the uses of general aviation, (2) improvement of mission effectiveness, (3) reduction of fuel consumption, (4) exploitation of electronic and many other advanced technologies, (5) reduction of engine noise and pollutants, (6) increasing the capacity of already crowded airspaces, and (7) reduction in the cost of operating air traffic control and navigation facilities.

Descriptions Of Pilot Performance Problems. A logical starting point in seeking to develop solutions for pilot performance problems--whether existing or anticipated--is to identify and describe them. As a consequence, a number of schemes for classifying problems have been developed, derived principally from accident data. At one time, all pilot performance problems were grouped in one category and labeled simply as "pilot error." This categorization has been recognized as being of limited usefulness and has been the subject of extensive criticism (Beaty, 1969; Hurst, 1976; Roscoe, in press; Wiener, 1977; 1979). The term implies that accidents are due to pilot negligence or incompetency, or, in some cases, to human failure that is unpreventable. While this explanation may satisfy certain public (and legal) demands, it does little or nothing to advance our understanding of cause, and it provides no guidance concerning means for preventing similar accidents in the future.

More detailed description and categorization schemes for pilot performance problems associated with aviation accidents have appeared in recent years. Performance problem descriptions vary in accord with the schemes employed to classify or categorize pilot behavior or the factors thought to affect pilot behavior. These classifications are of three general types. One type classifies performance problems in terms of the operational tasks that the pilot failed to execute correctly--e.g. failure to see and avoid other aircraft, failure to obtain or maintain flying speed, mismanagement of fuel, failure to extend landing gear, misjudgment of distance, speed, or altitude. Another describes performance problems in relation to various psychological constructs or processes--e.g., workload, fatigue, stress, attention, decision-making.

The third type of scheme is based on various factors that are associated with the occurrence of pilot performance problems. Such factors are derived from analyses of the variables that relate to the pilot, the aircraft involved, and the conditions surrounding the occurrence. Given the diversity within general aviation, the number of variables is quite large. Examples of variables used for classifications and analyses include (a) phase of flight (e.g., landing, cruise); (b) type of mission (e.g., personal transportation, aerial application); (c) type of aircraft; (d) time of day and season of the year; (e) geographic location and terrain features; (f) weather conditions; (g) characteristics of the pilot (e.g., total flight time, certificate held, age); (h) condition of the pilot (e.g., under the influence of alcohol or drugs, debilitating medical conditions, psychological problems); and (i) type of crash (e.g., midair, stall/spin, controlled flight into terrain).

These various classification schemes have been employed, separately or in conjunction with one another, in a number of different studies to analyze the general aviation accident data. Thus, trends in pilot performance problems have been described in several different ways. Table 4, for example, describes aviation accidents in terms of failures to perform certain operational tasks (NTSB, 1978). Table 5, in contrast, describes general aviation accidents over a five year period in terms of relative frequencies of accidents attributed to procedural, perceptual-motor, and decisional errors (Jensen and Benel, 1977). Table 6 illustrates the use of associative factors to describe general aviation accidents, i.e., phase of flight (NTSB, 1978).

TABLE 4.--TOP TEN CAUSE/FACTORS FOR SMALL FIXED WING AIRCRAFT ACCIDENTS CALENDAR YEAR 1977.

Cause/Factors	All Accidents Cause	All Accidents Factor	Total[a]
PILOT			
1. Failed to obtain/maintain flying speed	535	1	536
2. Inadequate preflight preparation and/or planning	430	67	497
3. Mismanagement of fuel	279	0	279
4. Failed to maintain directional control	274	0	274
5. Improper inflight decisions or planning	204	15	219
6. Selected unsuitable terrain	194	14	208
7. Improper level off	196	4	200
8. Misjudged distance and speed	159	7	166
9. Continued VFR into adverse weather	152	8	160
10. Improper compensation for wind conditions	135	9	144

[a] Total accidents for all causes = 3842 (NTSB, 1978).

TABLE 5.--GENERAL AVIATION ACCIDENTS FOR PROCEDURAL, PERCEPTUAL-MOTOR, OR DECISIONAL ERRORS.[a]

	1970 - 1974 Total Five-Year Accidents		
Type of Error	Fatal	Nonfatal	Total
Procedural	264	2230	2294
Perceptual-Motor	2496	14561	17057
Decisional	2940	9087	12027

[a] Jensen and Benel, 1977.

TABLE 6.--GENERAL AVIATION ACCIDENTS FOR CALENDAR YEAR 1977 BY FLIGHT PHASE.[a]

Phase	Accidents
Static	21
Taxi	134
Takeoff	1237
Inflight	1252
Landing	1666

[a] NTSB, 1978.

While these different descriptions are of value in the identification of existing pilot performance problems, they still do not provide direct guidance for determining actions that should be taken to prevent or remedy these problems. Simply put, they describe what happened in an accident, not why the pilot made an error--e.g., why did the pilot fail to maintain flying speed; or why was there an excessive workload? Identification of appropriate actions to prevent performance errors requires an understanding of why an error occurred. Describing the error and the circumstances of its occurrence is only the first step in the development of such knowledge.

HUMAN FACTORS AND PILOT PERFORMANCE PROBLEMS. Much of the lack of progress in solving many of the pilot performance problems derives from the failure of existing classification schemes to get beyond description. Corrective actions must be based on contributing conditions that are identified with some precision and the conditions must relate to factors that are feasible to be changed. Consequently, the point is advanced here that a structure based on the concepts of the discipline of human factors provides an effective means for developing corrective actions. This structure will be developed more fully later.

Pilot Performance Model. At a general level, the explanation of why pilot performance problems occur is straightforward. For example, Zeller (1978) attributes pilot performance problems to a mismatch between the level of demands imposed by pilot tasks and the ability (and motivation) of the pilot to perform these tasks. Mismatches--incongruities might be a better term--can occur with reference to a variety of physical, psychological, and physiological capability dimensions of the pilot.[1] Such incongruities can be identified and understood only by examining the human factors involved in relation to the situational requirements.

Incongruities can arise, for example, when the pilot's physical strength or size restricts the effective execution of control movements required by task demands. More complex and subtle incongruities can occur when performance of a task or a set of concurrently performed tasks requires capabilities for perception of stimuli, processing of information, or execution of precise psychomotor responses that are beyond the range of the pilot's current abilities. In other instances, incongruities may arise not because the pilot lacks the ability, but because he lacks sufficient attention or motivation to perform the task in the safest fashion, e.g., the pilot may take shortcuts to save time or money. Still other forms of incongruities may develop when the pilot is exposed to environments that fail to provide sufficient support for normal bodily functions or are physically damaging to the body. For example, the effectiveness of pilot performance decreases when the pilot is exposed to excessively high levels of vibration, acceleration, noise, or temperature, when sufficient oxygen is not supplied during flight at high altitudes, or when the pilot is exposed to toxic substances.

As noted, solution to a particular pilot performance problem requires not only that the incongruities be identified, but that one or more elements of any incongruity be susceptible to change. Thus, the solution to pilot performance problems requires that task demands and/or pilot capabilities be modified to eliminate the physical, psychological, and physiological incongruities that underlie these problems.

The concept developed here is one that is design oriented in nature, a view that underlies much of the field of human factors. Therefore, its development requires an analytic understanding of factors affecting the performance of general aviation pilots as part of a complex system. An understanding in terms of the system's components and elements is necessary to identify those components and elements that are susceptible to change.

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[1] It should be noted that these incongruities are probablistic in nature. There are differences in their relative occurrence across pilots and even on a day-to-day basis within pilots. Thus, such incongruities are matters of relative degree.

As will be discussed in subsequent sections of this report, it is possible to identify the major factors that can be manipulated to modify task demands and pilot capabilities. In the remainder of this report, such modifiable factors will be referred to as "system components."[1] Figure 2 presents an overview of six such components and their relationship to pilot performance.[2] For convenience, the system components are broken into two major groups--those that relate to task demands, and those that relate to pilot capabilities. As shown in Figure 2, three major system components interact to determine task demands: (1) aircraft, (2) airports, and (3) aeronautical information systems.

Of these three components, the design of the aircraft and its associated systems likely has the single greatest influence on the nature of the tasks performed by general aviation pilots. The design of aircraft displays and controls, for example, largely determines the types and degrees of information processing demands that will be imposed on the pilots in the conduct of flight control, navigation, and communications tasks. Additionally, the design of numerous aspects of the cockpit will affect the level of physiological demands made upon the pilots by their immediate environments.

The design of airports interacts with the aircraft variables to influence the nature of tasks performed. For instance, the size, markings, and lighting of runways, combined with the presence or absence of visual approach aids, interact with aircraft design factors such as navigation systems to determine the difficulty of approach and landing tasks.

Task demands are also influenced by the characteristics of the aeronautical information employed by general aviation pilots. Such information can be classified into three general categories: (1) documental information concerning operation of the aircraft (e.g., normal and emergency operating procedures); (2) documental information concerning use of the National Airspace System (e.g., airspace allocation, instrument flight procedures); and (3) communications exchanged with various FAA agencies to enable or facilitate flight planning and coordination. All three categories of information influence task demands, in that their content either prescribes actions to be taken by the pilot, or serves as a major input for the pilot's own decisions concerning actions he may take.

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[1] Some factors that influence task requirements and pilot capabilities cannot be manipulated feasibly. For example, characteristics of the external environment (e.g., weather conditions) cannot usually be directly manipulated, although they do influence task requirements. Similarly, many psychological and social factors that influence pilot capability cannot be manipulated directly. Even though they cannot be manipulated directly, however, these factors may be related to the design of system components that can be changed and, as such, are included in following discussions.

[2] The human factors "model" or conception represented here is a simplified view of a quite complex set of relationships. Other components might well have been identified or selected for exposition. However, the conception depicted in Figure 2 provides an adequate means of presenting an overview of pilot performance and the major design factors related to it. It has been developed for the purposes of analyzing and reviewing a wide variety of information. For other purposes, other conceptions might be used.

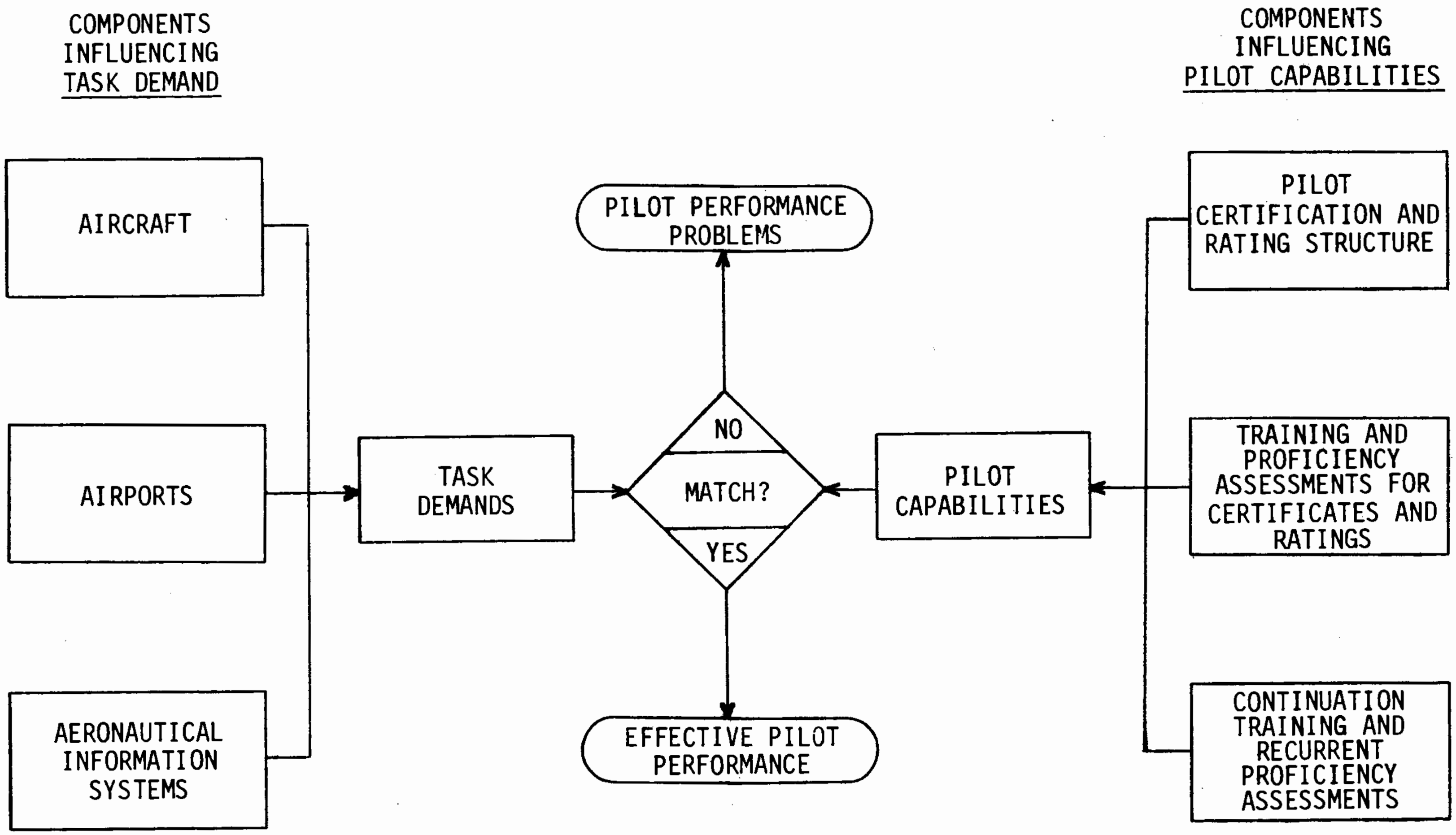

FIGURE 2.--SYSTEM COMPONENTS INFLUENCING TASK DEMANDS AND PILOT CAPABILITIES.

These three components, then, can be manipulated to modify task demands to make them congruent with the range of capabilities present in the general aviation pilot population. Conversely, the existing and projected designs of these components determine the level of demand that these pilots must be capable of meeting and, hence, define required pilot capabilities.

The capabilities of the pilot for meeting these demands are determined by three major system components, as shown by the right hand side of Figure 2. The first of these components, the pilot certification and rating structure, is the major mechanism employed in general aviation to screen and select personnel for the various subsets of tasks performed by general aviation pilots. The entry level requirements for the student pilot certificate, for example, determine who in the general population might become pilots. The second component, training and evaluation, encompasses the requirements that individuals must satisfy before receiving certificates and ratings. The influence on pilot capabilities of training programs and of the written and flight tests used to assess pilot proficiency is extensive. Following initial achievement of a certificate or rating, pilots must maintain their proficiency on the skills required by their certificates or ratings for as long as they exercise them. Thus, the activities subsumed under the third component, continuation training and recurrent proficiency reviews (e.g., the biennial flight review), are of critical importance to the continued safety of general aviation pilots.

These system components--both task and capability types--will be discussed in greater detail in subsequent chapters. The important point to note here is that solutions to general aviation pilot performance problems will lie primarily in the design of aircraft, airports, aeronautical information systems, certification/rating requirements, training programs, and evaluation tests and procedures. It is the interactions among these system components that determine the congruity between task demands and pilot capabilities. Thus, the harmony and integrity of the design of this total system of components--i.e., the general aviation system--determines the quality of pilot performance.

Given the diversity within general aviation, it is understandable that the components of this system are designed by a number of different individuals, teams, and organizations. Furthermore, each of these designers has his own set of component-specific requirements or design goals. Aircraft designers, for example, try to optimize aircraft characteristics with reference to the effectiveness, efficiency, and reliability of mission performance. They must also minimize cost, meet federal requirements, and produce a product with market appeal. Designers of each of the other components (e.g., airports, information systems, training systems) also have their own specific concerns. Since there is no system designer responsible for integrating all of the components in general aviation, each of these independent design personnel should consider the impact of the design of his component on the physical, psychological, and physiological congruity between task demands and pilot capabilities. The aircraft designer should consider the range of capabilities of the pilots who will fly the aircraft; the designer of a training program should consider the total set of task requirements that graduates of the program will have to satisfy, etc. If these independent designers do not consider interactions among the various components and the effects of the design of their component on the congruity between task demands and pilot capability, the performance of the pilot will almost surely suffer. General aviation pilots are the common link across all of the above components; they are the final integrators of the total system. The effectiveness of their performance depends on the effectiveness with which this integration is effected, and, in turn, this is dependent on the congruity of task demands and pilot capabilities.

The Role Of Human Factors Research. The necessity for congruity of task demands and pilot capabilities makes human factors the focus of solving problems of pilot performance. As indicated in the foregoing discussion, relevant issues encompass a broad range of factors as represented in the diversity of general aviation missions, aircraft characteristics, avionic systems, and pilot characteristics. These factors affect, and are affected by, pilot training and certification, airport design, and regulations governing flight. What these issues have in common, and specifically what makes them relevant to flight safety, is their impact, separately and jointly, on the congruity of task demands to pilot capabilities.

Necessarily, the pilot must be the central concern. It is not a matter of what an aircraft can do, but what a pilot can do with an aircraft; not a matter of what information is available, but of the information that can be properly processed by the pilot. What should be done, or avoided, with respect to all the system components discussed ultimately depends on the human element. It is in this context, then, that we define the domain of human factors.

Accordingly, human factors research in general aviation was the primary concern of the project reported here. It should be clear, however, that human factors had to be viewed within the total system of forces shaping and governing general aviation, for pilot performance cannot be viewed meaningfully except within the context of the forces as a whole.

As can be seen from the view developed here, the treatment of factors affecting pilot performance as a system is the key to alleviating or eliminating pilot performance problems and increasing flight safety. Further, that view assumes that the various components of the system--be they man, machine, or rules--must be designed with deliberation and with system insight. Such design requires that the designer have information about system interrelationships and about the effects of system components on human performance. When the information base to support informed design is lacking or absent, a human factors design issue can be said to exist. Thus, human factors, as a design-oriented discipline, has as one of its major goals the development of the information required to resolve such deficiencies or design issues. For this reason, much of the discussion of subsequent chapters in this report is devoted to identifying, through examination of the current knowledge base, such design issues for general aviation, and thereby identifying the human factors problems on which future research must focus. The reader should take special note of the meaning of the term, 'design issue,' as it is used here, because an understanding of its intended meaning is necessary to an appreciation of the discussions of design issues that follow.

APPROACH.

The objectives of this study were to (1) identify major performance problems of general aviation pilots; (2) determine types of data needed to solve these problems (i.e., identify major human factors design issues); and (3) analyze the implications of these needs for planning future human factors research. The study was restricted by its charter to the analysis of existing information concerning the performance of pilots. Therefore, the first step in the accomplishment of the three objectives stated was to identify and acquire information concerning pilot performance problems and associated human factors design issues. The second step was to analyze this information to identify major human factors design issues. The third and final step was to analyze these issues for the purpose of planning future human factors research programs.

ACQUISITION OF INFORMATION. The acquisition of information concerning pilot performance problems and associated human factors design issues was complicated by the large number of sources from which subsets of information are available and by the diversity of methods that have been employed to generate such information. Such methods have included:

- analyses of general aviation accidents;
- analyses of reports of incidents involving general aviation pilots and/or aircraft (e.g., near midairs or other near accidents);
- analyses of information other than accident or incident data that describes actual occurrences of pilot performance problems (e.g., "flight assists" in which air traffic controllers provide aid to pilots who are lost, low on fuel, or who need other forms of assistance);
- observations made by experienced pilots (e.g., test pilots);
- empirical research (e.g., investigations of the effects on pilot performance of different aircraft designs, or different methods of pilot training); and
- analytical research (e.g., the use of mathematical models of pilot performance to predict the impact of different factors on performance, or of operations research techniques to design airways and air traffic control procedures).

Results of studies employing these various methodologies have been published in a variety of sources, including the scientific research and engineering literature of a number of disciplines, regulatory reports of various government agencies, and aviation publications. A comprehensive review of these published materials was made. In addition, personnel in various private and government organizations involved with general aviation or aviation safety were interviewed to provide an overall perspective for the information derived from the published sources, as well as to identify issues that might not have been adequately addressed in the documentation.

Literature Search. Both automated and manual search procedures were used in pursuit of a comprehensive coverage of the published literature. The DIALOG Information Retrieval Service was employed for the automated searches. While the main searches were concentrated on the National Technical Information Service data base, other data bases were searched for items of specific interest. These other data bases included PSYCHOLOGICAL ABSTRACTS, COMPENDEX (a computerized listing of The Engineering Index), and ERIC (a data base for the educational research literature).

Approximately 2,000 abstracts were obtained through the automated searches. These abstracts were reviewed and reports were selected for further examination. Such reports were those that were either (1) directly concerned with human factors in general aviation, or (2) overviews of research of human factors in all of aviation.

In addition to the above activities, the search was extended through examination of reference lists from various published items acquired and through examination of selected documents already in the Seville Research Corporation and Embry-Riddle Aeronautical University libraries. In addition, articles cited by individuals interviewed during the present project provided another source.

Interviews. To supplement the literature reviews, 28 individuals in 9 different private and government organizations were visited and interviewed. These organizations were (1) the FAA Technical Center, (2) FAA Headquarters, (3) the National Transportation Safety Board, (4) National Business Aircraft Association, (5) Aircraft Owners and Pilots Association, (6) General Aviation Manufacturers Association, (7) National Aeronautics and Space Administration (NASA) Langley Research Center, (8) NASA Ames Research Center, and (9) the Naval Safety Center. Names of individuals within these organizations who were interviewed are listed in Appendix A.

IDENTIFICATION AND ANALYSIS OF HUMAN FACTORS DESIGN ISSUES. The reports and other information acquired for the present study were analyzed to identify the major pilot performance problems of general aviation pilots identified in those sources, and to identify the human factors design issues[1] associated with these problems. Some of the reports were chiefly concerned with pilot performance problems, such as classifications of aviation accidents as to type (e.g., stall/spin accidents), with little or no treatment of underlying human factors design issues. These reports typically described or classified performance problems using one of the different classification schemes identified previously. Statistics were usually presented concerning the frequency of occurrence of these problems and factors associated with them. In some of these reports, human factors design issues were identified as a result of analyses of actions that could be taken to solve the performance problems.[2] Because of the interactive nature of the system components, the actions identified for a given problem often involved the modification of two or more of the system components. It might be proposed, for example, that a given performance problem be addressed through the concurrent modification of relevant aspects of pilot training and modification of flight displays related to the problem. In contrast to reports concerned with past pilot performance problems as reflected in historical data, a number of other articles reviewed focused on existing or potential future human factors design issues. These articles usually were reports of human factors research evaluating the design of selected aspects of the different system components (e.g., evaluation of different pilot training methods or of aircraft flight displays). They usually identified various pilot performance problems that were associated with the design issue being addressed. Several such problems might be identified related to a given design issue. Given the use of the different classification schemes of pilot performance problems, however, it usually was not possible to relate these problems systematically to design issues across different reports.

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[1] The reader is reminded of the definition of "design issue" that was previously set forth.

[2] Appendix B discusses the limitations of the use of accident data for this purpose. The general point is made that such data are symptomatic of pilot performance problems, but they frequently are of little help in identifying appropriate solution alternatives.

The information available in all of these reports, regardless of their focus, served as the basis for the identification of pilot performance problems and associated human factors design issues. Two choices were available for organizing the information; it could be organized with respect to the problems, or with respect to the design issues. The choice was made to organize with reference to the human factors design issues. Thus, the pilot problems relevant to a set of related design decisions for a given component would be grouped together. This organizing framework is consonant with the actual design process. It also recognizes the fact that design of various components of the general aviation system (e.g., the training component, the aircraft component, etc.) is carried out by different persons and agencies, often in isolation from one another. Thus, the design process for the training program designer, for example, will be aided by the aggregation of design information pertinent to the training component. Since one of the basic objectives of human factors research is to provide information to aid the design process, the material presented in this report is organized with respect to such design issues.

An hierarchical structure was developed to depict and emphasize the various levels of interactions among the human factors design issues, and the relationship of those issues to task demands and pilot capabilities. That structure is shown in Figure 3.[1] As can be seen, moving from left to right in the figure, pilot performance is a function of task demands and pilot capability. Each of these factors, in turn, is determined by components, and each component has one or more "design elements" associated with it.[2] Design elements are defined as being the products of major design decisions. It is at this elemental level, then, that the design issues (i.e., lack of a necessary design information base) are identified in following discussions.

Design issues were grouped with respect to the 18 design elements generated from the six system components. These elements served to provide a reference and organizing framework for the discussions of the issues and their interrelationships.

ORGANIZATION OF REPORT. The structure described above is used in Chapters II through VII to organize the discussion of the human factors design issues and associated pilot performance problems. Each of these chapters addresses one of the six components identified in Figure 3 (e.g., Chapter II treats the Aircraft components, Chapter III, Airports, etc.). Organization within each chapter is as follows. The chapter introduction briefly describes the component addressed in the chapter, discusses the way in which it impacts on task demands or pilot capabilities, and outlines the elements in the component. For each element that follows, an introduction is provided that briefly describes that element and provides an overview of the human factors issues identified for it. These issues are then discussed individually.

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[1] Figure 3 extends the structure shown in Figure 2 by breaking "components" into their constituent "design elements." Other components and elements could have been included in this model; but for present purposes, those shown in Figure 3 are adequate.

[2] As was previously noted with reference to the term "design issue," the reader should review the usage made here of the terms "component" and "design element." These terms, along with "design issue," are basic to the expositional structure of this report.

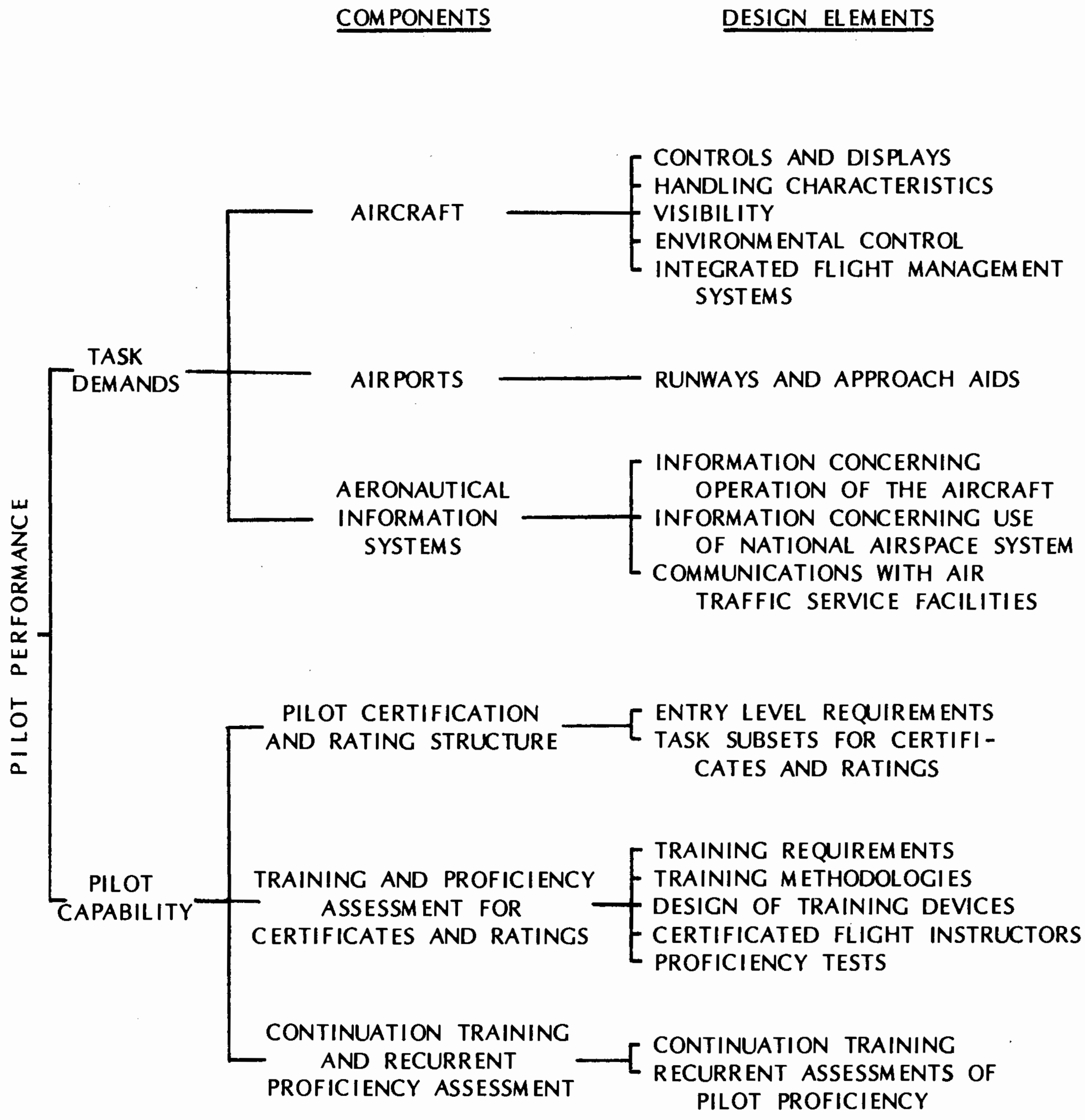

FIGURE 3.--STRUCTURE FOR ADDRESSING HUMAN FACTORS DESIGN ISSUES.

To aid the reader in following this organization of elements and issues, the following procedure is employed. As each element is introduced, that element is identified by a major capitalized heading followed by "(E)" to indicate that the heading denotes an element. Following the text that describes the element, the individual design issues associated with that element are presented. The design issues are numbered, with issue headings being designated as "ISSUE #1.--(title of issue)," "ISSUE #2.--(title)," etc. The issues are numbered serially from #1 through #35, since, in all, some 35 issues were identified.

The specific format of the discussions of the design issues differs slightly across issues due to variability in the information that was available concerning given issues, and to inherent differences in the nature of some of them. In general, however, each issue is discussed with respect to (1) the pilot performance problems associated with the design of the element, (2) requirements for the design or modification of that element to prevent or alleviate pilot performance problems, and (3) information required by the designers of that element to address the issues that are raised.

Given the breadth of coverage of this report, it was not possible to describe in great detail the information available in the literature with respect to each issue. Rather, such information is briefly summarized, and references to the articles are provided to enable the reader to consult them for further information.

ANALYSIS OF IMPLICATIONS FOR HUMAN FACTORS RESEARCH. The final objective of the present study was to analyze the human factors design issues that were identified in terms of their implications for planning future human factors research programs in general aviation. This analysis was accomplished in two separate steps: (1) development of rating criteria for assessing research priorities; and (2) use of the criteria to assign priorities to the issues.

Development Of Priority Criteria. The criteria that were employed to assess the relative research priorities of the human factors design issues were developed through the analysis of (1) criteria employed in past projects that have ranked the priority of human factors research topics in aviation (Bolz and Eisele, 1979; Post, 1970; Matheny, 1975; Prophet, Shelnutt and Spears, 1980), and (2) information obtained during the interviews with personnel in private and government organizations concerning their criteria for ranking research priorities.

On the basis of this information, two dimensions for rating the design issues were identified. The first dimension assessed the criticality of current operational needs for information. This dimension represented the assessment of the frequency and severity of current pilot performance problems associated with a given design issue. Such assessments of criticality considered accident data; but they also considered analytical judgments concerning nascent problems, i.e., problems that have not yet occurred or reached some critical level of frequency, or problems that are forecast based on changes to general aviation, changes in supporting technologies, and other similar evolutionary or revolutionary changes. The second dimension was designed to assess the feasibility of using human factors research to address a given design issue. The feasibility of the use of research to address a topic is a complex professional judgment, one that is based on a combination of factors. These include: (1) the amenability of an issue to quantification with respect to factors affecting performance, and to the measurement of relevant aspects of pilot performance; (2) the cost and practicality of conducting research on a given topic; and

(3) the feasibiity of implementing the results of the research given operational constraints, and the estimated resistance of these constraints to change.

Use Of The Criteria To Evaluate The Issues. Each of the human factors design issues was evaluated by the authors on the basis outlined above. This judgment was based mainly on the review of information acquired for the present study, but also involved their experience in human factors research in civil and military aviation and their experience as general aviation pilots. Judgmental evaluations of criticality were employed, rather than quantitative indices of general aviation accidents, because of (1) inadequacies in the current general aviation accident data bases, and (2) limitations on the use of accident data for identifying critical human factors design issues (see Appendix B). However, as noted, accident data are indicative of pilot difficulties and so were part of the information base on which criticality judgments were made.

On the basis of these evaluations, the design issues were assigned to one of three priority groupings: (1) high priority issues that should be investigated in future research programs; (2) issues that are of secondary priority, but are nevertheless important and should be investigated given the availability of research funds; and (3) issues of low priority. It should be recognized, however, that all of the identified issues are important, and there is a need for development of the information implied by the issues. Inevitably, there will be constraints on research funding to support such efforts. Therefore, the evaluations of priority are provided to aid in decisions in the allocation of these scarce funds, though it is recognized that the final decisions in that regard must necessarily consider other factors as well. The results of the research priority evaluations developed are presented in Appendix C and are discussed in Chapter VIII.

II. AIRCRAFT

The relationship of the pilot to the aircraft in accomplishing flight tasks can be characterized as a closed-loop feedback system (Williams, 1971). If the pilot manipulates a control to achieve a desired goal, information concerning that action and its effect is fed back to the pilot. In this manner, the pilot can perceive whether additional control movement is needed to achieve the goal and can close the loop by taking that action. As illustrated in Figure 4, the pilot may receive the feedback information through the perception of the external visual scene (e.g., the use of the horizon in contact flight), or he may employ information available from aircraft displays (e.g., the attitude indicator in composite or instrument flight).

The pilot's task consists of the concurrent performance of several such control tasks plus a number of partially independent information processing and decision-making tasks (Childs, 1979). As diagramed in Figure 4, the pilot interfaces with the aircraft in a number of different ways in the performance of these tasks. Aircraft displays, for example, provide him with information collected by aircraft sensors that extend and supplement his own perception of the external world. Indeed, when he is unable to make perceptual judgments concerning the relation of the aircraft to the external world through direct viewing of that relationship, the reliability of his performance is a function of the adequacy of such displayed information with respect to his needs, as well as the efficiency and effectiveness of his interpretation of it. Thus, the design of these information displays in terms of what is presented and how it is presented determines a significant portion of the task demands faced by the pilot.

Similarly, the interface between the pilot and aircraft with respect to the control system and aircraft dynamics also determines a significant portion of the task demands faced by the pilot. These two factors interact with display and other interface factors to determine pilot workload and requirements for psychomotor skills associated with the execution of control tasks. In addition to displays and controls, the design of the windscreen, glareshield and other aspects of the cockpit and airframe determines requirements placed on the pilot with respect to viewing the surrounding visual scene. Other features of the design of the cockpit determine the intra-aircraft environment in which the pilot must perform his tasks. If this environment does not provide sufficient support for the pilot's physiological needs, or if it is distracting or fatiguing, then additional demands are placed on the pilot.

There are other similar aspects of the pilot-aircraft interface that combine to exert a major influence on the performance of the pilot.[1] In recognition of the importance of this influence, human factors engineering standards are often specified for use in the design of aircraft to promote compatibility of the cockpit displays, controls, and environment with the capabilities and needs of the pilot. Many such standards exist for use in the design of military and civil aircraft, as well as for many other types of equipment systems. Within the Federal Aviation Regulations (Part 23), for instance, several of the airworthiness standards are concerned with aircraft displays, handling, and other

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[1] Comprehensive discussions of the pilot-aircraft interface can be found in Williams (1971) and Roscoe (in press).

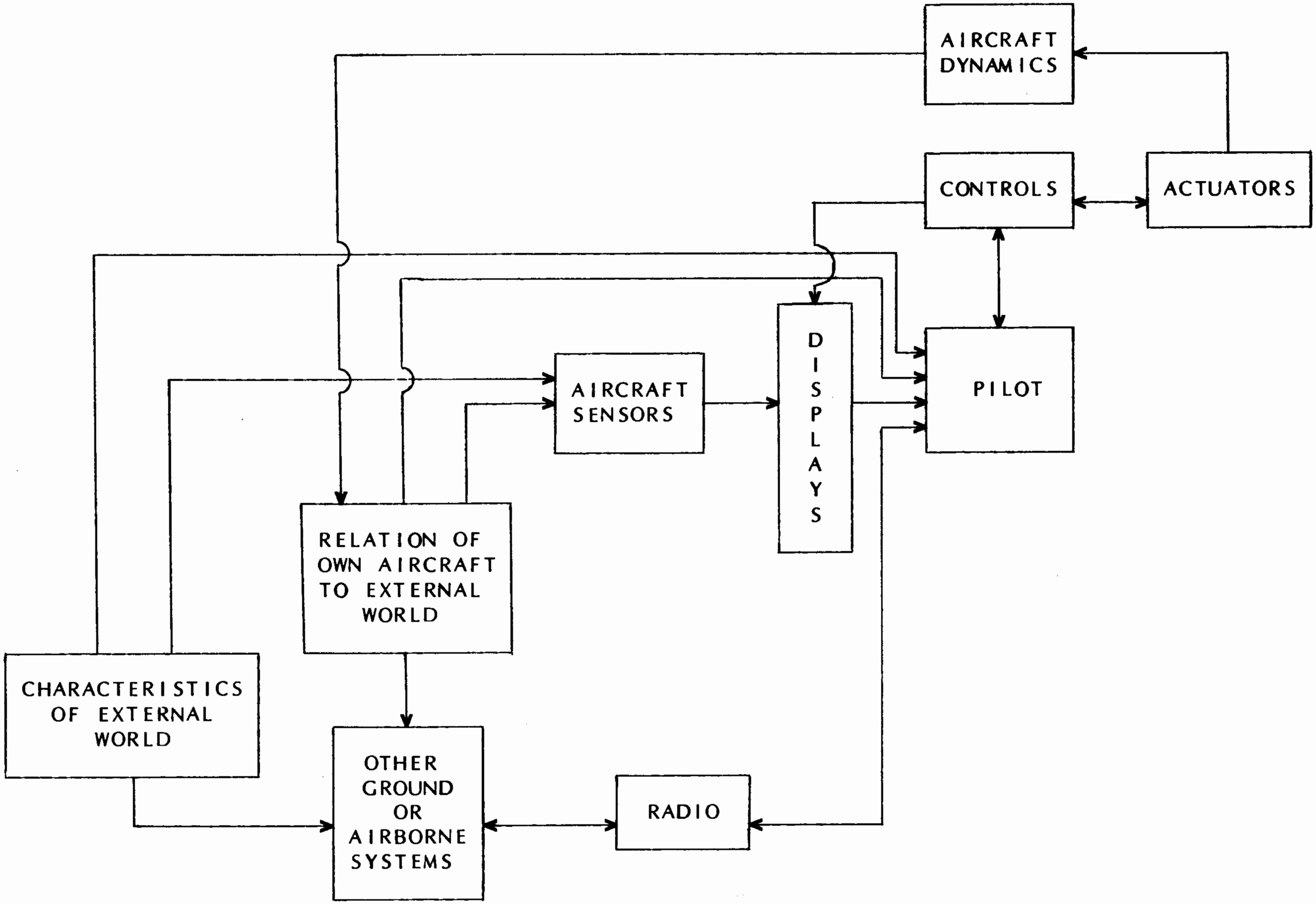

FIGURE 4.--DIAGRAM OF RELATIONSHIPS AMONG THE PILOT, AIRCRAFT, OTHER SYSTEMS, AND EXTERNAL WORLD.

factors related to pilot performance. Other examples of such standards include Military Standard 1472B (Department of Defense, 1974) and Military Handbook 759 (Department of the Army, 1974).

The major function of these standards is to furnish information that can be employed by designers to develop design alternatives that are compatible with, or even exploit, pilot capabilities. Furthermore, the standards, especially if they are specified as design criteria in regulations, serve to assure the commonality of designs across different aircraft. The standardization function is particularly important when pilots fly different aircraft frequently, as is often the case in general aviation.

In addition to these standards, human factors information is available to designers in the form of less formal guidance, such as guidebooks, handbooks, textbooks, technical reports, and other reports in the scientific and engineering literature. In fact, these sources tend to be employed more frequently than formal human factors engineering standards (Rogers and Armstrong, 1977). This informal guidance serves the same function as standards, with the difference that use of such guidance is voluntary, and, given the variety of sources, it is difficult to access and integrate by design personnel not familiar with the human factors literature.

The major goal of human factors research on aircraft design is to provide information that can be employed as standards and guidance for design. Some of this research is conducted for specific aircraft, displays, or other pieces of equipment, and is tailored to provide specific information needed for the design, development and testing of that equipment. The focus of human factors research in equipment design, however, ranges from this level of system specificity to the development of general information that can be employed in a variety of applications (e.g., general guidance for the design of all displays). With respect to general aviation, the major goal of most of the research conducted by government agencies, such as the FAA and NASA, is to provide a comprehensive basis for developing (1) airworthiness standards that will direct the design of the pilot-aircraft interface by the large number of independent individuals, teams and private organizations who do such work, and (2) informal guidance that can be employed by such designers as a systematic foundation for their designs. As discussed in Chapter I, such foundations are necessary to assure or enhance congruity between task demands and pilot capabilities.

The human factors design issues discussed in the remainder of this chapter focus on the identification of requirements for information needed to develop standards and furnish informal guidance for the design of general aviation aircraft.[1] Five elements were identified (see Figure 3) to organize the discussion of these issues. Four of these

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[1] It is recognized that many other human factors research issues could be specified with respect to aircraft design--e.g., the design of specific displays. The focus of this report, however, is on the determination of issues related to the performance and safety of general aviation pilots and the determination of institutional actions that can be taken to resolve these issues; in this case, these actions are the specification of human factors engineering standards and the provision of informal guidance to the various designers of general aviation aircraft and subsystems. Moreover, as will be discussed in subsequent sections, there is a major need at this time for systematic study of where general aviation is now and where it is going, as opposed to independent investigations of different aspects of aircraft design.

elements are related to aspects of the pilot-aircraft interface discussed earlier in this section. These are (1) controls and displays, (2) handling characteristics, (3) visibility, and (4) environmental control. The fifth element, integrated flight management systems, represents design concerns related to the incorporation of advanced electronics technology in general aviation aircraft--e.g., airborne microprocessors, data link, variable content displays such as cathode ray tubes (CRTs), and fly-by-wire control systems. While the use of this technology is extensive within some current military aircraft, it is only in its beginning stages in general aviation. The changes that will result from this technology will be major--perhaps revolutionary--in their effects on general aviation pilot task demands. Unless appropriate guidance and standards for the various applications of this technology are provided, the very flexibility of applications this technology affords may result in a proliferation of pilot performance problems. Thus, the issue raised for this element concerns the need for information to guide the increased utilization of this technology.[1]

CONTROLS AND DISPLAYS (E).

While general aviation aircraft vary greatly in sophistication, their basic displays and controls are essentially the same. Displays provide the pilot with (1) flight status information (e.g., airspeed, altitude); (2) powerplant status (e.g., revolutions per minute); (3) subsystem status (e.g., ON-OFF, radio frequency tuned); (4) navigation information (e.g., course and deviation from course); and (5) alerts or warnings (e.g., stall warning). Additionally, almost all aircraft have radios for voice communications. Basic aircraft controls include (1) flight controls; (2) powerplant, fuel management system, and propeller controls; (3) flaps, trim, and landing gear controls; and (4) various knobs and dials for tuning radios and setting displays.

The more sophisticated general aviation aircraft may have a variety of additional subsystem components, each with its own displays and controls. Examples might include: (1) autopilots of varying capabilities; (2) flight director systems that furnish command signals to the pilot, thus guiding his control actions; (3) area navigation systems that provide the pilot with the ability to set up courses in two and three dimensions regardless of the location of ground-based navaids; and (4) weather radar, anti-icing equipment and other equipment designed to facilitate all-weather flying. A comprehensive review of avionics that are employed in general aviation aircraft can be found in Schwenk (1979).

The following issue (Issue #1) concerns the development of human factors engineering standards and guidance for the design of both the basic and more complex conventional displays and controls described above.

ISSUE #1.--HUMAN FACTORS ENGINEERING STANDARDS AND GUIDANCE FOR AIRCRAFT CONTROLS AND DISPLAYS. In the past, the design of basic aircraft controls and displays was limited by engineering constraints associated with the use of analogue equipment (e.g.,

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[1] For purposes of discussion, controls and displays currently in most general aviation aircraft will be referred to as "conventional" equipment to differentiate them from the "advanced technology" equipment described. Since some forms of digital electronic equipment and CRT displays are already employed in general aviation aircraft, there is, by necessity, some overlap in the following discussions between "conventional" and "advanced technology" equipment.

mechanical linkage of display indicators to sensors). Moreover, few of these controls and displays were designed on the basis of systematic analysis of their human factors characteristics or requirements. As a result, numerous pilot performance problems have been identified that can be attributed to the design of fuel management, powerplant, flight, and other basic controls and displays.

A number of techniques have been employed to identify these problems, such as (1) analysis of accidents (e.g., NTSB, 1967; 1972f; 1974a); (2) analysis of incidents (e.g., Fitts and Jones, 1947); (3) formal and informal analysis of design deficiencies in current aircraft (e.g., Ontiveros, Spangler, and Sulzer, 1978; Schiff, 1980; Thurston, 1980); and (4) experimental research on basic controls and displays (e.g., Hasbrook, Rasmussen, and Willis, 1975; Ince, Williges, and Roscoe, 1975; Jensen, 1979; Johnson and Roscoe, 1972; Roscoe, 1968; in press).

Examples of problems identified through the use of these techniques include:

- incorrect operation of controls (e.g., selection of empty instead of full fuel tanks);
- misinterpretation of displays (e.g., incorrect readings of altimeters or attitude indicators);
- failure to respond to display of critical information (e.g., stall warning horns or lights);
- inadvertent operation of controls (e.g., operation of flaps instead of landing gear);
- mistaking one display for another; and
- difficulties in locating a display or control due to confusion over the layout of the instrument panel.

An illustration of the extent and criticality of some of these problems is provided by the high frequency of accidents due to engine failures among general aviation pilots across all levels of flight experience (NTSB, 1979a). Many such accidents are attributed to errors in operation of powerplant and fuel system management controls (NTSB, 1972f; 1974a).

Possible reasons for these problems can be identified through the human factors analysis of conventional controls and displays. Such analyses reveal several deviations from long-established human factors engineering principles.[1] Examples of such deviations include (1) display scale markings that are difficult to interpret; (2) locations of displays that make them difficult to see; (3) arrangements of displays that are incompatible with the arrangements of related controls; (4) display of information in a manner that is contrary

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[1] Comprehensive descriptions and explanations of human factors principles for displays and controls can be found in several human factors texts and handbooks (e.g., Department of the Air Force, 1977; McCormick, 1976; Parker and West, 1973; Van Cott and Kincade, 1972).

to expectations of the general population;[1] (5) layout of displays in patterns that are not optimally arranged to facilitate scanning of displays with respect to the structure of pilot information needs; (6) poor lighting of displays at night; (7) locations of controls that make them difficult to operate; (8) ambiguous labeling of control settings; (9) control operating logic that is contrary to, or does not exploit, expectations of the general population; and (10) placement of controls with similar appearance in close proximity to one another.

In addition to these deficiencies, there is lack of standardization across aircraft with respect to design of individual displays and controls that accomplish similar functions, and to the layout of these displays and controls. The lack of such standardization creates problems for pilots who are transitioning into new aircraft or who frequently fly different aircraft, as is often the case in general aviation.

All of the above deficiencies can increase the risk of error in the use of particular controls and displays. Moreover, such deficiencies can also increase workload of pilots since they may have to expend more mental and physical effort to use displays and controls with deficient designs. This increment in workload can lead to errors in the performance of other tasks critical to the safety of flight (Fitts and Jones, 1947; Ontiveros, Spangler, and Sulzer, 1978).

Support for the assertion that the above deficiencies can cause pilot performance problems can be found in the results of experimental research on the use of improved aircraft displays and controls that incorporate human factors guidance (a comprehensive review of this research can be found in Roscoe, in press). These results reveal increases in the efficiency and effectiveness of pilot performance with the use of such displays and controls in comparison with performance resulting from the use of conventional displays and controls.

Recognition of the need to assess the impact of different display and control design alternatives on pilot performance has increased over the past few years. This trend is evidenced, for example, by the conduct of human factors research to aid in the development of area navigation systems for use in general aviation aircraft (e.g., Adams, 1975; Edmonds, Pursel, and Gallagher, 1977). This research has assessed the influence on pilot performance of a number of design variables, such as display formats, and waypoint entry and storage devices, and techniques. While this research has guided the development of such systems to a certain extent, various area navigation units include heterogeneous design characteristics that do not necessarily reflect conclusions drawn from this research.

While it is recognized that user needs and constraints differ, and that ingenuity in design should be encouraged, it is logical to assume that the proliferation of designs for these systems may well lead to problems similar to those described for basic displays and controls. Given the projected increases in all-weather flying and the associated increase

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[1] For example, a basic principle of display, according to Roscoe (1968) is that the movement in a display could reflect movement of the aircraft. Roscoe presents evidence that pilots have less difficulty using displays in which this principle is followed (e.g., vertical speed indicators) in comparison with displays in which it is not (e.g., conventional attitude indicators).

in the sophistication of general aviation aircraft, many other new systems will be incorporated soon into certain general aviation aircraft (e.g., equipment for use of LORAN-C or the Global Positioning system). It is possible that such problems will occur for these and other new systems.

To prevent the possible proliferation of new pilot performance problems, as well as to address many of the present ones described above, human engineering standards and guidance need to be developed that will direct and guide the design of controls and displays for general aviation aircraft. The question arises, however, of what is needed in addition to the formal standards (such as in Part 23) and the volumes of human factors guidance concerning display and control design that currently exist. Programmatic research should be conducted that (1) reviews existing and projected future needs within general aviation for human factors criteria for the design of displays and controls, (2) determines if such needs are best addressed through standards or through more informal guidance, (3) identifies and systematizes the information that currently exists that can be adopted and employed in such standards or guidance, and (4) identifies needs for additional information that should be addressed through future research. Additionally, this research should also investigate how human factors engineering standards should be formatted and disseminated in the general aviation context since such considerations are crucial to their acceptance and use (Meister, 1971; 1972; Rogers and Armstrong, 1977; Rogers and Pegden, 1977).

Human factors engineering standards and guidance developed through the above research will serve to direct the future development of displays and controls in general aviation aircraft in a systematic manner. As such, the standards and guidance should not be overly restrictive of design ingenuity or free market competition. They should also reflect consideration of the well-established skills of the 800,000 pilots who employ current displays and controls, and of the economic and other constraints on design of general aviation aircraft. It is highly probable that the desire to avoid excessive restrictions and concern for the promulgation of standards that do not consider the above constraints have hindered the development of human factors engineering standards in the past. Rather than serving to restrict future research on these standards, however, these considerations should serve to underscore the need for programmatic, objective research. Such research should support the development of human factors engineering standards that will address pilot performance problems in an efficient, effective, and practical manner.

HANDLING CHARACTERISTICS (E).

Cooper and Harper (1969) defined handling characteristics as 'qualities or characteristics that govern the ease and precision with which a pilot is able to perform the tasks required in the support of an aircraft role.' Ellis (1974) states that handling qualities deal with 'the ease and precision with which an airplane can be flown.' The importance of handling can be seen from a human factors standpoint, because it is a complex topic dealing with both the dynamics of the aircraft and the characteristics of the human operator. Handling is of interest here as influenced by the design of the airframe and powerplant, which affects aircraft dynamics and, hence, pilot performance. Performance problems which might be expected to occur as a result of poor handling characteristics include loss of control in turbulence, poor directional control during takeoffs and landings, loss of control due to poor stall/spin characteristics, and loss of directional control during landing rollout for tailwheel aircraft. The major issue (Issue #2) identified for handling characteristics concerns the development of objective measures of handling quality and the utility of these measures in developing standards for assessing handling quality.

ISSUE #2.--OBJECTIVE ASSESSMENT METHODS FOR AIRCRAFT HANDLING QUALITIES. In 1967, the FAA initiated a program to quantify aircraft handling characteristics for the purpose of employing these data in the design process. Despite its subjective nature, a great deal was already known about the importance of handling as an aircraft design parameter. Much has subsequently been learned about what constitutes good, marginal, and unsafe handling qualities (Ellis, 1970; 1971). It has been noted, however, that descriptions and assessments of handling qualities remain rather subjective processes, with minimal FAA standards and little incentive for manufacturers to concentrate on improvement in aircraft handling. Further, FAA airworthiness standards are intended as minimal, and minimal standards appear to function more effectively for such design characteristics as structures and propulsion than for handling qualities (Roskam and Kohlman, 1974). Without sufficient impetus for change, (e.g., documented improvements in accident data or increased sales), handling criteria continue to be vague or nonexistent, and handling requirements continue to lag behind general aviation technology (Roskam, 1975; Ellis and Griffith, 1978). Consequently, a large number of general aviation aircraft, although adequate for nonturbulent VFR conditions, have marginal or dangerous handling characteristics in IFR or turbulent conditions (Roskam and Kohlman, 1974; Ellis and Steinberger, 1977). Many of these aircraft also are dangerously unstable in stalls, spins and spirals, and have poor damping characteristics, having undergone less than comprehensive airworthiness tests (Roskam, 1975). Ellis (1974) has noted that handling qualities research has failed to include experiments specifically designed to combine undesirable handling characteristics factorially. Rather, the conventional approach has been to examine the effects of several good characteristics (held constant) on one bad characteristic.

Capabilities to improve handling characteristics in the design of general aviation aircraft have been cited repeatedly (e.g., Bergey, 1978; Roskam and Kohlman, 1974; McCollough, 1979; Roskam, 1975). To support the development of such capabilities, research is needed to identify objective techniques for assessing aircraft handling qualities. Such techniques could be derived from any of a number of quantitative pilot models (e.g., Anderson, 1970; Onstott, 1972; Kleinman, Baron and Levison, 1970; Hess, 1977). The disadvantage of these models for deriving quantitative handling criteria, however, is that they are overly reductionistic in their treatment of pilot behavior. Specifically, they deal with the pilot only as a static feedback source. If standards for aircraft handling qualities are to be useful, they must be based upon objective measures which account for the complexities of both pilot and aircraft as represented by their interface. Since state-of-the-art technology has enabled a firm understanding of aircraft variables, it is the identification and analysis of human performance variables that will result in objective measures and standards of general aviation aircraft handling characteristics.

VISIBILITY (E).

Cockpit visibility is primarily a function of the design of the glareshield, windscreen viewing area, forward fuselage, wing characteristics, and seat characteristics. Visibility requirements vary with flight phase. Vertical visibility (i.e., the ability of the pilot to see what is above and below his aircraft) is critical for takeoffs, approaches, and landings. Horizontal visibility (i.e., the ability of the pilot to see what is to either side of his aircraft) is critical for avoiding midair collisions. The major design issue (Issue #3) identified for cockpit visibility concerns the development of human factors guidelines and minimum criteria for extracockpit field of view.

ISSUE #3.--EXTRACOCKPIT VISIBILITY CRITERIA AND GUIDELINES. Although the "see-and-avoid" concept has been criticized (Bain, 1969), it remains the major source of vertical and horizontal separation for VFR aircraft operating in the National Airspace System. The ability to see and avoid other aircraft is, pilot visual capability excepted, a function of external field of view. No specific empirical research on field of view requirements for general aviation aircraft was found, but the need for such research was expressed by some interviewees.

Because cockpit visibility, like aircraft handling, traditionally has been studied subjectively, minimum visibility criteria have not been carefully defined and enforced (NTSB, 1968; 1969; McCourt and Hewin, 1979). For example, current general aviation aircraft visibility guidelines are based on transport aircraft with two pilots and, as such, likely should be revised. Thielges and Matheny (1971) have developed a mathematical model for detecting shifts between internal and external reference points for helicopter pilots and for plotting the potential information density of the visual envelope. The use of such a model for depicting the pilot's visual scene may be useful in generating minimum visibility criteria for various general aviation aircraft. Examples of performance problems resulting from a lack of validated minimum visibility criteria include glidepath deviations during visual approaches, potential midair collisions, and controlled flight into terrain, all of which might result from restricted vertical visibility. Future visibility problems will be further complicated by the increased use of larger, higher performance aircraft for business purposes.

Research is needed to provide information for developing, publishing, and implementing objective minimum cockpit visibility criteria for general aviation aircraft. Such criteria should result in improved pilot performance by assuring that pilot visibility is adequate to accomplish the range of intended missions safely and efficiently.

ENVIRONMENTAL CONTROL (E).

Certain intracockpit environmental variables (e.g., oxygen, temperature, noise, and vibration) known to have adverse, and in certain cases lethal, effects on pilots in the early days of aviation have received a great deal of research and engineering attention (McFarland, 1946; 1953). Due mainly to significant improvements in aircraft design, these variables no longer present the extensive threat that they once did. However, they are still of concern (Brantigan, 1974; Roskam, 1975). The effects of these variables on performance may be sudden and dramatic, but are more often subtle and cumulative, and they may be manifested physically, physiologically, or psychologically. The major design issue (Issue #4) identified for these design variables concerns the development of human factors guidelines and standards for intracockpit noise and vibration.

ISSUE #4.--HUMAN FACTORS GUIDELINES AND STANDARDS CONCERNING INTRACOCKPIT NOISE AND VIBRATION. The effects of noise on human performance are complex, task-specific, and hard to predict (Kryter, 1970). However, previous research has determined that various types and levels of noise can degrade performance (Eschenbrenner, 1971; Hornick and Lefritz, 1966; Tobias, 1972; Childs and Halcomb, 1972). Mozell and White (1958) and Garill and Snyder (1957) have reported tracking decrement under conditions of vibration. Burns (1963) has warned that exposure to noise and vibration should be minimized because of their tendency to induce fatigue and, hence, to increase accident probability. Shaw and Allen (1968) state that lateral vibration can be especially disruptive to accurate interpretation of instrument readings and to smooth and precise control movements.

Research is needed to provide more detailed information concerning the effects of current general aviation aircraft noise and vibration characteristics upon pilot proficiency over extended time periods. The product of this research would be human factors guidelines and standards to be employed in the design of general aviation aircraft.

INTEGRATED FLIGHT MANAGEMENT SYSTEM (E).

Technological forecasts have indicated that advances in digital electronics and related technologies will have a substantial impact on the design of future general aviation aircraft (Bergey, 1978; McCollough, 1979; Smyth, 1979; Tashker, 1976; Teper, Hoh, and Smyth, 1977). Such advances include (1) airborne microprocessing units; (2) variable content displays such as cathode ray tube displays, head-up displays, and flat panel displays; (3) data entry devices for interacting with the microprocessor (e.g., keyboards, multi-function switches); (4) fly-by-wire or fiber optics control system technology; (5) new aircraft sensors; and (6) data link. This technology is currently expensive and, thus, is rarely employed in present general aviation aircraft. Projected trends toward lower costs and greater reliability indicate, however, that such technology will be used extensively in many future general aviation aircraft, such as business airplanes.

While this technology can be employed for a variety of separate functions aboard these general aviation aircraft, its full potential can only be achieved through the development of integrated flight management systems. Thus, the major human factors issue (#5) raised with respect to the use of this technology concerns the development of such systems.

ISSUE #5.--REQUIREMENTS FOR INTEGRATED FLIGHT MANAGEMENT SYSTEMS. The design of early aircraft displays and controls was limited by engineering constraints inherent in the technology that was available at that time. Thus, these displays and controls were not optimally designed with respect to pilot information processing and psychomotor abilities. Since pilots became accustomed to them, however, variations of many of these early designs continue to be employed at present. As a result, several pilot performance problems have been identified that are associated with the use of many conventional aircraft displays and controls. (These problems are reviewed in the discussion of Issue #1.)

The advanced electronics technology described above can be used to develop displays and controls that prevent such performance problems. The microprocessor, for example, can be employed to reduce pilot information processing requirements through the integrated analysis of information from different aircraft sensors and data link sources, and the transformation of this information into useful forms for display to the pilot. It also can be employed to generate information not previously available to the pilot, such as predictions of the future path of the aircraft. The flexibility of variable content displays will enable all of this information to be presented in more easily and reliably interpreted forms than possible with current analogue displays. Furthermore, use of these displays will allow the time-phase presentation of information tailored to different requirements that arise during different phases of flight. Such advances in the display of information are paralleled by advances in control system design. Use of microprocessors and fly-by-wire technology, for instance, will enable augmentation or automation of all flight control tasks, thus greatly changing the nature of the role of the pilot.

Research is being conducted at present that is exploring the use of this advanced technology for a variety of such functions, (reviews of this research can be found in FAA, 1978; and Roscoe, in press). A number of different systems are being evaluated as part of this research. As with existing aircraft displays and controls, these systems are often thought of as being separate entities; thus, their development is independently pursued by different organizations. While this research is of value in expanding knowledge concerning the use of this advanced technology, the continued independent development of applications for such technology may result in an even greater proliferation of unstandardized displays and controls than are present in current aircraft.

In addition to the pilot performance problems that may be caused by this proliferation, many other such problems may also be created if this new technology is not systematically developed. For example, given the lack of systematic analysis of information needs, variable content displays might be employed to present information in the same format as in existing analogue displays. Such 'new' displays would not solve the problems inherent in the design of old displays. On the other hand, if completely new displays are developed that require interpretative skills that seriously conflict with the well-established habits of some 800,000 current pilots, then these pilots may err in the use of the new displays. Another possible problem is that the flexibility of variable content displays may be over-exploited, resulting in too much information being presented to the pilot. Conversely, if control of the aircraft is highly automated, then the pilot may suffer from 'underload' and fail to keep track of system activities, thus lowering his ability to detect malfunctions and respond to them efficiently. Given such inactivity, many of his control skills may also degrade over time due to lack of practice.

These problems and many others may occur if the capabilities of pilots and the new technologies are not systematically considered in the design of future aircraft. Such considerations will, by necessity, include (1) identification and analysis of all of the functions that must be performed in order to accomplish mission goals; and (2) allocation of these functions to either the pilot or aircraft systems based on their relative capabilities to perform them. Only after such analyses have been conducted, can the tasks to be performed by the pilot be defined. In turn, only after these tasks have been defined can the requirements for displays and controls be specified.

The need for such a systematic approach to design is, of course, not unique to general aviation, but is common to all man-machine systems. As such, several analytical techniques have been developed to structure the design process employed in the development of these systems (reviews of such techniques can be found in DeGreene, 1970; Meister and Rabideau, 1965; Meister, 1971; Rouse, 1980; and Van Cott and Kincade, 1972). The use of such techniques has frequently resulted in the design of man-machine systems in which the role of the operator is greatly changed from that of preceding systems. In military aircraft, for example, many of the functions concerned with the direct control of the aircraft and its subsystems have been allocated to the microprocessor due to its extensive information processing capabilities. The pilot, therefore, has become more of a manager of this computerized system, rather than a direct controller of the aircraft. Correspondingly, the pilot-aircraft interface has been designed to support the pilot's role as a manager. Hence, this complex of equipment can be referred to as an 'integrated flight management system.'

When first considered, the development of flight management systems and the use of complex system analytic techniques to design these systems may seem excessive with respect to general aviation resources and needs. However, the truly revolutionary capabilities of the microprocessor and associated display and control technologies necessitate that revolutionary approaches be taken to exploit their potentials. These technologies do not simply represent opportunities for new independent displays and controls; they offer the capability to reshape the entire pilot-aircraft interface to optimize pilot performance.

Such a complete reshaping will not occur within the next few years; nor will it occur all at one time. Rather, the present interfaces will slowly evolve into new configurations. Such change should not occur, however, without a specific set of goals. Systematic human factors guidance is needed to assure that the capabilities of the new technologies and of the pilot are driving factors in the design of future pilot-aircraft interfaces.

Such guidance has been provided in military aviation through the use of generic models of pilot-aircraft interfaces that have been developed utilizing systems design procedures (Czuchry, Engel, Dowd, Baran, Dieterly, and Greene, 1976; Elson, 1977; Fink, 1978; Greer and Hanking, 1977). These models, and the information produced during their design (e.g., specification of functions, tasks, and interface requirements), provide a comprehensive design data base that can be accessed by the different sets of individuals and organizations who will design specific aircraft in the future.

Programmatic research is needed that will develop generic models of integrated flight management systems for the diverse types of general aviation aircraft that will probably employ such systems in the future (e.g., business airplanes, commuter aircraft, helicopters). Such research would employ system design procedures to determine missions that will be performed by these systems. On the basis of these and subsequent analyses, requirements for integrated flight management systems would be developed. The products of this research would serve as a systematic foundation for subsequent research on the design of future general aviation displays and controls, and for the development of human factors guidance and formal standards for such systems. They would also serve as a basis for future research on the design of other system components--e.g., aeronautical information such as that which specifies aircraft operating procedures, pilot training programs, and the certificate and rating structure.

III. AIRPORTS

Airports may be classified according to the size or type of aircraft they serve, their ownership, number of annual operations, functions, physical layout, facilities, or administrative organization (Sincoff and Dajani, 1975). There are approximately 13,000 airports (Smith, 1977) in the United States. While they exhibit many differences, one characteristic that is common to all of them is that each of these airports serves general aviation to some degree. As is true for general aviation aircraft, airports have undergone many improvements in their design and development through technological advancements that have occurred during the last two decades. These improvements have made their use easier, safer, and more efficient. However, as with aircraft, airports continue to vary greatly along a number of dimensions that affect pilot performance. For example, the location, condition, and characteristics of runways and landing aids at various airports affect landing difficulty (Bain, 1969; Bolz and Eisele, 1979; NTSB, 1973; Trammell, 1974).

The importance of airport development for community economic and industrial growth is recognized (Sincoff and Dajani, 1975; Smith, 1977). However, as with any aspect of general aviation's utility, realization of that potential is related to pilot performance capabilities. The purpose of this chapter, therefore, is to identify human factors variables in the design of airports that have known or hypothesized potential adverse effects upon the performance of pilots flying into or out of those airports. The following discussion of the runway/approach aid element of airport design includes issues related to the design of the runway and its approach aids.

RUNWAYS AND APPROACH AIDS (E).

Takeoffs, visual approaches, and landings are flight phases characterized by high accident rates (NTSB, 1973; 1976a). Aspects of airport design that contribute to accidents during these phases are conditions that affect pilot control of the aircraft while on the ground, and cueing systems that help the pilot recognize his flight status relative to takeoffs, approaches, and landings.

To some extent, the nature of problems in runway and approach aid design that adversely affect pilot performance is understood. In some instances, however, there are operational constraints related to cost and other factors that have prevented practical solutions to these problems. For example, lengthening of runways and installation of expensive runway lighting and approach aids would reduce the difficulty of landing in many conditions at some small airports. Such solutions, however, are often economically infeasible. For these reasons and because of the variability in existing runways and approach aids, there are human factors questions yet to be resolved, even though under ideal conditions some of the questions may not arise.

Two design issues concern characteristics of runways (Issue #6) and approach aids (Issue #7). These issues are not completely separable because runway characteristics also provide cues for approach. They will be treated separately, however, because feasible solutions to each issue vary with the type of airport and resources available.

ISSUE #6.--RUNWAY SURFACE, MARKING, AND LIGHTING. The relation of runway surfaces, markings, and lighting to landing accidents has been noted (Trammel, 1974; NTSB, 1973). Runway surfaces are important because they affect the stability of directional control during ground roll. Irregularities such as fractures, indentations, and potholes are significant hazards to safe and reliable takeoffs and landings (NASA, 1978a; 1978b; 1978c; 1978d; 1979; Kowalsky, Masters, Stone, Babcock, and Rypka, 1974). Also, some surfaces are dangerously slippery when wet, and even though new paving materials and friction-grooving reduce this hazard (Dosch, 1978), the expense of the new materials and friction-grooving has resulted in limited adoption of these improvements.

Of perhaps greater concern for general aviation safety is the fact that some 60 percent of the nation's airports have unpaved runways. Turf runways are naturally rougher than properly paved ones, and they are more subject to sudden deterioration. Many of them are unlighted and unmarked (Dosch, 1979).

It is primarily because of the large number of turf runways in use that runway markings pose a problem, even though much is known about types of markings that provide reliable cues to pilots. The problem is that marking systems known to be adequate involve painted patterns, and a surface must be available that can be painted. Any alternative system for use with turf runways must provide the information and cues needed to enable pilots to identify the correct turf runway and acquire a touchdown point.

Considerable effort has gone into identifying types, sizes, and shapes of objects, and colors to paint them, that can be arranged on turf to substitute for the conventional markings on pavement. Guidance for airport identification, circling guidance, final approach, taxiing, etc., may have been defined (Dosch, 1978). However, there is still a need for empirical data to verify the adequacy of newly developed low-cost systems for general use in marking turf airports. Also of concern is the large number of inadequately marked paved runways that have been reported, as well as variability in runway marking across airports (NASA, 1978a; 1978b; 1978c; 1978d; 1979).

Problems with runway lighting for turf (and in this case many paved) runways closely parallel those of marking. Generally, airports that cannot afford paved runways cannot bear the expense of acquiring and maintaining state-of-the-art lighting either. The task is to develop lighting systems that fulfill pilots' perceptual needs but that, as with marking, do not require sizable capital investments or maintenance expenditures.

The minimum needs for lighting are clearly identifiable references for taxiing, for lateral and vertical control during takeoffs and landings, and for touchdown points (NASA, 1978a; 1979; Kowalsky, Masters, Stone, Babcock, and Rypka, 1974). Difficulties in designing lighting systems derive from glare and the absence of contextual depth cues. The lights must not blind the pilot, and, more or less by themselves, they must provide the depth cues needed for accurate judgments of aircraft status relative to the runway (Roscoe, 1979).

The study of marking systems for turf airports referenced above (Dosch, 1978) included development of a lighting system that may satisfy at least minimum requirements. As with marking, however, empirical verification of the adequacy of the system for general use is needed.

In view of the considerable work that has already been done regarding runway surfaces, markings, and lighting, the human factors problems that remain concern mostly adaptations of, or substitutions for, state-of-the-art accomplishments for the numerous airports without paved runways and many other small facilities that cannot afford to acquire and maintain the technology available. As for turf surfaces per se, it is not known how varying textures of turf, weight and takeoff/landing speeds of aircraft, and control characteristics of aircraft interact to present control problems to pilots. If the nature of these interactions were known, limits for safe aircraft operation could be derived for combinations of these factors.

The problems of marking and lighting for turf and other small airports may be partially solved. However, tests of prototype systems have apparently been restricted to a single location. It has not yet been determined whether the systems are adequate for the range of general aviation pilots, missions, and aircraft.

The development of applicable human factors standards and guidelines related to these airport design issues depends on the availability of research data.

ISSUE # 7.--APPROACH AIDS. The purpose of approach aids is to provide information and cues during landing that enable the pilot to maintain a precise glideslope and proper closure rate. State-of-the-art approach aids such as the Visual Approach Slope Indicators (VASI), Instrument and Microwave Landing Systems (ILS and MLS), and Runway End Identifier Lights (REIL) can generally be adequate for these purposes. Information regarding wind source and sudden variations in wind can also be provided with precision.

For general aviation, the problem with approach aids is largely the lack of availability of the above systems at many of the airports. Increased installations are anticipated, especially for ILS and MLS (Scheftel, 1979) at higher density airports. But, even so, the MLS, which is more accurate and more resistant to interference than ILS, and which permits curved approaches, will be installed at fewer than 10 percent of the nation's airports by 1982 (Sincoff and Dajani, 1975). The VASI system is not available at many airports (and apparently will not become so in the near future), and a number of facilities do not have wind direction, speed, or gust information (NTSB, 1973; 1976a).

Furthermore, questions remain regarding optimum configurations of VASI. Variables such as form, location, range, signal characteristics, and display pattern have been shown to affect pilot proficiency in acquiring and maintaining proper glide slope (Mertens, 1978; Lewis and Mertens, 1978; Dosch, 1979; Lintern, 1979). In some cases, the findings introduced additional human factors complications. For example, Lewis and Mertens (1978) found that a VASI configuration that yielded greater precision in glideslope information than usually provided by conventional configurations also made greater information processing demands on pilots. As stated in Chapter II, providing the pilot with more information does not necessarily improve performance unless the pilot knows how and when to use the additional information.

Questions remain even regarding optimum ways to identify obstacles near the approach path. This is clearly a matter of perceptibility and interpretability of the markings on obstacles (Van Cott and Kincade, 1972). While recommendations for markings have recently been made (Dosch, 1978), it is not known, for example, whether they are adequate during nonprecision IFR approaches which are common at most smaller airports.

As with runways, state-of-the-art technology regarding approach aids appears sufficient for most present purposes. Whether it will be adequate as airport traffic increases is another matter, however. The difficulty is mostly lack of approach aid availability at a large number of airports. It is therefore necessary to provide alternative cueing systems that smaller facilities can and will procure. Runway markings, discussed earlier, can provide the necessary cueing under many conditions, but their value varies with clarity of the visual scene. Furthermore, the efficiency of use of information provided by approach aids depends on the precision inherent in the cueing and the pilot's ability to interpret the information precisely. If too much attention and effort are required, other aspects of task performance may be slighted to the extent that flight safety is jeopardized.

These points are only examples of the uncertainties still surrounding use of approach aids and alternatives for state-of-the-art systems. Additional specific questions cannot be raised at this time because research up to now has not been sufficient to pinpoint design issues that affect pilot performance. Hence, future research should be concerned as much with defining critical questions concerning these issues as with answering existing ones.

IV. AERONAUTICAL INFORMATION

General aviation pilots employ a variety of information, in addition to that available from aircraft displays, in the preparation for and conduct of their flights. A portion of this information is published in various written documents concerned with (1) operation of the aircraft (e.g., normal operating procedures), and (2) utilization of the national airspace system (e.g., instrument flight procedures). The other principal aeronautical information source is the real-time communications with various FAA agencies. Such information is vital to a variety of flight planning and coordination functions (e.g., weather information, ATC clearances).[1]

The content and format of this information are considered here because they are operant factors in determining the nature of the task demands faced by general aviation pilots. Some of the information, for example, is in the form of directly prescriptive procedures that the pilot should follow. Such procedures may vary with respect to (1) the demands they impose upon the pilot's information processing capabilities, (2) their adequacy in guarding against pilot errors, and (3) the margin of safety they provide with respect to unforeseen problems. Simply put, some procedures can be less demanding and safer than other procedures designed for the same task.

Other aspects of the information used by the pilot may involve data which the pilot employs as input for making decisions. In such cases, the adequacy of the data with respect to the pilot's needs can influence the decisions he makes and, thus, performance resulting from those decisions. Moreover, the way in which this information is presented can influence the pilot's ability to interpret it correctly and efficiently.

Aeronautical information should be designed to match the requirements of pilots for the information, and their ability to interpret and utilize it. The human factors issues associated with the design of this information relate to its content, means of delivery, and format. To structure their review, the issues for this component have been grouped into three major design elements, as follows:

(1) documented information concerned with operation of the aircraft,

(2) documented information concerned with use of the national airspace system, and

(3) information exchanged in real-time between pilots and FAA agencies (i.e., tower and en route control centers, flight service stations).

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[1] In a less formal or structured way, the pilot also receives third-party information by way of his 'party-line' listening to communications involving other aircraft and ground agencies. Certain design manipulations of aspects of such party-line communication are possible, but they are not considered here. For example, studies have been conducted in Canada relating to the party-line losses or gains in information by third-party pilots as a function of whether such communications are monolingual or bilingual.

INFORMATION CONCERNING OPERATION OF THE AIRCRAFT (E).

Information concerning operation of the aircraft and its various optional subsystems (e.g., navigation and communications equipment) is generated in a number of ways. Design and flight test data, for example, are employed to determine aircraft performance capabilities and limitations. Moreover, such data are used to identify methods of operation that maximize mission efficiency and provide sufficient margins of safety, while minimizing fuel consumption and wear on the aircraft. Similarly, subsystem design and test data are used to determine capabilities and limitations, as well as to identify or develop methods of operation that maximize those capabilities and minimize the limitations. Additional information concerning the operation of specific aircraft and subsystems accumulates over time as experience is gained with their use in a variety of different contexts. Such aircraft- and subsystem-specific information is supplemented further through the judicious extrapolation of information generated for other similar aircraft and subsystems.

Thus, a considerable amount of information is available that is employed to guide or aid pilots in the operation of their aircraft. While use of some of this information may be at the pilots option, much of it is directive in nature and, thus, plays a major role in defining pilot task demands. Such information can be classified into two basic categories: (1) normal and emergency operating procedures; and (2) descriptions of aircraft and subsystems performance.

Normal operating procedures are specified for a number of the tasks that the pilot performs routinely, such as takeoffs, landings, and operation of navigation systems. Additionally, emergency procedures are specified to direct the pilot in coping with equipment malfunctions and other disruptive events. Specifications of these procedures serve as (1) pilot aids that can be consulted each time a task is performed, and (2) input for the determination of pilot training requirements. The content of procedures for a given task influences the manner and adequacy with which both these functions are served. Thus, if pilot capabilities are not considered in the design of procedures, pilot performance problems may occur as a result of their use.

Not every action of the pilot can, or should, be guided by procedures. Indeed, the majority of pilot actions depend on real-time decisions made without specific procedural guidance. To make these decisions, however, pilots need accurate data concerning what their aircraft and its subsystems can and cannot do. Thus, general aviation pilots should be provided with all relevant data concerning the performance capabilities and limitations of the aircraft and its subsystems.

Four major human factors issues (Issues #8 - #11) were identified that are associated with the specification of information concerning operation of the aircraft: (#8) identification of requirements for normal and emergency procedures; (#9) determination of methods for disseminating information describing procedures; (#10) determination of requirements for aircraft and subsystem performance data; and (#11) specification of formats for presenting such data to pilots.

ISSUE #8.--AIRCRAFT OPERATING PROCEDURES. The principal sources of information concerning aircraft operating procedures are the pilot handbooks that are produced for each make and model aircraft by the manufacturer of the aircraft. In recent years, some of the procedures presented in these handbooks have been criticized in a number of accident analysis reports as being incomplete, inappropriate, unclear, lacking in detail, or difficult to use (NTSB, 1967; 1969; 1971a; 1972b; 1975b). In response to these criticisms, the General Aviation Manufacturers Association developed specifications for pilot operating handbooks that were intended to improve the way in which procedures were specified (General Aviation Manufacturers Association, 1975). Recent informal reviews of handbooks designed to meet these specifications have concluded that they are much improved (NTSB, 1979b; Lawton and Livack, 1979). No systematic, empirical assessments have been made, however, of the effects on pilot performance of the procedures specified in current handbooks or of those specified in various other sources. Given the importance of these procedures and their previous attribution as potential factors in pilot performance problems, it would appear that such an evaluation is needed.

In addition to information needed to assess the adequacy of procedures as currently specified, there is also a need to identify requirements for procedures for the use of new equipment being introduced into the general aviation fleet. An illustration of the criticality of this need is furnished in the results of research on different procedures for using area navigation systems (Eldredge, Goldberg, and Crimbring, 1978; Jensen and Roscoe, 1974). These results indicate that the type of procedures employed to direct operation of area navigation systems can influence the workload of pilots and, consequently, their ability to prevent navigational errors. Thus, requirements for procedures will increase as aircraft complexity increases.

Not much is known, however, concerning the manner in which different aspects of such procedures affect general aviation pilot performance. Indeed, procedures can be considered to be one of the "gray areas" of aviation safety (Hurst, 1976). Research is needed that will aid in the development of requirements for the specification of normal and emergency operating procedures. Emphasis should be placed on the analysis of pilot information needs with respect to the operation of new equipment being introduced into the general aviation fleet. Additionally, the results of recent investigations in military aviation and air carrier contexts have highlighted the need for research to aid in the development of improved emergency and crew coordination procedures (Kowalsky, Masters, Stone, Babcock, and Rypka, 1974; Lucaccini, 1978; NTSB, 1976; Smith, 1979). In view of the increasing numbers of crewed aircraft in general aviation, research on procedures for use in general aviation should also focus on these topics.

ISSUE #9.--DISSEMINATION OF AIRCRAFT AND SUBSYSTEM OPERATING PROCEDURES INFORMATION. Aircraft and subsystem operating procedures are available to the pilot from a variety of sources other than pilot handbooks. Procedures specific to a given aircraft and its subsystems are specified in a variety of other manuals, bulletins, placards, and other such publications produced by the aircraft and subsystem manufacturers. Additional information concerning procedures common to all aircraft or common to all aircraft of a given kind can be found in a number of government publications, as well as in books, magazines, and other aviation literature available to the general aviation pilot.

Some of the information concerning procedures is provided in the form of job aids designed to be consulted regularly by pilots as they perform their tasks. Other information is presented in material designed to support general pilot training. Questions arise as to which procedures should be specified in job aids and their format. As aircraft become more complex, requirements for procedures increase. One has only to look at the voluminous operating manuals utilized in military and commercial aviation to confirm the potential magnitude of this problem. The sheer size and bulk of these manuals present substantial problems, not to mention the more complex questions of determining what should go into these manuals, how they should be organized, and the preferred format for presenting information (Smith, 1979).

Ample guidance exists for (1) conducting tradeoff analyses between training requirements and requirements for the content of job aids, and (2) the design of job aids (Foley, 1979; Booher, 1978). Further research is needed, though, that will adapt this guidance to requirements and constraints existing in general aviation, and that will provide means to implement such guidance to the development and evaluation of job aids for general aviation pilots.

ISSUE #10.--AIRCRAFT AND SUBSYSTEM PERFORMANCE DATA. Pilot handbooks have been criticized in the past with respect to the adequacy with which they have presented performance data related to the aircraft and its subsystems (Aarons, 1973; Ellis and Steinberger, 1977; NTSB, 1967; 1972e; 1973; 1979b; Trammel, 1974). Such criticisms concerned (1) the lack of aircraft performance data critical to the conduct of safe flight and to the avoidance of flight hazards, (2) the lack of data or correction factors describing the effects of different conditions (e.g., different runway surfaces or load conditions) on aircraft and subsystem performance, and (3) the inclusion of performance data that were misleading to the average general aviation pilot. The latter criticism stems from the fact that such data usually are calculated using test pilots who are able to attain maximum performance from the aircraft that may be beyond the capabilities of the typical general aviation pilot. The General Aviation Manfacturers Association specifications for pilot operating handbooks addressed these criticisms (General Aviation Manufacturers Association, 1975), but as with procedural information, the adequacy with which performance and limitations data are currently presented and the effects of such data presentations on pilot performance have not been systematically and empirically assessed.

Just as with procedural information, the need for aircraft and subsystem performance data will increase as general aviation aircraft become more complex. Indeed, much of this new equipment will be quite foreign to most general aviation pilots. Furthermore, given the present lack of specifications for standardizing many aspects of such equipment, there will probably be substantial differences in performance capabiliites between makes and models of equipment designed to accomplish similar functions. The efficient and safe use of this varied equipment will depend in large part on the quality of information provided to the pilots. A particularly important concern is that new equipment should not be exploited to increase mission efficiency at the expense of increasing the risk of accidents.

Research is needed to determine requirements for aircraft and subsystem performance data. Emphasis should be placed on the determination of requirements related to the operation of advanced equipment.

ISSUE #11.--FORMATS FOR AIRCRAFT AND SUBSYSTEM PERFORMANCE DATA. In addition to past criticisms of the content of performance data in pilot handbooks, other problems were identified concerning the format in which those data were presented (NTSB 1967; 1979b).

These problems included, for example, the presentation of data in charts and tables that were difficult to interpret. The instructions for use of the charts and tables were, at times, complicated and difficult to understand. Further, data were often specified in dimensions more useful to engineers than to pilots. Such problems can confuse and frustrate the pilot and increase the likelihood of his making errors in interpreting such data. As a result, pilots may initiate actions that exceed the capabilities of their aircraft. Thus, the format for such information can have definite consequences for flight safety.

Already accomplished research on job aids (Booher, 1978) provides substantial guidance for the development of adequate formats for the presentation of data describing aircraft and subsystem performance capabilities. Research is needed, however, to determine how this guidance can be employed in the general aviation context.

INFORMATION CONCERNING USE OF THE NATIONAL AIRSPACE SYSTEM (E).

The FAA is responsible for assuring the safety and efficiency of the nation's airspace. As part of the activities performed to carry out this responsibility, the FAA specifies regulations for use of the airspace and operates an extensive system of air traffic control (ATC) and navigation facilities. These activities are designed to respond to a number of objectives, chief among which are (1) meeting requirements for the safety of civil aviation, (2) meeting the growing demands for use of air routes and terminals, (3) increasing the productivity of the ATC system to keep down operating costs as it continues to grow, (4) protecting the environment, and (5) conserving energy consumed by civil aviation (FAA, 1975). Because of their importance, these activities have been the subject of extensive research (see reviews in Albrecht, 1980; FAA, 1978; and Poritzky, 1977). With respect to the objectives of this report, however, only the aspects of these activities that impact on the performance of the general aviation pilot are of interest.

General aviation pilots interact with such activities in two major ways. First, the pilots are responsible for interpreting and adhering to regulations and other documental information prescribing rules for use of the nation's airspace. They also communicate with ATC facilities to aid in the planning, conduct and coordination of their flights. In this section, three human factors issues (Issues #12 - #14) impacting on the use of documented information concerning use of the National Airspace System are identified: (#12) assessment of the impact of different airspace assignments on pilot performance; (#13) determination of minimum visibility requirements for flight under visual flight rules[1] in uncontrolled and controlled airspace; and (#14) development of guidance for the design of instrument flight procedures that are optimized in terms of their effects on pilot performance.

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[1] All flights are conducted under either visual flight rules (VFR) or instrument flight rules (IFR) (FAR 91). While a number of distinctions exist between visual and instrument flight rules, for purposes of the present discussion the major differences are (1) VFR flight may be conducted without the need for coordination by ATC agencies, except in certain types of controlled airspace; and (2) IFR flights, which are coordinated and monitored by ATC agencies, may fly in instrument meteorological conditions with limited or no visibility, while VFR flights have minimum visibility and cloud clearance standards.

ISSUE #12.--IMPACT OF DIFFERENT AIRSPACE ASSIGNMENTS ON PILOT PERFORMANCE.

To assure the safety and efficiency of flight, the national airspace is divided into uncontrolled and controlled segments. Only a few restrictions are placed upon pilots operating under visual flight rules with respect to the use of uncontrolled airspace--e.g., minimum visibility and cloud clearance requirements to assure that pilots operating within uncontrolled airspace are able to see and avoid other aircraft.

Other segments of the airspace are designated as a variety of different types of controlled airspace--i.e., continental control area, control area, control zones, terminal control areas, and transition areas. When so designated, the airspace is supported by ATC facilities, and additional restrictions are placed upon some or all of the aircraft operating in this airspace to assure safe operations. Controlled airspace segments, particularly control areas associated with certain heavily used airports, are specified when the FAA believes that positive control of aircraft by ATC facilities is necessary to assure adequate separation between aircraft and/or to enable more efficient use of the airspace.

Airspace allocation decisions are often controversial, particularly when they pertain to the establishment of terminal control areas (TCAs) (NASA, 1977b). The designation of such controlled airspace in terminal areas with dense traffic is usually favored by air carrier pilots who feel that the high workload requirements and high speeds of their aircraft restrict their ability to see and avoid other aircraft, especially smaller, slower aircraft. TCAs are also usually favored by air traffic controllers who are responsible for terminal radar operations. They feel that they cannot cope safely with large numbers of high speed aircraft in combination with slower aircraft not under their control. Many general aviation pilots, however, find mandatory traffic control awkward and time consuming. Indeed, some feel that the extra workload required for operations in many controlled areas detracts from their ability to carry out other actions required for safe flight (Wiener, 1979). Increased impetus to the demands for increased restrictions on airspace utilization result when a general aviation aircraft collides with an air carrier aircraft, regardless of the cause of the accident (Wiener, 1979).

The controversy over TCAs, as well as the other forms of controlled airspace, can be expected to expand in future years as the volume of air traffic increases. Moreover, changes in general aviation missions and aircraft, as well as in air traffic control systems, will create new demands for airspace utilization. For example, optimization of the use of civil helicopters will require changes in the design of route structures and other types of controlled airspaces (FAA, 1978; 1979). Similarly, optimization of the use of area navigation systems will impose new demands for the allocation and design of airspace to assure effective margins of safety (Edmonds, Pursel and Gallagher, 1977; Jensen and Roscoe, 1974). The same will be true of other advanced aircraft systems.

Present and future demands for airspace allocation require that a number of decisions be made. The need for controlled airspace must first be clarified. Given this clarification, the actual configuration of the controlled airspace must then be designed. The configuration is driven by a number of factors--e.g., the number and type of airports located in close geographic proximity, the number and type of aircraft that will be utilizing the airspace, the terrain and communities beneath the area (NASA, 1977b). The performance of general aviation pilots must, however, also be considered in the design of airspace segments. The design of the airspace can influence the performance of general aviation pilots in several ways. The complexity of the configuration of the airspace, for example, in combination with the equipment on a particular aircraft, determines the tasks the pilot must perform to identify boundaries of the airspace. Additionally, the size of an airspace, particularly air corridors, determines demands on the pilot for precision of navigation. Most importantly, the very existence of controlled airspace greatly changes task demands for general aviation pilots by increasing requirements for certain navigation and communication tasks.

To assure that factors governing pilot performance are adequately considered in the design of controlled airspace, programmatic research is needed that will furnish a systematic method of analyzing and empirically evaluating the impact of different aspects of the design of controlled airspace on the performance of general aviation pilots. To be efficient, such research should be integrated with other efforts designed to address airspace allocation issues from other viewpoints--e.g., their impact on the proficiency and productivity of controller performance.

ISSUE #13.--MINIMUM VISIBILITY AND CLOUD CLEARANCE STANDARDS FOR VFR FLIGHT. Operations within controlled or uncontrolled airspace utilizing visual flight rules require that the pilot be able to see and avoid other aircraft, and navigate safely with respect to high obstacles and other terrain features. Visibility from the cockpit is, in part, determined by the design of the aircraft. Visibility is also influenced by atmospheric conditions such as fog, haze, clouds, and smoke. Federal Aviation Regulations (FAR 91.105) specify minimum visibility and cloud clearance standards for VFR flight in controlled and uncontrolled airspace. These standards tend to be more restrictive for controlled than for uncontrolled airspace due to the increased probability of mixed VFR and IFR flights.

The adequacy of these standards at present has been questioned with respect to the margins of safety provided for the detection of and reaction to threats of midair collisions. These questions have arisen due to concern over the trend toward increased airspeeds and rates of climbs and descents of modern aircraft. It is felt that as these speeds increase, the danger of midair collisions will also increase. Moreover, the trend toward increasing frequency of IFR flights (Bolz and Eisele, 1979) will result in an even greater mix of IFR aircraft and VFR aircraft in some airspace.

Many of these factors were considered in an analytic study of minimum VFR visibility and cloud clearance standards conducted by Rowland and Reichwein (1971). Based on the results of that study, several recommendations were made for changes in such standards. Some of the recommended changes concerned requirements for increased distances from clouds to accommodate the greater airspeeds and climb and descent rates of modern aircraft. Other changes represented attempts to vary the visibility requirements with respect to airspeed, allowing faster flight when visibility is greater.

Advocacy of these proposals was limited, however, by certain constraints that restricted the confidence that Rowland and Reichwein felt could be placed on their findings. They felt that additional work, particularly empirical investigation, was needed to verify and extend the results of their analytic study. Such research should also systematically investigate the need for modifications to these standards.

ISSUE #14.--GUIDANCE FOR THE DESIGN OF INSTRUMENT FLIGHT PROCEDURES. When pilots are flying under instrument flight rules, their actions with respect to navigation and coordination with ATC facilities are prescribed by instrument flight procedures. Since these procedures and aircraft operating procedures jointly define task demands, their design has a substantial impact on pilot performance. While the specific content of a given set of instrument flight procedures depends on factors unique to a particular air route or terminal area (e.g., availability of navaids, terrain features, configuration of runways), standardized methods for designing such procedures are availabile for use by the personnel who have responsibilities for this function (FAA, 1976). One of the major considerations in the development of instrument flight procedures is the ability of pilots to perform the procedures safely and efficiently.

When instrument flight procedures are properly followed, they assure safe and efficient flight. Such procedures, however, are often inherently difficult. They may require pilots to timeshare the tracking of several different navigation displays with the performance of other activities related to the safe and efficient operation of the aircraft. Moreover, pilots must periodically communicate with ATC facilities and consult assorted charts and other documents that provide them with information concerning the instrument flight procedures appropriate for their flights. The total demand created by this complex of activities must be considered in the design of procedures. If not, the demands imposed on pilots by instrument flight procedures may exceed pilot capability to perform them. If, for example, procedures require pilots to perform tracking tasks that are beyond their capabilities, given their skill and the precision of their navigation systems, then they may make critical flight errors resulting in excursions from prescribed airspace. Or, if procedures are overly complex, pilots may be distracted from the performance of other activities required for safe flight, such as maintenance of an effective scan of flight and engine instruments and of the outside airspace. Accidents that can result from such performance problems are varied. They include midair collisions, controlled flight into the ground, loss of control of the aircraft, or a variety of approach and landing mishaps. Several accident and incident analyses have attributed some of these problems to the design of certain instrument flight procedures (NTSB, 1969; 1973; NASA, 1978a). However, such information does not provide an adequate basis for systematic revision of instrument flight procedures.

Guidance for the design of instrument flight procedures is also needed for the prevention of possible future problems. Projected changes in general aviation aircraft and in the ATC system will have a dramatic impact on the nature of instrument flight. Full exploitation of area navigation systems, for example, will require the continued analysis of how these systems can be accomodated by the modification of current instrument flight procedures (Adams, 1976; Bolz and Eisele, 1979; McConkey and Halverson, 1978; Malo, 1977). Similarly, exploitation of the capabilities of other advanced airborne equipment, as well as new ATC system equipment to assure safer and more efficient IFR flight, will also depend on the modification of current instrument flight procedures.

Thus, instrument flight procedures will be undergoing continual modification for a variety of reasons. To aid in design decisions concerning these modifications, research is needed to generate data that describe the impact of different procedural alternatives on pilot performance.

COMMUNICATIONS WITH AIR TRAFFIC SERVICE FACILITIES (E).

During their preparation for and conduct of flights, general aviation pilots frequently communicate with three major types of air traffic service facilities--Flight Service

Stations, control towers, and Air Route Traffic Control Centers (FAA, 1977a). Flight Service Stations have the prime responsibility for preflight briefings of pilots, enroute communications with VFR flights, assisting lost aircraft, broadcasting aviation weather information, accepting and closing flight plans, operating national weather teletypewriter systems, and several other functions that necessitate their frequent interaction with general aviation pilots. Control towers are tasked with the responsibility for the safe, orderly, and expeditious flow of traffic at or in the vicinity of airports. In addition, airports may have responsibility for the separation of IFR aircraft in the terminal areas (referred to as approach control). The Air Route Traffic Control Centers provide air traffic service to aircraft operating on IFR flight plans within controlled airspaces, principally during the enroute phase of flight.

Given the importance of these information services to pilots, their efficiency and adequacy with respect to pilot needs have substantial impact on pilot tasks and pilot performance. Two major human factors issues were identified for this element: (#15) determination of requirements for communications between general aviation pilots and air traffic control personnel; and (#16) determination of requirements for communications between these pilots and flight service personnel.

ISSUE #15.--COMMUNICATIONS BETWEEN GENERAL AVIATION PILOTS AND AIR TRAFFIC CONTROL PERSONNEL. Given the growing size and complexity of the National Airspace System, the problem of the ground control of aircraft is itself a subject of extensive research. (Reviews of such research and its projected impact on general aviation can be found in Albrecht, 1980; Bolz and Eisele, 1979; Del Balzo, 1977; and Poritzky, 1977.) Indeed, the subject of human factors in the ground control of aircraft has been a major concern (Hopkins, 1970; Buckley, House, and Rood, 1978).

The major objectives of research in this area are to improve aviation safety, increase the productivity of air traffic control systems to handle more aircraft, and minimize expense to the FAA and to the users in traffic movement. With respect to the objective of the present report, however, the major interest in air traffic control is with respect to the adequacy of information provided to general aviation pilots in meeting their needs.

Several analyses of aviation accidents and incidents have identified a number of problems in communications between air traffic control personnel and pilots (NASA, 1971; 1977a; 1978a, 1978b; Wiener, 1979). Examples of such problems include (1) misunderstandings of communications; (2) high communications workloads that distract pilots (and controllers) from other tasks necessary for safe flight; (3) saturated communications channels, due to the large numbers of concurrent users, that inhibit communications; (4) omissions of information needed or expected (whether legitimately or not) by the pilot; (5) errors in the content of information; and (6) failure of pilots to remember clearances or other transmissions correctly. These problems lead not only to the occurrence or increased risk of midair collisions, but also to controlled flight into the ground or high obstacles, loss of control of aircraft, and landing/takeoff accidents.

Additional information concerning pilot and air traffic control personnel is derived from the results of research that has investigated such problems (Hopkins, 1970; Loftus, 1979; Smith and Parker, 1969). The results of this research have indicated that there is substantial room for improvements that will reduce communication errors and workload and that will increase the utility of the information that is transmitted.

To address these problems and several other criticisms made of current air traffic control systems (GAO, 1979; Richardson, 1979), the FAA has instituted research to develop new air traffic control equipment and procedures. Many of these programs will have a substantial impact on the nature of communications between general aviation pilots and air traffic control personnel, as well as on the nature of their shared responsibilities. The implementation of data link (discussed in Chapter II), for example, will greatly change ground to air communications. Smith and Parker (1969) reported research that showed that data link can improve such communications (1) by reducing the need for oral communication (and, hence, reducing pilot workload); (2) by enabling a greater amount of information to be transmitted; and (3) when supported by advanced aircraft displays, enabling weather, traffic, and vectoring information to be presented in a visual format that is more efficient and more easily interpreted than verbal descriptions. Furthermore, the use of data link to transmit information concerning other air traffic can enable the pilot to assume greater responsibility for the separation of his aircraft from that traffic. (A review of the other types of information that may be transmitted via data link can be found in Smyth, 1979.)

Another change that will have a large influence on air-to-ground communications is the increased automation of air traffic control systems (Klass, 1979; Poritzky, 1977). Various automation programs have the potential for increasing the efficiency and effectiveness of air traffic control. However, the achievement of this potential, as well as the potential projected for other ground and airborne advances in air traffic control, will depend on the adequacy of transmitted information, both oral and data link, with respect to the general aviation pilot's needs. Advances, such as automation, will result in even greater demands in this area.

Programmatic research is needed to determine systematically the requirements of general aviation pilots for information from towers and Air Route Traffic Control Centers. This research should identify the information that (1) pilots want, (2) they need, (3) they can get from present and future air traffic control systems in different segments of the national airspace, and (4) the information that pilots can and will use, given their capabilities and concurrent workload. Emphasis should be placed in this research on the determination of information for IFR and VFR operations by pilots who do and do not have airborne equipment (e.g., data link) for using new air traffic control services. This investigation will lay a comprehensive foundation for determining the type of information to be collected and processed on the ground, and the optimal formats (e.g., data link or oral) for transmitting this information to the pilot.

ISSUE #16. COMMUNICATIONS BETWEEN GENERAL AVIATION PILOTS AND FLIGHT SERVICE STATION PERSONNEL. The FAA is currently revising and modernizing the Flight Service Station system. The goals of this effort are to address problems that degrade the effectiveness and efficiency of Flight Service Station operations. Examples of these problems are (1) delays in services to pilots, (2) inefficient data management systems, and (3) inefficient information dissemination systems that are labor intensive and costly (Roche, 1977). With respect to the objectives of this report, interest in Flight Service Stations and programs for their improvement is derived from concern over the interchange of information, particularly weather information, between pilots and Flight Service Station personnel. Weather information is important because general aviation accidents frequently result from the flight of non-instrument and instrument-rated pilots into weather conditions that create demands which exceed their abilities. Several of the reports that were reviewed concluded that weather information to better serve the requirements of general aviation pilots is needed (Bolz and Eisele, 1979; Forsyth and Shaughnessy, 1978; Goff, 1979; NTSB, 1974b; 1976b). Additionally, concern was expressed over the use of technical jargon and complex weather charts that might be confusing to some general aviation pilots (NTSB, 1974b).

One of the objectives of the Flight Service Station modernization program is to address the problem of providing better weather data to general aviation pilots (Sowar, 1977). Improvements in data management systems will enhance the quality of weather information that will be available to Flight Service Station personnel. Questions arise, however, concerning the transmission of this information to general aviation pilots. This concern is especially acute with respect to the use of automated pilot briefing systems. These systems are being developed to increase the capacity and to reduce the costs associated with disseminating weather and other information to pilots (Pazera, 1976). A number of interfaces are being considered, such as touchtone telephones, voice recognition systems and telephones, and mini-computers with video terminals.

The automation of the interface between pilots and Flight Service Stations increases the need for precise descriptions of pilot information requirements. Given the diversity of general aviation pilots and missions, these needs, as well as the abilities of the pilots to interpret weather information, are quite varied. There is concern that the automated systems, as planned, will not be able to serve these varied needs (GAO, 1979).

Research is needed that will identify and analyze the requirements of general aviation pilots for information from Flight Service Stations. As part of this research, the ability of general aviation pilots to interpret and use information presented in a range of automated formats should be evaluated.

V. PILOT CERTIFICATION AND RATING STRUCTURE

Due to constraints on the design of aircraft, airports, and aeronautical systems, flying is, and will remain for the foreseeable future, a demanding job. Thus, pilot performance problems must also be addressed through the implementation of actions designed to improve the abilities of general aviation pilots and to increase their motivation to perform flight tasks reliably. In large military, government, or industrial systems, the identification and performance of such actions are frequently the responsibility of a unified personnel system. Although no such system exists within general aviation, many of the functions that are performed by these systems--i.e., selection, training, and proficiency assessment--are performed through a variety of loosely structured, formal and informal mechanisms.

In the present framework for viewing human factors issues in pilot performance problems, three personnel-related components were identified (see Figure 3) that accomplished the above functions in general aviation. These components are (1) the pilot certification and rating structure, (2) training and proficiency assessments conducted for certificates and ratings, and (3) continuation training and recurrent proficiency assessments. The present chapter reviews issues in the design of the pilot certification and rating structure, while the next two chapters concern the other components.

The pilot certification and rating structure is the primary mechanism for matching general aviation pilots with task requirements. Four levels of pilot certification are specified in Part 61 of the Federal Aviation Regulations. These are (1) student, (2) private, (3) commercial, and (4) airline transport pilot. There is also a separate certificate covering flight instructors.

The regulations specify that certain tasks may be performed only by pilots holding particular <u>certificates</u>. They also specify that certain other tasks may be performed only by pilots holding several different types of <u>ratings</u>, which may be placed on all of the above certificates except for student. Most of these ratings pertain to the type of aircraft a pilot may fly, such as aircraft category ratings (airplanes, rotor craft, glider, lighter-than-air), and airplane class ratings (single-engine land, single-engine sea, multi-engine land, multi-engine sea). The instrument rating designates which pilots can fly under instrument flight rules. Performance of tasks not specifically limited to certain certificates or ratings by the regulations is left to the discretion of the individual pilot.

With respect to the pilot certification and rating structure, human factors issues have arisen concerning the following elements: (1) entry level requirements for each of the certificates and ratings, and (2) the subset of tasks that can be performed by a pilot holding a given certificate or rating.

ENTRY LEVEL REQUIREMENTS (E).

Federal Aviation Regulations specify different entry level requirements for each of the certificates and ratings. These requirements serve as one selection mechanism for screening out individuals who are not likely to be able to perform competently the tasks required by the certificate or rating. As with other Federal Aviation Regulations, the standards imposed by these entry level requirements represent a tradeoff between the need to protect public safety and the desire to prevent undue restriction of an individual's freedom to use public airspace.

Two major design issues have been raised with respect to entry level requirements: (#17) determination of experience requirements, and (#18) determination of medical/ psychophysiological requirements.

ISSUE #17.--EXPERIENCE REQUIREMENTS. Certain certificates and ratings require a minimum amount of flight time before pilots become eligible for them. For example, 200 hours of total flight time are required before a private pilot may obtain an instrument rating. This particular requirement has recently received considerable attention. Specifically, suggestions have been made that the experience requirement be lowered to enable private pilots to obtain instrument ratings soon after they finish private pilot training or even in conjunction with such training (Collins, 1980; McCourt and Hewin, 1979; Lawton and Livack, 1979).

Impetus for these suggestions is derived from concern over the disproportionately high percentage of pilots with fewer than 200 hours who crash after inadvertently entering instrument meteorological conditions where visibility is reduced and flight by reference to aircraft instrument displays is necessary (NTSB, 1974b). An additional concern derives from the increases in the frequency of general aviation missions requiring operations under instrument flight rules. Research is currently underway as part of the overall program in which this project was conducted that addresses this specific question.

Additional research is needed that will assess experience requirements for other certificates and ratings (e.g., certificated flight instructor) to determine their utility with respect to the prevention of current and potential future pilot performance problems. This research should also include the investigation of alternative methods that can be employed to determine entry level proficiency, such as the use of written and flight tests designed to serve as screening mechanisms for entry into training for the different certificates and ratings.

ISSUE #18.--MEDICAL/PSYCHOPHYSIOLOGICAL REQUIREMENTS. Another form of entry level requirement is the specification of minimum medical/psychophysiological standards for the different types of medical certificates (FAR, Part 67) that must be obtained by general aviation pilots. Different medical certificates, which vary with respect to stringency of their requirements, are required for the various pilot certificates and ratings. The medical/psychophysiological requirements are designed to prevent individuals from attempting to perform tasks that are beyond their physical capabilities, and also to screen out individuals who may become incapacitated during flight. Accidents due to such performance problems are continually monitored by FAA personnel as part of continuing research to refine these standards (Booze, 1977; Dille and Booze, 1977; Dille and Mohler, 1968; Dille and Morris, 1968; Siegel and Mohler, 1969). Additionally, researchers have investigated the performance of pilots with various types of static medical defects--e.g., blindness in one eye (Grosslight, Fletcher, Masterton, and Brucchan, 1979; Welsh, Vaughan, and Rasmussen, 1976).

As stated previously, the specification of medical/psychophysiological requirements is complicated by the need to protect public safety without unduly restricting individual freedom. For example, a recent specific issue has been the determination of maximum age requirements for airline pilots.[1] It is difficult to predict an individual pilot's capability using only age (Pyle, 1977). Therefore, some recent research has sought to establish a functional age index through the use of objective performance tests (Gerathewohl, 1977; 1978a; 1978b). Additional research is needed to continue definition and refinement of medical/psychophysiological entry requirements, possibly extending the innovative approach being employed to develop the functional age index to other problems.

TASK SUBSETS FOR CERTIFICATES AND RATINGS (E).

One function of the certification and rating structure is to define the subset of tasks that a pilot with a given capability, as measured by training and experience, may perform. The FAA regulatory philosophy is that of specifying the minimum requirements necessary for safe operations. Therefore, only certain tasks are so specified in the regulations; performance of tasks that are not specified is left to the pilot's discretion. The task subsets that are specified, or in some cases implied, provide the foundation for (1) determining training and evaluation requirements for a given certificate or rating, and (2) managing pilots to insure that they do not perform tasks which exceed their training and experience.

Three major design issues (Issues #19 - #21) were identified with respect to the specification of the task subsets. These are identification of the (#19) different subsets of tasks that pilots holding the various certificates and ratings may perform, (#20) needs for new certificates, and (#21) needs for new ratings.

ISSUE #19.--TASK SUBSETS FOR CURRENT CERTIFICATES AND RATINGS. Accident data provide some insight to the appropriateness or adequacy of task subset specifications for the various certificates and ratings. For example, pilots with low total flight time or low time in a specific make and model of an aircraft are involved in a disproportionate number of accidents (NTSB, 1972d; 1974b; Munley, 1976). It is possible that these pilots, who are trained to required standards, are simply not prepared for all of the tasks they are legally permitted, or required by circumstances, to perform. Stated differently, such data indicate an incongruity between task demands and pilot capabilities.

If pilots who hold a given certificate or rating on occasion are required or elect to exceed their capabilities, and do so legally, then it is possible that the current certification and rating structure is not adequately specified.

A possible reason for this deficiency is that it is not possible to describe completely the different subsets of task requirements faced by general aviation pilots who hold various certificates and ratings (Eggspuehler, 1977; McCourt and Hewin, 1979). While a few studies have analyzed general aviation task requirements (Bolz and Eisele, 1979; Eggspuehler and Weislogel, 1968; Hinton and Shaughnessy, 1978; Hudock and Hudock, 1970; Weislogel and Miller, 1970), they have focused on only small segments of general aviation.

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[1] Age requirements are of concern for both entry level requirements and as part of the continued monitoring of the competency of certificated pilots, as are all medical/psychophysiological requirements. Thus, these requirements serve as continuing screening mechanisms for selecting or defining those persons who can fly the different general aviation missions.

Additionally, some of these studies are likely outdated, given recent changes in general aviation. Results of these studies indicate, however, that there are tasks permitted by a given certification (e.g., certain tasks required for complex mission profiles) that are likely beyond the capabilities of many of the general pilots who hold that certificate.

Analytic research is needed that will identify the subsets of task requirements for each of the certificates and ratings. Given the disproportionately high number of accidents involving "pleasure" pilots (Strickler and Eggspuehler, 1975) and the number associated with instrument meterological conditions (NTSB, 1973b), attention should be focused on the private pilot certificate and the instrument rating. Further, these analyses should consider the increasing frequency of instrument flying in general aviation and focus on determining task subset requirements to be effective in the future (e.g., 1985, 1990, 2000).

The results of these task subset analyses could serve several functions. One such function would be to provide the necessary comprehensive foundation for a number of the research projects suggested in this report. For example, valid task subset information will be required for research on determination of the need for new certificates and ratings, analysis of functions with respect to the design of the pilot-aircraft control interface, and determination of training requirements. Indeed, the conduct of such task subset analyses is crucial to the planning of almost any programmatic human factors research in general aviation and to the systematic design of all of the components affecting pilot performance.

ISSUE #20.--IDENTIFICATION OF NEEDS FOR NEW CERTIFICATES. The changes that are taking place in general aviation suggest the current certification structure may need to be modified to match future demands. McCourt and Hewin (1979), for example, concluded from their recent review of general aviation safety problems that the present certification structure may be less than well-suited to the needs, even for many current needs. An illustration of the need for new certificates can be found in proposals for "pleasure" and "utility" certificates (Olcott, 1977). These proposals are based on predictions of increased all-weather business flying, and of changes in the nature of pleasure flying due to fuel and economic restrictions. Simply put, it is believed that the proposed certifications would better match projected mission requirements with pilot capabilities and economic realities. This particular proposal may not be an optimal solution, however, so research is needed to identify needs for new certificates. To be efficient, this research should also identify and assess methods that do not involve regulatory changes for resolving problems underlying these needs.

ISSUE #21.--IDENTIFICATION OF NEEDS FOR NEW RATINGS. As with certificates, it is also possible that new ratings need to be specified. Most current ratings are specified to match pilot ability with the different categories, classes, and types of aircraft flown in general aviation. Most of these ratings require that pilots receive special training and be evaluated before flying an aircraft not covered in the ratings which they already hold. For example, pilots with a single-engine land rating, who desire to fly multi-engine land airplanes are required to receive instruction in the use and operation of a multi-engine land airplane. If these pilots wish to transition to an aircraft that falls within the ratings they currently hold, for example another single-engine land airplane, then no special training or evaluation is required by the regulations. The determination of the need for, and type of, such training is left to the discretion of individual pilots, and to those individuals who sell, rent, or lease the aircraft to them. It should be noted that insurance companies also have a voice in such matters.

The lack of formal training requirements for aircraft within the same rating has been referred to as the "open" rating concept. This concept has been questioned for certain categories and classes of aircraft. These questions have resulted from analyses of accidents involving experienced pilots with low flight time in a given aircraft that falls within the rating they hold (NTSB, 1967; Munley, 1976).

Additional concern arises from analyses of accidents that reveal that certain aircraft within a class are involved in a disproportionately high percentage of accidents of a certain kind--e.g., differences in rates of stall/spin accidents among various makes and models of single-engine land aircraft (NTSB, 1967; 1979a; Silver, 1976). These differential accident rates can be interpreted as indicating that some aircraft within a class are more difficult to fly or require different skills to operate than others. If so, it is then suggested that such aircraft should require special training.

Yet another source of concern is derived from studies that have documented substantial differences (non-standardization) in the displays, controls, and handling characteristics of different aircraft that can be flown by pilots holding a given rating (Ellis and Steinberger, 1977; Ontiveros, Spangler, and Sulzer, 1978). These differences can create problems for pilots who transition across aircraft within a given class.

Research is needed to determine if new ratings should be developed to address the problems described above. Recognizing the economic consequences and regulatory complexity that would result from increasing the number of ratings, this research should also explore additional regulatory and nonregulatory methods for assuring that pilots are sufficiently familiar with the aircraft they fly.

VI. TRAINING AND PROFICIENCY ASSESSMENTS FOR CERTIFICATES AND RATINGS

Given the number of certificates and ratings and the heterogeneity of pilots and individuals desiring to be pilots, the needs for training within general aviation are extremely diverse. These needs are met by a variety of organizations and individuals (Garvey, 1974). Such training is conducted, for example, by (1) universities and colleges; (2) large commercial aviation training centers which provide training for aircraft ranging from the small "puddle jumpers" to large jets; (3) specialized aviation training centers that focus on training for agricultural aircraft, helicopters, gliders and other specific types of aircraft; (4) small fixed base operators, located at many local airports, that offer flight instruction as well as sell, rent, lease, charter, and maintain aircraft; (5) general aviation associations and organizations, which offer seminars and clinics designed to prepare students for specific certificates or ratings; and (6) certificated flight instructors working independently of any organization. There is also a prodigious amount of aviation training literature that is designed to be used in any of the above contexts, or by individuals for self-instruction. Such literature is produced by the FAA in the form of handbooks, guidelines, advisory circulars, and other documents available to the public,[1] as well as by the aviation industry in the form of programmed texts, textbooks, audio-visual programs, and a variety of other instructional media.

To accommodate such diversity, the FAA regulates training in two ways. Some training courses are approved under FAR Part 141, which sets forth certain requirements for training programs and for the evaluation and monitoring of them by the FAA. To provide as much flexibility as possible, Part 141 leaves some of the design of instruction to the discretion of the organization conducting the training. Even more flexibility is enabled through the use of FAR Part 61, which specifies only the performance requirements that the graduate of a program must meet before receiving a certificate or rating. In this case, the content and structure of training are left entirely to the training organization, instructor, and student. To assure that pilots meet performance requirements, however, the FAA requires that they undergo written and flight proficiency tests administered by FAA personnel or by FAA designated examiners.

General aviation training is therefore characterized by the diversity in its needs, and in the way in which these needs are addressed. This diversity must be taken into consideration in the development of training to address pilot performance problems. Indeed, while an abundance of guidance exists for the systematic development of training and evaluation systems (Montemerlo and Tennyson, 1976), even the most well intended use of this guidance will be thwarted if operational constraints on training development and the conduct of training are not considered. Such problems are illustrated by the continuing difficulties within the military in the use of instructional system development procedures (Miller, Swink, and McKenzie, 1978; Montemerlo, 1979; Prophet, 1978; Vineberg and Joyner, 1980).

On the whole, general aviation training does an admirable job of preparing pilots to handle aircraft and utilize airports and aeronautical information systems that are not optimally

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[1] A complete listing of FAA publications is available from the FAA (FAA, 1979).

designed for pilot performance. There is need, nevertheless, for improvements. Five design elements were identified to structure the discussion of this need. They are (1) training requirements, (2) training methodologies, (3) training devices, (4) certificated flight instructor training and evaluation, and (5) proficiency tests. These elements represent the products of major decisions in the process of designing instructional systems.

TRAINING REQUIREMENTS (E).

Given the specification of tasks that may be performed by a pilot holding a certificate or rating, the first step in the systematic development of instruction for that certificate or rating is the determination of training requirements. These requirements serve as the basis for specifying the knowledge, skills, and attitudes that will be the objectives of instruction. The major human factors issue (Issue #22) identified with respect to training requirements is the need to identify comprehensive sets of such requirements for the various certificates and ratings.

ISSUE #22.--TRAINING REQUIREMENTS SETS. The military and air carriers usually employ formal analytic procedures to specify comprehensive sets of training requirements for their instructional systems. In general aviation, on the other hand, training is seldom based on such comprehensive specifications. Rather, as discussed previously, part of the training is guided by FARS 61 and 141, and the balance is left to the discretion of those involved. Over the past years, however, numerous independent proposals have been made to require the addition of new training, or an increased emphasis on some particular area in existing training, that addresses specific pilot performance problems. These proposals are usually the result of accident analyses or research projects that have identified or investigated training related to such problems. The nature of these proposals varies greatly. While some proposals are specific to a given certificate or rating, usually the private pilot certificate, many others would affect all pilot training. Additionally, some of the proposals are set forth in very general terms, while others specify detailed requirements to be included in training.

To illustrate their number, range and extent, several examples of the topics of such proposals are listed below (along with sources of the proposals).

- pilot judgment errors (Jensen, 1978; Jensen and Benel, 1977)
- spatial disorientation (Collins, Hasbrook, Lennon, and Gay, 1977; Kirkham, Collins, Grape, Simpson, and Wallace, 1978)
- stall/spin prevention (FAA, 1979a; Hoffman and Hollister, 1976; NTSB, 1972e)
- approach/landing task errors (NTSB, 1973; Trammel, 1974)
- traffic patterns at uncontrolled airports (NASA, 1978c; Parker, 1973)
- use of ground-based radar services (NASA, 1977d)
- awareness of the effects of alcohol, drugs, and toxic hazards (Dille and Mohler, 1968; Lacefield, Roberts, and Blossum, 1978; Mohler, 1966)

- awareness of individual psychological and medical problems (Dille and Booze, 1977; Mohler, 1977; Siegel and Mohler, 1969)

- effects of hypoxia and use of oxygen (Brantigan, 1974)

- obtaining weather reports, visualizing the weather, recognizing unfavorable weather (Lawton and Livack, 1979; NTSB, 1974b; 1976b)

- performing weight and balance calculations, and understanding the effects of different centers of gravity and weight conditions on aircraft performance (NTSB, 1972d)

- prevention of icing problems (NTSB, 1972a)

- emergency landing techniques (NTSB, 1972b)

- preflight planning (NTSB, 1976a)

- timesharing and allocation of priorities (Hopkins, 1977; Roscoe and Hopkins, 1975)

- collision avoidance awareness and scan techniques (NTSB, 1969; 1972c)

- familiarity with a given aircraft's unique handling characteristics, stall characteristics, cockpit design, operating procedures, fuel system operation (Ellis and Steinberger, 1977, NTSB, 1967; 1972f; 1974a; Ontiveros, Spangler, and Sulzer, 1978)

- use of pilot operating handbooks (NTSB, 1976a; Trammel, 1974)

- awareness of factors causing accidents (Lawton and Livack, 1979)

- attitudes toward safe practices (Beaty, 1969)

While a large number of such proposals have been made, there have been no comprehensive efforts to assess the effectiveness of systematically integrating these recommendations into training for the different certificates and ratings for which they are appropriate.

In addition to existing pilot performance problems, new instruction will need to be developed that addresses potential problems that are likely to occur in the future, particularly those relating to the increased utilization of advanced aircraft and modern avionics in general aviation. For example, researchers investigating the use of sophisticated equipment, such as automated flight management systems, have observed that proper training is crucial to the safe operation of this equipment (Chien, 1977; Curry, 1975). Additional indications of the need for the development of effective training for new equipment derives from analyses of air carrier pilot problems in the use of advanced systems that are, or soon will be, in many general aviation aircraft, such as weather radar and various alert/warning systems (NTSB, 1971; 1973).

In summary, numerous proposals have been made for the development of training that independently addresses various existing or potential future pilot performance problems. Research is needed that will identify, by certificate and rating, comprehensive and integrated sets of training requirements necessary for safe pilot performance. Such research should emphasize the development of training for more advanced equipment being introduced into general aviation. Such efforts are necessary to guide subsequent programmatic research on general aviation pilot training. This research will also provide a common foundation for the independent development of training by the different organizations that perform this function.

TRAINING METHODOLOGIES (E).

In addition to the identification of what should be taught, the determination of how pilots should be trained also has a substantial impact on the subsequent performance of pilots. In the early days of aviation, pilots usually taught themselves how to fly. The instructor provided minimum guidance and served mainly to prevent the students from injuring or killing themselves. During World War II, the expense of aviation training and the great demand for trained pilots served as impetus for a substantial amount of research on improved pilot training methods (Crawford, Sollenberger, Ward, Brown, and Ghiselli, 1947; Viteles, 1945). This research has continued over the years, and has resulted in the accumulation of an extensive technology on how to train pilots.

Although most of this technology was developed in other contexts, much of it is of great value to general aviation. Indeed, several research institutions and private organizations have applied this technology to general aviation training. The value of its use has been illustrated in numerous studies that have revealed increases in training effectiveness and efficiency as a result of the utilization of innovative training methods (see review in Roscoe, in press).

Two major human factors design issues were identified for this element. These are (#23) determination of training techniques for use in aircraft, and (#24) determination of methods for the use of pilot training devices.

ISSUE #23.--INSTRUCTIONAL TECHNIQUES FOR USE IN THE AIRCRAFT. One of the major tasks faced by flight training program developers and instructors is the determination of how training will be conducted in the aircraft. Techniques must be selected that will optimize the effectiveness and efficiency of training. Effective instruction is necessary to reduce pilot performance problems by imparting necessary skills to the pilot to better enable him to fulfill task demands and by making his skills more resistant to degradation from stress. Also, in consideration of the proposals for increased number and complexity of training requirements, more training may be needed to solve many pilot performance problems. More efficient instruction can result in better pilot performance by enabling training on more requirements for the same or less cost than is possible with less efficient techniques.

Although there is an extensive technology concerning flight training techniques, there has not been any systematic research that (1) identified all applicable techniques, (2) determined conditions for their use, and (3) empirically assessed their use in general aviation training. Programmatic research is needed that will accomplish these functions.

ISSUE #24.--METHODS FOR THE USE OF PILOT TRAINING DEVICES. Although a variety of instructional media are availabile for use in general aviation pilot training, pilot training devices are of prime interest due to their substantial potential for improving general aviation training (Bergey, 1978). For present purposes, the term "pilot training device" refers to the wide range of training equipment that simulates portions of the pilot-aircraft control interface. Examples of such devices include (1) high fidelity simulators employed by commercial aviation training centers that simulate specific makes of larger general aviation aircraft; (2) sophisticated pilot trainers, such as the GAT 1 and GAT 2, that are designed to be employed in training for a variety of aircraft; (3) smaller, less complex devices, such as "table top" trainers that are also designed to be employed in training for different aircraft within a given class; (4) computer generated video presentations of generic aircraft displays with interactive input devices; and (5) static photographic or graphic mockups for specific aircraft or for aircraft of a given class. These devices have been demonstrated to be effective media for use in general aviation pilot training (Crook, 1967; Finnegan, 1977; Kitely and Harris, 1978; Lanier and Butler, 1966; Ontiveros, 1975; Povenmire and Roscoe, 1971; Riddle, 1977; Smith and Melton, 1976; Stanek, 1972; 1973; Trollip, 1977), as well as in aviation in general (see Orlansky and String [1977] and Semple, Hennessy, Sanders, Cross, Beth, and McCauley [1980], who review the results of a large number of such studies).

The use of these devices improves the safety of training by furnishing a safe environment for the practice of tasks that are dangerous to practice or impractical to perform in the aircraft. Moreover, they provide the potential for more effective and efficient instruction on many skills than is possible in aircraft or with other media. Indeed, certain skills in which many current pilots appear to be deficient, such as judgment and emergency procedures skills are those that can be effectively and efficiently taught in training devices (Caro, Shelnutt, and Spears, 1980; Lucaccini, 1978).

An additional impetus for the increased use of training devices in general aviation is derived from the predicted continued rapid increase of fuel and other aircraft operating costs, and the associated projected decreases in flying time. The use of training devices will be necessary to reduce the impact of these factors on the effectiveness of pilot training.

The benefits that are derived from pilot training devices, however, are dependent on how they are used in training (Caro, 1973). Since such devices are obviously different from aircraft, different instructional techniques should accompany their use to maximize their advantages and minimize their disadvantages. While conceptual guidance concerning techniques for using training devices in military aircrew training is available (Caro, Shelnutt, and Spears, 1980; Miller 1953), research is needed to develop guidance specifically concerning their use in general aviation training.

DESIGN OF TRAINING DEVICES (E).

The benefit of training devices is derived from how they are used, but they must be designed to enable and facilitate the uses desired of them. A substantial amount of literature exists for the design of such devices for military and air carrier training (Caro and Pohlmann, 1979; Miller, 1954; Semple, Hennessy, Sanders, Cross, Beth, and McCauley, 1980; Semple, Cotton, and Sullivan, 1980; and Smode, 1972). Military aircrew training devices, however, are usually built for a specific aircraft, a defined pilot population, and clearly stated and circumscribed training requirements. The context for the use of training devices in general aviation is greatly different. Most general aviation training devices must be designed to be used in training for a variety of aircraft of different makes and models and in training for different certificates and ratings, as well as for continuation training. Procurement cost constraints and maintenance capabilities are also more restrictive in general aviation.

These restrictions may be lessened in future years, given projected trends toward lower costs and greater reliability in electronics technology. The potential exists for the development of new types of training devices that are affordable, better suited to general aviation needs, and that offer more capabilities than current devices. Guidance is needed to assure effective and efficient design and development of such devices. Two design issues were identified for this element. These are (#25) determination of fidelity requirements, and (#26) design of instructional support features.

ISSUE #25.--FIDELITY REQUIREMENTS. Fidelity of a training device is often viewed in terms of the degree of physical correspondence between the device and the aircraft flown by the pilot undergoing training--i.e., how much it looks, handles, and sounds like that aircraft. This 'physical fidelity' approach to training device design can be costly, particularly considering the general aviation market. A more cost-efficient design approach to determining fidelity requirements begins with analyses of uses of devices in training--i.e., what is needed to enable, facilitate, and promote learning (Bryan and Regan, 1972; Caro, 1977; Smode and Hall, 1975). Training devices designed through the use of such analyses can turn out to be quite different from the aircraft, but be as effective, or more so, for instruction than devices with higher physical correspondence to the aircraft. (Additionally, they tend to be much less expensive.) Demonstration of their effectiveness can be found in numerous studies that have evaluated devices which are quite different in appearance and functioning from the aircraft they simulate (Crosby, Pohlmann, Leshowitz, and Waag, 1978; Eddowes, McRee, Matheny, and Crowder, 1975; Finnegan, 1977; Prophet and Boyd, 1970; Trollip, 1977).

A training device design approach focusing on training requirements could prove very useful in the design of general aviation training devices. To begin with, the cost constraints within general aviation require device designs that are relatively low in cost. High physical fidelity of devices, without regard to training task fidelity requirements, will almost invariably result in higher than necessary cost. Furthermore, the need for generic trainers that can be used for several different makes and models of aircraft indicates that training requirements, rather than physical fidelity, should guide device design. Indeed, the single-minded pursuit of physical fidelity, constrained and compromised as it must be by cost restrictions, can result in poorly designed trainers that actually have negative effects on pilot performance in the aircraft.

To assure the effective and efficient development of the many different types of trainers that are required for general aviation, research is needed that will provide the designers of such devices systematic guidance concerning the determination of fidelity requirements. The development of guidance for the design of low cost systems for simulating external visual scenes is of particular interest, given their potential for expanding the use of general aviation trainers. While extensive research has been conducted on visual systems for training devices (summarized in Semple, Hennessy, Sanders, Cross, Beth, and McCauley, 1980), only a few studies have been devoted to their design and use in a general aviation context (Jensen, 1973; Kiteley and Harris, 1978; Lintern, 1979; Lintern and Roscoe, 1978; Young, Jensen, and Treschel, 1973). To guide future device development and use in general aviation, programmatic research on the determination of functional requirements for low cost visual systems is required.

ISSUE #26.--INSTRUCTIONAL SUPPORT FEATURES. Some features of training devices are designed solely to enable or facilitate instruction. They have nothing to do with simulation of the pilot-aircraft interface as such. These features, referred to as instructional support features, have been developed through the analysis of design requirements necessary to facilitate the application of basic principles of learning and instruction to the pilot training process.

Examples of these features include capabilities for (1) "freezing" the device in midflight to enable the instructor to provide appropriate guidance or feedback, (2) automation of instructor functions that allows students to practice by themselves, (3) recording and replaying of student performance to enable them to observe their actions, and (4) presenting performance information via alpha-numeric and graphic displays to allow the instructor and student to make better assessments of student performance. A complete listing and explanation of instructional support features can be found in Semple, Cotton, and Sullivan (1980).

It is highly probable that increased availability and use of instructional support features on general aviation training devices would improve the effectiveness and efficiency of pilot training. While guidance is available concerning the design of these features (Caro, Pohlmann, and Isley, 1979; Charles, 1977; Semple, Cotton, and Sullivan, 1980), it is oriented toward military and air carrier simulation devices. Research is needed that will adapt this guidance to general aviation needs and assess the utility of various instructional support features in the general aviation context.

CERTIFICATED FLIGHT INSTRUCTORS (E).

The impact that instructors have on the effectiveness and efficiency of general aviation training is obvious. They are the only source of instruction in some flight programs. In other programs, where formally developed audio-visual programs and accompanying texts are employed, the instructor must still aid the students in the integration of what they learn with what they do in the aircraft. Furthermore, the instructors serve as "role" models, so to speak, for the pilots they instruct. Their performance and their attitudes toward safety have a substantial impact on students. In addition to their role in initial training for certificates and ratings, the instructors are the major assessors of the continued proficiency of almost all general aviation pilots, and they are the major source for the continued training of these pilots.

The importance of the instructor's role in training makes it desirable to try to improve pilot performance by improving the teaching skills of the instructors. Little research, however, has been conducted on instructors to generate the information needed to guide this improvement. Two major human factors design issues were identified for this element. These are (#27) determination of instructor training requirements, and (#28) development of guidance for recurrent instructor training.

ISSUE #27.--INSTRUCTOR TRAINING REQUIREMENTS. A review (Olcott, 1977) of deficiencies in general aviation training identified several problems with that training. It concluded that one of the keys to improving this training was improvement in instructor training. Similarly, attendees at a recent general aviation safety workshop made several recommendations for improving instructor training and proficiency assessment that they felt would act to improve general aviation safety (Lawton and Livack, 1979). Both of these reports noted, however, that economic constraints (e.g., low pay for instructors) restricted the nature of improvements that could be implemented. Nevertheless, if general aviation training is to be improved, instructor training and the assessment of instructor proficiency must also be improved.

If new training requirements are added to pilot training, then these requirements must be added to instructor training. If new techniques of instruction are developed, then the instructor should be taught to employ them, and his manner of use of such techniques evaluated.

Some guidance exists for structuring instructor training--e.g., the Aviation Instructor's Handbook (FAA, 1977b); the Flight Training Handbook (1980), and Federal Aviation Regulations that specify instructor training and proficiency assessment requirements. Systematic research is needed, however, to develop and evaluate instructor training requirements, as well as to develop techniques for use in training instructors--e.g., practice teaching internships. Part of this research should also focus on the organizational and economic problems that restrict instructor training and determine actions that can be employed to decrease the inhibiting effects of such problems.

ISSUE #28.--GUIDANCE FOR RECURRENT INSTRUCTOR TRAINING. As with all other pilots, the aeronautical skills of the instructor can degrade over time if these skills are not used regularly. Additionally, the continuing changes in general aviation require that instructors stay current regarding new aircraft, ATC regulations and procedures, pilot training requirements, and training techniques. Instructors need current information, not only to aid them in their job, but to pass such information on to the general aviation pilots who depend on them for such information. Thus, the continued training of the instructor is crucial to the safety of general aviation.

As with the instructor's original training for certification, however, certain economic and organizational constraints restrict the effectiveness of his continuation training. Research is needed to (1) develop additional guidance for the continued training and recurrent assessments of the proficiency of instructors, and (2) determine actions that can be taken to reduce the economic and organizational constraints on their continued training.

PROFICIENCY TESTS (E).

Student pilots who have completed the training required for the private pilot certificate must pass both a written test and a flight check before receiving the certificate. The written test is usually developed, administered, and scored by FAA personnel. The flight check, on the other hand, is usually administered by examiners who do not work for the FAA, but who have been designated by the FAA to perform such flight examinations. Guidance concerning the flight check is provided to the student and designated examiner in an FAA publication (e.g., FAA, 1975). Similar proficiency assessment procedures are employed for the other certificates and for selected ratings.

If general aviation training is to be expanded or otherwise improved to enhance pilot performance, these written tests and flight checks must also be modified to assure that the performance of each student is indeed enhanced. Guidance is needed, however, to determine how these assessments should be modified. Three human factors design issues were identified for this element: (#29) development of guidance for modifying the written tests; (#30) development of objective flight checks; and (#31) identification of techniques for employing alternative testing media in the assessment of pilot proficiency (e.g., training devices, computer-based systems).

ISSUE #29.--GUIDANCE FOR MODIFYING THE WRITTEN TEST. The major purpose of the written test is to assess a pilot's aeronautical knowledge related to the safe operation of the aircraft. As such, recommendations for adding training requirements designed to reduce pilot performance problems frequently are accompanied by recommendations to modify written tests to assess each pilot's achievement of that requirement (see list of references in Issue #22). These recommendations, however, have been made on a topic-by-topic basis and, thus, represent independent suggestions for modification. They do not provide a comprehensive foundation for such change.

In addition to recommendations for covering additional topic areas, suggestions were made during the interviews conducted for this project that the written tests be criterion-referenced.[1] That is, the items in the tests need to be (1) more performance-oriented than at present, and (2) scored on the basis of an analysis of the minimum knowledge required for safe flight. Performance-oriented items would focus on knowledge required to perform tasks related to the safe conduct of flights, rather than on "theory." Criterion-referenced scoring would assure that a pilot is proficient in each topic area covered in the test.

Research is needed to assess the adequacy of the current written tests and to develop guidance, if any is needed, for the development of criterion-referenced tests. Furthermore, research is needed that will assess, on a systematic basis, the need for additional content on the tests.

ISSUE #30.--OBJECTIVE FLIGHT CHECKS. The purpose of flight checks is to assure that each pilot has the aeronautical skills necessary for safe flight. As with written tests, recommendations that have been made to improve general aviation training to reduce pilot performance problems have usually been accompanied by recommendations for additional content on the flight checks (see list of references in Issue #22). Also, as with written tests, no studies have been published that systematically review these requirements in order to develop comprehensive recommendations for modifying the flight tests.

In addition to the recommendations for added topics for testing during the flight check, it has been suggested that guidance be developed to improve the objectivity of checks, particularly the private pilot check (Forrest, 1970; GAO, 1976). The development of objective flight checks has received considerable attention from aviation researchers (see review by Forrest, 1970), but attempts to develop and implement such checks in general aviation have failed.

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[1] Criterion-referenced testing is explained in Siegel, Musetti, Federman, Pfeiffer, Wiesen, Delro, and Sheppard (1979) and Swezey and Pearlstein (1975).

Research is needed that will review the content of current checks, review recommendations for additional test topics, and determine if the current test guidelines need to be modified. Furthermore, research should be conducted to determine proficiency assessment requirements associated with the implementation of any new training requirements. Finally, research should be conducted to develop and assess the use of objective flight tests in general aviation.

ISSUE #31.--TECHNIQUES FOR USING ALTERNATIVE TEST MEDIA. In addition to the aircraft and paper-and-pencil test formats, several other test media are available for use in assessing the proficiency of general aviation pilots. Two of the most promising are (1) training devices, and (2) computer-based test systems which present written or graphic information on computer-generated displays. Preliminary analyses and evaluations of the capabilities of both types of media for assessing pilot proficiency have already been performed (Finnegan, 1977; Koonce, 1974; Ontiveros, 1975; 1976; Trollip, 1977). As a result of these analyses, several advantages associated with the use of these test media have been identified. For example, such media can potentially increase the efficiency of skill and knowledge testing. Adaptive testing techniques that can be employed in both training devices and computer-based test systems can enable much more material to be covered in a test.

Items are selected in real time based on the analysis of the student's competence as revealed by answers to previous test questions. Further, instructional support features available on training devices make it possible to assess varied tasks in minimal time (e.g., different instrument approaches can be examined without extensive time being consumed getting into position for the approach tasks). As a result of increased efficiency in testing, more skills and knowledges can be assessed without increasing total costs. This is one way to accommodate increased proficiency assessment requirements as a means toward reducing pilot performance problems.

Use of training devices can also facilitate the conduct of objective flight checks. (Requirements for increased objectivity were discussed in the preceding section.) Greater objectivity can be obtained in the device than in the aircraft because (1) the conditions for the conduct of checks can be controlled precisely, (2) measurements of student performance can be collected using special displays or even automated performance measurement features, and (3) the examiner is not distracted by operational constraints present in the aircraft (Shelnutt, 1978).

In conclusion, training devices and computer-based test systems offer several potential advantages as media for testing the proficiency of general aviation pilots. Additional programmatic research is needed to continue study of the roles these media can play in such assessment.

VII. CONTINUATION TRAINING AND RECURRENT ASSESSMENTS OF PILOT PROFICIENCY

Since most pilot certificates are issued without specific expiration dates, general aviation pilots may fly with these certificates as long as (1) they are not revoked or suspended, and (2) the pilots meet the standards for the required medical certificates. The flight skills of even the most accomplished pilots will degrade, however, if they are not performed or practiced regularly. Moreover, their knowledge needs to be updated continually with respect to changes in general aviation and the National Airspace System. Thus, all general aviation pilots need to receive some form of continuation training in order to maintain their knowledge and skills at a safe level of proficiency.

Federal Aviation Regulations do not specifically cover requirements for continuation training for most general aviation pilots. Part 61.57, however, specifies currency requirements for pilots in command of civil aviation aircraft.[1] In addition to certain limited currency requirements for takeoffs and landings, night flying, and IFR experience (for instrument rated pilots), Part 61.57 specifies that pilots receive a flight review every 24 months. This review, which is commmonly referred to as the Biennial Flight Review, is the major regulatory mechanism for assuring that pilots can safely exercise the privileges of their pilot certificates.

This chapter reviews human factors design issues related to the conduct of continuation training and to the Biennial Flight Review.

CONTINUATION TRAINING (E).

As with training for certificates and ratings, continuation training is conducted in a variety of ways. Almost all, if not all, of the organizations providing training for certificates and ratings also offer various continuation training activities. These activities include refresher programs, seminars, flying proficiency programs, safety clinics, and a number of other formal and informal programs designed to maintain, refine, and extend the proficiency of certificated pilots. The FAA also has several programs designed to evaluate certificated (as well as student) pilots, such as the General Aviation Accident Prevention Program (FAA, 1975) and the Pilot Proficiency Award Program (FAA, 1979). Additionally, the FAA publishes a variety of literature, such as Advisory Circulars, to aid in the accomplishment of this function. Much of the aviation literature published by the private sector is also designed to educate certificated pilots. Finally, as in any profession or serious avocation, a major source for continuation training comes from the experience gained by the pilots themselves on their own initiative, and from discussions with their fellow pilots.

Two major human factors issues were identified for this design element. These are (#32) determination of requirements for continuation training, and (#33) identification of methods for encouraging continuation training.

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[1] In addition to Part 61.57, Part 61.58 of the Federal Aviation Regulations specifies pilot-in-command proficiency checks for operation of aircraft requiring more than one pilot. These checks, which are not included in the following discussions, are much more formal and extensive than requirements specified in Part 61.57.

ISSUE #32.--REQUIREMENTS FOR CONTINUATION TRAINING. General aviation accidents frequently involve certificated pilots who either lack recent flight experience of any kind, or are current, but err in the performance of infrequently performed tasks. As a result of these associations, analyses of general aviation accidents and incidents have frequently concluded that certificated pilots should receive training to address performance problems identified in the analyses (Munley, 1976; NASA, 1978c; NTSB, 1972f; 1972e; 1974a; 1974b; 1976a; 1979b). As with proposals discussed in the previous section on training for certificates, these proposals are numerous and varied. Indeed, many of the recommendations made for training for certificates also contained associated recommendations for continuation training (or simply did not specify when a pilot should receive the training).

Also as with training for certificates and ratings, numerous new requirements for continuation training will arise in future years as new aircraft, avionics, and ATC services and regulations are introduced. These new requirements will occur at a time when projected increases in operating costs and fuel shortages may force many general aviation pilots to reduce their flying. The limitation of flight time will make it even more difficult for many pilots, particularly pilots who fly for nonbusiness reasons, to remain proficient in the complex skills required to cope safely with increasingly sophisticated aircraft and flight environments.

Abundant information is available concerning continuation training requirements. As with training for certificates and ratings, however, these requirements have been proposed more or less on an ad hoc basis to cover particular needs. Training is often developed to meet these specific requirements, frequently in the form of an audio-visual program, a seminar, an advisory circular, or an article in an aviation magazine. The proficiency of general aviation pilots, however, depends on the comprehensiveness with which their training addresses their needs. Research is needed that will systematically address the total continuation training needs for the different types of general aviation pilots. Such research can build on the results of past studies on the retention of flight skills by general aviation pilots (Hollister, LaPointe, Oman, and Tole, 1973; Seltzer, 1971), and military and air carrier pilots (Meyers, Laveson, Page, and Edwards, 1978; Goorney, 1965; Prophet, 1976a; 1976b), as well as the general psychological literature on the retention of motor skills and knowledge (reviewed in Schendel, Shields, and Katz, 1978). The research suggested here would (1) identify the types of flying skills most susceptible to degradation over time, (2) determine conditions and individual pilot characteristics that affect retention of the skills, and (3) determine requirements for continuation training to prevent skill deficiencies. The results of this research would serve as the foundation for further programmatic investigation of other questions related to the development and conduct of continuation training.

ISSUE #33.--METHODS FOR ENCOURAGING CONTINUATION TRAINING. The development of continuation training, regardless of its comprehensiveness, will not be beneficial unless pilots take advantage of the instruction. While there are not any formal regulations requiring specific types of continuation training, a number of less formal methods currently exist for encouraging general aviation pilots to continue their training to maintain their skills and update their knowledge. For example, Federal Aviation Regulations (Part 61.57), as previously discussed, specify certain limited currency requirements. Additionally, the FAA and various general aviation organizations encourage pilots to continue their training through a number of different promotional activities. Such activities include the General Aviation Manufacturers Association Safe Pilot 80 Sweepstakes in which prizes are awarded to pilots attending safety seminars, and the FAA Pilot Proficiency Award Program in which tie tacks, lapel pins, and certificates are given to pilots who participate in the program.[1] On occasion, continuation training is also recommended by FAA or other concerned personnel as a result of violations of regulations or demonstrations of unsafe airmanship. The major sources of motivation for continuation training, however, lie within the pilots themselves and in informal pressure from their colleagues and associates.

Given the lack of formal regulations requiring continuation training, the question arises as to whether all general aviation pilots, particularly pleasure pilots who often do not fly extensively, are likely to continue training. Pleasure pilots typically are not as intimately involved in aviation as full-time pilots, and as a group they have the highest accident rate (Strickler and Eggspuehler, 1975) of all general aviation pilots. Even active professional pilots, however, may omit needed training due to operational constraints, lack of awareness of their need, or even complacency. This problem is evidenced by accidents involving high-time pilots who fly extensively, but make errors on infrequently performed tasks such as emergency procedures. The need for continuation training for even the most experienced pilots is illustrated by the formal programs which exist within the military and air carriers to accomplish this function.

Research is needed to determine if current methods for encouraging continuation training are indeed effective for all general aviation pilots. This research would also identify and assess alternative regulatory and nonregulatory methods for encouraging continuation training within the constraints present in general aviation.

RECURRENT ASSESSMENTS OF PILOT PROFICIENCY (E).

The regulation (Part 61.57) specifying requirements for the Biennial Flight Review (BFR) reads as follows:

> 61.57 Recent flight experience: pilot in command.
>
> (a) Flight review. After November 1, 1974, no person may act as pilot in command of an aircraft unless, within the preceding 24 months, he has--
> (1) Accomplished a flight review given to him, in an aircraft for which he is rated, by an appropriately certificated instructor or other person designated by the Administrator; and
> (2) Had his logbook endorsed by the person who gave him the review certifying that he has satisfactorily accomplished the flight review.
>
> However, a person who has, within the preceding 24 months, satisfactorily completed a pilot proficiency check conducted by the FAA, an approved pilot check airman or a U.S. Armed Force for a pilot certificate, rating or operating privilege, need not accomplish the flight review required by this section.

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[1] It has been observed that the training sessions specified in the Pilot Proficiency Award Program do not have a stated completion standard. Thus, it is theoretically possible for an award to be given in recognition of poor performance (Lawton and Livack, 1979).

(b) Meaning of flight review. As used in this section, a flight review consists of--

(1) A review of the current general operating and flight rules of Part 91 of this chapter; and

(2) A review of those maneuvers and procedures which in the discretion of the person giving the review are necessary for the pilot to demonstrate that he can safely exercise the privileges of his pilot certificate.

Two major human factors issues were identified with respect to the BFR. These are (#34) determination of assessment requirements, and (#35) determination of procedures and other structure for the BFR.

ISSUE #34.--SPECIFIC REQUIREMENTS FOR RECURRENT ASSESSMENTS OF PILOT PROFICIENCY. Part 61.57 does not furnish guidance concerning specific skills and areas of knowledge to be assessed during the BFRs. Sets of guidelines for the BFR that have been developed and published by various general aviation organizations (e.g., National Association of Flight Instructors, 1976) provide more extensive guidance to instructors conducting the BFRs, but they still do not identify specific assessment requirements. These guidelines recommend, however, that the BFR should focus generally on the tasks with which most certificated pilots have problems and, more specifically, on the subset of such tasks or any other tasks with which the pilot being reviewed has difficulty.

To be efficient and effective, BFRs should focus on the set of skills and areas of knowledge that are (1) critical to safe flight, (2) most susceptible to degradation over time, and (3) most likely to need updating due to changes in general aviation and the National Airspace System. Instructors could employ such guidance concerning these skills for determining what should generally be covered in BFRs and also for determining specific subsets of skills that need to be addressed for each pilot.

Given the absence of such guidance, the content of BFRs varies across instructors (Boody, 1980; GAO, 1976). Research is needed that will identify specific skills and areas of knowledge that should be assessed during BFRs. This research could be conducted jointly with research to develop requirements for continuation training. As part of the effort, consideration should be given to the possibility of recording, perhaps on an anonymous basis, the results of current BFRs. Such results are not recorded at present. However, they could furnish valuable insight into current problems within the general aviation pilot population.

ISSUE #35.--GUIDANCE FOR STRUCTURING THE BFR. As with the content of the BFR, guidance concerning how BFRs should be conducted is also lacking in Part 61.57. The industry guidelines (National Association of Flight Instructors, 1976) do furnish a general description of steps recommended for accomplishing the BFR--i.e., (1) review of the pilot's background for use in planning the BFR, (2) review of operational and flight provisions of Federal Aviation Regulation Part 91 appropriate to the operations of the pilot receiving the BFR, (3) review of preflight procedures, (4) review of the pilot's flight skills, and (5) post flight discussion and recommendations. As a general directive, the guidelines continually emphasize that the BFR be accomplished in a manner that is economical and expeditious (NTSB, 1979b).

Thus, how the BFR is actually conducted is mostly left to the discretion of the instructor and pilot undergoing the BFR, and a variety of alternative procedures for administering the

BFR can and have been employed. Additional variance is derived from the selection of conditions for the conduct of the BFR and of the aircraft employed in the evaluation with respect to the ratings held by the pilot undergoing the review. There can also be wide variability in the way in which skills are measured and evaluated, as well as in the criteria employed by the instructor to determine if a BFR is satisfactorily accomplished.[1]

A critical review of the BFR, which was conducted by the General Accounting Office (GAO, 1976), resulted in the recommendation for additional standards to structure the BFR and make it more objective. Many individuals in the general aviation community have resisted such standardization because they believe (1) a flexible approach is needed, given the diversity in general aviation, and (2) additional regulations governing general aviation are to be avoided whenever possible (Lawton and Livack, 1979). Additionally, the extent of recurrent reviews of pilot proficiency in general aviation is restricted by economic constraints.

In conclusion, the notion of furnishing additional structure to the BFR involves some controversy. Since the BFR is the major regulatory mechanism for assuring the continued safety of performance of general aviation pilots, the adequacy of these reviews is of great concern. The present guidance for the BFR is inadequate from a measurement standpoint. Whether this guidance is sufficient to assure safe performance is an empirical question that should be addressed through research. Such research would also identify any needs for structuring the Biennial Flight Review and investigate regulatory and nonregulatory means for providing the structure.

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[1] If an instructor believes the BFR was accomplished satisfactorily, he enters the appropriate endorsement in the pilot's logbook. If, on the other hand, the instructor believes it was not satisfactory, he may recommend remedial actions to the pilot. No entries are made, however, concerning unsatisfactory BFRs in the pilot's log or elsewhere.

VIII. SUMMARY AND DISCUSSION

PILOT PERFORMANCE AND SAFETY.

Attainment of the economic and social benefits that general aviation holds for the future will depend on many factors--e.g., technology advances, the world energy situation, and the state of the economy. However, one factor that will surely affect the degree of such attainments quite directly will be the safety record of general aviation in the years to come. That record, considering past performance and future projections, will be a matter of concern, and every effort will be made to improve it. General aviation, like all segments of the aviation community, is constantly seeking means for improving or enhancing flight safety in its operations.

The position advanced in this report is that the safety with which general aviation fulfills its missions is in large part a function of the degree of congruence between pilot capabilities and the task demands imposed by the aircraft, the airspace system, and associated flight tasks. When demands exceed capabilities, pilot performance problems result, sometimes with major consequences. While general aviation accident rates have steadily declined, the proportion of accidents attributable to pilot problems has remained substantial and relatively constant. Indeed, the great majority of general aviation accidents are attributable, in some degree or other, to such pilot performance factors. Therefore, it would appear that some change in the manner of seeking to solve pilot performance problems is in order; at the very least, alternative approaches to the solution of such problems should be investigated. The effort described in this report represents the beginning of such an alternative approach; as such, it is felt that the directions for future human factors research and applications programs it presents offer real potential for reducing pilot performance problems in general aviation and, hence, for enhancing general aviation safety in the future.

ALTERNATIVE APPROACH. The approach taken in the present effort has focused on the interface between pilot capabilities and task demands, the factors that affect the functional effectiveness of that interfacing, and the needs for human factors information to support constructive changes (i.e., design changes) to that interface. The present study has provided an opportunity to view these human factors aspects of general aviation with a breadth and depth that generally has not been afforded to previous investigators. This increased breadth and depth of analytic scope in examining human factors problems is one desired aspect of an effective alternative approach to solving pilot performance problems in general aviation.

Another principal feature of such an alternative approach relates to the manner in which pilot performance problems are identified and in which solutions are sought. Past efforts, understandably, have received much of their impetus from the frequency and criticality of accident experience in general aviation. Thus, research and corrective actions have been driven on a reactive, symptomatic basis. While clearly this impetus will and should continue, the approach taken here is to examine the other side of the 'antecedent conditions - pilot performance - outcome consequences' chain, i.e., to examine the antecedent conditions underlying pilot performance. Stated differently, the present approach has sought to examine systematically those man-machine system factors that affect or underlie pilot performance, whether that performance be adequate or inadequate, in order to understand the interworkings of those factors and to provide better avenues of solution to those aspects of pilot performance in which manifest or projected problems exist.

An outgrowth of this concentration on developing a 'process[1] understanding' in the present effort has been the identification of those system components and elements that (1) affect performance outcomes and (2) are potentially capable of deliberate design or modification. Thus, for effective pilot performance problem solutions to be devised, the approach must exhibit a design emphasis.

The present study was undertaken with the objectives of (1) identifying major pilot performance problems in general aviation, (2) specifying the nature of the human factors information needed to solve such problems, and (3) analyzing the implications of such information needs for planning future human factors research. To accomplish these objectives, a wide variety of documental and interview information was collected concerning the performance problems of general aviation pilots and, when relevant, of pilots in general. The analysis of this information was structured through the use of a conceptual model of the complex of factors affecting pilot performance in general aviation. The central premise of this model is that pilot performance problems result from incongruities between task or performance demands made on the pilot and his physical, physiological, and psychological capabilities to meet those demands. Thus, individual actions that can be taken to reduce pilot performance problems must increase pilot capabilities and/or reduce task demands. The identification, management, and modification of those factors that affect task demands and/or pilot capabilities is the key to improved safety. Such factors that affect task demands and pilot capabilities are referred to as system components in this model.

In the development of the model, six such components were identified. Three of these interact to influence task demands, while the other three interact to influence pilot capabilities. Those components that influence task demands are: (1) aircraft, (2) airports, and (3) aeronautical information systems. Those that influence pilot capabilities are: (1) the pilot certification and rating structure, (2) training and assessments of pilot proficiency for these certificates and ratings, and (3) continuation training and recurrent assessments of pilot proficiency.

In application of this model, the key to the solution of pilot performance problems lies in the design of each of these components.[2] That is, each component must be designed so as to interact with other components to attain or maintain congruity between task demands and pilot capabilities. Because of the diverse nature of general aviation, however, each of these components typically is designed by different personnel working independently of one another. Since there is not a single system designer responsible for integrating all the components, each of these independent component designers has the responsibility, wittingly

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[1] The term 'process' is used here to denote the task demand and pilot capability factors and the manner in which they interact to produce pilot performance.

[2] The reader is reminded again that the usage of the terms 'component' and 'design' in this discussion should not be interpreted in a strictly hardware sense. The general aviation system has 'software' components--e.g., training, pilot certification structure, etc.--that must be 'designed' just as is the aircraft or its associated hardware components.

or unwittingly, for selecting from among the design alternatives pertinent to his component, and, as a consequence, for aiding or hindering the achievement of the overall system goal of harmony between task demands and pilot capabilities.

Such determinations require that these component design personnel have information about system interrelationships and the effects of design alternatives on pilot performance. When such information is incomplete or absent, a human factors design issue exists. In accord with the model, then, human factors research is needed to generate the data required to support design decisions. These human factors design issues serve as the basic units for describing research needs. Some 35 such issues were identified in the present study through analysis of the documental and interview information collected.

GENERAL CHARACTERISTICS OF ISSUES.

The human factors design issues that were identified are listed in Appendix C and have been discussed in detail in Chapters II through VII. While each of these issues addresses a different design consideration, they share several common characteristics. First, by definition, each of the issues describes a requirement for information needed to design or modify elements of the system components in such manner as to enhance pilot performance. Some of the information needs pertain to current or existing pilot performance problems, while others are derived from future or predicted pilot performance problems. While future general aviation pilot performance problems will have much in common with those of the present and past, the changes projected for the future in general aviation aircraft, equipment, and missions, along with changes in the National Airspace System, will introduce a number of new pilot performance problems, as well as complicating many of the old ones.

In addition, these issues all will require systematic research to collect the information needed for design purposes. Each of the issue areas requires a comprehensive and systematic supporting human factors data base on which specific design decisions can rest. Such data bases are necessary for enlightened design decisions, whether the decision be a routine design-development decision for a component or element thereof, or a design modification decision for a component related to some critical occurrence such as a series of accidents.

It follows from the preceding that the research required to resolve the various issues should be organized and programmatic in nature. That is to say that those areas of human factors research concern relevant to pilot performance should be pursued in a continuing series of research activities that will develop the technology base required to deal effectively with pilot performance in its entirety. The support of such programmatic research efforts on a sustained basis will produce the greatest long-term benefits for the general aviation community. As has been noted, reactive research to symptomatic problems will continue, but prevention of problems before they become acute, or immediate response to them when they become acute, both require that the necessary research to develop the information base have been done beforehand in anticipatory fashion.

HIGH PRIORITY ISSUES.

While all of the 35 issues were deemed to be important, they were grouped into three categories with respect to their relative research priorities to aid research managers in the use of the results of this effort. The procedures and criteria employed to make this judgment are described in Chapter I, and the category to which each issue was assigned is listed in Appendix C.

Nine issues were grouped into the category representing the highest priority. These issues[1] pertained to the determination of:

(1) requirements for human factors engineering standards and guidance for aircraft controls and displays;

(5) requirements for integrated flight management systems;

(15) requirements for communications between general aviation pilots and air traffic control personnel;

(19) task subsets for current certificates and ratings;

(22) training requirements for certificates and ratings;

(27) instructor training requirements;

(32) requirements for continuation training;

(34) requirements for recurrent reviews of pilot proficiency; and

(35) guidance for structuring the Biennial Flight Review.

Specific information and discussions concerning the reasons these issues were rated highest in priority are contained in the treatment of each of the issues located in the main body of this report. However, certain general reasons related to the priority of these issues should be noted. For example, the design of the pilot-aircraft interface is obviously a major determinant of the demands placed upon the pilot. Thus, Issue #1 was given a high priority because it addresses needs for standards and guidance information that is central to the improvement of the design of such interfaces. Without an understanding of requirements for human factor standards and guidance (Issue #1), it is impossible to develop such information systematically. In turn, without systematic human factors standards and guidance, it is difficult to make informed decisions concerning the design of pilot-aircraft interfaces.

The research proposed in Issue #1 will likely provide a sufficient information base to guide the improvement and standardization of conventional aircraft controls and displays. However, the rapid changes that are occurring in control and display technologies suggest that many of the conventional control-display concepts will be radically altered or replaced altogether, rather than simply exhibiting the leisurely evolutionary changes of the past. These radical alterations have been labeled here as "integrated flight management systems" for purposes of discussion. Given the revolutionary changes and opportunities afforded by the use of microprocessors and related digital technologies in the development of such integrated, multipurpose systems, it was felt a similarly revolutionary approach was needed

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[1] The number beside each issue corresponds to its "Issue #" or position in the sequence of issues in Chapters II through VIII.

to determine how such technology should be employed in general aviation (Issue #5). Such an approach is available through the use of the systems analysis and design techniques that were developed to guide the incorporation of human factors considerations into the design of complex aircraft, space vehicles, and other types of complex man-machine systems. The use of such techniques will allow systematic determination of effective applications of microprocessors and related technology to the design of the general aviation pilot-aircraft interface and of the role of the pilot with respect to these applications. The results of such analyses can be used to guide exploration of these and related technology to the design of the general aviation pilot-aircraft applications. Unguided, the exploitation of the great power and flexibility that microprocessors and related technologies afford to the control-display designer may result in a proliferation of non-optimal, substandard, and possibly even dangerous displays and controls. Such unguided proliferation is virtually certain to produce some negative influences on pilot performance in the long run.

The incorporation of microprocessors and associated technologies into air traffic control systems will also have a substantial influence, particularly on the nature of future communications and information interchanges between air traffic controllers and general aviation pilots. Indeed, the achievement of the potential increases in the efficiency and effectiveness of air traffic control due to the use of such technology will depend in large part on the adequacy of these communications, both oral and data link, with respect to information needs of general aviation pilots. Thus, Issue #15 was given a high priority because of the pervasive nature and criticality of such communications and their changing nature. Changes in the design of air traffic control systems, as well as in the design of general aviation aircraft, will take place over many years. Research, such as that suggested in Issues #1, #5, and #15 is needed to guide the conceptualization and planning of such changes in an effective manner. Thus, human factors research is needed now to provide such a basis. Once future hardware systems have been designed and developed, it will be much more difficult and expensive to alter them to incorporate modifications necessary to enhance pilot performance.

Research must also be conducted that is oriented toward improving the capabilities of general aviation pilots. In fact, six of the nine issues that were rated highest in priority are concerned with research aimed at pilot capabilities (Issues #19, #22, #27, #32, #34, and #35). The pilot certification and rating structure is the basic mechanism for matching pilot capabilities with task demands, and there is an urgent need to determine exactly what tasks are required and permitted by the various certificates and ratings (Issue #19). The results of such research would not only serve as a comprehensive basis for subsequent study of the need for new entry level requirements, certificates, and ratings, but also for research on training, aircraft design and almost all other system components. Indeed, if one were seeking the most effective design integration of the various general aviation components, the conduct of mission analyses would be the first step in the design of the system. Such mission analyses could serve as a common foundation for research planning and design efforts by separate organizations.

The specification of mission requirements does not provide all the information that is needed to determine the training that is required for those missions. Such information is determined through the analysis of what must be learned by personnel entering into training to be able to perform those missions. Thus, Issue #22 was rated high in priority because it focuses on research needed to identify comprehensive sets of training requirements for the different certificates and ratings. Such research is needed because the performance of general aviation pilots depends on the comprehensiveness and effectiveness with which their training addresses their total needs. While numerous independent proposals have been made to modify pilot training to address various specific pilot performance problems, such proposals need to be analyzed in terms of their relationships to the different subsets of training requirements for each certificate and rating. Moreover, training requirements research is also needed to promote and facilitate the development of training programs to prepare pilots for future changes in aircraft and the National Airspace System.

The key to effective instruction for all certificates and ratings lies in the ability of the certificated flight instructor to teach the student. The instructor provides the principal interface between the student and the various training operations. Accordingly, Issue #27 was rated high in priority. It highlights the need for programmatic research to determine comprehensive requirements for instructor training. Given the key role of the instructor, such research is necessary if flight training is to be modified to enhance the performance of general aviation pilots. Moreover, this research is needed to determine how organizational and economic problems that restrict instructor training at present can be circumvented.

Finally, one of the most urgent needs for research, with respect to the determination of methods for improving pilot capabilities, pertains to the continued training and recurrent assessment of the proficiency of certificated pilots (Issues #32, #34, and #35). There are several reasons for this urgency. To begin with, actions that are identified through such research will affect all pilots. Given the extent of this potential impact, any proposals to modify continuation training or recurrent proficiency tests will need to be supported by substantial evidence that such modifications are indeed effective, efficient, practical, and needed. To obtain such evidence, research is required that will (1) determine comprehensive training and proficiency testing requirements; (2) assess objectively the extent to which current training and testing fulfill these requirements; (3) determine what modifications to training and proficiency testing need to be made; and (4) generate information that demonstrates that such modifications will improve pilot performance. While it is apparent that past training and proficiency assessment techniques have served general aviation well, as the flight task demands grow and as the National Airspace System increases in complexity, these factors need to be examined systematically and revised where appropriate. Continuation training and proficiency assessment are the only real means for effectively influencing and managing the performance capabilities of the general aviation pilot population. Hence, the issues identified in these areas are extremely critical to direct solutions to pilot performance problems.

These high priority human factors issues are important, as are the other issues identified in this effort. Each deals with a pilot performance problem area of concern to general aviation. However, certain aspects of the likely future circumstances of general aviation will serve to magnify or exacerbate most of these problems. The kinds of changes that microprocessors and display technologies offer have been noted. These technologies with their tremendous flexibility of application are likely to result in rates of change in pilot task demands far greater than those experienced by general aviation in the past, thus highlighting the urgency of needed human factors research in these areas. Another complex of factors that will perhaps be of overwhelming importance are the various effects that will result from escalating fuel costs and decreasing fuel availability. It seems certain that many general aviation pilots will fly less in the years to come because of these factors. Consequently, retention and forgetting of flight skills and ways to alleviate adverse effects will loom ever larger in importance. Further complicating this concern is the ever increasing procedural complexity of both general aviation aircraft and the National

Airspace System, since it is known that the forgetting of procedural skills is generally quite rapid. In any event, research solutions to these problem areas must deal with training content and proficiency assessment, and with new approaches in training including devices and other supporting media.

NEED FOR A HUMAN FACTORS RESEARCH MANAGEMENT SYSTEM.

In reviewing this substantial body of literature pertinent to general aviation pilot performance problems and in interviewing a broad sampling of general aviation personnel, the enthusiasm of the individuals and organizations involved and their serious concern with flight safety became clearly evident. While this effort has concentrated on problem identification and, by implication, needed changes, it must be noted that great strides have been made in general aviation safety in spite of the increases in its size and the complexity of its equipment and operations. Thus, the fact that the emphasis here has been on pilot performance problems should not obscure the achievements and progress that have been made.

Taken as a whole, the 35 issues that have been identified indicate that there is much yet to be done to alleviate pilot performance problems. As has been noted, research programs to settle these various issues differ in terms of their relative priorities, but all are important to an effective general aviation system. However, in reviewing these issues and their related research needs, and in examining the profusion of research efforts from the past, it became apparent that there exists an 'issue' that relates to all of the 35 issues identified, one that is of superordinate importance to human factors progress in general aviation. That issue is the need for an integrated research management structure for human factors research in general aviation.

The findings of this report represent an initial attempt to provide an organizing framework for human factors and to develop the use of the systems approach in the general aviation context. The full development of such an approach will require the establishment of a human factors research management system. The goals of this system would include at least the following: (1) that general aviation human factors design issues be defined and refined on a continuing basis in future years; (2) that programmatic research be planned and conducted to address these issues in a coordinated and integrated fashion and to provide required design data bases; and (3) that the results of such research be disseminated throughout general aviation and implemented and evaluated in operational contexts.

While the conceptual model developed for the present study and the issues identified in this report furnish a foundation for the development of such a research management system, additional effort is needed to define in detail the functional requirements for it. For example, one of the functions of such a system would be to acquire, organize for easy access, and analyze information that identifies pilot performance problems and associated human factors design issues. Such information would include (1) accident and incident data; (2) data aside from accidents and incidents that describe occurrences of pilot performance problems (e.g., flight 'assists' by air traffic controllers, regulatory reports of perturbations in daily operations); (3) results of ongoing and past human factors research in general aviation; (4) results of other human factors research in aviation and elsewhere (i.e., all man-machine systems) that is related to general aviation problems; (5) analyses of the potential of new technologies for use in the design of any of the system components; and (6) projections of change in general aviation and the National Airspace

System. With respect to this one function, research is needed (1) to identify sources of such information, (2) determine their utility for identifying human factors issues and solutions to these issues,[1] (3) determine how information from such sources could be improved, and (4) develop taxonomies and procedures for organizing the information for subsequent analysis.

Ideally, the entire management system would be operated as part of a larger aviation research management system that coordinated research on all human factors issues (e.g., research concerned with crash survivability) as well as all engineering research concerned with the development of advanced technology for the design of aircraft, air traffic control systems, and other equipment systems. Such coordination would be necessary to assure that the effectiveness of general aviation pilot performance is considered as a major factor in the design of the National Aviation System. Functional requirements for the human factors research management system, however, should be developed separately to assure that the full scope and complexity of human factors considerations are recognized. Given the importance of research to define these requirements with respect to the provision of comprehensive information to guide the design of the system components, the need for such an effort is ranked higher than any other issues identified in this report.

The development of a human factors research management system would bring a desired degree of order to what is now a rather diverse series of research efforts and projects, often with little or no interchange of ideas and technology. A good deal more is known in the human factors areas than has been applied in general aviation. The achievement of a constructive and effective technology transfer both into and out of general aviation would be a major goal of the human factors research management system described. The benefits of such research management would be substantial, and, considering the imminent changes looming for general aviation, the penalties of non-integrated research management will be paid in time, money, and human resources.

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[1] Appendix B, for example, describes current problems limiting the use of aviation accident data for identifying human factors design issues.

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APPENDIX A

LIST OF PERSONNEL INTERVIEWED

Following is a list of organizations and individuals interviewed.

Aircraft Owners and Pilots Association

- Russell S. Lawton

Federal Aviation Administration Headquarters

- Bernard A. Geier
- Raymond J. Hilton
- Patrick E. Russell

General Aviation Manufacturers Association

- Gary S. Livack

National Aeronautics and Space Administration (Ames)

- Charles E. Billings
- Sandra G. Hart
- John K. Lauber

National Aeronautics and Space Administration (Langley)

- James J. Adams
- Hugh P. Bergeron
- John D. Shaughnessy
- Joseph W. Stickle
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- Anthony J. Barile
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- Lee E. Paul
- Robert H. Pursel
- Constantine Sarkos

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- William Fanning
- William H. Stine

National Transportation Safety Board

- James W. Danaher
- Emmerson Eitner
- Bernard Loeb
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APPENDIX B

LIMITATIONS ON THE USE OF ACCIDENT DATA FOR IDENTIFYING HUMAN FACTORS DESIGN ISSUES

The identification and prevention of pilot performance problems requires knowledge of a variety of factors that influence performance during flight. Taken as a whole, these influences have been referred to as "human factors" in this report. That is, they are the variables that affect pilots' acquisition and processing of information needed to perform flight tasks and that govern the actions pilots take because of this information.

Discussions in Chapters II through VIII reveal how diverse such relevant human factors are, and how joint effects of factors form patterns that govern pilots' responses in ways that often cannot be traced to individual factors per se. Therefore, pilot performance problems cannot generally be attributed to a "cause" in the usual sense of the term. Undershooting a runway on landing may be due to a misjudgment of altitude by the pilot; but saying that the perceptual error was the cause of the mistake reveals nothing that can help in avoiding similar problems in the future. Would manipulation of the characteristics of the visual scene peculiar to that airport, such as runway markings and lighting, prevent other pilots from making the same error? Would changing the dynamics of the aircraft enable other pilots who realize they have made the same perceptual error to avoid the crash? If a different type, or timelier, information is made available from aircraft displays or from tower personnel, would other pilots make the necessary adjustments in their approach? Would modifying training with respect to processing the cue information pertinent to those circumstances reduce the number of pilots who made such errors?

Roughly analogous questions could be raised regarding failures of aircraft structural and mechanical components that lead to accidents. Suppose the landing gear on a new aircraft tends to fail during routine landings. The accident reports will reveal that such failures occurred. But, simply knowing that it failed does not tell the manufacturer how to make a safer landing gear; or, indeed, even if he needs to do so (e.g., the problem may be due to maintenance procedures). Is a different structure needed? How might changes in composition of materials used in the landing gear increase strength? What changes in testing standards would identify potentially faulty landing gear? What changes should be made in maintenance procedures that would prevent the problem from occurring?

Such questions are asked, of course, and improvements are made through answering them. But the questions are asked and answered by engineers who realize that a faulty landing gear that "caused" an accident is a result of one or more of a host of physical factors and engineering decisions that went into its manufacture and maintenance. One does not expect to find the set of possible remedies to a given difficulty in the record of the accident itself.

Similarly, ascribing an aircraft accident to "pilot error" does not answer the question that must be answered before similar accidents can be avoided. It is necessary that human factors engineers attack the problem in terms of the factors that govern pilot performance and of the decisions that prescribe contexts and contingencies for performance.

While solving pilot performance problems involves analyses that go beyond data normally available in accident analyses, there are things that can be learned from studying accidents that will aid in identifying and preventing performance problems. Analyses of accidents frequently provide indications, or at least hints, as to the nature of factors that led to the accidents. The validity, quality, and specificity of the information is usually better for structural and mechanical failures than for pilot failures, however. When it comes to pilot performance problems, accident data usually provide little information that can clearly point to a particular pilot error, much less to its source.

With respect to pilot performance problems, general inadequacies in current NTSB and FAA general aviation accident data systems have been identified by Connor and Hamilton (1979), Couch, Hill, Kolankiewicz, and Skelton (1979), GAO (1980), Lawton and Livack (1979), McCourt and Hewin (1979), and NTSB (1976); 1979a).[1] The general inadequacies may be summarized as follows:

- Resources for accident investigations, including availability of appropriately trained investigators, are not adequate to collect human factors data.

- The coding of accident data is not adequate for identifying critical human factors design issues.

- The criticality of different performance problems cannot be determined because exposure data needed to determine accident rates are not available.

- The computerized information systems used are not organized to facilitate analyses of human factors data.

- Organizational constraints regarding resources, recognition of value of human factors analyses, etc., have restricted use of information that is available in data banks.

The FAA and NTSB have recognized these inadequacies and several programs are planned or underway to improve these accident data systems (Couch et al., 1979; GAO, 1980). Improvements, however, are hindered by certain practical constraints. For example, it will be difficult, given present funding constraints, to provide the trained human factors specialists that are required for the collection of adequate human factors data during investigations of aviation accidents. There are also certain limitations on the information concerning pilot performance that can be collected during the investigation of general aviation accidents. Flight data recorders and cockpit voice recorders generally are not available to furnish objective data. Moreover, because the most extensive investigations are usually conducted only for fatal and severe accidents, pilots and passengers are seldom available either. Witnesses are also frequently unavailable because many general aviation accidents occur in remote areas. While many physical malfunctions in the aircraft may be identified after a crash, without pilots or other witnesses to interview, it is very difficult to collect data on pilot performance under such circumstances.

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[1] While the NTSB is primarily responsible for the analysis of civil aviation accident data, due to resource limitations it delegates responsibility to the FAA for most general aviation accidents, except for fatal and a few selected other types of accidents. Thus, both the NTSB and FAA maintain general aviation accident data bases (Couch et al., 1979; Edwards, 1975).

Even when pilots or other witnesses are available, reliable and valid human factors data may be difficult to obtain. Humans are not good observers of complex events. It is hard for us to remain uninvolved in events, and record objectively what transpires, especially in a situation as emotionally arousing as an accident (Chapanis, 1959). Furthermore, the possibility of legal complications or fines as a result of violation of Federal Aviation Regulations can bias the testimony of those involved in the accident.

In view of the general inadequacies of current accident data, and limitations on the improvement of accident data systems with respect to the identification of pilot performance problems, identification of such problems should be approached in a comprehensive manner utilizing the gamut of analytical and empirical research methods that are available to aid in the design of the system components discussed in this report. Such an approach is described in Chapter VIII.

The use of this comprehensive approach has the additional advantage over the use of accident data of providing a framework for anticipating and preventing pilot performance problems. General aviation is expected to change substantially in the near future. Appropriate identification and analysis of human factors issues associated with these changes can reveal actions that will be needed to promote flight safety before the changes themselves appear (and before accidents can occur). With such preparation, pilot performance problems can certainly be reduced in number and severity compared with what they would be without a comprehensive human factors framework to anticipate their nature and guide development of preventive measures.

APPENDIX C

LIST OF THE HUMAN FACTORS DESIGN ISSUES AND THEIR ASSESSED PRIORITIES

This appendix contains a listing of each of the human factors design issues identified in this project. Each of the issues was assigned to one of three categories of research priority. Design issues that were considered to be of greatest research priority are assigned to Category 1. Category 2 includes those design issues judged to be of somewhat lower priority than Category 1. Category 3 contains those issues, although important, that were considered to be of lowest research priority. Descriptions of the criteria and procedures employed to make these assignments are provided in Chapter I.

HUMAN FACTORS DESIGN ISSUES	PRIORITY CATEGORY
1. Identification of Requirements for Human Factors Engineering Standards and Guidance for Aircraft Controls and Displays	1
2. Development of Objective Assessment Methods for Aircraft Handling Qualities	2
3. Identification of Requirements for Extracockpit Visibility Criteria and Guidelines	3
4. Identification of Requirements for Human Factors Guidelines and Standards Concerning Intracockpit Noise and Vibration	3
5. Identification of Requirements for Integrated Flight Management Systems	1
6. Generation of Runway Surface, Marking, and Lighting Requirements	3
7. Identification of Requirements for Airport Approach Aids	3
8. Identification of Requirements for Normal and Emergency Aircraft Operating Procedures	2
9. Determination of Information Dissemination Methods for Aircraft and Subsystem Operating Procedures	2
10. Determination of Requirements for Aircraft and Subsystem Performance Data	2

	HUMAN FACTORS DESIGN ISSUES	PRIORITY CATEGORY
11.	Specification of Formats for Presentation of Aircraft and Subsystem Performance Data	2
12.	Assessment of Impact of Different Airspace Assignments on Pilot Performance	2
13.	Identification of Requirements for Modification of Minimum Visibility and Cloud Clearance Standards for VFR Flight	3
14.	Development of Guidance for the Design of Instrument Flight Procedures	2
15.	Identification of Requirements for Communications Between General Aviation Pilots and Air Traffic Control Personnel	1
16.	Identification of Requirements for Communications Between General Aviation Pilots and Flight Service Personnel	2
17.	Determination of Flight Experience Requirements for Certificates and Ratings	3
18.	Determination of Medical/Psychophysiological Requirements for Certificates and Ratings	3
19.	Identification of Task Subsets for Current Certificates and Ratings	1
20.	Identification of Needs for New Certificates	3
21.	Identification of Needs for New Ratings	2
22.	Identification of Training Requirements for Certificates and Ratings	1
23.	Determination of Training Techniques for Use in the Aircraft	3
24.	Determination of Training Methods for Use in Pilot Training Devices	2
25.	Determination of Training Device Fidelity Requirements	2
26.	Design of Instructional Support Features	2
27.	Determination of Instructor Training Requirements	1
28.	Development of Guidance for Recurrent Instructor Training	2

	HUMAN FACTORS DESIGN ISSUES	PRIORITY CATEGORY
29.	Development of Guidance for the Modification of Written Proficiency Tests	2
30.	Development of Objective Flight Checks	3
31.	Identification of Techniques for Using Alternative Test Media	3
32.	Determination of Requirements for Continuation Training	1
33.	Identification of Methods for Encouraging Continuation Training	2
34.	Determination of Requirements for the Recurrent Assessment of Pilot Proficiency	1
35.	Determination of Guidance for Structuring the BFR	1