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for General Aviation IFR Operations

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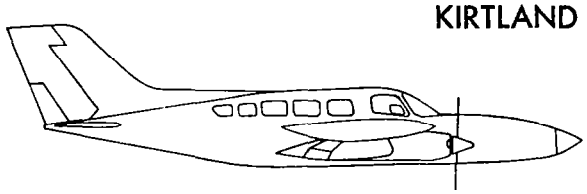

Proceedings of a workshop held at
NASA Langley Research Center
Hampton, Virginia
August 30-31, 1982

25th Anniversary
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Controls, Displays, and Information Transfer

for General Aviation

IFR Operations

Edited by
Hugh P. Bergeron
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NASA Langley Research Center
Hampton, Virginia

Proceedings of a workshop held at
NASA Langley Research Center
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August 30-31, 1982

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and Space Administration

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Information Branch

1983

PREFACE

A workshop on controls, displays, and information transfer for general aviation IFR operations was sponsored by NASA Langley and held in Hampton, Virginia, August 30-31, 1982. The purpose of the workshop was to review and evaluate the work performed under the NASA Single Pilot IFR (SPIFR) program, to highlight and disseminate major research findings, and to provide a forum for industry, universities, and government to interact and discuss the future thrust of research in the SPIFR program. Approximately 60 government, industry, and university representatives attended the workshop.

The first day consisted of selected presentations by NASA personnel on in-house studies and by industry and university personnel on work performed under contract or grant to NASA. The presentations selected represent key elements of the SPIFR program. These elements are classified into five disciplinary areas: program definition, controls, displays, information transfer, and research simulation facilities. A forum was held on the second day, followed by a tour of the NASA facilities used in the SPIFR research. The forum, in which all attendees participated, consisted of a general discussion of the research performed to date and the future thrust of the NASA SPIFR program.

This publication contains a summary of the forum and copies of the materials used in the presentations.

Use of trade names or names of manufacturers in this report does not constitute an official endorsement of such products or manufacturers, either expressed or implied, by the National Aeronautics and Space Administration.

Hugh P. Bergeron
John D. Shaughnessy
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INTRODUCTION

A workshop on controls, displays, and information transfer for general aviation IFR operations was sponsored by NASA Langley and held in Hampton, Virginia, August 30-31, 1982. The purpose of the workshop was to review and evaluate the work performed under the NASA Single Pilot IFR (SPIFR) program, to highlight and disseminate major research findings, and to provide a forum for invitees from industry, universities, and government to interact and to discuss the future thrust of research in the SPIFR program.

Richard H. Peterson, Deputy Director of NASA Langley Research Center, welcomed the attendees and reemphasized the NASA commitment to research on general-aviation SPIFR problems. Dr. John D. Shaughnessy, SPIFR Program Manager, followed Mr. Peterson's remarks with a briefing, discussing the background, overview, and current status of the program. Dr. Shaughnessy's briefing, presented in the section entitled SPIFR PROGRAM OVERVIEW AND STATUS, was followed by selected presentations by NASA personnel on in-house studies and by industry and university personnel on work performed under contract or grant to NASA. The selected presentations represent key elements of the SPIFR program. These elements are classified into five disciplinary areas: problem definition, controls, displays, information transfer, and research simulation facilities. Copies of the materials used in these presentations are presented in Appendix A.

A forum was held on the second day, followed by a tour of the NASA facilities used in the SPIFR research. The forum, in which all attendees participated, consisted of a general discussion of the research performed to date and the future thrust of the NASA SPIFR program. The key observations and recommendations discussed in the forum are presented in the section entitled SUMMARY OBSERVATIONS.

SPIFR PROGRAM OVERVIEW AND STATUS

Since FY 1978 the NASA Langley Research Center has sponsored a research program entitled General Aviation Single Pilot IFR Systems. This section of the report discusses the justification, objectives, and technical approach for this program. Appendix B presents a bibliography of the publications that have resulted from this research. A list of acronyms and symbols used throughout this publication is contained in Appendix C.

Justification

IFR operations with FAA air traffic control service can be divided into four categories. These categories and their corresponding numbers of IFR operations in 1981 were: air carrier, 10.2 million; air taxi and commuter, 4.6 million, general aviation, 18.5 million; and military, 3.9 million. By 1993 these numbers are forecasted to increase, in some cases dramatically, to: air carrier, 13.3 million; air taxi and commuter, 8.8 million; general aviation, 30.4 million; and military, 3.9 million. A large portion (in some cases, most) of the IFR operations in three of these categories (air taxi and commuter, general aviation, and military) involves a single crewman who is expected to perform as effectively as the two- or three-man crew of transport class aircraft. It is thought by many that this level of effectiveness, in general, does not exist.

A recent analysis of National Transportation Safety Board (NTSB) accident data for general-aviation single-pilot IFR (SPIFR) shows that single-pilot operations account for 79 percent of all accidents during IFR operations. About 50 percent of the single-engine (SE) accidents are occurring in the high-workload landing phase of flight. The findings also indicated that about one-half of the accidents are controlled collisions with the ground; that is, situations in which the airplane is functioning normally and the pilot flies into terrain due to a lack of situational awareness. A nationwide survey of 5000 currently rated IFR pilots was recently conducted under the NASA SPIFR program to identify problem areas and possible solution concepts. Typical problems include: detection and timely processing and dissemination of weather information, air traffic control (ATC) in-flight demands and cockpit duties which cause high cockpit workload, complex and/or excessive ATC procedures, and maintaining currency of experience. Specific solution concepts include: better and more accurate weather information in the cockpit, better pilot interface with increased automation and display formats, and a data link for enhanced information transfer.

Efforts have been conducted under the NASA SPIFR program to investigate the pilot interface with aircraft automation. An autopilot complexity-benefit trade-off study (ref. 1), completed in FY 82, evaluated the relative benefits of various levels of state-of-the-art autopilot complexity. A trend towards more frequent pilot blunders with the more complex autopilots was discovered. Poor pilot interface with automation was thought to be the reason. A second study (ref. 2), also completed in FY 82, used the same simulator and flight scenario and evaluated an Automatic Terminal Approach System (ATAS) concept which automatically flies instrument approaches by using stored instrument approach data to control the simulator's autopilot and radios. This represents a level of automation well above the highest level evaluated during the first study. The results were encouraging in that fewer pilot blunders were committed with ATAS than with a low-level autopilot mode that in the

first study had relatively few pilot blunders. This improvement was due to a much improved pilot interface in the case of ATAS concept. It is thought that research should continue in this area to enhance single-crewman effectiveness in more automated aircraft operations.

A study conducted by the University of Kansas and supported under the SPIFR program (refs. 3 and 4) assessed the potential of various nonconventional manual control devices for general-aviation aircraft. The study showed that the conventional yoke is not the best aircraft control arrangement when considering the pilot workload requirements of IFR flight. The study indicated that the side-stick controller exhibits the most desirable interface characteristics. Compared to the yoke, the side stick should provide better two-axis integration of control inputs, fewer inadvertent inputs, higher closed-loop-system frequency response, a better pilot-aircraft control interface, an increase in unobstructed panel display area, and increased space behind the instrument panel. Simulation and flight tests need to be conducted to verify these advantages and document system requirements.

Simulator and analytical studies of the use of conventional primary displays in instrument landing approaches have been conducted under the SPIFR program. Piloted simulator results show that the pilot aircraft display-system lateral response on the localizer has a period of about 60 seconds and is stable when the aircraft is 5 n.mi. from touchdown, but this system period reduces to about 40 seconds and can be unstable when the aircraft is 1.25 n.mi. from touchdown. This unstable condition is sometimes called "chasing the needles." Pilot model analyses have verified this unstable condition. During nonprecision instrument approaches, conventional displays tend to be disorienting and can cause high pilot workload during this critical phase of the flight. The development of CRT and microprocessor technology has made it possible to consider combining many sensor signals in one display. Such information integration can improve performance and/or reduce pilot workload. Research should be conducted to document the performance and human factors advantages offered by advanced primary displays and to determine the optimum display content.

Because of the increase in air traffic and the more sophisticated and complex ground control systems handling this traffic, IFR flight has become extremely demanding, frequently taxing the pilot to his limits. It is rapidly becoming imperative that all the pilot's sensory and manipulative skills be optimized in managing the aircraft systems. New and innovative concepts must be developed to assist the pilot in interfacing with these systems. One new technology that appears to have the potential for a revolutionary impact in assisting in this pilot-aircraft interface is computer-based voice recognition/synthesis. It is now conceivable that application of voice recognition/synthesis in the cockpit environment could have the potential for greatly improving the pilot's ability to manage cockpit responsibilities, thereby reducing pilot workload and increasing the safety of the flight. Research needs to be conducted to determine applicability and human factors design guidelines of voice input/output systems for single-crewman flight operations.

Technical Objectives

The basic objective of NASA's SPIFR program is to provide a technology base to enhance single-crewman effectiveness in future aircraft operations and automated ATC systems through exploitation of modern computers.

Specific objectives of this program are as follows.

- Investigate new concepts for providing low-cost, timely, and efficient weather data to the pilot in flight.
- Improve the man/machine interface with aircraft automation and investigate advanced autopilot concepts.
- Determine the benefits and system design requirements of side-stick controllers in future automated aircraft.
- Determine the performance and human factors benefits offered by advanced primary displays, optimize display content and format, and investigate display control concepts.
- Determine the applicability and human factors design guidelines of voice input/output systems for flight operations.
- Determine Mode S data link applications for the next-generation ATC system and optimize the display content from an operations point of view.
- Determine guidelines for selection of performance- and cost-optimized integrated control and display systems.
- Conduct an operational evaluation of the NASA Cessna 402 Demonstration Advanced Avionics Systems.

Technical Approach

The technical objectives of the SPIFR program will be addressed by LaRC, industry, and universities in both analytical and experimental efforts. The LaRC general-aviation Visual/Motion Simulator (fig. 1) and Cessna 402 (fig. 2) aircraft will be utilized for the experimental efforts. Coordination and information interchange will be carried out between NASA, DOD, and the FAA with respect to single-crewman flight operations problems and research. Similarly, coordination between this program and NASA's Flight Management and Operating Systems programs will provide cross fertilization of technical ideas for single-crewman and multicrewman operations.

An effort to provide low-cost, timely, efficient weather data to the pilot in flight is ongoing. A grant has been awarded to Ohio University to study a concept for taking digitized weather data generated by ground-based weather radar and spherics equipment and displaying this information on a CRT in the cockpit. To take this weather data, which starts as a north-up map, and translate and rotate this information so that an aircraft-centered, heading-up map can be provided will constitute a heavy burden for the aircraft computer. In FY 83 the computer problem will be studied. A typical weather data base will be demonstrated on tape, a computer algorithm for manipulating the data will be derived, and the use of this system will be demonstrated. NASA will then take this data-handling system and incorporate it in a manned simulation program. Variations in cycle time for the airborne computer will be examined to determine the rate that will allow the pilot to maneuver this aircraft in the weather system in an effective manner. In FY 83 experimental hardware to be installed in LaRC simulators and in the Cessna 402 will be developed. This hardware will allow evaluation of the concepts discussed above in an operational environment.

An effort is under way to improve the pilot-machine interface with aircraft automation. An Automatic Terminal Approach System (ATAS) was conceived as a means of improving this critical interface. The ATAS can automatically fly a published instrument approach by using stored instrument approach data to automatically tune aircraft avionics and control an aircraft's autopilot. The ATAS will execute the missed-approach procedure at the completion of the approach unless the pilot takes over to land. The system is designed for easy pilot override to accommodate air traffic control radar vectors and altitude assignments. Emphasis for the design and study was on a reduction in pilot workload and blunders by improving the pilot-automation interface. A simulation study was performed in FY 82 (ref. 2) to determine the feasibility of an ATAS, determine pilot acceptance, and examine pilot interaction with such a system. A generic ATAS system was simulated in the LaRC General Aviation Simulator, and seven pilots each flew four instrument approaches with the ATAS and four approaches with a baseline heading-select autopilot mode. The ATAS runs resulted in lower flight technical error, lower pilot workload, and fewer blunders than did the runs with the baseline autopilot. The ATAS status display enabled the pilots to maintain situational awareness during the automatic approaches. The system was well accepted by the pilots.

As a result of the ATAS study and an earlier state-of-the-art autopilot complexity-benefit trade-off study (ref. 1) that documented a trend towards more frequent pilot blunders with more complex autopilots where the man-machine interface was not optimized, a third study is planned for FY 83. This effort will consider the intelligent autopilot (IA) as an extension of autopilot complexity levels rather than as an addition to existing autopilots. The IA will have knowledge of the appropriate flight paths and the aircraft state. The study will evaluate autopilot complexity levels from simple heading-hold devices to IA's that monitor pilot inputs and a fully automated IA. The man-machine interface will be optimized and evaluated and operational benefits and problems will be documented. Based on the results of the simulator study, the DAAS will be utilized beginning in FY 84 to evaluate the IA concept.

An in-house study to test and determine the applicability, the desirable controller characteristics, and the benefits of a side-stick controller in IFR operations will be completed in FY 83. The first phase of this effort is a motion base simulation study to determine a matrix of controller parameters versus aircraft dynamics. A programmable force/feel two-axis controller is being used in this study. In addition to the various quantitative data on aircraft control, data on aircraft control, data on pilot comments, opinion, and acceptance will also be collected and analyzed. The study will result in a definition of guidelines for implementation of a side-stick controller in a wide range of aircraft types.

A continuing effort to evaluate computer-derived, path-in-the-sky-type advanced aircraft display formats is under way. One particular display format being investigated presents a box that moves along the desired path ahead of the aircraft. This format combines simplicity with many useful advantages. The display provides flight director and raw data information required for precise control of aircraft position. A previously conducted simulation study has shown that a two-box configuration can be used for both enroute navigation and terminal area guidance. As a continuation of this effort, a flight test study was conducted during FY 82 using the Princeton Avionic Research aircraft at Wallops Flight Center (ref. 5). The flight test results verified that the short, curved, descending, precisely controlled landing approach executed in the simulation study could also be performed in flight. The subject pilots have shown acceptance of the display. During FY 83, further simulation studies will be conducted on variations of the two most important parameters of the

box display, the distance to the box and the field of view. A determination of the optimum combination of these parameters for path-following performance and also for pilot workload will be sought. In FY 83 a study to determine the operational requirements of the box display will be initiated, and based on the results of the simulation studies, the box display may be installed in the DAAS software. This installation will allow the box display to be flight tested together with the DAAS electronic map in an operational environment.

During FY 83 a contract study will investigate the human factors aspects and the potential for using voice recognition/synthesis techniques in the cockpit environment to reduce workload, increase safety, and increase aircraft utility. More specifically, the study will (1) review the state of the art of voice recognition/synthesis and project this technology 5 years into the future, (2) define and analyze the potential of the technology for control of flight systems and for information transfer applications in the aircraft cockpit environment, (3) determine the suitability of the above applications in an operational environment, and (4) identify and recommend specific applications through a hierarchy of benefits. The study will concentrate on the pilot-aircraft cockpit interface and on the integration of this interface into the total aircraft system from an operational human factors point of view. Applications in the cockpit will include the independent use of voice recognition and voice synthesis techniques as well as the integration of the two in solving problems, performing functions, or fulfilling any other requirement for interfacing with aircraft systems. Depending on the results of this paper study, a simulation effort may be conducted in FY 84, followed by a flight test evaluation using the DAAS in FY 85 to verify and refine the applications of voice input/output systems.

A flight data console (FDC) was developed under contract (refs. 6-7) to simulate and test the concept of a visual presentation for in-flight ATC communications via a data link. This would either replace or supplement the current voice communications systems. The use of an FDC implies the use of a digital data link (for example, the proposed Mode S Data Link Concept). The FDC was evaluated in flight using GA pilots flying in the Washington, DC, area in FY 82. The results showed that for terminal area operations, the cockpit workload was reduced for single-pilot operations and flight performance was comparable to that in dual-pilot IFR flight. This indicates that a digital data link communications system could be beneficial in GA flight operations in the current ATC system. The tests also showed that a two-way voice link is frequently desirable to supplement the data link when unforeseen or unanticipated events occur. This is especially true for enroute flight segments, when conditions frequently require route changes. The combination of data link plus limited two-way voice communication has been shown to significantly reduce pilot workload in the terminal area. During FY 83 the Cessna 402/DAAS Mode S transponder software and documentation will be upgraded, and in FY 84 flight tests of Mode S ATC and weather message formats will begin in the Cessna 402. These tests will be conducted jointly with the FAA.

As part of the effort to determine guidelines for selection of performance- and cost-optimized integrated control and display systems, a contracted study was initiated in FY 82 to perform an optimization trade-off study of integrated control and display systems. The study will compare both the individual and interrelated functional benefits of specific combinations of controls and displays with the complexity and cost of the combined systems. An optimization matrix of maximum benefits (increased safety, reduced workload, added utility, etc.) as compared with minimum complexity and cost will be defined for a wide range of state-of-the-art and advanced control and display system concepts. Candidate systems will be recommended for various levels of airplane sophistication for IFR flight scenarios in the current

and future air traffic control system. As part of the contract effort, the DAAS will be flown and evaluated as an advanced integrated control and display system.

During FY 83 an evaluation of the DAAS itself will be conducted in an operational environment. Particular attention will be given to the pilot-machine interface, pilot training and workload requirements, and the utility of individual DAAS features such as an electronic moving map, a flight warning advisory system, RNAV/VNAV, in-flight performance calculations, weight and balance computations, and onboard navigation simulators.

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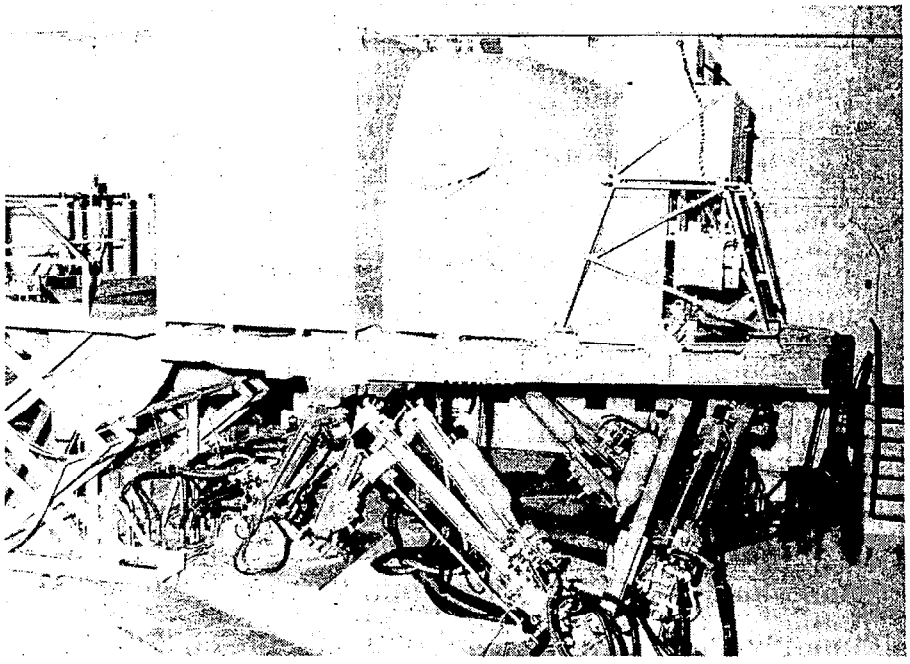

Figure 1.- Langley Research Center general aviation Visual/Motion Simulator.

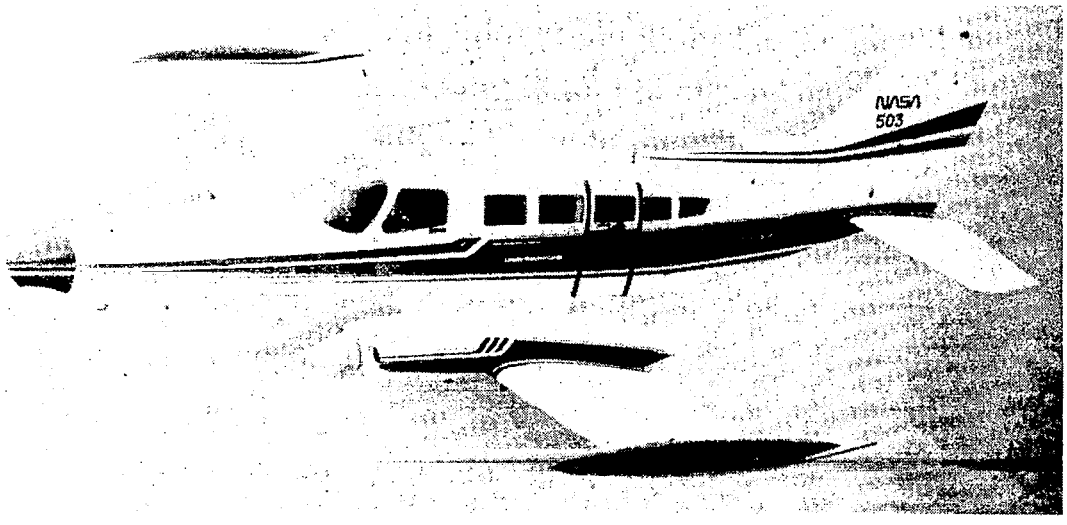

Figure 2.- Langley Research Center Cessna 402.

SUMMARY OBSERVATIONS

This section presents a summary of the key observations and recommendations resulting from the 2-day workshop. The summary primarily addresses and is a compilation of the main issues discussed during the forum held on the second day. The forum, which was considered a key element of the workshop, was attended by 61 people. The observations and recommendations are presented in light of the previously stated purpose of the workshop (see Introduction) and the objective of the NASA Langley SPIFR program (i.e., to provide a technology base to enhance single-crewman effectiveness and safety in future aircraft operations and automated ATC systems through exploitation of modern computers, controls, and displays.

This summary consists of an overview, followed by a discussion of the five specific areas that were identified as high-priority items in the workshop. These areas are: problem definition, controls, displays, information transfer, and research simulation facilities. This discussion is followed by a perspective discussion of NASA's role in SPIFR research and concludes with a brief discussion of the future thrust of the NASA SPIFR research effort.

Overview

The general consensus of the attendees was that previous and ongoing NASA research on SPIFR problems is relevant, timely, and cost effective. However, it was also felt that, considering the magnitude of the problems encountered in SPIFR operations, the NASA effort should be increased. The current level of the NASA SPIFR effort requires trade-offs that limit the benefits that could potentially be derived from the program. This point was emphasized in a discussion on the relative effort that should or could be allocated to research on near-term problem-solving as compared to high-technology, high-risk, but potentially high payoff research. Due to the limited NASA funding, trade-offs had to be made as to which area NASA should emphasize in its research. Pursuant to a lively discussion, a compromise recommendation was reached by the attendees. Within the limits of the present budget, it was recommended that NASA place primary emphasis on solving near-term problems but should also continue, at a lower level of effort, research to develop new and innovative approaches and to maintain an overall balanced program.

Regardless of the specific problems being addressed, it was unanimously agreed that NASA should emphasize the man-machine aspects of the pilot interface in the cockpit. The man-machine relationship is considered to be inherent to all the research being performed in the SPIFR program. The need to consider the synergistic interrelationship of all the pilot tasks and operations when looking for solutions to specific problems was also discussed and emphasized. In the past, for example, some solutions have, by their nature, created new problems in other modes of the pilot interface.

In addition, regardless of the research to be performed, it was also agreed that NASA's job was to generate data bases to be used as guidelines, as opposed to designing hardware systems. To be more specific, NASA should concentrate its efforts on the development and validation of solution concepts. In this approach, however, consideration must be given to the current and projected state-of-the-art hardware technology (CRT, computers, etc.) as it relates to the implementation of the concepts being proposed and researched. This includes the reliability aspects of new-technology hardware systems (i.e., the problem of system failures) and the effects of

these systems on mission success and safety. It is important that the new technologies be closely monitored for potential application in developing the solutions to SPIFR problems. An example of one such technology which has recently experienced a rapid advancement and which has the potential for reducing pilot workload in the cockpit is the computer-based voice recognition/synthesis technology. The point was also made that all concepts showing promise should be tested in the operational environment. Environmental conditions and problems need to be factored into the design concepts.

Finally, it was emphasized that NASA SPIFR research must be sensitive to the needs of both the general public and industry, and must also be coordinated very closely with the FAA. The effective utilization of NASA resources requires close contact and coordination with both industry and user organizations.

Research areas other than those listed earlier were also mentioned; however, they either did not fall under the SPIFR program description or were considered to be of lower priority than those mentioned. Examples included training, cockpit lightning, cabin noise, and hardware reliability. Only one area, training, received any serious consideration. It was felt by some of the attendees that if funds were available, research in this area should be performed by NASA. In particular, it was felt that previous work with the NASA oculometer showed the potential of this device as tool in SPIFR training applications (ref. 1).

Problem Definition

The work performed in this area is primarily directed toward determining the problems and their relative significance in SPIFR operations and is used, among other things, to assist in directing the NASA SPIFR research effort. The problem definition studies encompass several independent and different data bases (NTSB accident data, ASRS incident data, mail questionnaire survey data, workshop results, expert opinion). The use of the various data sources results in a good overall perspective of the type and magnitude of SPIFR operational problems.

Previous efforts have been responsible for the current direction of the NASA SPIFR research program (refs. 2 and 3). The emphasis on the landing and approach problems, for example, is due to the relatively large percentage of accidents associated with this phase of flight. Also, the three SPIFR research areas (controls, displays, and information transfer) are all direct products of the problem definition studies. The specific research performed in these three areas can be directly linked to one or more of the studies. Additionally, a recent analysis of a correlation of several of these studies has shown that the pilot interface is a factor in most if not all of the problems. New emphasis is now planned to address this issue as it relates to the various problems.

The forum endorsed this approach of defining problems and using the results to direct the NASA SPIFR research. It was further felt that even though a large amount of data had been accumulated and additional analysis could be and should be done on this data, a reduced effort should continue in this area to maintain currency of the problems as they relate to the rapidly changing operational environment.

Controls

Aircraft controls, as considered here, encompasses the complete range, from basic manual control up through augmentation and sophisticated levels of automation. SPIFR research includes several efforts throughout this range.

These efforts are currently directed both at improving the basic control modes as well as developing new concepts to supplement and/or replace present systems.

Studies have shown, for example, that various levels of augmentation and automation can significantly lower the pilot workload, thus allowing him to better manage his other cockpit tasks. Research is presently being performed in these areas.

In the area of manual control, research has shown that the basic yoke controller exhibits many undesirable characteristics. In particular, an earlier study (refs. 4-5) has shown that a side-stick controller, which is the subject of a current SPIFR research effort, should correct some of these deficiencies. The side stick, for example, would provide better two-axis integration of control inputs, fewer inadvertent inputs, higher closed-loop-system frequency response (hence tighter control), a better, more natural pilot-aircraft control interface, an increase in unobstructed panel display area, and an increased space behind the instrument panel.

This SPIFR program will concentrate on simple, inexpensive, augmented and automated control concepts. This will include the use of manual control in augmentation schemes as well as various levels of intelligent autopilot concepts. Advances in computer hardware and software development have recently reached the level at which artificial intelligence concepts now appear feasible, and they will also be considered. Specific examples of research being considered include the use of manual controllers (side stick) to operate the autopilot modes and fly the aircraft through the autopilot systems, programming small computers to automatically fly various autopilot modes (intelligent autopilot), and using the intelligent autopilot concept to monitor manual control. Other concepts, such as full fly-by-wire, even though possible, are not considered practical or economically feasible at this time for most general-aviation aircraft, and are therefore not being actively pursued.

Studies have shown that some of the major problems in developing these control concepts are associated with the pilot interface of the system. The implementation of automation without careful consideration being given to the pilot interface can frequently create more problems than it solves. Therefore, in the future the NASA SPIFR approach will place more emphasis on the human factors aspects of the pilot interface problems of controls research. One apparent solution is to incorporate good display feedback information in the operation of the control systems to keep the pilot continuously informed on the aircraft status, situation, and location. It is our intention to take full advantage of the potential of the interactive/synergistic relationship of controls and displays when performing research in both controls and displays.

One other important point discussed during the forum was that of hardware reliability. Even though the SPIFR program cannot address the problem of reliability directly, consideration is given to the level of the state of the art of the various hardware capabilities in considering and developing the various control concepts.

Displays

The use of the term displays, in the context of the aircraft cockpit, can include all visual feedback information to the pilot. It encompasses not only guidance and navigation, but also visual feedback information on cockpit systems control, data management, and so forth. Except for some associated work in information transfer, however, the main thrust of the SPIFR display effort deals primarily with display requirements for aircraft control and navigation. These display requirements relate to all levels of aircraft control, from basic manual control to high levels of augmentation and automation.

The SPIFR research assumes the availability of onboard computing and CRT display capabilities. The advent of this multifunction/multimode CRT display capability has produced a virtual revolution in new display concept development. Practically speaking, there is no display format, static or dynamic, that cannot be created. Opportunities now exist for greatly improving aircraft display formatting.

The SPIFR approach to display research, in consensus with the forum discussions, can be stated as follows:

(1) Analyze and determine problems with present displays

(2) Develop new evolutionary concepts, building from present display concepts

(3) Exploit computer and multifunction CRT display capabilities to develop and evaluate new, innovative pictorial display concepts to form a technology data base of display formats.

An example of the last item (refs. 6-8) is a simple pictorial display concept that integrates both aircraft attitude and position into one simple format. It was the concensus of the forum that this particular effort is representative of the type of work that should continue.

The forum discussion reemphasized several other relevant points. NASA SPIFR display research should be both evolutionary and innovative; that is, state-of-art display concepts should be upgraded, but this should be accomplished by exploiting the unique capabilities of computers and multifunction display hardware to develop easy-to-use natural display formats that will both improve precision of aircraft control and increase situational awareness.

Information Transfer

The term information transfer can refer to many relationships. For the purpose of the SPIFR program, the term implies the transfer to the pilot of information that is necessary for him to manage and successfully complete his flight. The key element and the controlling factor in this transfer loop is the pilot.

The SPIFR program concentrates its efforts on the information that would normally be up- and down-linked between the ground and the aircraft (i.e., two-way communications, weather data, messages) and on information within the cockpit which is necessary to manage and control the various aircraft subsystems. As in the area of displays, much of the rapidly evolving technology (computers, voice recognition/synthesis) can be exploited to assist the pilot in the task of flying and managing the aircraft.

As previously mentioned, the pilot is considered the key element in the information transfer loop. Fast, concise, and clear methods of presenting the final form of the information to the pilot is the ultimate goal. New and innovative methods can be developed using advances in specific areas of technology. One example is the cockpit use of voice recognition/synthesis (R/S) hardware. The application of voice R/S technology in the cockpit environment has the potential for improving the pilot's ability to manage many cockpit systems. This is especially true during high-workload flight segments.

This technology is fairly new, however, and considerable time and research may be required to prove or disprove its value. The general consensus was that, due to limited funds, this type of advanced-technology research should continue, but only as a secondary effort. On the other hand, an effort that is actively under study by the FAA to uplink ground-based weather radar data appears to have an immediate payoff and should continue as a primary effort. A third area, which is receiving general support as a primary effort is the development of application concepts for using the ATC Mode S data link.

The pilot interface in the cockpit is basic to all the research being performed in the SPIFR program. As we go to higher and higher levels of automation and more computer control of the aircraft systems, making the pilot interface more user-friendly is becoming more important. Therefore, this aspect of information transfer within the cockpit will necessarily be given more attention in future research.

Research Facilities

NASA SPIFR research is typically accomplished through one of three methods: contracts, grants, or in-house studies. The in-house research can include analytical studies, simulator studies (using the NASA LaRC General Aviation Simulator), or flight tests (primarily using the NASA Cessna 402 and other general-aviation aircraft). This section on facilities pertains to in-house research only.

As mentioned, the NASA SPIFR in-house research tools are the LaRC General-Aviation Simulator and the Cessna 402 aircraft with its digital advanced avionics system (DAAS). The General Aviation Simulator has several sophisticated capabilities that make it a unique research facility. It has the following features: motion base (three degrees of freedom), full compliment of instrumentation and avionics, force feedback reversible controls (with either yoke or side-stick controller in pitch and roll, and rudder pedals in yaw), out-the-window visual scene (day, night, variable visibility/ceiling both in flight and taxiing), realistic engine and airstream noise, full avionics and navigation interface capability, full simulated ATC communications capability, full autopilot and automation capability, several aircraft dynamics (single and twin), and all necessary peripheral equipment to record and analyze data. The simulated navigational area extends from the Washington, DC, area south approximately 180 n.mi. to include portions of South Carolina, and west from the Atlantic Ocean for about 150 n.mi. All the enroute navigation aids and the terminal area navigation aids at 13 airports are included in the data base. The avionics and instrumentation are installed on modular panels and can be rapidly exchanged to accommodate several research programs during the same day. The instruments and displays include both electromechanical and monchromatic CRT's. Plans are to upgrade to color CRT's in the near future.

The Cessna 402 aircraft with the DAAS is a light twin-engine cabin class aircraft with an onboard research computer (ref. 9) which controls the avionics,

autopilot, and displays through a common bus. Two high-contrast monochromatic CRT's are included as part of the DAAS. One CRT serves as an airborne electronic map display and is programmed through the computer. The other CRT is used with a keyboard to interface with the computer. The DAAS also has the ability to simulate a complete autopilot-controlled flight scenario in real time while still on the ground. Plans are to upgrade the aircraft's monochromatic CRT's to color in the near future.

These two classes of facilities, simulator and aircraft, are considered adequate to perform the research presently being pursued in the SPIFR program. The only major suggestion made during the forum was that NASA should not delay upgrading to color CRT's in either the simulator or the aircraft, since operational color systems for GA aircraft are presently being manufactured.

An additional point that was discussed in the overview section and is appropriate to reemphasize here is that concepts, once proven on the simulator, should be carried into the operational environment. The Cessna 402 is the primary flight vehicle for accomplishing this in the SPIFR program.

NASA's Role in SPIFR Program

NASA is one of several organizations looking at the problems and researching solutions for GA operations. These include industries, which are interested in specific areas pertaining to their individual product; user organizations, which are interested in helping their clientele; and other government agencies that serve the public as a whole. The NASA SPIFR program should perform research on problems requiring immediate attention, and should also conduct research that uses high-risk technology and therefore cannot be justified in the economics of individual companies, but which has a potentially high pay off. The SPIFR program should concentrate on studying generic solution concepts rather than on building prototype hardware. This work, however, should be carried through to the proof-of-concept stage, which frequently implies the need for flight tests. The SPIFR program attempts to meet these criteria.

One additional point emphasized during the forum was that NASA should maintain close contact and coordinate efforts with both industry and user organizations to verify where the problems really exist and to minimize duplication of efforts.

Future Thrust of NASA SPIFR Research

The purpose of the workshop, as stated in the Introduction, was successfully accomplished. In particular, the forum held on the second day was considered very successful. The discussions throughout the forum were both lively and constructive. The results of this workshop will be a major input in the future NASA SPIFR research effort.

Several general conclusions can be drawn from the forum discussions. Previous SPIFR research has been timely, relevant, and cost effective. It was also concluded, however, that considering the magnitude of problems encountered in SPIFR operations, the NASA effort should be increased if at all possible. As for specific program direction, it was the consensus of the forum that the primary emphasis should be placed on near-term problem solutions, but work at a lower level of effort should also continue on research in areas of new technology to develop new and innovative concepts and to maintain an overall balanced program. Emphasis should be placed on

developing simple, inexpensive augmentation and automation control concepts. The implementation of these concepts must, however, rely heavily on the application of good human factors principles to guarantee a good pilot-aircraft interface. It is expected that this can be accomplished through appropriate feedback, principally through innovative visual-display formats. This work should take full advantage of the potential of the interactive and synergistic relationship of controls and displays.

It was also suggested that the results of the workshop could be useful to other agencies and organizations in their own individual and specific programs and should therefore be given wide distribution outside NASA.

Another topic, which not specifically discussed but was perceived by the authors, was that, based on the success of this workshop, a second GA workshop should be held in 2 or 3 years to update and redirect the GA SPIFR effort. One change, however, should be made. The next workshop should also include formal presentations by industry and user organizations on SPIFR research not sponsored directly under NASA programs.

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SINGLE PILOT IFR PROGRAM OVERVIEW AND STATUS

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ABSTRACT

The history of the General Aviation Single Pilot IFR research program at NASA LaRC was discussed in general terms. The program objective, justification, and technical approach were given. The facilities used to conduct the research were discussed briefly. A general overview of recent accomplishments, present activities and near term plans were given. (This overview is essentially section II of this report.)

SINGLE PILOT INSTRUMENT FLIGHT RULES RESEARCH PROGRAM.

OBJECTIVE: TO PROVIDE A TECHNOLOGY BASE TO ENHANCE SINGLE CREWMAN EFFECTIVENESS AND SAFETY IN FUTURE AIRCRAFT OPERATIONS AND AUTOMATED ATC SYSTEMS THROUGH EXPLOITATION OF MODERN COMPUTERS, CONTROLS, AND DISPLAYS.

JUSTIFICATION: GA IFR OPERATIONS ARE FORECASTED TO INCREASE FROM 18.5 MILLION IN 1981 TO 30.4 MILLION BY 1993, AND SPIFR ACCIDENTS DUE TO "PILOT ERROR" ARE FORECASTED TO INCREASE FROM ABOUT 150 PER YEAR TO 250 PER YEAR IN THE SAME TIME PERIOD. RESEARCH INTO MORE EFFICIENT METHODS FOR TRANSFERRING WEATHER INFORMATION TO THE PILOT, IMPROVING THE PILOT'S INTERFACE WITH AUTOMATION AND AIRCRAFT CONTROL, AND DEVELOPING NEW PRIMARY COCKPIT DISPLAY FORMATS AND INFORMATION TRANSFER CONCEPTS SHOULD PROVIDE A TECHNOLOGY BASE THAT WILL ALLOW FOR SAFER MORE EFFICIENT SPIFR OPERATIONS.

APPROACH: ANALYTICAL AND EXPERIMENTAL RESEARCH IS BEING CONDUCTED AT LANGLEY, IN INDUSTRY AND AT UNIVERSITIES. AT LaRC, VARIOUS SIMULATORS, AND NASA AIRCRAFT ARE BEING UTILIZED FOR THE EXPERIMENTAL EFFORTS. SINGLE CREWMAN FLIGHT OPERATIONS RESEARCH IS COORDINATED BETWEEN NASA, FAA, DoD & USER/MANUFACTURER ORGANIZATIONS.

SINGLE PILOT INSTRUMENT FLIGHT RESEARCH SIMULATOR

The general aviation (GA) simulator at LaRC has recently been upgraded to provide a valid simulation environment for research in full mission IFR studies. The simulator is constructed around a light twin GA aircraft cabin and is mounted on a two degree-of-freedom motion base (pitch -10° +15°, roll ±16°).

Control inputs in pitch and roll are applied through a standard yoke arrangement. This arrangement is reverse driven by hydraulic actuators in order to feed back aerodynamic control force cues. This allows a realistic simulation of aircraft controller forces in pitch and roll.

An out-the-window visual display is obtained by using a closed circuit TV system and a terrain model board. The system is called the visual landing display system (VLDS). The model board is scaled so as to encompass an area of approximately 2 x 6-1/2 miles. The model includes two airports, country and suburban terrain, and a small city. The model airports are equipped with runway, approach, and sequence flashing lights. Both night and day scenes and various ceilings and visibilities can be simulated.

The GA simulator is equipped with an oculometer. This system provides pilot look point information over an area defined by a pilot's view angle of 40° x 60°.

A high quality full range engine and airstream noise simulation has been developed and installed in the GA simulator. The system can be used to provide both the detrimental and beneficial effects of the real world aircraft noise environment.

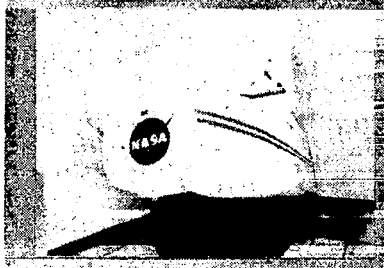
The GA simulator incorporates a complete dual radio/ATC communications network capability.

The GA software program includes the simulation of two geographical areas, Atlanta and Washington/Norfolk. The Washington/Norfolk area, for example, encompasses an area approximately 170 x 180 miles. All VOR's and NDB's in the area are programmed with respect to the latitude/longitude, elevation, frequency, and coded identification. Twelve airports were also chosen in this area and all associated navaids with respect to these airports (ILS, LOM, OM, MM, etc) were programmed. All of the twelve airports, and their corresponding navaids, can be oriented to coincide with the VLDS runway.

A complete autopilot capability, encompassing the pitch and roll control modes (heading select, altitude select, nav couplers, etc), has been installed on the GA simulator.

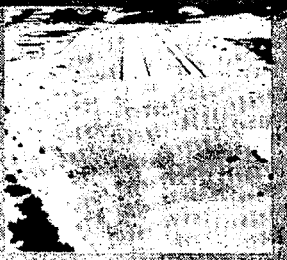
The simulator hardware and computer software allows the programming of any single or twin GA aircraft for which the stability derivatives exist. Presently, a Cessna 172 and a Cherokee 180 are programmed on the computer. A Cessna 402 is being developed and should be completed shortly.

GENERAL AVIATION SIMULATION STUDIES OF PROBLEMS IN THE SINGLE PILOT IFR (SPIFR) FLIGHT ENVIRONMENT



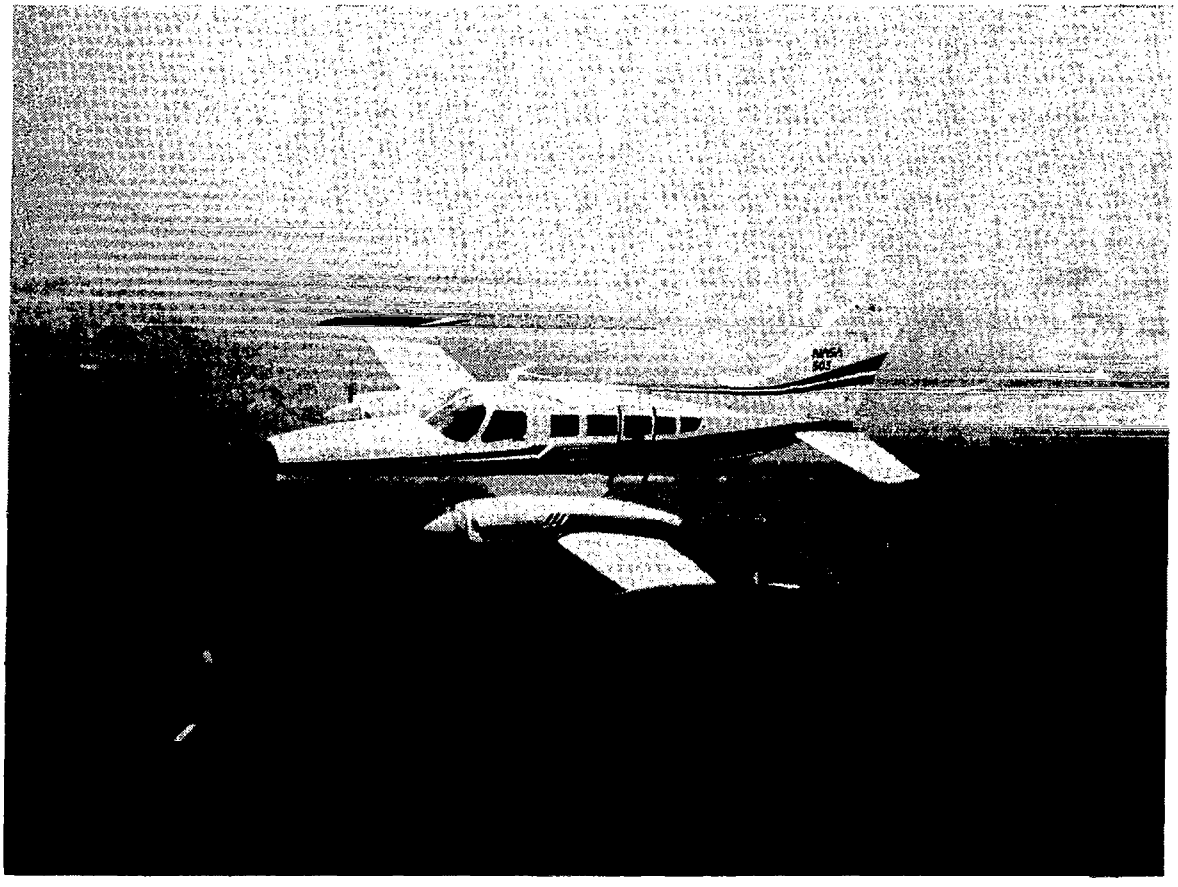
SIMULATOR CAPABILITY

- MOTION BASE
- CONTROL LOADER (YOKE)
- VLDS (VISUAL SCENE)
- SIDE WINDOW VIEW
- OCULOMETER
- ENGINE AND AIRSTREAM
- ATC STATIONS/COMMUNICATIONS
- ATLANTA OR NORFOLK/WASHINGTON AREA NAV AIDS
- AUTOPILOT
- VARIETY OF AIRPLANE TYPES



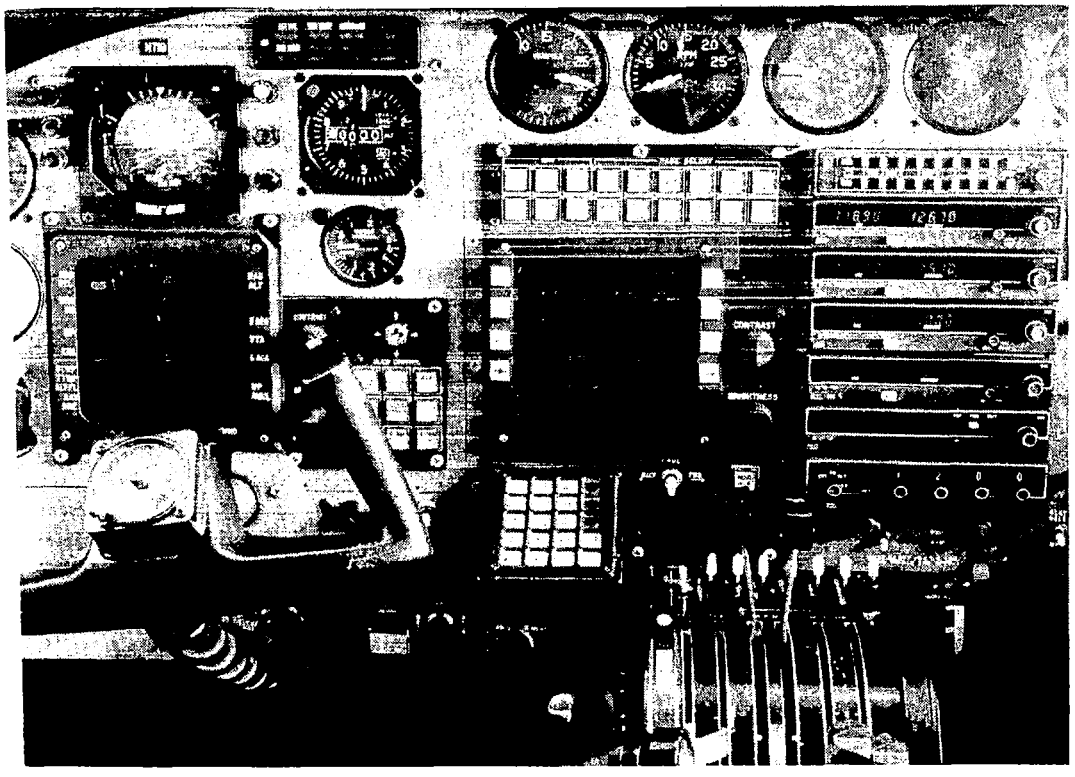
Cessna 402B

The NASA LaRC Cessna 402B is a research aircraft used in the Single Pilot Flight Management program. The instrument panel and nose baggage compartment have been modified to accept the DAAS research system displays and computer. The C402B is a turbo-charged twin engine airplane with performance characteristics typical of the general aviation aircraft used for business and corporate transportation.



DAAS

The Digital Advanced Avionics System (DAAS) is a highly integrated flight control system consisting of a central integrated data/control console (IDCC) moving map display CRT, digital autopilot/flight director, navigation radios, airplane configuration monitoring/warning, and built-in test logic. After manual entry of navaid and waypoint data, the system automatically tunes navigation receivers and draws a moving map display. The autopilot/flight director can be commanded to follow the programmed flight path. Airplane operating checklists can be called up on the IDCC. Airplane distance to, time to, and fuel remaining at each programmed waypoint can be displayed on the IDCC. Airplane wing flap, landing gear, cowl flap, and trim positions as well as altitude, vertical speed, airspeed, and engine parameters are monitored and the pilot is alerted to out of tolerance conditions. The DAAS is implemented with a modular computer architecture to permit additional capabilities to be added. Various DAAS functions are allocated to individual microprocessor modules. The modules communicate over a common IEEE-488 bus. The addition of new features can be accomplished by adding a processor module to the bus. The DAAS system is installed in NASA Langley's Cessna 402B research airplane.



DEMONSTRATION ADVANCED AVIONICS SYSTEM (DAAS) CAPABILITIES

- AUTOPILOT/FLIGHT DIRECTOR
- 10 WAYPOINT RNAV/VNAV WITH AUTOMATIC VOR/DME TUNING
- ELECTRONIC MOVING MAP DISPLAY
- WEIGHT AND BALANCE COMPUTATIONS, TAKEOFF AND CRUISE PERFORMANCE
- DISPLAY OF TIME TO, DISTANCE TO, AND FUEL REMAINING AT EACH WAYPOINT
- MONITORING OF ENGINE PARAMETERS, AIRPLANE CONFIGURATION, AIRSPEED, AND RADAR ALTITUDE
- MODE S TRANSPONDER DATA LINK
- NAVIGATION SIMULATOR

SPIFR PROGRAM REVIEW OUTLINE

PROBLEM IDENTIFICATION RESEARCH

- o SINGLE PILOT IFR ACCIDENT DATA ANALYSIS
- o STUDY TO DETERMINE THE OPERATIONAL PROFILE AND PROBLEMS OF THE SPIFR PILOT
- o SPIFR PROBLEM DEFINITION CORRELATION STUDY

INFORMATION TRANSFER RESEARCH

- o EFFICIENT TRANSFER OF WEATHER INFORMATION TO THE PILOT
- o FLIGHT INVESTIGATION OF SIMULATED DATA LINK COMMUNICATIONS DURING SPIFR FLIGHT
- o STUDY TO DETERMINE POTENTIAL FLIGHT APPLICATIONS AND HUMAN FACTORS GUIDELINES OF VOICE INPUT/OUTPUT SYSTEMS

COCKPIT DISPLAYS RESEARCH

- o PILOT RESPONSE WITH CONVENTIONAL DISPLAYS
- o ADVANCED THREE DIMENSIONAL PICTORIAL DISPLAY FOR ENROUTE, TERMINAL AREA, AND FINAL APPROACH GUIDANCE

AIRCRAFT CONTROLS RESEARCH

- o SPIFR AUTOPILOT COMPLEXITY/BENEFIT TRADEOFF STUDY
- o AUTOMATIC TERMINAL APPROACH SYSTEM FOR SPIFR OPERATIONS
- o NONCONVENTIONAL HAND CONTROLLER STUDY
- o CONTROL/DISPLAY TRADEOFF STUDY

NASA CESSNA 402B/DEMONSTRATION ADVANCED AVIONICS SYSTEM (DAAS)

- o SYSTEM CAPABILITY/DESCRIPTION
- o LaRC UTILIZATION PLAN

PROGRAM OUTPUT

- o OVER 30 REPORTS PUBLISHED
- o GA WORKSHOP HELD

SINGLE PILOT IFR ACCIDENT DATA ANALYSIS

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Abstract

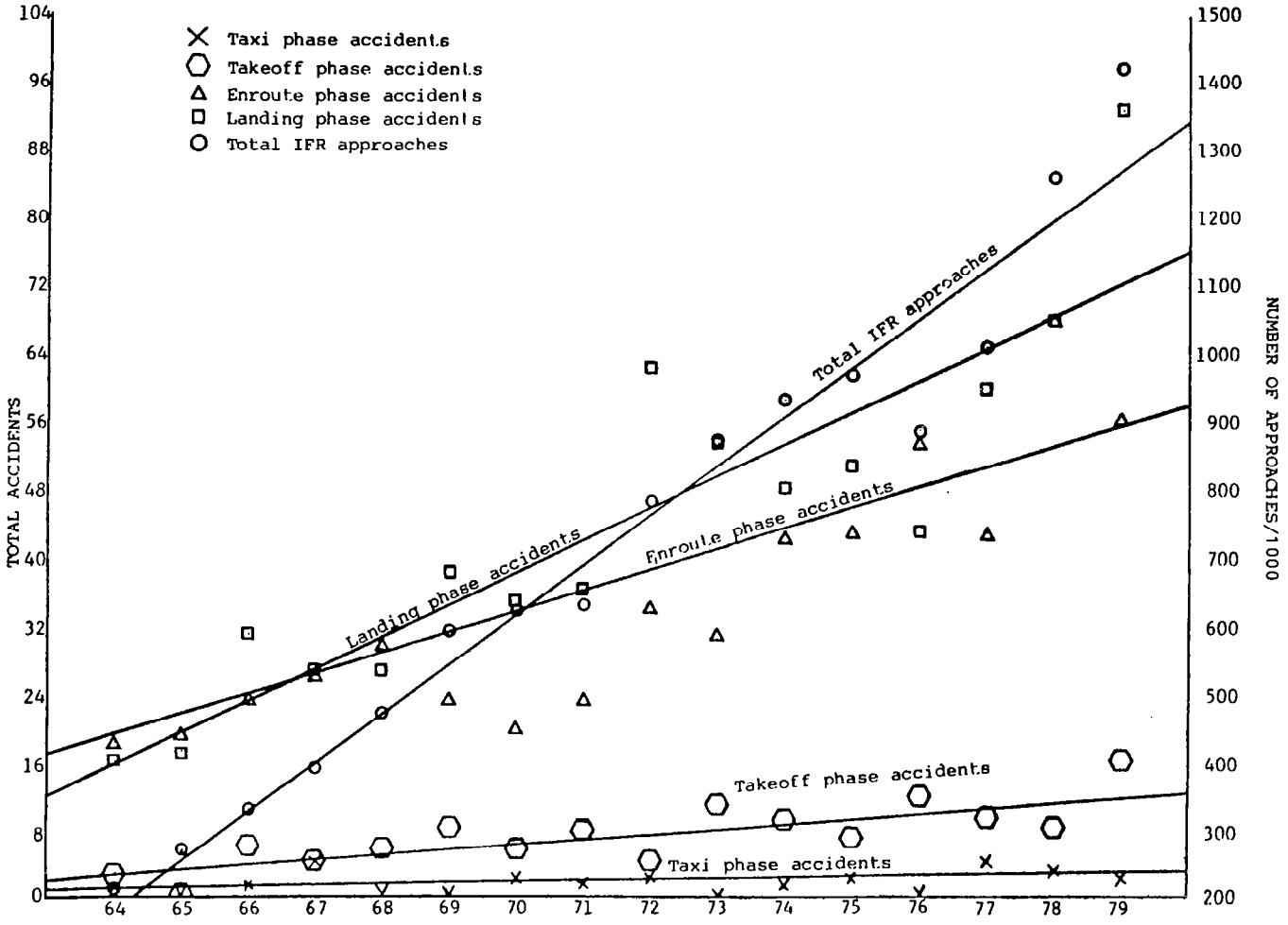
The aircraft accident data recorded by the National Transportation and Safety Board (NTSB) for 1964-1979 were analyzed to determine what problems exist in the general aviation (GA) single pilot instrument flight rule (SPIFR) environment [1]. A previous study conducted in 1978 for the years 1964-1975 provided a basis for comparison [2].

This effort was generally limited to SPIFR pilot error landing phase accidents but includes some SPIFR takeoff and enroute accident analysis as well as some dual pilot IFR accident analysis for comparison. Analysis was performed for 554 accidents of which 39% (216) occurred during the years 1976-1979.

Previous Trends Re-Examined

Linear regression and 95% confidence intervals were used to see if trends identified in the previous research were continuing. In general, previously identified trends are continuing. The absolute number of SPIFR pilot error accidents continues to increase but the accident rate per 10,000 approaches is decreasing. Each year, however, sees the accident rate decreasing more slowly.

About 50% of the SPIFR accidents occurred during the landing phase, 40% during the enroute phase, and 10% during taxi/takeoff.



SPIFR pilot error accidents and IFR approaches fitted with linear regression lines.

Accidents by Phase of Landing

The table below shows SPIFR landing accidents and ratios related to phase of instrument approach. The initial approach phase statistically improved during the 1976-79 period. Most accidents continue to occur during the final approach phase. There are three times as many night final approach accidents as during the day. This led to a further study of night accidents.

SPIFR LANDING ACCIDENTS AND RATIOS RELATING TO
TO PHASE OF INSTRUMENT APPROACH

PHASE OF FLIGHT	FINAL IFR	INITIAL IFR	MISSED APPR	PATTRN CIRC	LEVEL TCHDWN	ROLL	FINAL VFR	GO-RND VFR	OTHER	TOTAL
TOTALS										
1964-1975	139	59	20	7	59	27	16	1	7	335
1964-1979	224	75	41	16	107	46	26	5	14	554
PROPORTION OC-CURRED 1964-79	.38	.21	.51	.56	.45	.41	.38	.80	.50	.39
NIGHT/DAY										
1964-1975	3.30	1.20	.42	.75	.36	6.50	1.00	0.00	2.00	1.40
1964-1979	3.00	1.00	.85	.78	.38	.87	1.40	4.00	3.30	1.30

Day Versus Night Accident Rate

The absolute number of night SPIFR accidents involving pilot error has increased over the past four years at essentially the same rate as that of day and total accidents. The significance of the numbers does not become very meaningful, however, until they are converted to rates in the context of overall day and night activity. An FAA report, "General Aviation Pilot and Aircraft Activity Summary 1979" was used to estimate GA IFR activity in terms of approaches flown [3]. The results indicate that 87.6% of all GA IFR approaches are flown in the day and 12.4% are flown at night. The table below shows day versus night accident rates for single pilot (SP) and dual pilot (DP) operations. The night accident rate is about ten times the day rate.

RATIOS OF DAY TO NIGHT ACCIDENT RATES FOR SPIFR AND DPIFR LANDING PHASE ACCIDENTS

YEAR	SP(D)/DP(D)	SP(N)/DP(N)	SP(N)/SP(D)	DP(N)/DP(D)	ALL(N)/ALL(D)
1964	.75	.54	24.1	33.1	26.2
1965		2.73	23.4		25.6
1966	1.36	1.75	8.6	6.7	8.9
1967	1.14	4.26	12.4	3.3	10.2
1968	1.59	.39	5.8	23.9	9.4
1969	1.57	1.17	8.2	11.1	9.0
1970	.66	.82	6.7	5.3	6.1
1971	1.02	.63	5.4	8.8	6.3
1972	.83	1.95	10.5	4.5	8.6
1973	.73	2.14	11.2	3.8	8.8
1974	2.23	1.23	7.5	13.7	8.3
1975	1.33	.99	9.0	12.1	9.8
1976	1.53	2.92	6.2	3.3	5.6
1977	1.55	1.75	9.2	8.1	9.0
1978	.49	2.41	12.9	2.6	8.4
1979	2.10	1.06	6.2	12.3	6.9
MEAN	1.26	1.67	10.5	10.2	10.4

Vertigo Induced Uncontrolled Collisions With the Ground

The table below compares profiles of pilots involved in vertigo related accidents with those of other populations. Actual instrument experience and total flight hours appear to be the most critical experience factors when compared to other populations. Although not shown by this table, icing related uncontrolled collisions point to lack of time in type as an important factor.

SPIFR VERTIGO INDUCED UNCONTROLLED COLLISIONS WITH GROUND/WATER
STATISTICAL PROFILES

	TOTAL HOURS	TIME LAST 90 DAYS	ACTUAL INSTRUMENT	SIMULATED INSTRUMENT
GA SURVEY RESPONSE PROFILE				
MEAN	3814	98	245	166
STD. DEVIATION	4961	119	449	280
MEDIAN	2051	57	150	75
SPIFR TOTAL ACCIDENT PROFILE				
MEAN	3868	98	320	95
STD. DEVIATION	4457	86	499	164
MEDIAN	2394	71	150	61
SPIFR LANDING PHASE VERTIGO				
MEAN	2582	73	189	101
STD. DEVIATION	3405	73	430	116
MEDIAN	1399	53	48	66
SAMPLE SIZE	26	20	20	16
SPIFR ENROUTE PHASE VERTIGO				
MEAN	2802	59	128	63
STD. DEVIATION	4282	51	230	51
MEDIAN	975	38	48	63
SAMPLE SIZE	28	19	19	17

SPIFR Controlled Collisions With the Ground

A detailed analysis of controlled collisions with the ground was conducted. Descent below minimum altitudes consistently was the most prevalent factor in these accidents. The table below compares profiles of pilots involved in these accidents with those of other populations. The comparisons indicate that total flight experience is not an important factor.

SPIFR CONTROLLED COLLISIONS WITH GROUND/WATER
STATISTICAL PROFILES

	TOTAL HOURS	TIME LAST 90 DAYS	ACTUAL INSTRUMENT	SIMULATED INSTRUMENT
GA SURVEY RESPONSE PROFILE				
MEAN	3814	98	245	166
STD. DEVIATION	4961	119	449	280
MEDIAN	2051	57	150	75
SPIFR TOTAL ACCIDENT PROFILE				
MEAN	3868	98	320	95
STD. DEVIATION	4457	86	499	164
MEDIAN	2394	71	150	61
NIGHT CONTROLLED COLLISIONS				
MEAN	3775	104	341	78
STD. DEVIATION	4464	90	545	87
MEDIAN	2365	69	145	59
DAY CONTROLLED COLLISIONS				
MEAN	5041	97	276	101
STD. DEVIATION	4893	76	312	111
MEDIAN	3134	84	191	59

Summary

National Transportation Safety Board general aviation (GA) aircraft accident data for the years 1964 to 1979 were examined for single pilot instrument flight rule (SPIFR) accidents caused by pilot error. The 1396 accidents found were analyzed to determine the relationship of SPIFR accident types to phase of flight, pilot experience, and mission variables such as condition of light, ceiling, visibility, and type of approach. An estimate of GA day and night activity was made in order to estimate actual day and night accident rates.

The results of the data analysis indicate that about 50 percent of the SPIFR accidents occurred during the landing phase of flight, 40 percent occurred during the enroute phase, and 10 percent occurred during the taxi/takeoff phases.

Experienced pilots tended to have a lower accident rate than less experienced pilots. This trend was especially significant with vertigo related accidents and much less significant with icing related accidents.

The estimate of day GA activity was 87.6 percent of all GA activity and night activity was 12.4 percent. Based on these estimates and the number of day and night accidents the night accident rate was judged to be 10 times the day accident rate.

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STUDY TO DETERMINE THE IFR OPERATIONAL PROFILE AND PROBLEMS OF THE GENERAL AVIATION SINGLE PILOT

Stacy Weislogel
The Ohio State University

ABSTRACT

A study of the general aviation single pilot operating under instrument flight rules (GA SPIFR) has been conducted for NASA Langley Research Center. The objectives of the study were to (1) develop a GA SPIFR operational profile, (2) identify problems experienced by the GA SPIFR pilot, and (3) identify research tasks which have the potential for eliminating or reducing the severity of the problems. To obtain the information necessary to accomplish these objectives, a mail questionnaire survey of instrument rated pilots was conducted. Complete questionnaire data is reported in NASA CR-165805, "Statistical Summary: Study to Determine the IFR Operational Profile and Problems of the General Aviation Single Pilot" (ref. 1). Based upon the results of the GA SPIFR survey, this final report presents the general aviation IFR single pilot operational profile, illustrates selected data analysis, examples, identifies the problems which he is experiencing, and recommends further research.

INTRODUCTORY COMMENTS

Perhaps a few preliminary comments are in order before we get too far along.

First, let's define GA SPIFR: "A general aviation IFR flight operation which requires, by Federal Aviation Regulation or company policy, that only one instrument rated pilot perform all of the piloting functions. If another person is on board (instrument rated pilot or not) and assisting (with communications and navigation, for example), it is still considered a single pilot IFR operation."

Second, I am reporting to you the results of a survey, so that the operational problems that we have identified are the result of the pilot's personal perceptions of his problems. The relative importance of these perceptions must be weighed against the findings of other GA SPIFR problem identification efforts. Remember, however, that what the pilot perceives the real world to be is the real world to him, and he acts upon those perceptions as if they are real whether or not they are real in fact.

Third, as experienced researchers, many of you will not experience, overall, any revelations in the findings - indeed, it may be that instead you are seeing numbers to support your intuitive feel for GA SPIFR operational problems.

BACKGROUND

There are about 827,000 pilots, 260,000 (31%) of whom have instrument ratings. As you are surely aware, general aviation's participation in IFR flight operations has been impressive. Instrument operations at airports with FAA Traffic Control Service included 11 million air carrier and 20 million general aviation operations in 1980. By 1992 the FAA forecasts 13 million air carrier instrument operations (a 21% increase) and 31 million general aviation instrument operations (a 56% increase). The number of instrument rated pilots is expected to increase 48% during the same period.

Presently, many GA SPIFR operations are conducted by highly trained and experienced pilots flying modern, well equipped airplanes. However, a proportion of the general aviation IFR operations involves relatively inexperienced single pilots, often having limited equipment, who are expected to perform in the system at the same level of competency as the professional air carrier crews. As you know, concern has been expressed by aviation agencies and user organizations that the level of competency expected to be demanded of the future SPIFR will not be attained unless significant improvements in the design of the aviation system are achieved.

It is my opinion that because NASA sincerely believes that there should be a place for the GA SPIFR in the system of the future, NASA LaRC initiated a research program which has as its objective "to provide the background research and develop the technology required to improve the safety and utility of single pilot general aviation aircraft operating under instrument flight rules." An important element of this research program is problem identification. The GA SPIFR problems identified then become the bases for future NASA GA research.

SINGLE PILOT IFR OPERATIONAL PROBLEMS

SPIFR RESEARCH OBJECTIVES

As part of the problem identification effort, NASA LaRC retained the services of The Ohio State University Department of Aviation to conduct a questionnaire survey of instrument rated pilots. The objectives of this research are:

FIRST, TO
- DEVELOP AN OPERATIONAL PROFILE OF THE GA SINGLE PILOT OPERATING IFR

AND SECOND, TO
- IDENTIFY AREAS FOR RESEARCH

SPIFR RESEARCH METHODOLOGY

The Research Methodology has three elements:

FIRST, TO
- CONDUCT MAIL QUESTIONNAIRE SURVEY FOR INSTRUMENT RATED PILOTS

SECOND, TO
- DEVELOP A GA SPIFR DATA BASE

AND THIRD, TO
- ANALYZE DATA BASE
  - DEVELOP GA SPIFR OPERATIONAL PROFILE
  - IDENTIFY RESEARCH TOPICS

The research is complete, and the project is discussed in reference 2.

QUESTIONS CAN BE ASKED OF THE GA SPIFR DATA BASE

In addition to the profile of the typical GA SPIFR, what else have we learned from the survey? Well, one thing we have learned is that we can ask the GA SPIFR data base questions and get answers.

QUERY 1: IS THE TASK OF TUNING COMMUNICATIONS AND NAVIGATION RADIOS A MAJOR PROBLEM OR DISTRACTION?

CONCLUSION: THE TASK OF TUNING COMMUNICATIONS AND NAVIGATION RADIOS IS CLEARLY IDENTIFIABLE AS A PROBLEM IN THE RESPONSES, ALTHOUGH ON THE BASIS OF SPECIFIC RESPONSES (RATHER THAN A GENERAL PROBLEM RESPONSE LIKE "WORKLOAD"), IT DOES NOT APPEAR TO BE A MAJOR PROBLEM OR DISTRACTION.

RELATIONSHIP BETWEEN OPERATIONAL PROBLEMS AND EXPERIENCE

Another query resulted in an interesting hypothesis.

QUERY 7: ARE THE OPERATIONAL PROBLEMS EXPERIENCED BY THE SPIFR INDEPENDENT OF EXPERIENCE?

CONCLUSION: BASED UPON THIS ANALYSIS, WHICH REVEALS THE RELATIVELY HIGH COMMONALITY OF RESPONSE CODES REPORTED BETWEEN CATEGORIES OF PILOTS OF DIFFERENT EXPERIENCE LEVELS, IT APPEARS THAT THE OPERATIONAL PROBLEMS EXPERIENCED BY THE SPIFR ARE INDEPENDENT OF EXPERIENCE. IF THIS HYPOTHESIS IS VALID, THEN IT IS SUGGESTED THAT REMEDIES TO SPIFR OPERATIONAL PROBLEMS DO NOT LIE IN IMPROVING SPIFR CAPABILITIES THROUGH MORE TRAINING AND EXPERIENCE. RATHER, THE NATURE OF THE SPIFR TASK SHOULD BE CHANGED THROUGH THE REDESIGN OF COCKPIT SYSTEMS AND ATC PROCEDURES IN HANDLING THE SPIFR.

GA SPIFR PROBLEM AREAS

One way in which an insight can be gained into what areas trouble the GA SPIFR and in what priority is to rank order Questions 13 through 21 by percentage of respondents supplying a usable problem answer. The questions permitted the respondent to state the most common problem encountered in each of these nine areas:

QUESTION	PROBLEM AREA	PERCENT OF RESPONDENTS SUPPLYING USABLE PROBLEM ANSWER
13	INSTRUMENT APPROACHES	51%
19	WEATHER INFORMATION	51
14	COCKPIT ENVIRONMENT	48
21	COMMUNICATIONS	44
20	WEATHER ENCOUNTERS	38
17	TRAINING AND PROFICIENCY	36
15	NAVIGATION	31
16	OPERATIONS AND PROCEDURES	24
18	AIRPLANE STABILITY AND CONTROL	18

GA SPIFR PROBLEMS REPORTED BY MORE THAN 10% OF THE RESPONDENTS

Another approach to identifying GA SPIFR operational problems is to look at the top problem code responses appearing in Questions 13 through 21. Those reported by more than 10% of the respondents are:

QUESTION	PROBLEM CODE	PERCENT OF RESPONDENTS	PROBLEM DESCRIPTION
13	04	15%	ATC DEMANDS
14	01	14	INADEQUATE LIGHTING
19	05	12	RELIABILITY OF FSS WEATHER INFORMATION
14	02	11	HIGH CABIN NOISE LEVEL

MOST COMMON ERROR MADE BY THE GA SPIFR

A third approach is to inspect the most frequent responses within a question and aggregate them into another descriptive category. For example, the top three responses to Question 3 can be combined into a category of "Pilot Judgment and Decision Making," which accounts for 35% of the responses to the question "What is the most common error made by IFR single pilots?"

QUESTION 3

IN YOUR OPINION, WHAT IS THE MOST COMMON ERROR MADE BY IFR SINGLE PILOTS?

PROBLEM CODE	ERROR DESCRIPTION	NUMBER	PERCENT
(02)	NOT PLANNING AHEAD	266	16%
(06)	OVER CONFIDENCE IN BEING ABLE TO HANDLE WEATHER	185	11
(01)	EXCEEDING PERSONAL CAPABILITIES	133	08
(04)	MISUNDERSTANDING ATC	92	07
(20)	VIOLATING MINIMUMS	90	06

MOST SERIOUS PROBLEM ENCOUNTERED AS A GA SPIFR

An inspection of the most frequent responses to a particular question without aggregating the responses is also instructive in gaining insights into GA SPIFR operational problems. For example, in Question 4 the respondent had an opportunity to report the one most serious problem which he had encountered in his experience as a GA SPIFR.

PERCENT OF RESPONDENTS	MOST SERIOUS PROBLEM ENCOUNTERED AS A GA SPIFR
16%	ICING
07	THUNDERSTORMS
07	UNFORECAST/UNANTICIPATED WEATHER
05	WORKLOAD
04	LACK OF PROFICIENCY

Another approach is to inspect the most frequent responses between questions and aggregate them into another descriptive category. For example, the two most frequent responses to Question 4, "What has been the one most serious problem which you have encountered in your experience as an IFR single pilot?" and Question 20, "Weather Encounters" were icing and thunderstorms. Weather reporting information can be considered of concern to the GA SPIFR when the responses to Questions 4, 6, 7, 19, and 20 are aggregated.

ONE CHANGE IN THE SYSTEM WHICH WOULD MAKE GA SPIFR FLIGHT OPERATIONS EASIER

The GA SPIFR's perception about the one change in the system which would make his SPIFR flight operations easier also provides an insight into his operational problems.

QUESTION 7

WHAT ONE CHANGE IN THE SYSTEM (E.G., ATC, REGULATIONS, PROCEDURES, WEATHER DISSEMINATION), YOUR AIRPLANE AND EQUIPMENT, OR FLIGHT TRAINING, WOULD MAKE YOUR IFR SINGLE PILOT FLIGHT OPERATIONS EASIER?

CODE	DESIRED CHANGE	NUMBER	PERCENT
(40)	BETTER, MORE TIMELY WEATHER INFORMATION	119	07%
(14)	USE AUTOPILOT	102	06%
(52)	MORE STRINGENT INSTRUMENT RATING REQUIREMENTS	73	05%
(16)	WEATHER INFORMATION THROUGH ATC	66	04%
(08)	REQUIRE ACTUAL IFR TRAINING	52	03%

AREAS OF POTENTIAL GA SPIFR RESEARCH

As a result of our work with the survey data, these broad areas of GA SPIFR research emerge from our analyses as having the greatest potential for improving the safety and utility of the single pilot general aviation aircraft operating under instrument flight rules.

WORKLOAD

PILOT JUDGMENT AND DECISION MAKING

INSTRUMENT APPROACHES

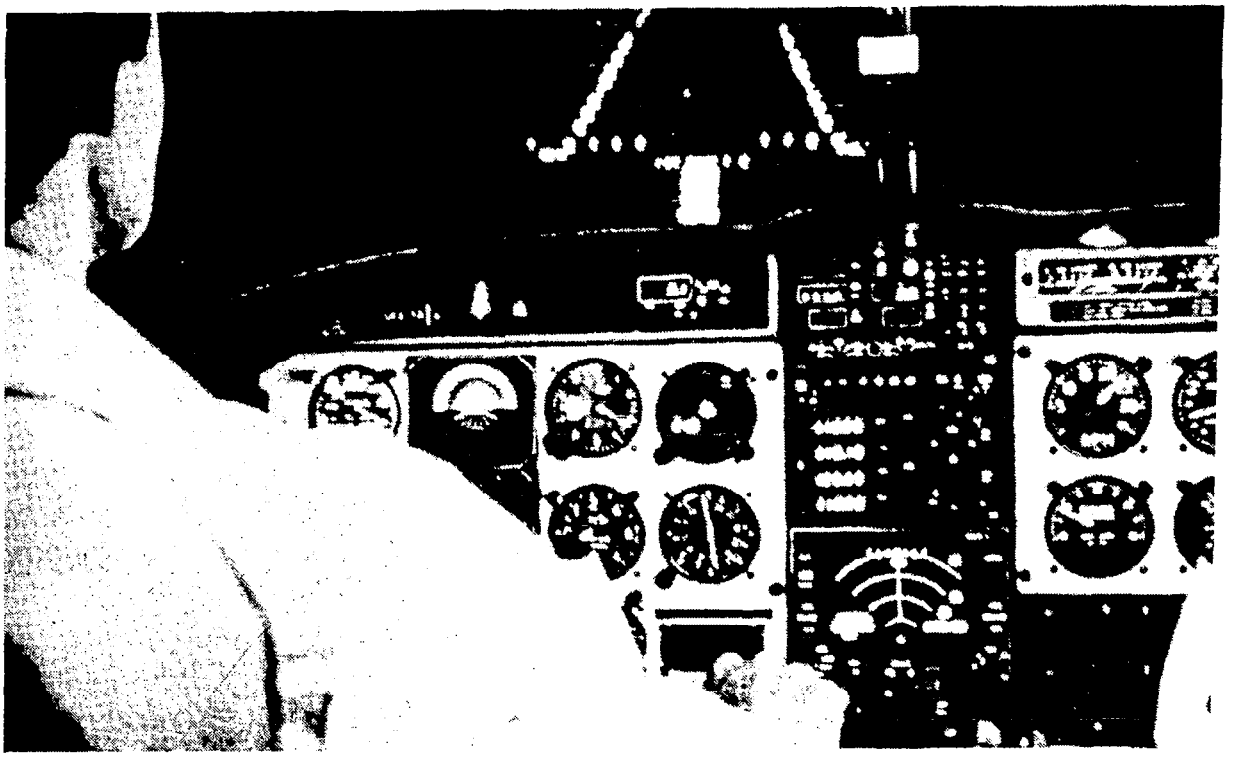
WEATHER INFORMATION

COCKPIT ENVIRONMENT

COMMUNICATIONS

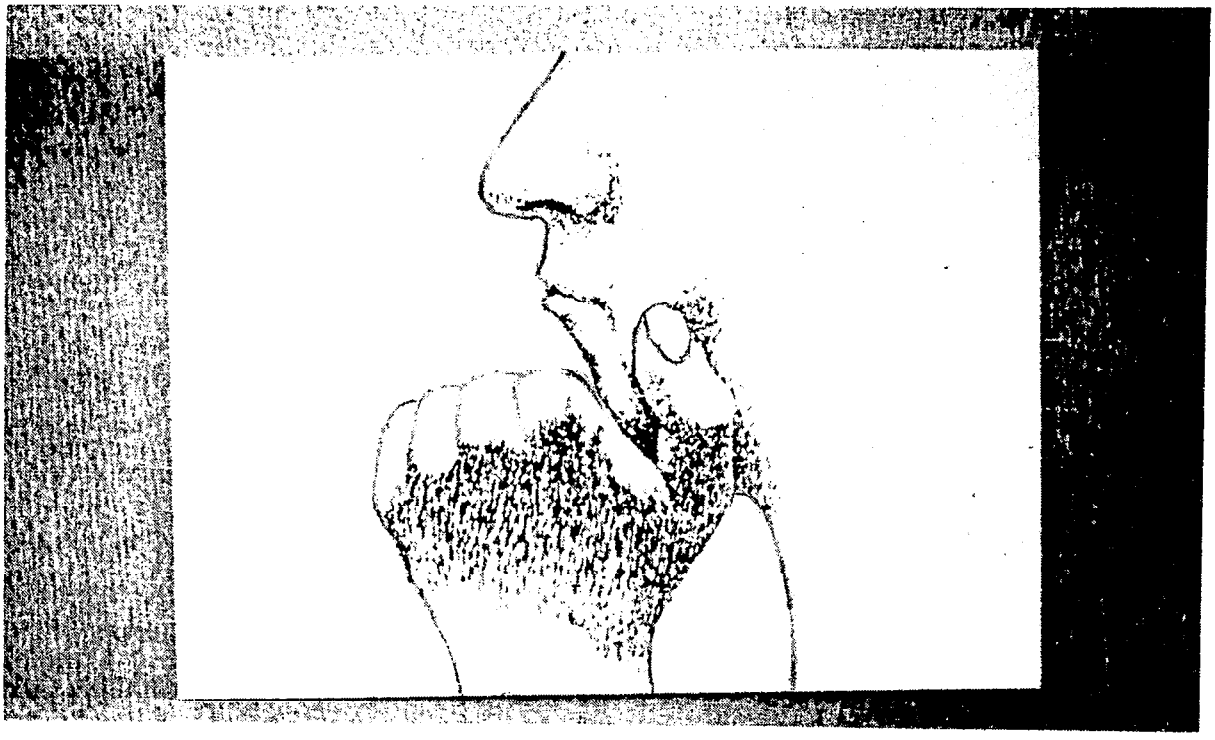
PILOT WORKLOAD

Workload reduction will result in increasing the effectiveness and safety of the GA SPIFR operation. Documentation and analysis of actual pilot performance and workload during IFR flight using conventional cockpit displays and autopilots is required to provide baseline data against which to compare advanced control and display concepts.



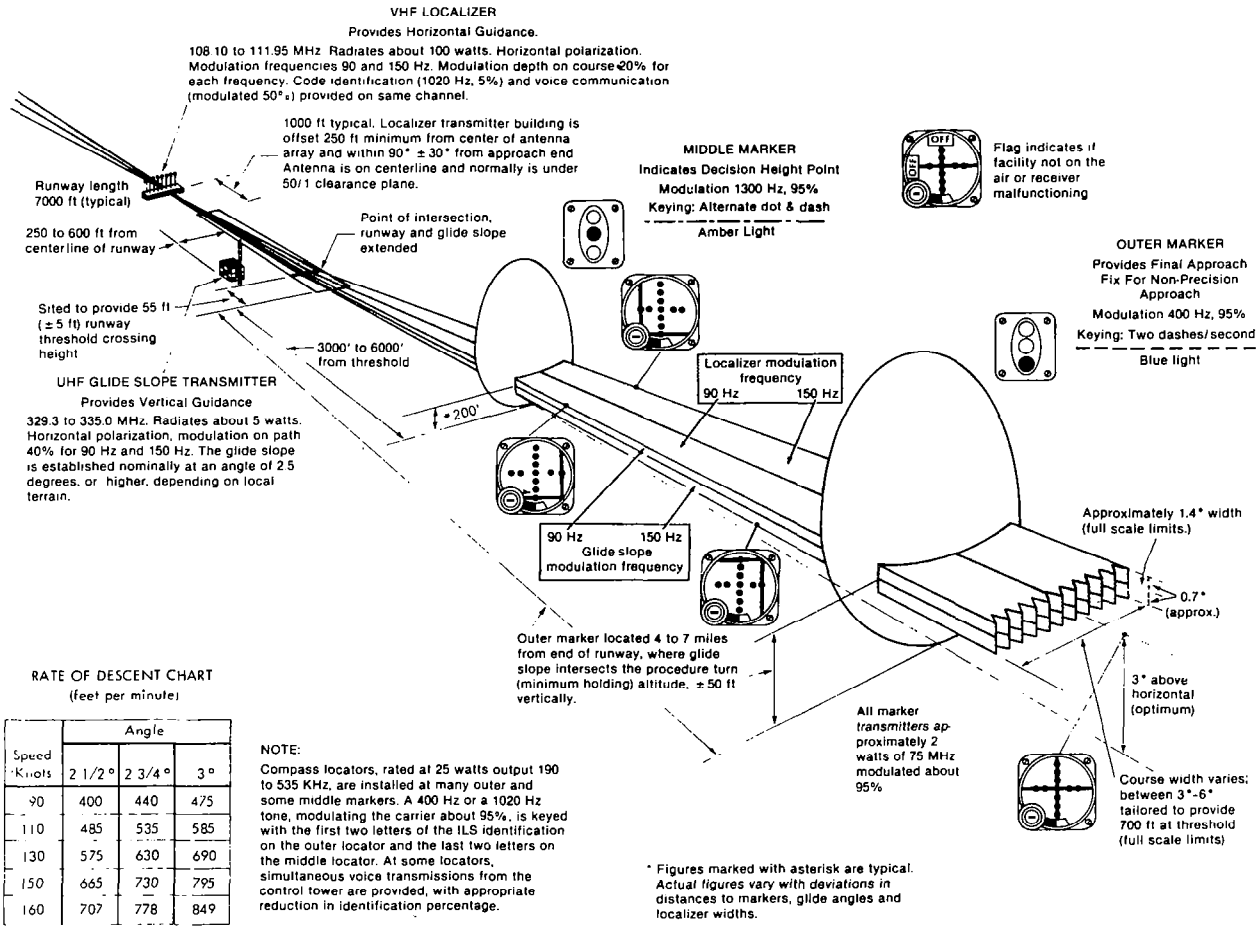
PILOT JUDGMENT AND DECISION MAKING

Improving pilot judgment and decision making with respect to his ability to plan ahead and more accurately assess his own capabilities and limitations is another means of increasing the effectiveness and safety of the GA SPIFR. This requires that the GA SPIFR's psychological state and the nature and quality of information available and being used by him be defined and characterized. Although the Federal Aviation Administration has recently begun to study the topic of pilot judgment, the research has not been focused on the GA SPIFR.



INSTRUMENT APPROACHES

The two problem areas troubling the greatest number of respondents were instrument approaches, with emphasis on workload, and weather information, with emphasis on improving its availability, reliability, and timeliness. Automatic flight control systems, advanced cockpit displays, and the development of GA SPIFR oriented ATC procedures are potential areas of research which can contribute to the reduction of workload during the approach phase of a GA SPIFR instrument flight.



RATE OF DESCENT CHART
(feet per minute)

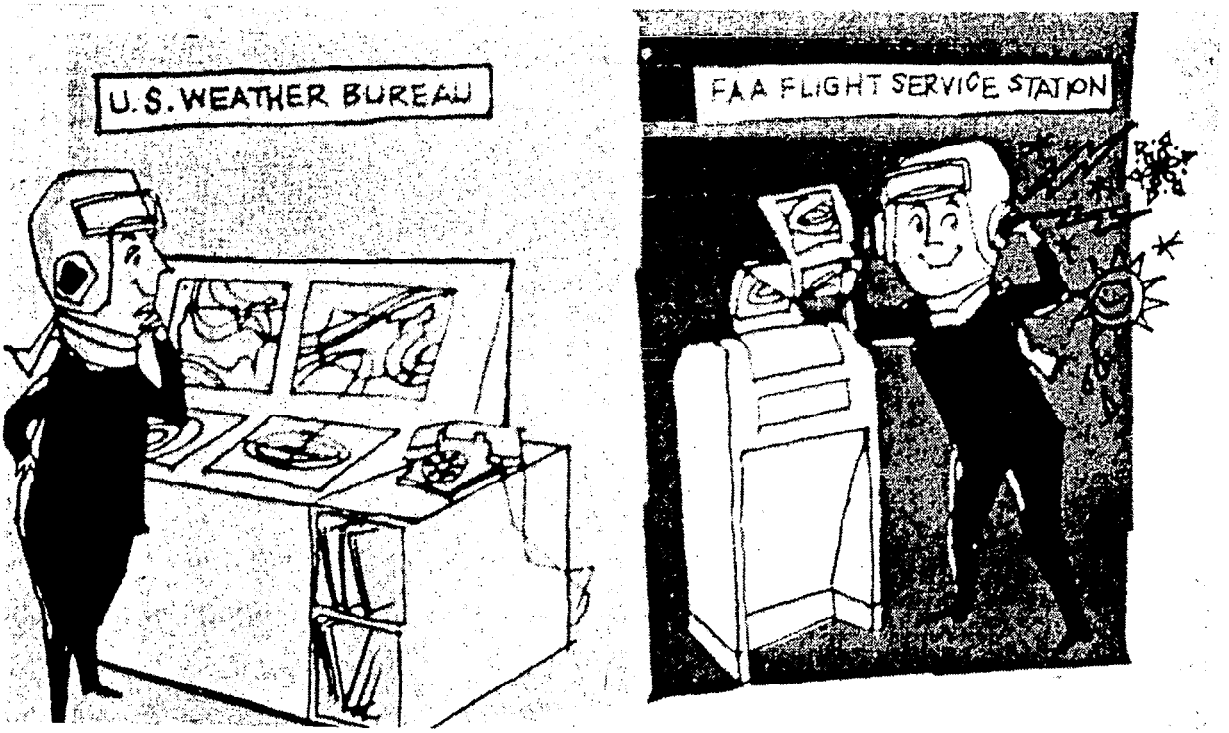
Speed Knots	Angle 2 1/2°	2 3/4°	3°
90	400	440	475
110	485	535	585
130	575	630	690
150	665	730	795
160	707	778	849

NOTE:
Compass locators, rated at 25 watts output 190 to 535 KHz, are installed at many outer and some middle markers. A 400 Hz or a 1020 Hz tone, modulating the carrier about 95%, is keyed with the first two letters of the ILS identification on the outer locator and the last two letters on the middle locator. At some locators, simultaneous voice transmissions from the control tower are provided, with appropriate reduction in identification percentage.

* Figures marked with asterisk are typical. *Actual figures vary with deviations in* distances to markers, glide angles and localizer widths.

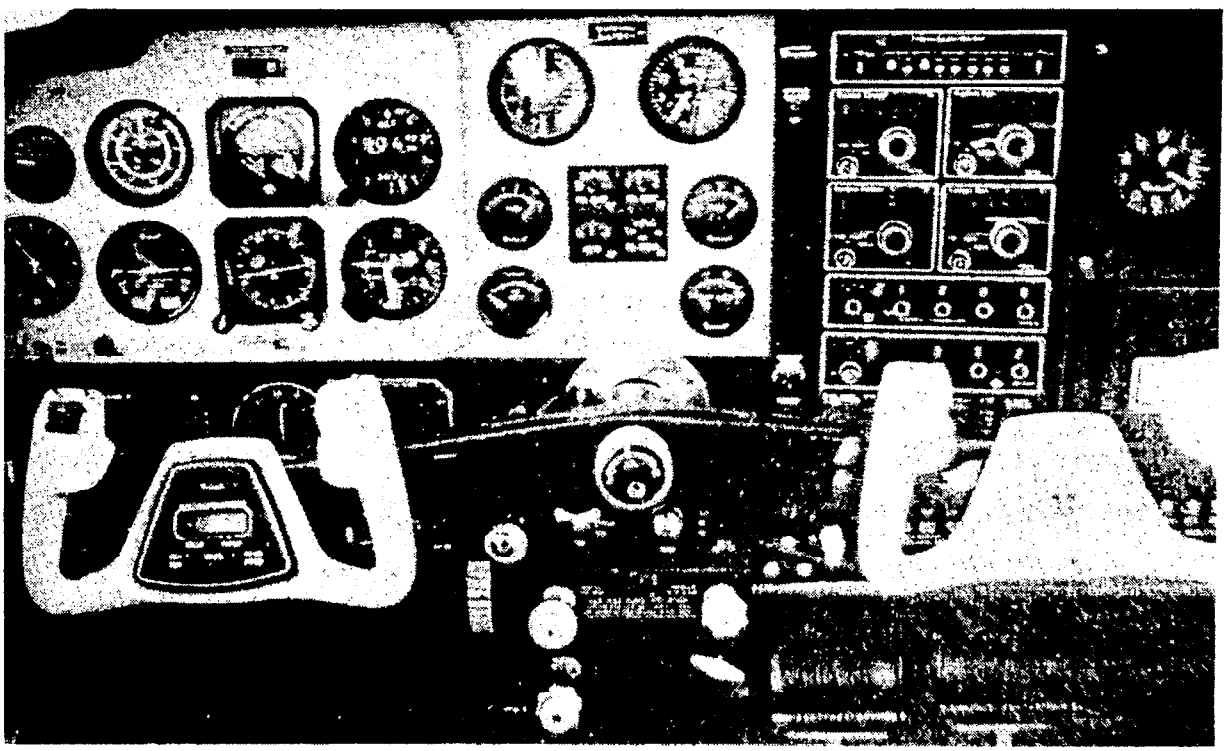
WEATHER INFORMATION

An investigation of improved preflight and inflight weather information dissemination methods to improve the availability, reliability, and timeliness of weather information for the GA SPIFR also emerges as a recommended area of research.



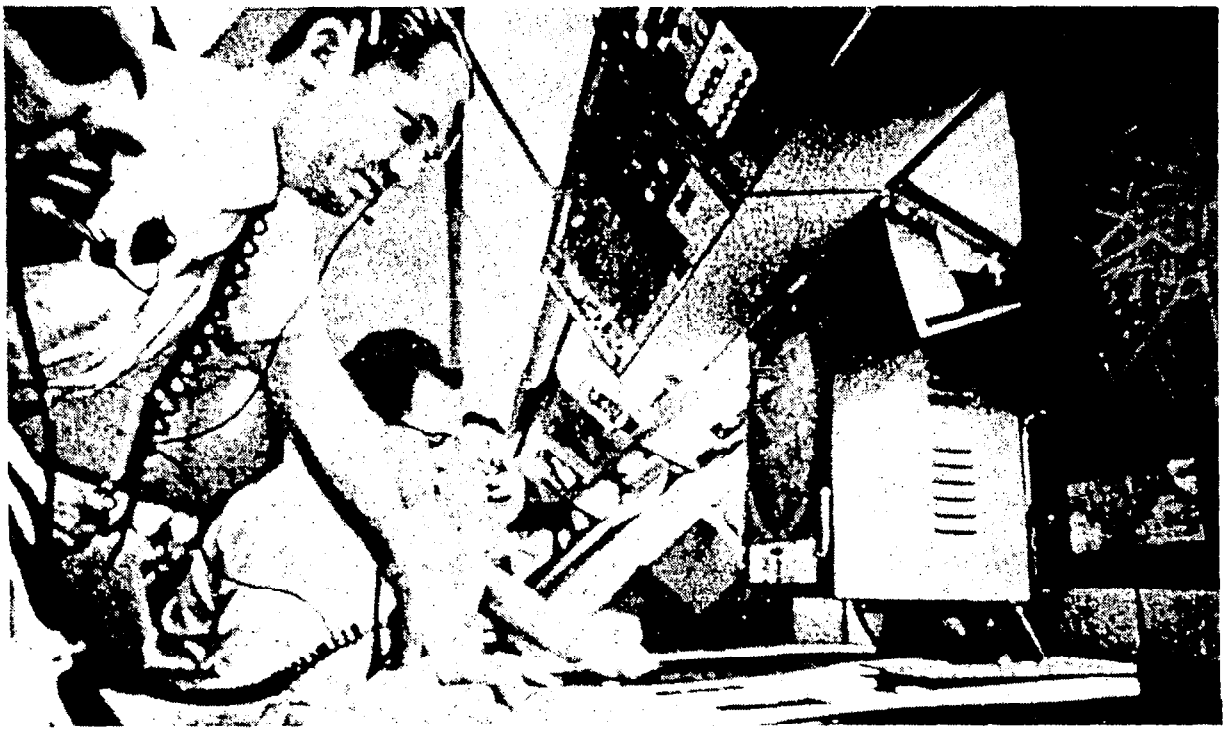
COCKPIT ENVIRONMENT

Improving the cockpit environment is of considerable interest to the GA SPIFR. It seems that a modest research effort could produce information useful in improving the cockpit environment with respect to improved lighting and noise protection.



COMMUNICATIONS

The GA SPIFR also has a high interest in reducing the radio communications workload, in terms of both too many frequency changes and excessive communications. Research into more efficient frequency assignment methods, automatic frequency switching, and improved information transfer methods has the potential for alleviating this concern of the GA SPIFR.



FSS WEATHER BRIEFING INADEQUACIES

It is interesting to note that certain of the needed areas of research which have emerged from the GA SPIFR study have been independently identified as needing attention by others. In addition to the FAA's research interest in pilot judgment, the NTSB in August 1981 issued a Special Investigation Report on FSS weather briefing inadequacies (NTSB-SIR-81-3) (ref. 3). The board found that in a significant number of fatal weather related accidents, pertinent weather information was not made available to pilots during weather briefings.

COCKPIT NOISE

The NTSB has also determined that cockpit noise levels interfering with direct voice communications aboard commercial aircraft were a factor in commercial aircraft accidents, and it has asked FAA to establish maximum cockpit noise levels in commercial aircraft. Perhaps this recommendation also has validity with respect to the GA SPIFR operation (ref. 4).

AIAA PAPER

The GA SPIFR survey research has generated three publications. The first was an AIAA paper presented at the Aircraft Systems and Technology Meeting in Dayton, OH, August 11, 1981 (ref. 5).

STATISTICAL SUMMARY

A statistical summary report prepared for NASA Langley, contains raw data, frequency counts, and frequency distributions of data from the GA SPIFR survey (ref. 1).

FINAL REPORT

A final report on the IFR operational profile and problems of the GA single pilot has been prepared (ref. 2). This report contains the GA SPIFR operational profile, selected data analysis examples, problem identification, and recommended research. All 1980 usable questionnaires and the 231 unusable responses are on file at LaRC. Further, two magnetic data tapes have been prepared, one containing data from the 1980 usable questionnaires returned, the other containing data from the 1619 questionnaires forming the GA SPIFR data set. Interested organizations and individuals may obtain copies of the data tapes from NASA LaRC.

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ANALYSIS OF GENERAL AVIATION SINGLE-PILOT IFR INCIDENT DATA OBTAINED FROM THE NASA AVIATION SAFETY REPORTING SYSTEM

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An analysis of incident data obtained from the NASA Aviation Safety Reporting System (ASRS) has been made to determine the problem areas in general aviation single-pilot IFR (SPIFR) operations. The Aviation Safety Reporting System data base is a compilation of voluntary reports of incidents from any person who has observed or been involved in an occurrence which was believed to have posed a threat to flight safety. This paper examines only those reported incidents specifically related to general aviation single-pilot IFR operations. The frequency of occurrence of factors related to the incidents was the criterion used to define significant problem areas and, hence, to suggest where research is needed. The data was cataloged into one of five major problem areas: (1) controller judgment and response problems, (2) pilot judgment and response problems, (3) air traffic control (ATC) intrafacility and interfacility conflicts, (4) ATC and pilot communication problems, and (5) IFR-VFR conflicts. The relative significance of each of these problem areas was determined by the number of citations corresponding to each area. In addition, several points common to all or most of the problems were observed and reported. These included human error, communications, procedures and rules, and work load.

The ASRS incident data analyzed in this report is limited to the general aviation operations typically involved in SPIFR. Since no specific category in the ASRS data base relates directly to general aviation SPIFR, the following criteria were chosen in interrogating the data base. All fixed-wing operations under air taxi, charter operations, utility operations, corporate aviation, personal business, pleasure flights, and training flights were selected for the analysis. All rotary wing operations were deleted. Also, only those flights on either an IFR or SVFR flight plan were used. These criteria produced 79 reports out of the total 2174 reports collected during the period from May 1, 1978 (the beginning of ASRS report reformatting) to January 1, 1979. Based on their sources, these 79 reports included pilot reports of flight crew errors (14 reports), ATC reports of flight crew errors (15 reports), pilot reports of ATC errors (16 reports), and ATC reports of ATC errors (34 reports).

FORMULATION OF INCIDENT DATA

ALL FIXED-WING OPERATIONS UNDER AIR TAXI, CHARTER OPERATIONS, UTILITY OPERATIONS, CORPORATE AVIATION, PERSONAL BUSINESS, PLEASURE FLIGHTS, AND TRAINING FLIGHTS ON EITHER AN IFR OR SVFR FLIGHT PLAN

The incident data reports consisted of a synopsis and several categories of factors related to the incidents. These categories included enabling factors, associated factors, descriptors, recovery factors, and supplemental key words. Only two of these, enabling factors and associated factors, were considered relevant to this study and were used in the analysis. An enabling factor is an element that is present in the history of an occurrence and without which the occurrence probably would not have happened. An associated factor is an element that is present in the history of an occurrence and is pertinent to the occurrence under study, but which does not fulfill the requirements of an enabling factor. Examples of both enabling and associated factors are controller perception, intrafacility coordination, pilot discretion, and pilot vigilance.

There were 40 different enabling factors and 58 associated factors listed in the 79 incident reports. The 40 enabling factors were cited a total of 99 times; the 58 associated factors were cited 82 times. (A factor citing is a listing of that factor in the incident report.) These data imply that more than one factor was cited in some of the incident reports.

DATA ANALYSIS CRITERIA

ENABLING FACTOR (40):	AN ELEMENT THAT IS PRESENT IN THE HISTORY OF AN OCCURRENCE AND WITHOUT WHICH THE OCCURRENCE PROBABLY WOULD NOT HAVE HAPPENED.
ASSOCIATED FACTOR (58):	AN ELEMENT THAT IS PRESENT IN HISTORY OF AN OCCURRENCE AND IS PERTINENT TO THE OCCURRENCE UNDER STUDY, BUT WHICH DOES NOT FULFILL THE REQUIREMENTS OF AN ENABLING FACTOR.
EXAMPLES:	o CONTROLLER PERCEPTION o INTRAFACILITY COORDINATION o PILOT DISCRETION o PILOT VIGILANCE

The ASRS synopsis and various categories assigned to each reported incident were examined by the author to determine the types of problems suggested by the data. This review of the incident reports revealed five major problem areas that were considered to be general aviation SPIFR specific. These problem areas are (1) controller judgment and response problems, (2) pilot judgment and response problems, (3) ATC intrafacility and interfacility conflicts, (4) ATC and pilot communication problems, and (5) IFR-VFR conflicts.

- CONTROLLER JUDGMENT AND RESPONSE PROBLEMS
- PILOT JUDGMENT AND RESPONSE PROBLEMS
- ATC INTRAFACILITY AND INTERFACILITY CONFLICTS
- ATC AND PILOT COMMUNICATION PROBLEMS
- IFR-VFR CONFLICTS

The analysis of the data showed that the problem areas could be described by more specific subelements. The "controller judgment and response problems", for example, can be primarily attributed to three elements: (1) excessive/impeding procedural requirements, (2) training/proficiency/experience related mistakes, and (3) equipment operational problems. Similarly, "pilot judgment and response problems" can be attributed primarily to three elements: (1) excessive/impeding procedural requirements, (2) training/proficiency flight infractions, and (3) limitations due to limited avionics. These problem elements can be used to determine the areas that need further research.

- o CONTROLLER JUDGMENT AND RESPONSE PROBLEMS
  - -EXCESSIVE/IMPEDING PROCEDURAL REQUIREMENTS
  - -TRAINING/PROFICIENCY/EXPERIENCE RELATED MISTAKES
  - -EQUIPMENT OPERATIONAL PROBLEMS
- o PILOT JUDGMENT AND RESPONSE PROBLEMS
  - -EXCESSIVE/IMPEDING PROCEDURAL REQUIREMENTS
  - -TRAINING/PROFICIENCY FLIGHT INFRACTIONS
  - -LIMITATIONS DUE TO LIMITED AVIONICS
- o ATC INTRAFACILITY AND INTERFACILITY CONFLICTS
  - -INTERNAL COMMUNICATION PROBLEMS
  - -HAND-OFF PROBLEMS
  - -MIXED DEPARTURE AND ARRIVAL CONFLICTS
  - -EQUIPMENT OPERATIONAL PROBLEMS
- o ATC AND PILOT COMMUNICATION PROBLEMS
  - -MISUNDERSTANDING OF INSTRUCTIONS
  - -FREQUENCY CONGESTION
  - -EXCESSIVE FREQUENCY CHANGES
  - -EXCESSIVE/IMPEDING PROCEDURAL REQUIREMENTS
- o IFR-VFR CONFLICTS
  - -AIRCRAFT PROXIMITY AT BREAKOUT
  - -IFR FLIGHT IN VFR AND MVFR CONDITIONS

A review of the problem areas pinpointed several points common to all or most of the problems. These included human error, communications, procedures and rules, and work load.

COMMON DENOMINATOR TO ALL PROBLEM AREAS

- HUMAN ERROR
- COMMUNICATIONS
- PROCEDURES AND RULES
- WORK LOAD

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A SUMMARY AND INTEGRATION OF RESEARCH CONCERNING SINGLE PILOT IFR OPERATIONAL PROBLEMS

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A review of seven research studies pertaining to Single Pilot IFR (SPIFR) operations was performed. Two studies were based on questionnaire surveys [1,2], two were based on National Transportation Safety Board (NTSB) reports [3,4], two were based on Aviation Safety Reporting System (ASRS) incident reports [5,6], and one report used event analysis and statistics to forecast problems [7]. The results obtained in each study were extracted and integrated. Results were synthesized and key issues pertaining to SPIFR operations problems were identified. The research that was recommended by the studies and that addressed the key issues is cataloged for each key issue.

A SUMMARY AND INTEGRATION
OF RESEARCH CONCERNING
SINGLE PILOT IFR
OPERATIONAL PROBLEMS

TITLE:

Study to Determine the Operational Profile and Mission of the Certificated Instrument Rated Private and Commercial Pilot, Report No. FAA-RD-70-51. July 1970 [1].

STUDY TO DETERMINE
THE OPERATIONAL PROFILE
AND MISSION OF THE
CERTIFICATED INSTRUMENT RATED
PRIVATE AND COMMERCIAL
PILOT

Objective: Determine Operational Profile and Mission of Instrument Rated Private and Commercial Pilots. It was the first phase of an FAA effort which had as its objective the feasibility of training pilots to a standard of operational competence instead of using flight time as a criterion for instrument rating certification.

OBJECTIVE
DETERMINE OPERATIONAL PROFILE AND MISSION
OF
INSTRUMENT RATED PRIVATE AND COMMERCIAL PILOTS

Methodology: Conduct a Mail Questionnaire Survey of Instrument Pilots. Approximately 3,000 of the then 120,000 instrument rated pilots were surveyed.

METHODOLOGY

CONDUCT A MAIL QUESTIONNAIRE SURVEY

OF

INSTRUMENT PILOTS

Results: Two Operational Profiles Were Developed: Most Complex, Medium Complex. The results of this study led to minor changes in the mid 1970's in the certification requirements for instrument rated pilots.

RESULTS:

TWO OPERATIONAL PROFILES WERE DEVELOPED:

- MOST COMPLEX
- MEDIUM COMPLEX

TITLE:

Single Pilot IFR Operating Problems Determined From Accident Data Analysis, NASA TM-78773, September 1978 [3].

SINGLE PILOT IFR
OPERATING PROBLEMS
DETERMINED FROM
ACCIDENT ANALYSIS

Objective: Determine Single Pilot IFR Operating Problems from Analysis of Accident Data.

OBJECTIVE:

DETERMINE SINGLE PILOT IFR OPERATING PROBLEMS FROM ANALYSIS OF ACCIDENT DATA

METHODOLOGY:

Examine NTSB Aviation Accident Data for 1964-1975.

The accident reports examined were restricted to instrument rated pilots flying in actual IFR weather. A brief examination was made of accidents which occurred during all phases of flight and which were due to all causes. A detailed examination was made of those accidents which involved a single pilot which occurred during the landing phase of flight and were due to pilot error.

METHODOLOGY:

EXAMINE NTSB AVIATION ACCIDENT

DATA FOR 1964 - 1975

Results: SPIFR pilot error landing accidents are increasing at three times the dual pilot error rate.

It was found that the SPIFR pilot error landing accidents examined increased three times faster than the dual pilot error accidents during the same time period.

Problem areas were found to be pilot workload, low visibility at night due to fog and low ceilings, icing on aircraft not de-ice equipped, imprecise navigation, failure to remain above minimum altitudes, mismanagement of fuel and low instrument time.

Some suggested areas of research include new types of de-icing or anti-icing equipment, standardized navigation instrument displays, improved fuel management systems and better methods for pilots to safely acquire experience and increase proficiency in SPIFR operations .

RESULTS:

SPIFR PILOT ERROR LANDING ACCIDENTS ARE INCREASING AT THREE TIMES THE DUAL PILOT ERROR RATE

TITLE:

General Aviation IFR Operational Problems, NASA CR-159022, April 1979 [7].

GENERAL AVIATION

IFR

OPERATIONAL

PROBLEMS

Objective: Perform Study of GA IFR Operational Problems.

OBJECTIVE:

PERFORM STUDY OF

GA IFR

OPERATIONAL PROBLEMS

Methodology: Examine Statistics and Projections, Perform Detailed Analysis of Typical GA IFR Operations.

METHODOLOGY:

- EXAMINE STATISTICS AND PROJECTIONS
- PERFORM DETAILED ANALYSIS OF TYPICAL GA IFR OPERATIONS

Results: GA SPIFR Major Segment of U. S. Air Transportation System. FAA provides ATC services with emphasis on improving efficiency with which the services are provided without concentrating on particular needs of various classes of operators. GA is being driven out of airspace through expansion of positive controlled airspace (e.g., floor, TCA). Result is to drive lower capability GA IFR operator away from services he needs. Cost to improve mission reliability too high (e.g., flight planning information availability, delays in terminal areas, delays in actual IMC limited landing and availability, enroute Wx avoidance).

RESULTS:

- GA SPIFR MAJOR SEGMENT
- FAA PROVIDES ATC SERVICES
- GA BEING DRIVEN OUT OF AIRSPACE
- COST TO IMPROVE MISSION RELIABILITY TOO HIGH

TITLE:

Analysis of General Aviation Single Pilot IFR Incident Data Obtained From the NASA Aviation Safety Reporting System, NASA TM-80206, October 1980 [5].

ANALYSIS OF GENERAL AVIATION

SINGLE PILOT IFR

INCIDENT DATA OBTAINED

FROM THE

NASA ASRS

Objectives: Determine problems in GA SPIFR Operations.

OBJECTIVES

DETERMINE PROBLEMS

IN

GA SPIFR OPERATIONS

Methodology: Examine NASA ASRS Data Base for Those Incidents Specifically Related to GA SPIFR Operations.

METHODOLOGY:

EXAMINE NASA ASRS DATA BASE

Results: Problem areas identified: controller judgment and response, pilot judgment and response, ATC intra/inter-facility conflicts, ATC/pilot communications, IFR-VFR conflicts

PROBLEM AREAS AND PRIMARY ELEMENTS

- Controller judgment and response problems
  - -Excessive/impeding procedural requirements
  - -Training proficiency/experience related mistakes
  - -Equipment operational problems
- Pilot judgment and response problems
  - -Excessive/impeding procedural requirements
  - -Training/proficiency flight infractions
  - -Limitations due to limited avionics
- ATC intrafacility and interfacility conflicts
  - -Internal communication problems
  - -Hand-off problems
  - -Mixed departure and arrival conflicts
  - -Equipment operational problems
- ATC and pilot communication problems
  - -Misunderstanding of instructions
  - -Frequency congestion
  - -Excessive frequency changes
  - -Excessive/impeding procedural requirements
- IFR-VFR conflicts
  - -Aircraft proximity at breakout
  - -IFR flight in VFR and MVFR conditions

RESULTS:

PROBLEM AREAS IDENTIFIED

- CONTROLLER JUDGMENT AND RESPONSE
- PILOT JUDGMENT AND RESPONSE
- ATC INTRA/INTER FACILITY CONFLICTS
- ATC/PILOT COMMUNICATIONS
- IFR-VFR CONFLICTS

TITLE:

Operational Problems Experienced by Single Pilots in Instrument Meteorological Conditions, NASA CR-166236, July 1980 [6].

OPERATIONAL PROBLEMS

EXPERIENCED BY SINGLE PILOTS

IN INSTRUMENT

METEOROLOGICAL

CONDITIONS

Objective: Identify and describe operational problems reported to NASA ASRS by the GA SPIFR.

OBJECTIVE:

IDENTIFY AND DESCRIBE OPERATIONAL PROBLEMS

REPORTED TO NASA ASRS BY THE GA SPIFR

Methodology: Examine NASA ASRS data base for occurrences where difficulties were experienced by single pilots on IFR flight plans in IMC.

METHODOLOGY:

EXAMINE NASA ASRS DATA BASE

Results: Ten conclusions developed about GA SPIFR operational problems.

Ten problem categories observed, in decreasing order of reporting frequency, were: (1) pilot allegations of inadequate service, (2) altitude deviations, (3) improperly flown approaches, (4) heading deviations, (5) position deviations, (6) below minimums operations, (7) loss of airplane control, (8) forgot mandatory report, (9) fuel problem, and (10) improper holding.

Examination of pilot experience data showed no correlation between inexperience and SPIFR problems, suggesting that experience may not be a primary factor. This led to a hypothesis that a solution to SPIFR problems may lie not in improving SPIFR capabilities through training but rather in changing the nature of the task. Safety, efficiency, and workload factors were present in the occurrences with over half involving an act or condition likely to lead to serious consequences and a third involving ignorant or imprudent departures from acceptable procedures. Human factors significant in many occurrences were: pilot "mind set", lack of pilot proficiency, lack of position awareness, distraction, and inadequate planning.

RESULTS:

TEN CONCLUSIONS DEVELOPED ABOUT

GA SPIFR OPERATIONAL PROBLEMS

TITLE:

Study to Determine the IFR Operational Profile and Problems of the General Aviation Single Pilot, NASA CR-3576, 1983 [2].

STUDY TO DETERMINE

THE IFR OPERATIONAL PROFILE

AND PROBLEMS

OF THE GENERAL AVIATION

SINGLE PILOT

Objective: Develop SPIFR operational profile, identify problems experienced, recommend research.

OBJECTIVE:

- DEVELOP SPIFR OPERATIONAL PROFILE
- IDENTIFY PROBLEMS EXPERIENCED
- RECOMMEND RESEARCH

Methodology: Conduct a mail questionnaire survey of 5000 of the 230,000 instrument rated pilots (47% response).

METHODOLOGY:

CONDUCT A MAIL QUESTIONNAIRE SURVEY OF INSTRUMENT PILOTS

Results: Areas requiring research: Workload, Pilot Judgment/Decision making, Instrument Approaches, Weather Information, Cockpit Environment, Communications.

RESULTS:

AREAS REQUIRING RESEARCH

- WORKLOAD
- PILOT JUDGMENT/DECISION MAKING
- INSTRUMENT APPROACHES
- WEATHER INFORMATION
- COCKPIT ENVIRONMENT
- COMMUNICATIONS

TITLE:

Single Pilot IFR Accident Data Analysis, NASA CR-3650, June 1982 [4].

SINGLE PILOT IFR PROFICIENCY ANALYSIS

Objective: Determine what changes, if any, have occurred in trends and cause and effect relationships reported in 1978 study by Forsyth and Shaughnessy [3].

OBJECTIVE:

DETERMINE CHANGES FROM PREVIOUS STUDY

Methodology: Examine NTSB Aviation Accident Data for 1976-1979, Compare to 1964-1975 study data.

METHODOLOGY:

- EXAMINE NTSB AVIATION ACCIDENT DATA FOR 1976-1979
- COMPARE TO 1964-1975 STUDY DATA

Results: General Conclusion: GA SPIFR accident frequency total, causes, and trends have undergone little overall change since the previous study. Further study required of impact of simulated instrument time on likelihood of SPIFR accident, disparity between day and night SPIFR accident rates.

RESULTS:

FURTHER STUDY REQUIRED OF

- IMPACT OF SIMULATED INSTRUMENT TIME ON LIKELIHOOD OF SPIFR ACCIDENT
- DISPARITY BETWEEN DAY AND NIGHT SPIFR ACCIDENT RATES

REFERENCES

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GENERAL AVIATION SINGLE PILOT IFR AUTOPILOT STUDY

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ABSTRACT

Five levels of autopilot complexity were flown in a single engine IFR simulation for several different IFR terminal operations. A comparison was made of the five levels of complexity ranging from no autopilot to a fully coupled lateral and vertical guidance mode to determine the relative benefits versus complexity/cost of state-of-the-art autopilot capability in the IFR terminal area. Of the five levels tested, the heading select mode made the largest relative difference in decreasing workload and simplifying the approach task. It was also found that the largest number of blunders was detected with the most highly automated mode. The data also showed that, regardless of the autopilot mode, performance during an IFR approach was highly dependent on the type of approach being flown. These results indicate that automation can be useful when making IFR approaches in a high workload environment, but also that some disturbing trends are associated with some of the higher levels of automation found in state-of-the-art autopilots.

Seven subjects were used in the tests, two NASA test pilots and five IFR rated pilots with various levels of IFR and autopilot experience. Each subject flew 27 data runs, for a total of 189 runs for this study. This included the 25 different combinations of five autopilot modes and five different approaches. The extra two runs per subject were repeats for replication purposes. The order of presentation was randomly determined for each pilot. Each data run lasted from 10 to 20 minutes, depending on the specific approach being flown. The ceiling and visibility for each run were randomly chosen from three conditions predefined for each of the five approaches. They were: (1) 15.2 m (50 ft) ceiling and 0.8 km (0.5 mi) visibility for the given approach, (2) published minimums for the given approach, or (3) 61 m (200 ft) above ceiling and double visibility of published minimums for the given approach. All the runs were flown in moderate turbulence (1.2 m/sec (4 ft/sec)) and 20 kt winds from a predefined direction. The piloting task consisted of flying the specified approach, making the required pilot reports, and performing a side task.

EXPERIMENTAL DESIGN

- SUBJECTS (7)
- NUMBER OF RUNS (189)
- RUN LENGTH (10-20 MIN)
- WEATHER (BELOW MIN, AT MIN, ABOVE MIN)
- TASK

Five levels of autopilot automation were tested. The five, in order of increasing levels of automation, consisted of 1) no autopilot (NA - the basic aircraft); 2) wing leveler (WL); 3) heading select (HS - a heading select directional gyro was used in this mode); 4) heading select with lateral navigation coupling (HC - this mode included lateral guidance for both very high frequency omni range (VOR) and instrument landing system (ILS) navigation); and 5) heading select with lateral navigation coupling and altitude hold with vertical navigation coupling (HAC). In addition to the previously discussed capabilities this mode also included a choice of pitch attitude hold, altitude hold, or vertical navigation guidance (i.e., glideslope coupler).

AUTOPILOT MODES

- o NA no autopilot
- o WL wing leveler
- o HS heading select
- o HC heading select with lateral nav coupler
- o HAC heading select with lateral nav coupler and altitude hold with vertical nav coupler

Five airports and their associated radio nav aids located in the general vicinity of Langley Research Center were programmed and used in this study. The types of approaches included two ILS approaches, one VOR approach, one Loc BC approach, and one NDB approach. These approaches, and other pertinent information, are given in more detail below.

APPROACHES

Airport	Runway	Approaches	Display	Wind
Norfolk, VA	5	ILS	CDI	$091^{\circ}/20$ kt
Atlanta, GA	8	ILS	CDI	$225^{\circ}/20$ kt
Newport News, VA	25	Loc/BC(Holding)	CDI	$290^{\circ}/20$ kt
Franklin, VA	9	VOR	CDI	$332^{\circ}/20$ kt
Wakefield, VA	20	NDB	Fixed compass card	$155^{\circ}/20$ kt

(From ref. 1.)

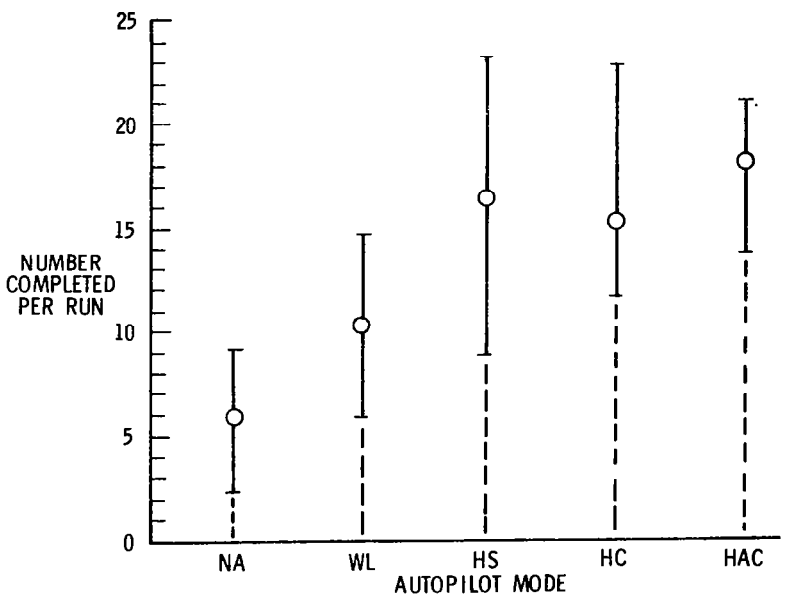
The data taken during each approach consisted of flight technical error, ground track and profile plots, pilot workload rating and comments, and side task results.

DATA

- FLIGHT TECHNICAL ERROR
- GROUND TRACK AND PROFILE PILOTS
- PILOT WORKLOAD RATINGS
- PILOT COMMENTS
- SIDE TASK RESULTS

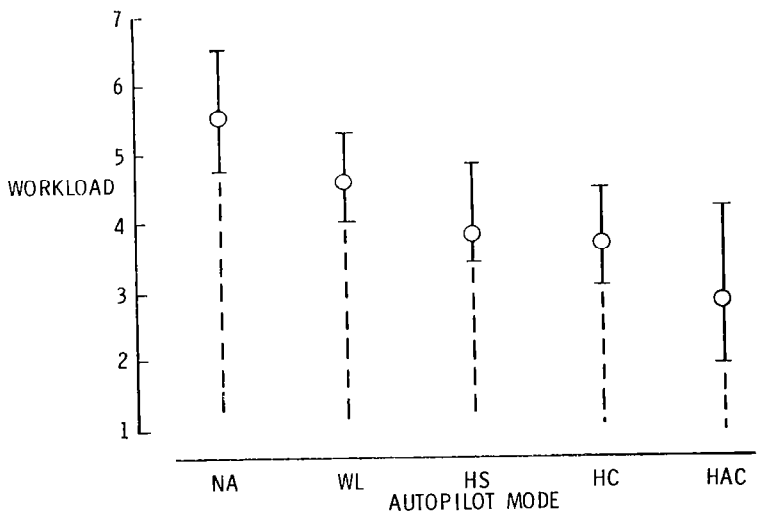
The side task results, in general, are representative of all the data. This figure shows the average number of problems completed per run during all the approaches for all the subjects at each level of autopilot complexity. The upper and lower limit bars represent the maximum and minimum of the averages of the individual subjects at each level of autopilot complexity. Implicit in using a secondary task is the assumption that the more difficult the task, the fewer problems completed, hence the higher the workload associated with the primary task. As can be seen by the data, the workload tends to decrease (increased secondary task performance) as automation level is increased. Significant, however, is the leveling off of the workload for automation levels greater than the HS mode. One interpretation of this phenomenon is that beyond the HS mode the subject trades off the workload associated with flying the control task for the workload required to monitor the autopilot's control of the flight task. This results in little net difference in primary task workload beyond the HS mode.

Average number of side tasks
(From ref. 1.)

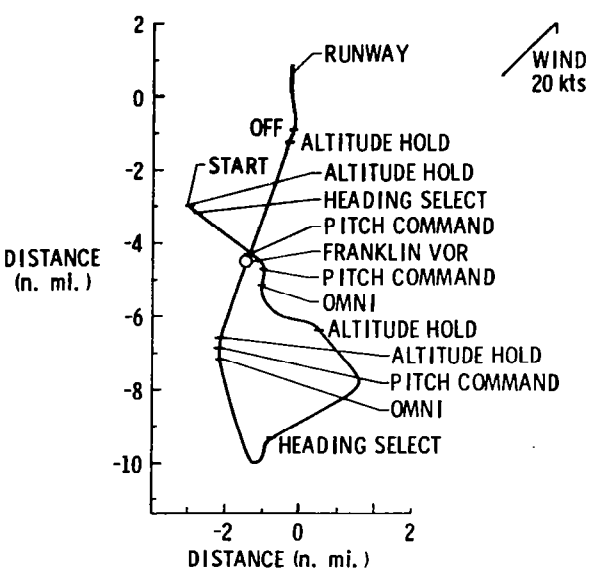


This figure shows a similar relationship with respect to subjective pilot workload ratings. At the end of each run the subject rated the primary task on a workload scale of 1 to 7 with 1 designated as the easiest and 7 as the hardest. It should be realized that this type of rating technique typically produces a relative workload rating of difficulty rather than an absolute workload rating. The format of this figure is similar to that of the previous figure; i.e., shown is the average workload rating per run during all the approaches for all the subjects at each level of autopilot complexity. The upper and lower limit bars represent the maximum and minimum of the averages of the individual subjects at each level of autopilot complexity. These results tend to agree with the side task results; i.e., increased automation decreases workload. There is also a slight leveling off of the workload beyond the HS mode, but it is not as dramatic as in the side task data.

Workload ratings
(From ref. 1.)

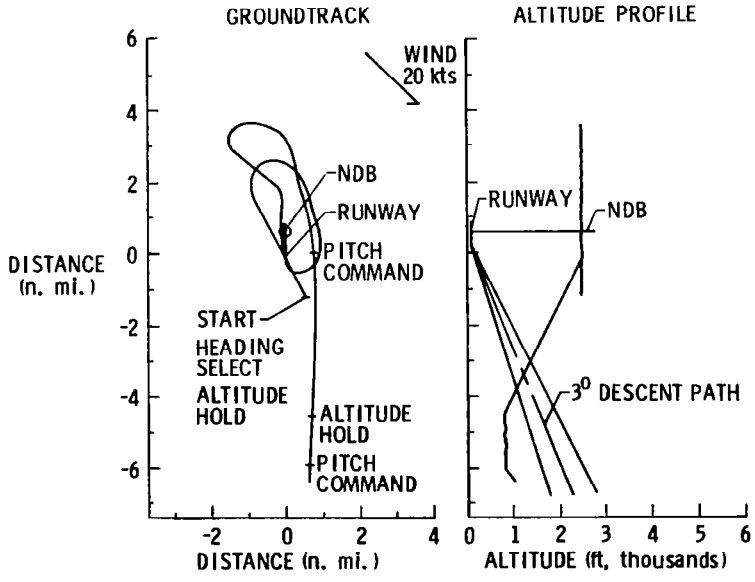


Several disturbing trends were noted as the level of autopilot automation was increased. In general, an increased level of automation tends to take the pilot out of the aircraft control loop. He becomes a manager of the autopilot functions. The effects of this change in duty appear to be emphasized in the HAC mode. The subjects were more likely to lose track of where they were in the approach. It seemed that in monitoring the autopilot the pilot would associate instrument readings with the autopilot functions rather than with situational awareness. Therefore, if the autopilot functions were either set incorrectly or interpreted incorrectly, the subject would frequently perform the wrong task, thinking that everything was normal. This would frequently lead to an incident or blunder. An example is shown below (Franklin VOR approach, HAC mode). The run began with the autopilot set in the heading select mode. After crossing the VOR, a right turn to the outbound course was initiated. At this point the autopilot was switched to omni coupler to intercept and track the outbound course. However, the subject had neglected to reset the correct bearing on the CDI. Therefore, the autopilot reintercepted and tracked the original bearing of the CDI. Eventually, he realized his mistake and set the correct outbound bearing on the CDI. The aircraft then took up a 45° intercept path to the new bearing. After a fair amount of time he still had not intercepted the outbound course turn using to the time into the approach he decided to make a pseudo procedure turn using heading select. At this point in time he also set in the correct inbound heading on the CDI. Upon completion of the procedure turn he continued in heading select until the CDI needle came alive. He then selected omni coupler and completed the approach without further incident. It is likely this incident would not have been detected in the real world.



Ground track Franklin VOR approach. HAC autopilot mode.
(From ref. 1.)

Another subject (Wakefield NDB approach, HAC mode) made his final let down on an outbound heading. He leveled off and made his missed approach without ever realizing his mistake. Another interesting facet related to this run is the fact that the NDB at Wakefield is located on the airport. The missed approach should have been executed when, if in this case, the NDB was crossed. In fact several otherwise normal runs were also flown at Wakefield in which the missed approach was executed prior to crossing the NDB inbound. It seems that the subjects would time their outbound leg and use this time, rather than the NDB crossing, to execute their missed approach. The 45° left headwind on the inbound heading was obviously a contributing factor in these incidents. These results imply a lack of positional awareness.



Wakefield NDB approach. HAC autopilot mode.
(From ref. 1.)

The results of this study suggests several general implications. Automation can reduce pilot workload, but a poor pilot interface with complex levels of automation can lead to disastrous blunders. In general, an increased level of automation tends to take the pilot out of the aircraft control loop. He becomes a manager of the autopilot functions. It seemed that in monitoring the autopilot the pilot would associate instrument readings with the autopilot functions rather than with situational awareness. The problem appears to be almost as if the pilot thinks of the autopilot as a copilot and expects it to think for itself. He allows himself to become completely engrossed in other tasks once the autopilot is set. Hence, he is frequently late in resetting new functions or he may become confused as to exactly where he is in the approach and not reset all the necessary functions or controls.

IMPLICATIONS

- AUTOMATION IS BENEFICIAL "BUT"
- PILOT BECOMES AUTOPILOT MANAGER
- LOSS OF SITUATIONAL AWARENESS
- AUTOPILOT/COPILOT

The results of this study indicate that automation is desirable when making IFR approaches in a high workload environment, but also that some disturbing trends are associated with the higher levels of automation as presently implemented in state-of-the-art autopilots. It is believed, however, that a better man/machine interface could alleviate these problems. The data further suggest that the heading select mode may currently be the best choice for the IFR approach task when considering both benefits and costs.

CONCLUSIONS

- AUTOMATION DECREASES WORKLOAD.
- THE MEASURED WORKLOAD BEGAN LEVELING OFF AT THE HEADING SELECT MODE.
- THE LARGEST INCREMENT OF BENEFIT WAS OBTAINED WITH THE HEADING SELECT MODE.
- THE MAJORITY OF THE BLUNDERS OCCURRED WITH THE MORE HIGHLY AUTOMATED MODES.
- AUTOMATION IS BENEFICIAL BUT CAN LEAD TO PROBLEMS IF NOT JUDICIOUSLY INTERFACED WITH THE PILOT.

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FLIGHT TEST VALIDATION OF A DESIGN PROCEDURE FOR DIGITAL AUTOPILOTS

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ABSTRACT

Commercially available general aviation autopilots are currently in transition from an analogue circuit system to a computer implemented digital flight control system. Well known advantages of the digital autopilot include enhanced modes, self-test capacity, fault detection, and greater computational capacity. A digital autopilot's computational capacity can be used to full advantage by increasing the sophistication of the digital autopilot's chief function, stability and control. NASA's Langley Research Center has been pursuing the development of direct digital design tools for aircraft stabilization systems for several years. This effort has most recently been directed towards the development and realization of multi-mode digital autopilots for GA aircraft, conducted under a SPIFR-related program called the General Aviation Terminal Operations Research (GATOR) Program. This presentation focuses on the implementation and testing of a candidate multi-mode autopilot designed using these newly developed tools.

OUTLINE

The sponsoring program for the GA autopilot work reported here is the GATOR program. A short background of GATOR is provided along with some of its major goals. The autopilot testing "environment", namely the airborne and ground support facilities, and the support software are then described. Flight test data is presented for an altitude command mode autopilot showing how the "environment" permits rapid autopilot performance tuning. The status of this work completes the presentation.

OUTLINE

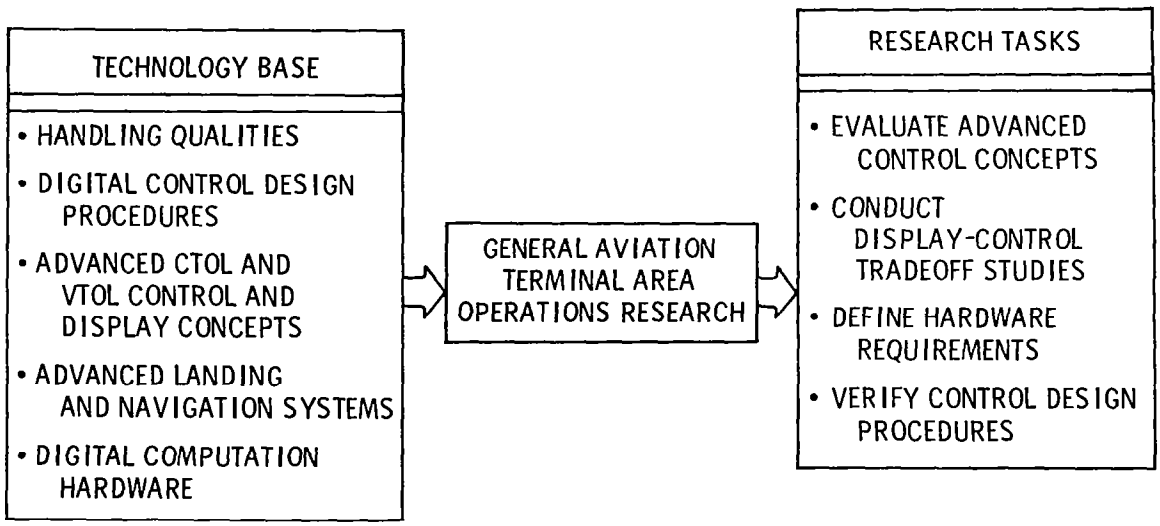
- Program Background and Goals
- Autopilot Testing Environment
- Altitude Command Mode Example
- Status

GATOR RESEARCH OBJECTIVES

The objective of the GATOR program was to reduce the pilot's workload during SPIFR terminal area approaches. The approach taken to meet this objective was to assess the technological state of the art in a number of areas germane to the GA terminal area approach problem. This technology base was then used or extended as required by specific research tasks. Two specific examples of this approach are (1) the autopilot work reported here, which used theory developed earlier for a helicopter autoland system (Ref. 1), and (2) an evaluation of advanced display symbology for general aviation (Ref. 2), which used portions of a display created for Langley's Terminal Configured Vehicle (TCV) program. More details of the GATOR program can be found in Ref. 3.

GENERAL AVIATION TERMINAL AREA OPERATIONS RESEARCH

OBJECTIVE: REDUCTION OF PILOT WORKLOAD FOR SINGLE PILOT IFR APPROACH TO LANDING OPERATIONS



AUTOPILOT DESIGN VALIDATION

To validate the the autopilot design procedure developed under the current program, a multi-mode autopilot for Princeton University's NAVION, a fully instrumented, fly-by-wire research vehicle, was designed. A NASA computer and instrumentation pallet, called the Digital Avionics Research Equipment (DARE) pallet, was installed in the NAVION and used to implement the candidate digital autopilots. More details on both the aircraft and the DARE pallet are contained in later figures. The autopilot control law structure was based on modern optimal control theory, handled all significant coupling, and had a low iteration rate (10 samples/second). During the course of the current testing, nine autopilot modes were evaluated through simulation and flight tests.

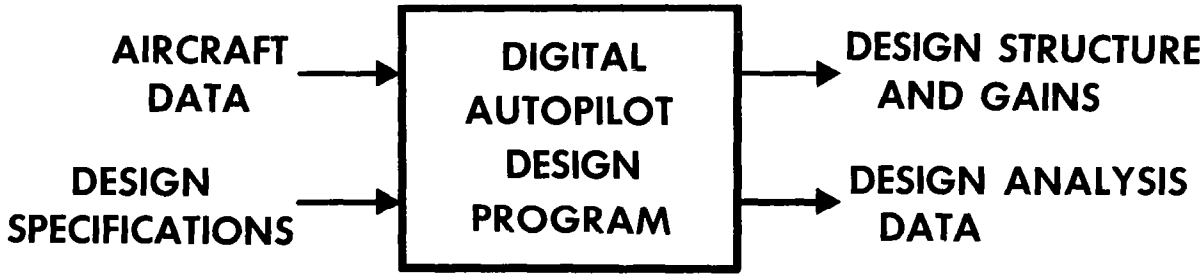
NAVION CONTROL EXPERIMENTS

- o PROPORTIONAL-INTEGRAL-FILTERED (PIF) DIGITAL CONTROL LAW STRUCTURE
  - BASED ON MODERN OPTIMAL CONTROL THEORY
  - LOW ITERATION RATE (10 SAMPLES/SECOND)
  - HANDLES ALL SIGNIFICANT COUPLING
- o AUTOPILOT DESIGNS EVALUATED
  - ALTITUDE COMMAND/HOLD
  - HEADING COMMAND/HOLD
  - PITCH COMMAND/HOLD
  - ROLL COMMAND/HOLD
  - ILS COUPLER MODE
  - VELOCITY COMMAND/HOLD
  - FLIGHT PATH ANGLE COMMAND/HOLD
  - VELOCITY RATE COMMAND/HOLD
  - PITCH RATE COMMAND/HOLD

DESIGN PROCEDURE DESCRIPTION

The autopilot design procedure itself is a computer program resident on the main Langley computer complex and has as inputs (1) the subject aircraft's stability and control derivatives and (2) the control system performance specifications in the form of closed-loop responses. The program determines the required gains for an assumed proportional-integral-filtered (PIF) control structure to realize the autopilot functions. The program also provides data to assist in the analysis of expected system performance.

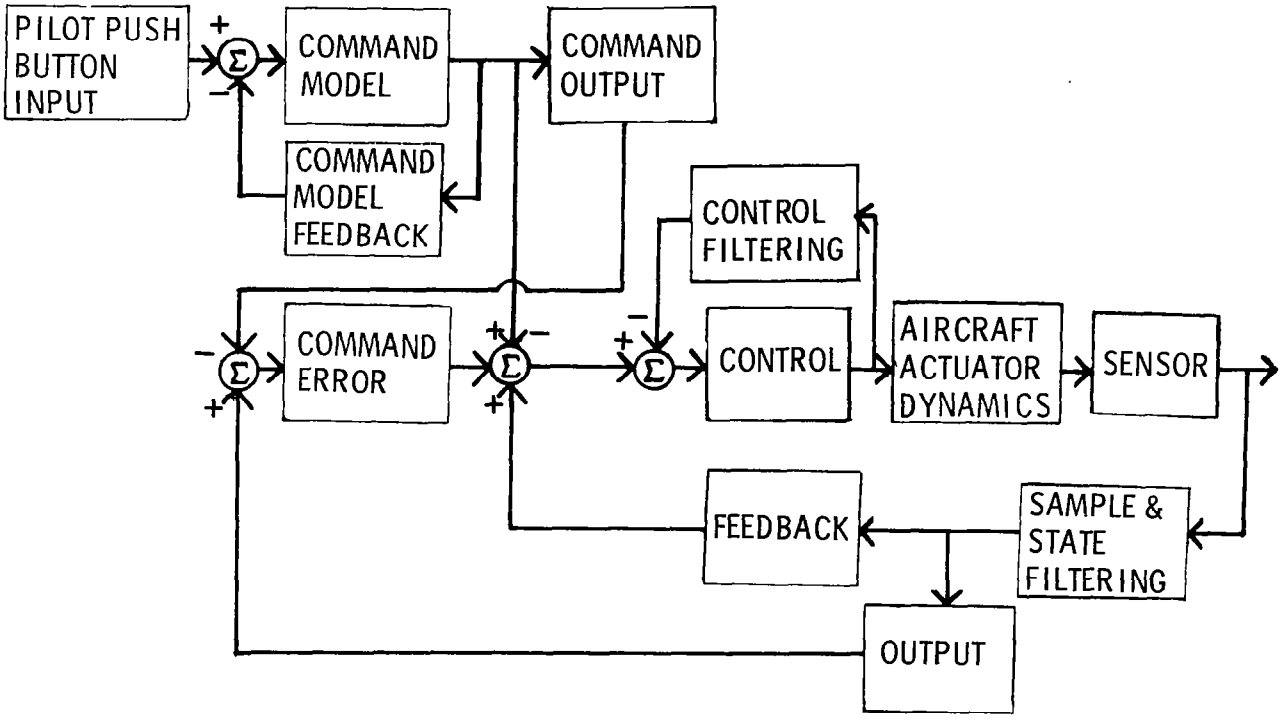
AUTOPILOT DESIGN PROCEDURE



PROPORTIONAL-INTEGRAL-FILTERED (PIF) ALGORITHM

The basic PIF control law block diagram for the GA autopilots realized in this study is shown in the accompanying figure. There are two main functions shown in this structure: (1) the command model which is used to create commands necessary to implement specific autopilot functions (modes) such as altitude command, heading command, etc., and (2) a command tracker and stabilization system which forces the aircraft to follow the command model outputs. The command model is essentially represented by the five blocks at the top left (four with "command" in them and the pilot input), and the command tracker by the remaining blocks. Creating a new autopilot mode or modifying a mode's behavior involves changing only the command model portion; the tracker and thus the closed loop stability is not changed. To adapt an existing autopilot to a different vehicle requires modifying only the command tracker portion; the command models do not change.

BASIC PIF CONTROL LAW BLOCK DIAGRAM



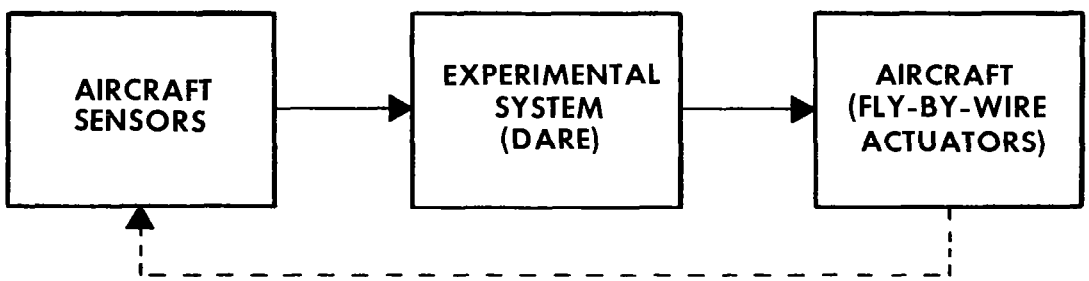
RESEARCH FLIGHT SYSTEM

A block diagram representing the autopilot flight research system is shown here, and consists of three main components. At the left are the aircraft sensors required for the autopilot implementation and include body-mounted flight control rate, vertical, and heading gyros; linear accelerometers; a barometric altimeter; and elevator, rudder, and aileron position measurements. Other capabilities available to assist in performance evaluation included airspeed, alpha, and beta measurements. An electric stick was available but not used in this test.

The center block represents the DARE system used for digital autopilot realization. The main components of the DARE required were a ROLM 1666 Mil-Spec general purpose mini-computer with 32 A/D and 15 D/A channels to interface to the research aircraft systems, and a digital tape recorder used for flight data storage and autopilot software loading. Through use of the in-flight program load feature, several autopilot candidates could be evaluated during a single flight. Other capabilities include a two-way digital data link used to send data to ground facilities for display generation. The uplink transmitted radar position data to the DARE pallet for use in a simulated ILS system.

The right block represents the NAVION aircraft used for these tests. The only capability required was electric input actuators for the elevator, rudder, and ailerons. Other capabilities available but not used include electric input throttle and flap control, and a variable stability system.

DIGITAL AUTOPILOT FLIGHT TEST SYSTEM



Required:
- Rates and Accelerations
- Barometric Altitude
- Control Surface Positions

Other Capabilities
- Airspeed
- Alpha, Beta
- Electric Stick

Required:
- General Purpose Mini Computer
- 32 A/D & 15 D/A Channels
- Digital Tape Recorder

Other Capabilities
- Two-Way Digital Data Link

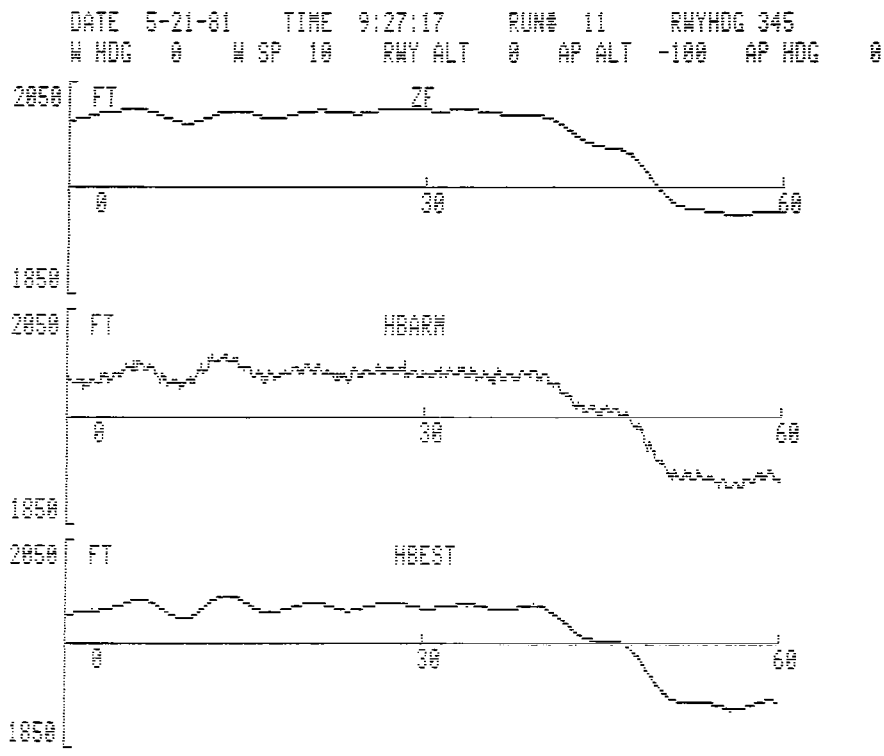
Required:
- Electric Input Actuators

Other Capabilities
- 5 DOF
- Variable Stability A/C

ALTITUDE COMMAND MODE PERFORMANCE

The next two figures are typical performance assessment plots available at the flight test station, and were generated from flight data tapes using ground support equipment to be described in later charts. These plots illustrate observed performance of the altitude command autopilot for two design iterations. The top trace on each chart is filtered radar altitude, the next, raw barametric altitude, and the bottom is filtered barametric altitude. Run identification data is found at the top. Each autopilot was given a -100 foot altitude command at 80 KIAS.

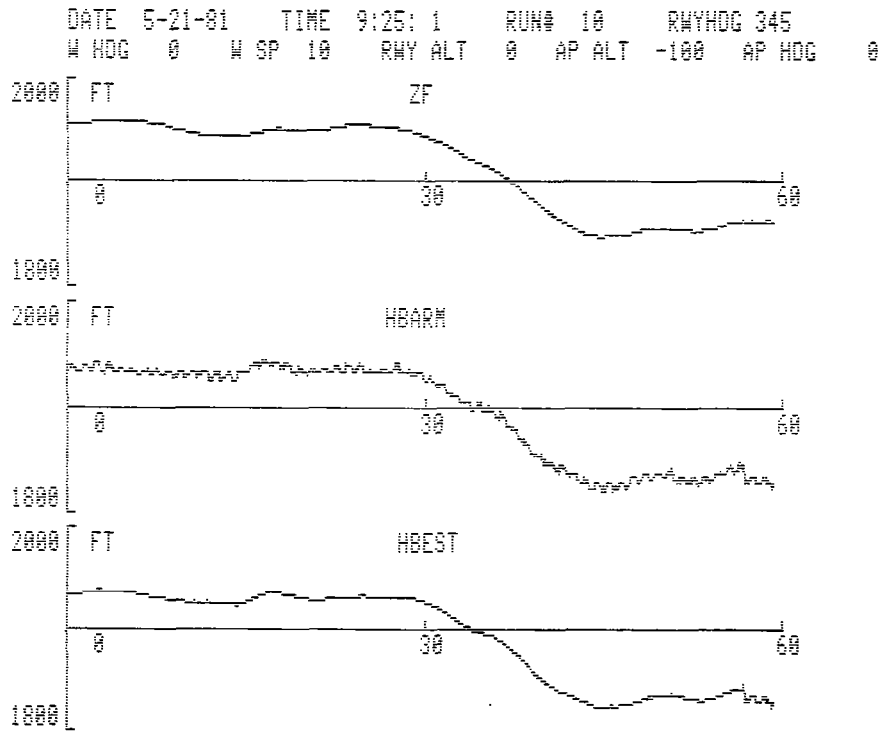
As can be seen in the first chart, the altitude hold system was slightly oscillatory. Additionally, while the altitude command was accurately executed, the "hesitation" noted in the transition was rated poorly by the evaluation pilots. After flight data examination, the autopilot command model (for the hesitation) and stabilization loop (for the altitude hunting) were modified and a new set of gains were included in the autopilot coding. The next chart illustrates the performance attained.



TUNING ALTITUDE COMMAND MODE

As can be seen here, the oscillatory "altitude hunting" has been reduced, but not completely eliminated; the "hesitation" was eliminated. This autopilot version was rated highly by the evaluation pilots, with no negative comments about the altitude hunting. This sequence of data illustrates one very important reason for iterative flight tuning in control system development: while it may be technically feasible to improve performance to eliminate all "undesirable" characteristics, some of these may not matter anyway, and additional efforts to refine performance will not result in significant perceived improvments. Batch or fixed-base real-time simulations do not provide this insight.

It can be observed that the "improved" autopilot (RUN# 10) was tested before its predecessor (RUN# 11). This was done to obtain a more accurate comparison of the two versions under the same atmospheric conditions, and to demonstrate consistent performance for a given system. Run #11 is actually a repeat of the run conducted on 5/20/81 which served as the basis for the autopilot modification made that day.

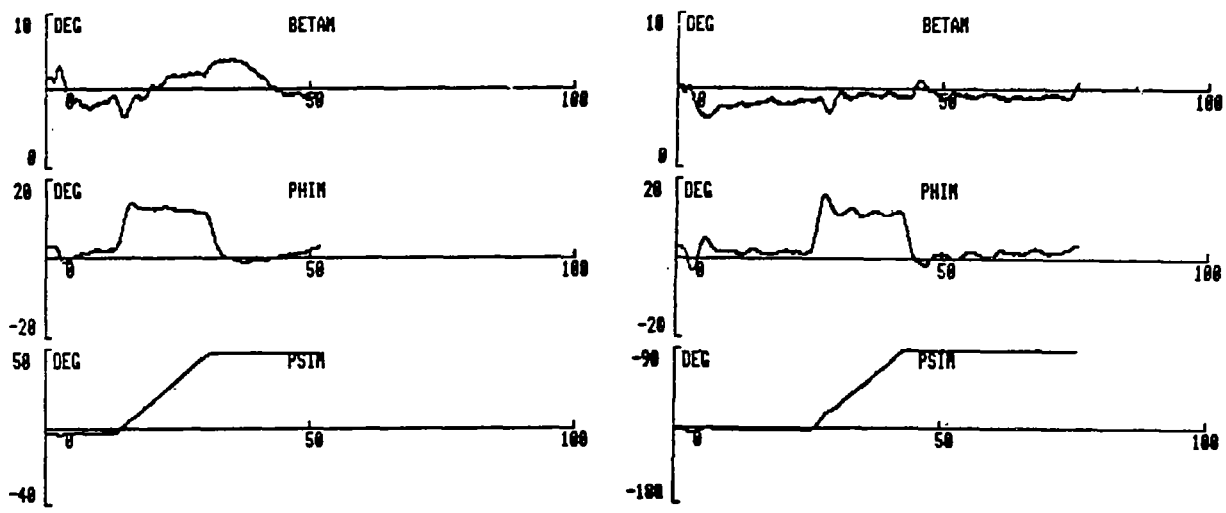


CONTROL DESIGN BASED ON DATCOM MATH MODEL

One important question in the use of the current design procedure is where one obtains the aircraft mathematical model used by the design program. This chart gives some insight by comparing two heading command autopilots. The traces generated on the left were obtained from a design using the best stability and control derivatives currently available; those on the right, from a design based on derivatives from a DATCOM analysis made about ten years ago. The DATCOM performance data was obtained from the first flight of this particular design, and no iterative refinement had been made. The top trace in each set is measured sideslip (Beta); the middle, measured roll attitude (Phi); and the bottom, measured heading (Psi). Each system executed a 45 degree heading change command at 80 KIAS.

While the DATCOM-based autopilot needs improvement in damping, its performance is nevertheless a good starting point for the iterative flight test design process.

FLIGHT TEST COMPARISON OF A MODERN CONTROL DESIGN
HEADING COMMAND/HOLD



DESIGN BASED ON TRADITIONAL MODELING PROCEDURES

DESIGN BASED ON DATCOM

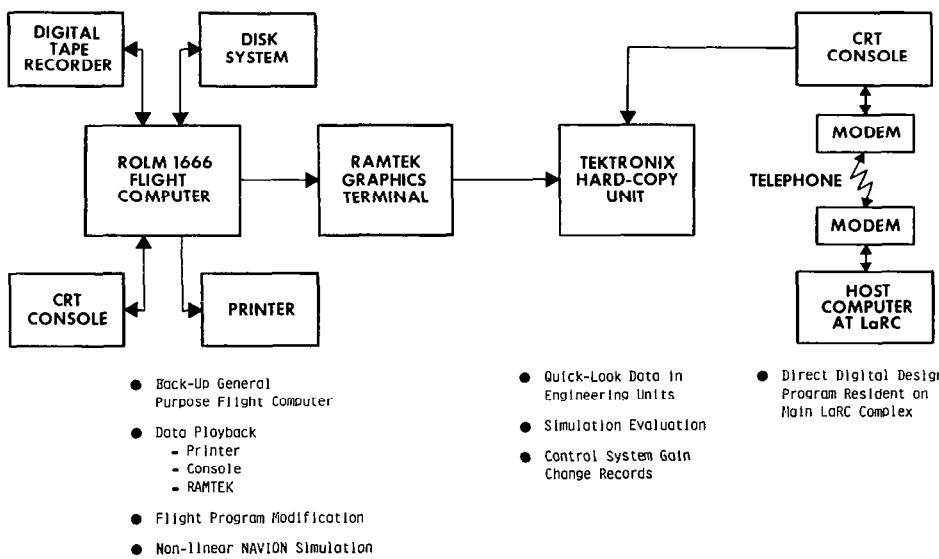
GROUND SUPPORT EQUIPMENT

This block diagram represents the equipment used in the autopilot ground support system to examine and plot flight data, redesign and simulate autopilot performance, and create new autopilot flight system tapes. At the left is a ROLM 1666 flight computer with its peripheral equipment. This system served as a back-up flight computer, as the flight and simulation data playback system, as the host for a non-linear simulation for preflight autopilot assessment, and as the tool to modify and create new autopilot flight software and program tapes. Evaluation data could be obtained at the CRT console or printer in numeric format from any combination of the 64 variables recorded every 0.1 second, or in graphical form using the Ramtek colorgraphics terminal.

The hard-copy unit was used to obtain permanent records of the Ramtek plots, to aid in simulation evaluation, and to transfer control system gains from the remote design program system (shown at the right) to the ROLM system for flight software modification. The data presented in earlier charts was obtained from the ROLM/Ramtek/Tektronix systems.

The direct digital design program, hosted on a Cyber 175 computer at LaRC, was remotely accessed using a CRT terminal, low-speed modems, and standard voice-grade telephone service. As mentioned above, hard copies were made of the autopilot gains obtained by exercising this program.

DIGITAL AUTOPILOT GROUND SUPPORT EQUIPMENT

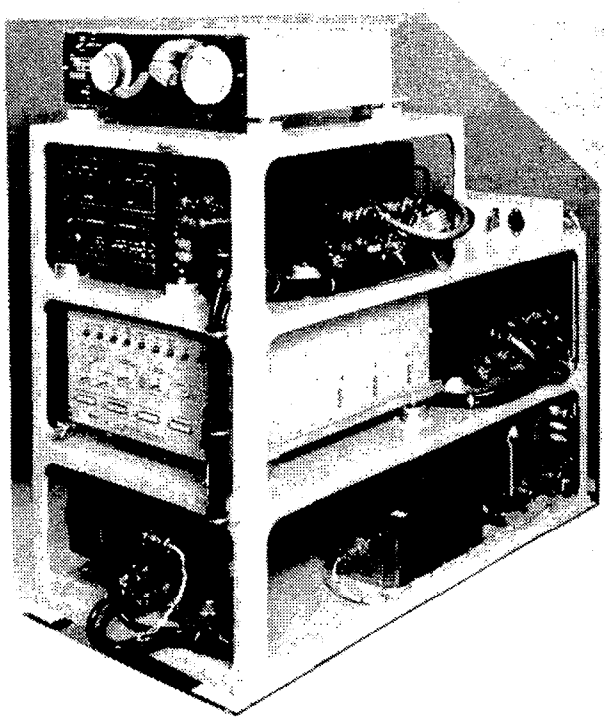


DIGITAL AVIONICS RESEARCH EQUIPMENT (DARE) PALLET

A photograph of the DARE pallet used in the research aircraft is shown here. The top shelf contains the digital tape recorder; the next shelf has the computer control panel and the interface electronics box for 1) the aircraft systems, 2) the tape recorder, and 3) the digital telemetry system (seen at the front of the third shelf). The bottom shelf contains the ROLM 1666 computer (front) and an S-Band television receiver (rear) used for display research and real-time performance evaluation. The ROLM computer is a 1976 vintage state-of-the-art machine (about 250K single-precision Whetstone operations/second). Efforts are under way by computer vendors to upgrade performance by developing a flight computer needing slightly more space than this one and having approximately eight times the computing capacity. With such a machine, it is envisioned that the entire design, simulation, and flight implementation of digital autopilots could be easily accommodated with one computer.

NASA/LaRC

DIGITAL AVIONICS RESEARCH EQUIPMENT



STATUS

The status of the direct digital autopilot work for general aviation aircraft is listed here. Five modes have been developed and evaluated, and documents that describe the design procedure and results of the flight tests are given in references 4 and 5. The design procedure software will be distributed through COSMIC in 1983. With these accomplishments, the current effort will be terminated.

S T A T U S

- Five Autopilot Modes Developed and Evaluated (15 Flights)
  - Altitude Command/Hold
  - Heading Command/Hold
  - Pitch Attitude Command/Hold
  - Roll Attitude Command/Hold
  - ILS Glideslope/Localizer Coupler
- Design Procedure and Autopilot Flight Evaluation Available as NASA Contractor Report (refs. 4 and 5)
- Design Procedure Software Distributed through COSMIC--Early 1983
- No Future Additional NASA Effort Envisioned for G.A. in Digital Autopilot Area

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3. Downing, D. R.; Bryant, W. H.; and Stengel, R. F.: "NASA/Princeton Digital Avionics Flight Test Facility." Presented at the 3rd Digital Avionics Systems Conference, Fort Worth, TX, November 6-8, 1979.

4. Broussard, John R.: PIFCGT - A PIF Autopilot Design Program for General Aviation Aircraft. NASA CR-166123, 1983.

5. Broussard, John R.: Design, Implementation and Flight Testing of PIF Autopilot Designs for General Aviation Aircraft, NASA CR-3709, 1983.

A SIMULATOR EVALUATION OF AN AUTOMATIC TERMINAL APPROACH SYSTEM

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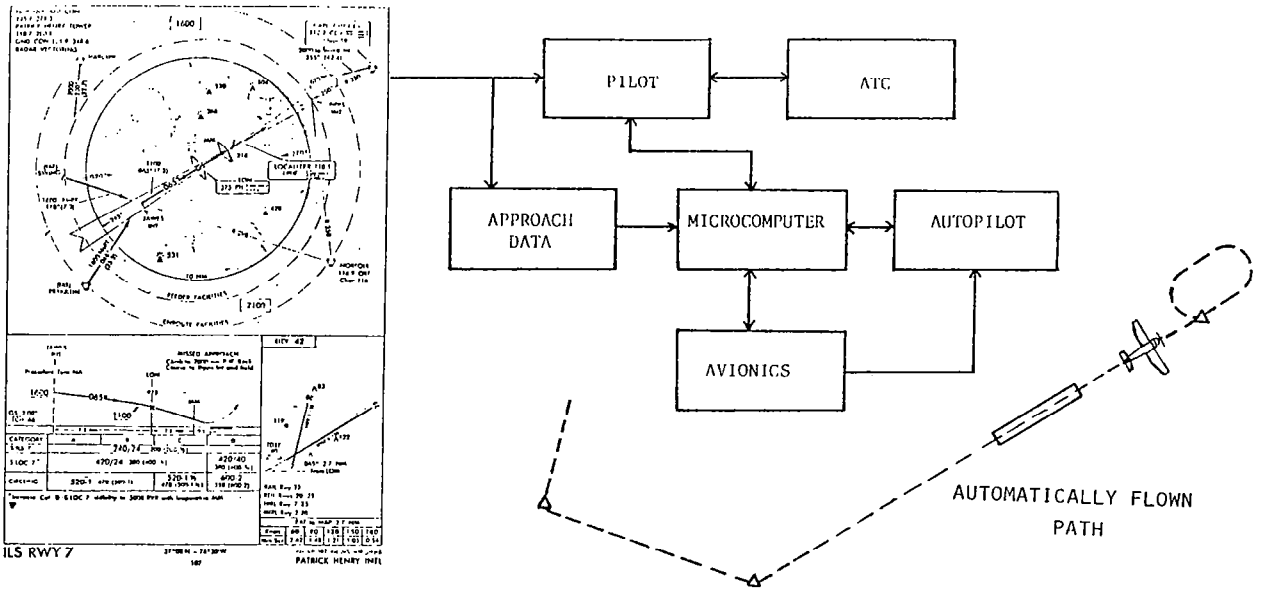
ABSTRACT

The automatic terminal approach system (ATAS) is a concept for improving the pilot/machine interface with cockpit automation. The ATAS can automatically fly a published instrument approach by using stored instrument approach data to automatically tune airplane avionics, control the airplane's autopilot, and display status information to the pilot.

A piloted simulation study was conducted to determine the feasibility of an ATAS, determine pilot acceptance, and examine pilot/ATAS interaction. Seven instrument-rated pilots each flew four instrument approaches with a baseline heading select autopilot mode. The ATAS runs resulted in lower flight technical error, lower pilot workload, and fewer blunders than with the baseline autopilot. The ATAS status display enabled the pilots to maintain situational awareness during the automatic approaches. The system was well accepted by the pilots.

ATAS CONCEPT

This figure depicts the ATAS concept in block diagram form. A flight system would store approach data in memory and use a microcomputer to control aircraft radios and autopilot and to accept inputs from the pilot. The pilot will use an approach chart for backup. Air traffic control (ATC) vectors and altitude assignments could be entered directly on the ATAS control panel. When the aircraft is cleared for the approach by ATC, the pilot would press a button to enable ATAS to automatically complete the approach. At the conclusion of the approach the ATAS would automatically execute the missed approach procedure unless the pilot disengages the system to land.



- MICROPROCESSOR-BASED SYSTEM
- STORAGE OF APPROACH DATA
- COMPUTER CONTROL OF AVIONICS AND AUTOPILOT
- AUTOMATIC EXECUTION OF HOLDING PATTERNS, PROCEDURE TURNS, AND MISSED APPROACH
- EASY PILOT OVERRIDE FOR ATC RADAR VECTORS/ ALTERNATE PROCEDURES
- EXPANDABLE TO ENROUTE AND DEPARTURE PHASES OF FLIGHT
- FREES PILOT FROM FLYING AND NAVIGATION RADIO TUNING TASKS
- WILL EXECUTE ALL TYPES OF APPROACHES

ATAS CONTROL PANEL

The ATAS control panel constructed for a simulation study is shown below. At the bottom of the panel is a conventional autopilot control head. The ATAS controls on the top half of the panel consist of a few rotary knobs and push-buttons around the CRT display. The three knobs to the left of the CRT are used to manually input heading, altitude, and speed to fly. The three push-buttons to the left of the CRT determine whether the course and altitude parameters are automatically or manually controlled and whether the autothrottle is on or off. Switches and buttons along the top turn ATAS on and off and select the go-around and holding pattern functions. The CRT provides a continuous display of approach status including reference course, altitude, and speed; distance and direction to the airport; position in approach (OUTBOUND TO PROCEDURE TURN, FINAL APPROACH, ENTERING HOLDING PATTERN, etc); and the actual autopilot mode.

The ATAS panel was installed in the Langley General Aviation Simulator immediately to the right of the flight instruments.

EXPERIMENT DESIGN

Seven instrument rated pilots were used in the simulation study. Each pilot flew 8 instrument approaches. In one half of each pilot's approaches the ATAS system was used. In the other half a baseline heading select autopilot configuration was used. Each pilot flew four ILS approaches with radar vectoring and four NDB approaches with no radar vectoring. An outside-the-windshield visual scene with variable ceiling and visibility was used for breakout and landing. The ceiling and visibility were set above landing minima for four of each pilot's runs and below minima for the other half of the runs.

Realistic ATC communications with the pilot were provided. The communications included radar vectors, altitude assignments, controlled handoffs, and clearance for the approach and for landing. A self-paced side task was used to estimate pilot workload. The pilot was given a circular slide rule type flight computer. On pilot request, a time-speed-distance problem was given verbally. The pilot solved the problem and announced the answer.

The airplane math model used was of a typical general aviation single engine airplane.

EXPERIMENT DESIGN

- ½ ILS (VECTORING, PRECISION)
- ½ NDB (NO VECTORING, NONPRECISION)
- ½ ATAS ON, ½ ATAS OFF (HEADING SELECT)
- ½ WEATHER ABOVE MINIMA, ½ WEATHER BELOW MINIMA
- 8 APPROACHES, 7 PILOTS (ALL IFR, 300 TO 7000 HRS)
- SELF-PACED SIDE TASK (TIME-SPEED-DIST)
- REALISTIC ATC COMMUNICATIONS
- DATA
  - -PILOT COMMENTS
  - -X,Y,Z PLOTS WITH PRINTS
  - -RESEARCHER OBSERVATIONS
  - -SIDETASK RESULTS

RESULTS

Fewer pilot blunders were made with the ATAS than with the baseline autopilot. A blunder is defined as any pilot error that results in a flight path deviation. Eleven blunders were made with the ATAS. Three factors were predominant in these errors. Problems with ATAS mode interaction were involved in 9 of the 11 blunders, a lack of situational awareness in 4 of the 11 blunders, and a data entry error in one of the occurrences. An example of a mode error would be trying to select automatic ATAS modes when the autopilot is off. An example of a situational awareness blunder is forgetting that a landing flap setting is selected while the ATAS is executing an automatic missed approach. The data entry error occurred when the pilot was assigned a heading of 160 by ATC and dialed in 060 instead.

Nineteen blunders were made with the baseline autopilot. Situational awareness was involved 11 times, instrument interpretation 7 times, input errors 3 times, and chart interpretation and basic airplane familiarization once each. Examples of situational awareness errors include descending below decision height in clouds, flying through the localizer instead of intercepting it, and not having the navigation radios tuned properly prior to reaching the localizer. Instrument interpretation errors were made on the NDB approaches and with the HSI on the localizer back course during ILS missed approaches.

BLUNDERS 11 ATAS ON

TYPES (ATAS)

- MODE ERRORS (9)
  - SETTING AUTO ALT IN DESCENT
  - TRYING TO SELECT AUTO WITH A.P. OFF
  - FORGETTING TO SELECT AUTO ALT OR CRS
- SITUATION AWARENESS (4)
  - CLIMBOUT WITH FLAPS
  - DIALED 060 FOR 160 VECTOR AND DID NOT REALIZE ERROR
- DATA ENTRY (1)
  - VECTOR INPUT ERROR

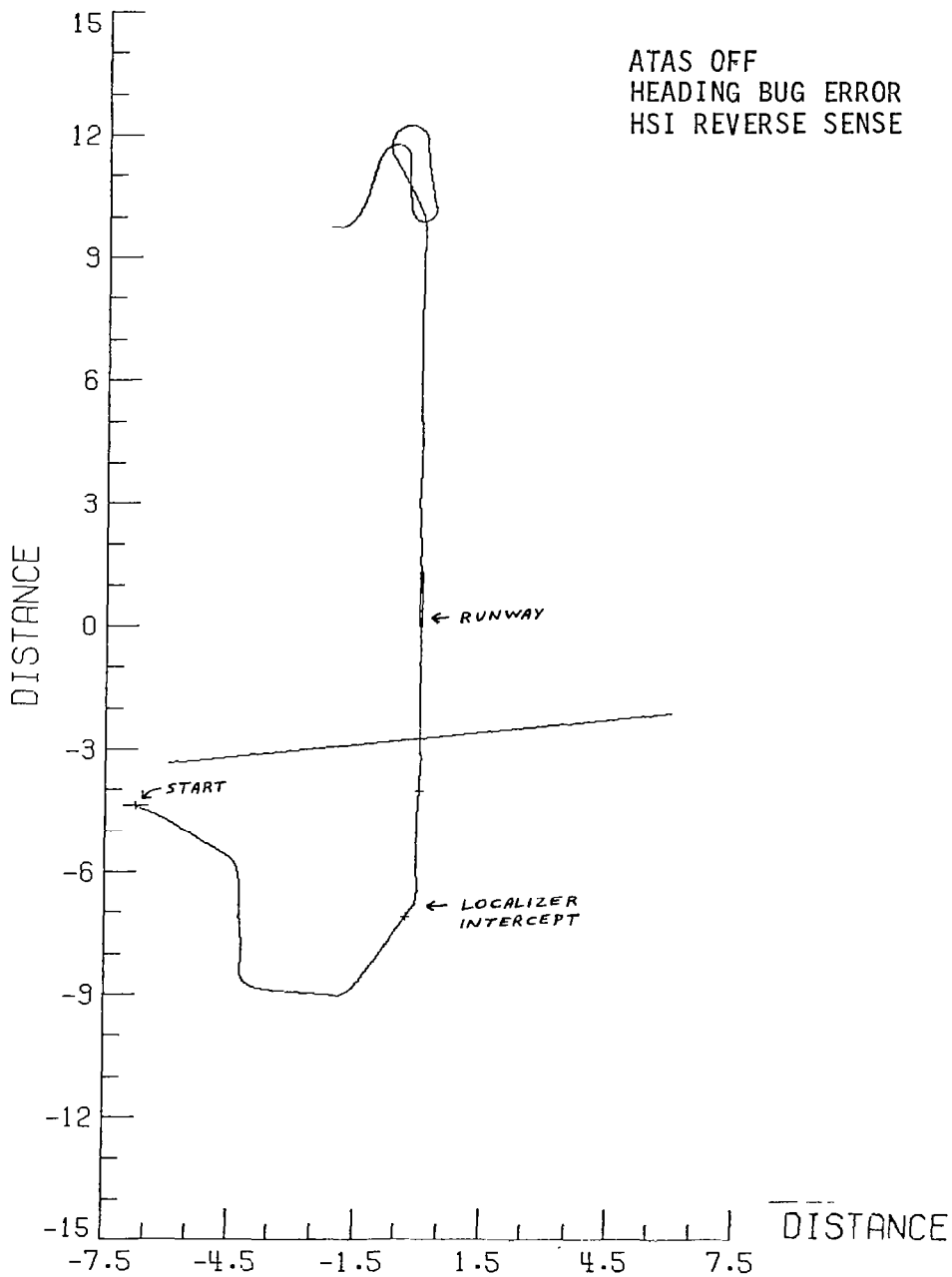
19 ATAS OFF

TYPES (NON-ATAS)

- SITUATION AWARENESS (11)
  - NOT REALIZING A WRONG DIRECTION TURN WAS COMMANDED
  - MADE MISSED APPROACH WITH RUNWAY IN SIGHT
  - LOCALIZER OVERSHOOTS
  - DESCENT BELOW DH/LANDED BELOW MINIMA
  - RADIOS NOT TUNED AT LOCALIZER
  - 2 MILE DEVIATION ON MISSED APPROACH
  - AT 1700 FEET (MDA+860) AT M.A.P.
- INSTRUMENT INTERPRETATION (7)
  - HSI REVERSE SENSING
  - NDB TRACKING
- INPUT ERROR (3)
  - COMMAND WRONG DIRECTION TURN
  - RADIOS NOT TUNED
- CHART INTERPRETATION (1)
- AIRPLANE FAMILIARIZATION (1)

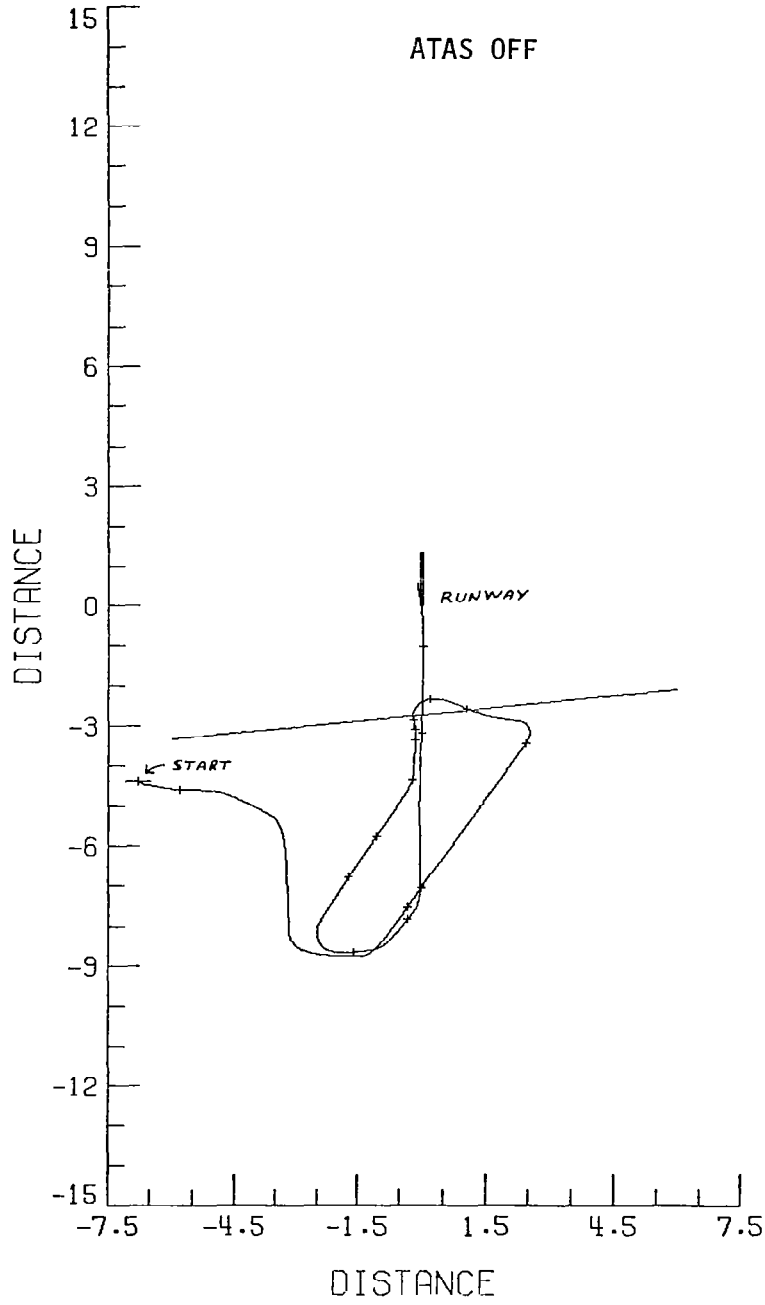
EXAMPLE OF BLUNDER WITH AUTOPILOT

A plan view pilot of an ILS approach, including a missed approach, is shown below. The ordinate and abscissa indicate distance in nautical miles along the runway axis and perpendicular to the runway axis, respectively. The run begins near the left edge of the plot. The airplane is vectored to the ILS and the approach and missed approach are flown normally. After making a normal holding pattern entry, however, the pilot rotated the HSI heading bug more than 180 degrees to the right. This caused an inadvertent left turn out of the holding pattern. The pilot then misinterpreted the HSI course error indicator and turned away from the localizer in an effort to intercept it.



ANOTHER EXAMPLE OF BLUNDER WITH AUTOPILOT

The plot below has the same format as the previous example plot. The run starts at the left edge and the airplane is vectored to the ILS localizer. The pilot was distracted by tuning to the tower frequency and communicating with ATC and did not intercept the localizer. The ATC controller had to call this to the attention of the pilot and radar vectored the airplane out for another try.

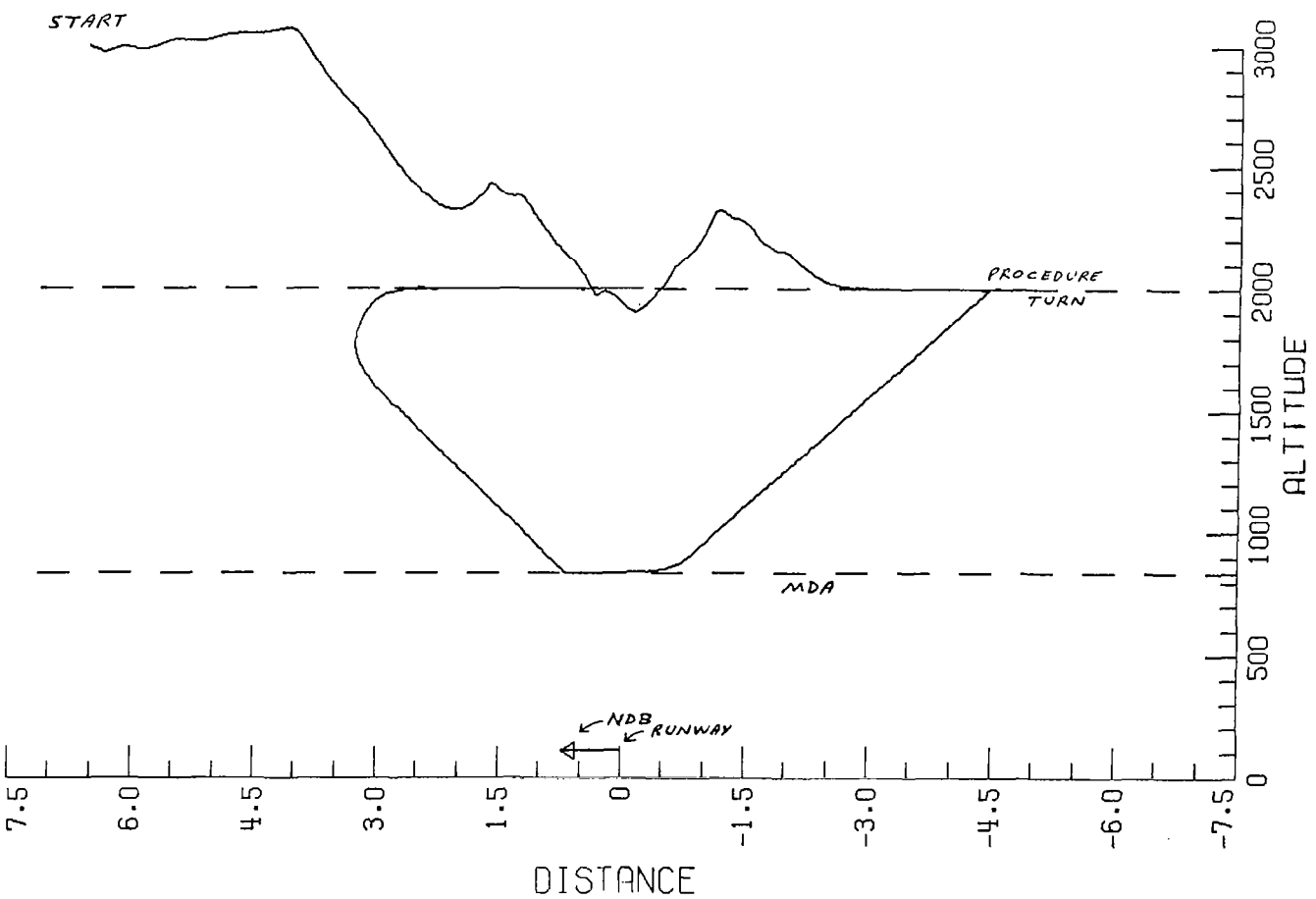


EXAMPLE OF BLUNDERS WITH ATAS

The plot below is a side view of an NDB approach. The ordinate depicts airplane altitude in feet and the abscissa shows distance along the runway axis in nautical miles. The NDB used in this approach is located on the airport.

The run began at the left of the plot. The pilot turned the autopilot on but did not turn the pitch channel on to engage the pitch "servo". This made it impossible to switch the ATAS altitude mode to automatic. The pilot tried to put the altitude mode into automatic, however, and allowed large altitude excursions while trying. The pilot finally turned the autopilot pitch channel on and had no further difficulty during the approach or missed approach.

ATTEMPT TO ENGAGE AUTO ALTITUDE WITH AUTOPILOT OFF



PILOT COMMENTS

Pilot comments were grouped into control, display, and mode interaction comments. Control comments tend to indicate that the autopilot and ATAS controls should be consolidated to reduce confusion. As the system was implemented, the pilot did not always use the same control for control of the same parameter. For example, the HSI heading bug was used to select heading when the ATAS was off and the heading knob on the ATAS panel selected heading when ATAS was on. The display comments indicate that situational awareness could be maintained with the information shown. The pilots desired additional data, however, such as time-to-airport and a positive indication that valid navigational signals are being received. The mode interaction comments indicate that much improvement is needed in this area. The system should provide for more prompting and should generate an appropriate advisory if the pilot attempts to select a mode when conditions required for that mode are not met. The AUTO and MANUAL labeling was confusing. Does MANUAL mean that they should hand-fly, manually make entries to the basic autopilot, or manually set parameters onto the ATAS display? Some pilots consistently made the error of dialing in a new ATC vector then selecting AUTO to "automatically" fly the heading. The pilots had confidence in ATAS once everything was running automatically but sometimes had difficulty reaching that mode.

PILOT COMMENTS

CONTROLS

- KNOB SCALINGS NEED IMPROVEMENT
- PUT ATAS POSITION ON AUTOPILOT MODE CONTROL
- SERVO DRIVE THE HSI HEADING BUG
- CONSOLIDATE ATAS AND AUTOPILOT CONTROLS

DISPLAY

- DISTANCE AND DIRECTION TO AIRPORT IS USEFUL
- WOULD LIKE TIME-TO-AIRPORT
- WOULD LIKE INTERSECTION PASSAGE ANNUNCIATION
- ALL NEEDED INFORMATION IS THERE, WELL THOUGHT OUT
- WOULD LIKE A SIMPLE MAP
- WOULD LIKE POSITIVE INDICATION OF RECEIVING VALID NAV SIGNALS
- WOULD LIKE INDICATION THAT FINAL VECTOR WILL INTERCEPT THE ILS

MODE/INTERACTION

- AUTO/MANUAL LABELING CONFUSING
- TRANSITION TO AUTO SHOULD BE SAME FOR COURSE AND ALTITUDE
- NEEDS PROMPTING
- WANT ABILITY TO CYCLE BETWEEN AUTO AND MANUAL WITHOUT RESTARTING APPROACH
- AUTOTHROTTLE SHOULD DISENGAGE WITH AUTOPILOT

SUMMARY

A piloted simulation study was performed to evaluate the concept of using stored instrument approach data to automatically fly an instrument approach through automatic control of airplane radios and autopilot. The pilots were able to maintain situational awareness with this high level of automation by using the ATAS alphanumeric display of flight status. Fewer blunders were made with the ATAS than with a baseline heading select autopilot mode. Many of the blunders committed with ATAS involved pilot confusion over the various ATAS modes. Pilot comments and blunders indicate that it will be necessary to consolidate the ATAS and autopilot into one device instead of using ATAS as an add-on to existing autopilots.

SUMMARY

- PILOTS HAD CONFIDENCE IN ATAS ONCE IT WAS ENGAGED BUT HAD SOME DIFFICULTY WITH MODE SELECTION
- PILOTS MAINTAINED BETTER SITUATIONAL AWARENESS WITH SIMPLE ALPHANUMERIC DISPLAY THAN WITH CONVENTIONAL INSTRUMENTS/AUTOPILOT AND PILOT IN THE LOOP
- FEWER BLUNDERS WERE MADE WITH ATAS THAN WITH BASELINE HEADING SELECT AUTOPILOT
- PILOT HAS FEWER BLUNDER OPPORTUNITIES WITH ATAS
  ATAS CAN MONITOR PILOT INPUTS
- 9 OF 11 ATAS BLUNDERS WERE MODE INTERACTION ERRORS

PILOT CONTROLS AND SPIFR FLIGHT

D. R. Downing
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A study was performed to determine the relative advantages and disadvantages of four candidate pilot control devices for use by a single pilot flying a general aviation aircraft in instrument meteorological conditions. Only the pitch and roll axes were considered. The control devices examined were the wheel-yoke, center-stick, Brolley handles, and side-arm controller. Qualitative evaluation criteria were established that included instrument panel visibility, control sensitivity, pilot comfort, and space requirement behind the instrument panel. The results of the study indicated that the side-arm controller offered the possibility of an improvement, but further research was necessary to determine its feasibility.

To assist in the discussion, it is useful to define certain terms related to a manual or reversible control system. The system is composed of three main subsystems: the control surface, the actuation system, and the pilot controller. The actuation system is usually implemented by cables or push rods. The pilot controller is the device the pilot uses to input his commands and is most often a wheel or center stick.

"MANUAL" AIRCRAFT CONTROL SYSTEM

- CONTROL SURFACE
- ACTUATION SYSTEM
- PILOT CONTROLLER

This study was aimed at examining several candidate pilot controllers and determining the relative advantages and disadvantages specifically for the single pilot flight in Instrument Meterological Conditions. The details of the study are documented in two NASA contractor reports (References 1 and 2). Only the pitch and roll axes were considered.

OBJECTIVE: INVESTIGATE THE APPLICABILITY OF SEVERAL PILOT CONTROLLERS FOR THE SPIFR MISSION

APPROACH:

- ESTABLISH QUALITATIVE CRITERIA
- COLLECT DESIGN DATA
- EVALUATE CANDIDATE CONFIGURATIONS
- IDENTIFY AREAS FOR FUTURE INVESTIGATION

The design of a manual control system is subject to FAA certification requirements as listed below. The designer then has at his disposal a set of design variables related to the control system.

Manual Control System Design

FAR Requirements

- Maximum Control Force Limits
- Control Travel Limits
- Stick Force per G
- Stick Force Speed Variation

Design Variables

- Control Surface Geometry (Area & Chord)
- Control Surface Airfoil (Hinge Moment)
- Gearing Ratio
- Mass Balancing
- Assist Systems

The important design variable at the pilot/vehicle interface is stick force, F_s. It is related to the actuator system gear ratio, G, and the hinge moment, HM. The hinge moment in turn is related to the area of the control surface, S; its chord, $\bar{c}$; the hinge moment coefficient, C_h; and the dynamic pressure, $\bar{q}$.

CONTROLLER STICK FORCE

$$F_S = G \cdot HM$$

$$G = \text{GEARING}$$

$$HM = \text{HINGE MOMENT} = \bar{q}\ S\ \bar{c}\ C_h$$

To compare candidate pilot controllers, evaluation criteria were established. The elements listed below, constituting the criteria, were selected after a review of typical single pilot IFR missions. No relative weighting of importance of the four elements was established.

SPIFR Controller Evaluation Criteria

- Instrument Panel Visibility
- Control Response or Sensitivity
- Comfort or Pilot Fatigue
- Space Required Behind the Instrument Panel

The four candidate controller mechanizations are listed below. As mentioned earlier, only control of the pitch and roll axes was considered. The yaw axis was assumed to use standard rudder pedals in all cases. A separate chart will be used to discuss each of these options, and supporting charts will illustrate specific points.

Candidate Pilot Controllers

- Wheel and Yoke
- Center Stick
- Brolley Handles
- Side-Arm Controller

Although it is the industry standard, the wheel yoke mechanization has several disadvantages including mechanical complexity, large requirements for space behind the panel, and obstruction of visibility of portions of the instrument panel.

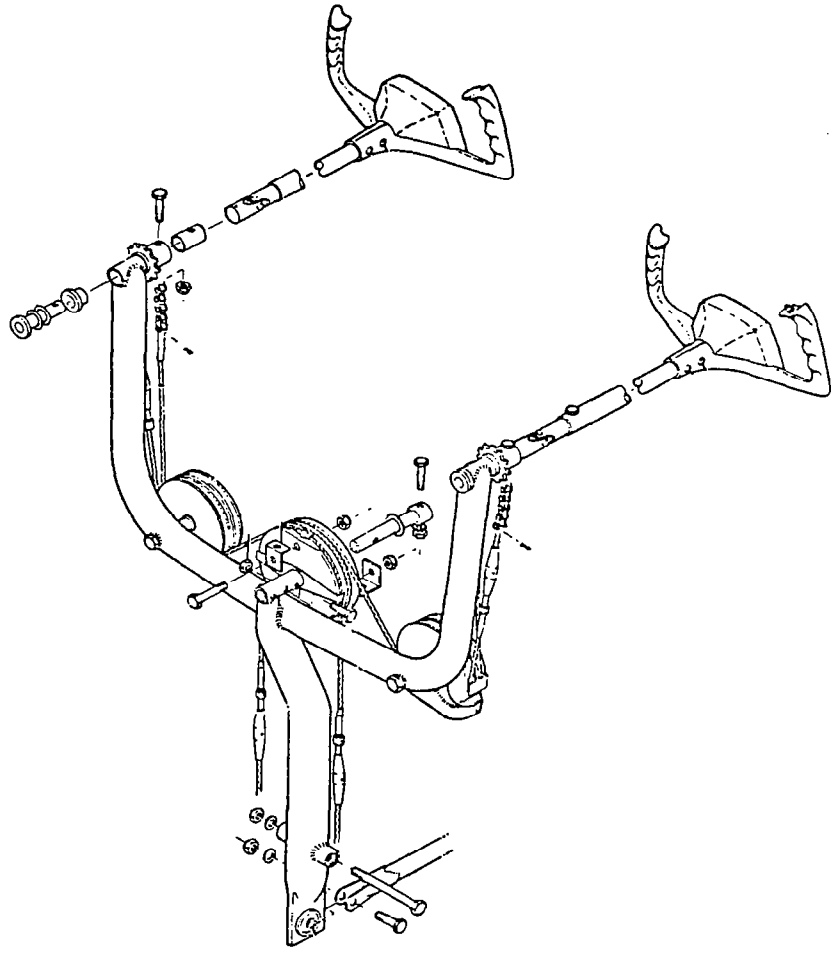
WHEEL YOKE CONTROLLER

- INDUSTRY STANDARD FOR "ALL" NEW COMMERCIAL AIRCRAFT
- STANDARD FOR ALL LARGE AIRCRAFT

ADVANTAGES	DISADVANTAGES
• ADEQUATE MECHANICAL ADVANTAGE	• MECHANICAL COMPLEXITY
• EXTENSIVE BODY OF DESIGN EXPERIENCE	• RESTRICTS SPACE BEHIND PANEL OR FLOOR SPACE
	• RESTRICTS PLACEMENT OF INSTRUMENTS ON PANEL
	• POSSIBLE TO INPUT INADVERTENT COMMAND

MECHANIZATION: DIRECT MECHANICAL LINK

This diagram illustrates the mechanical complexity of a typical behind-the-panel implementation. It also shows the large amount of volume behind the panel that must be dedicated to the controller.



The center stick was the general aviation industry standard until the 1940-1950 period. Reasons for changing to a panel-mounted wheel were not always technical. They included an attempt to relate to driving a car and a concern with women pilots wearing skirts. The center stick is still the standard in military fighters that operate in high g conditions.

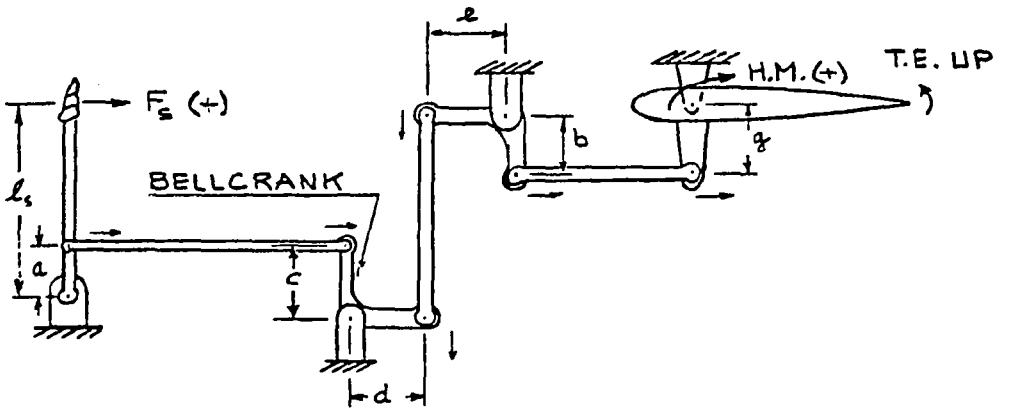
CENTER STICK CONTROLLER

- USED ON "ALL" HIGH PERFORMANCE AIRCRAFT

ADVANTAGES	DISADVANTAGES
• ADEQUATE MECHANICAL ADVANTAGE • EXTENSIVE BODY OF DESIGN EXPERIENCE • NO PANEL OBSTRUCTION • RELATIVELY SIMPLE MECHANIZATION	• RESTRICTS FLOOR SPACE • RESTRICTS MOVEMENT IN COCKPIT

MECHANIZATION: DIRECT MECHANICAL LINK

This diagram from Reference 3 illustrates the typical pitch axis arrangement of gearing between the center stick and the control surface. The large mechanical advantage of this arrangement comes from the ratio ℓ_s/a.



(From ref. 3. Reprinted by permission of the author.)

The Brolley handles were initially developed for the Boeing SST design and are presently implemented in the experimental cockpit of the Boeing 737 used at Langley Research Center. They consist of two controllers, one for each hand, that come out of the instrument panel. Both the roll input (rotation) and pitch inputs (push-pull) are standard, but there is no connection between the handles to obstruct the view of the instrument panel. This mechanization still has the complexity and space-behind-the-panel problems of a conventional wheel.

BROLLEY HANDLES

- EXPERIMENTAL IMPLEMENTATION

ADVANTAGES	DISADVANTAGES
• NO PANEL OR FLOOR RESTRICTIONS	• MECHANICAL COMPLEXITY • RESTRICTS SPACE BEHIND PANEL • NO EXPERIENCE IN GA AIRCRAFT

MECHANIZATION: DIRECT MECHANICAL LINK

The side-arm controller has had extensive use in spacecraft, in research aircraft, and (most recently) in military fighters (F-16). It has also been used in home-built design, e.g. Rutan's Long-EZE and Vari-EZE. Major disadvantages are the limited mechanical advantage and the limited experience in general aviation aircraft.

SIDE-ARM CONTROLLER

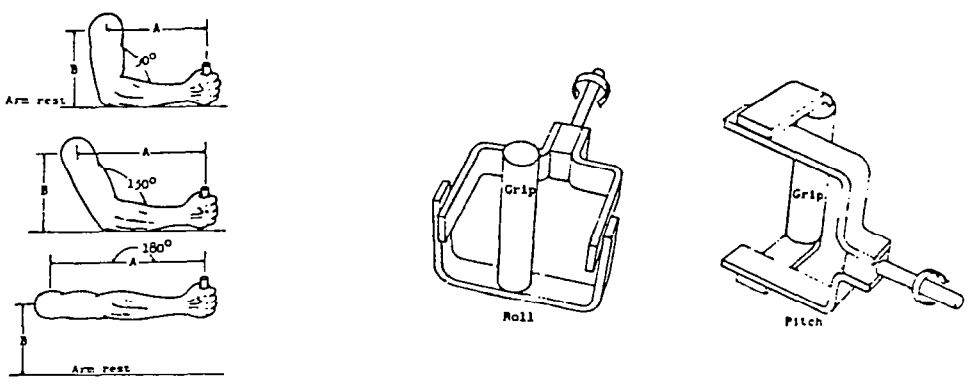
- EXTENSIVE USE IN SPACECRAFT AND RESEARCH AIRCRAFT

ADVANTAGES	DISADVANTAGES
• NO INSTRUMENT PANEL OBSTRUCTION	• LIMITED EXPERIENCE IN GA AIRCRAFT
• NO REQUIREMENT FOR SPACE BEHIND THE PANEL	• LIMITED STICK MECHANICAL ADVANTAGE
• NO OBSTRUCTION IN CABIN	• ONE HAND OPERATION
• PRECISE CONTROL POSSIBLE	
• RELATIVELY SIMPLE MECHANIZATION	

This figure, taken from Reference 4, shows typical data available that defines the mechanical limits (linear and angular) of a side-arm controller.

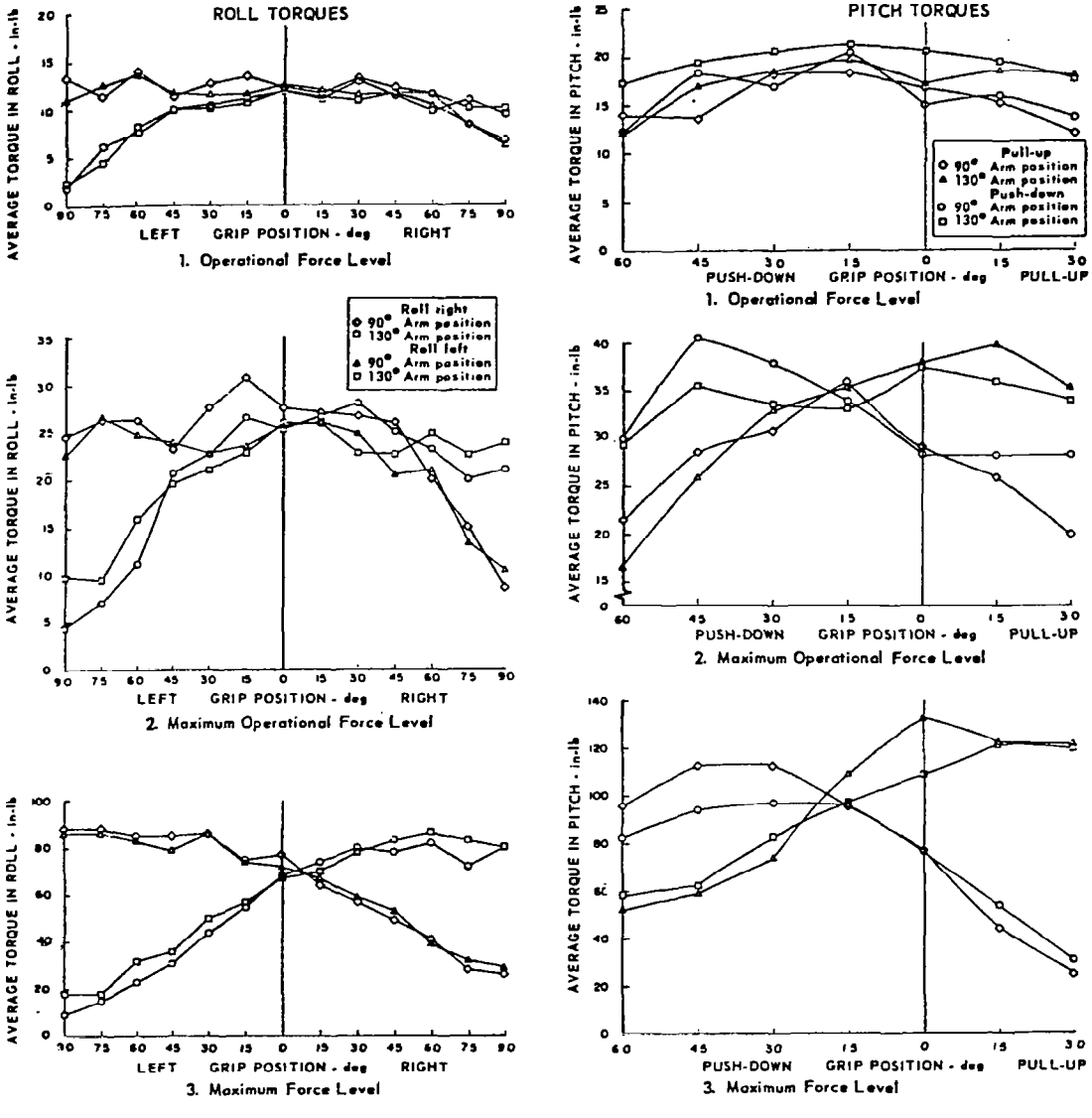
Data for Optimizing Location and Travel of a Side-Stick Controller

Pilot	Distance A in.			Distance B, in.		Maximum controller angle (unconstrained), deg							
						Right Roll		Left Roll		Forward Pitch		Rearward Pitch	
	Measured at elbow angle of -												
	90°	130°	180°	90°	130°	90°	130°	90°	130°	90°	130°	90°	130°
1	15.00	19.00	26.25	13.00	12.50	105	105	80	75	45	35	30	40
2	11.50	18.00	25.00	12.75	11.50	90	100	90	100	65	70	30	30
3	13.00	18.00	25.00	13.00	12.00	90	90	90	95	55	60	30	35
4	12.00	18.00	25.00	13.00	12.00	85	85	75	80	50	45	30	30
5	14.00	18.50	26.00	13.00	12.50	90	95	90	100	60	65	30	30
6	14.50	18.50	27.00	13.75	13.75	90	100	90	100	75	55	45	40
7	12.50	18.00	25.00	12.75	11.50	90	90	105	105	70	75	30	30
8	13.50	18.50	27.00	13.25	13.00	100	95	100	100	80	75	30	30
9	13.30	18.50	27.00	13.25	13.00	90	90	105	105	45	45	40	40
10	13.00	17.50	27.50	13.75	13.50	90	100	90	105	75	65	55	55
11	14.50	18.75	28.50	13 25	13.75	90	105	90	105	60	75	30	30
Average	13.35	18.30	26 30	13.15	12.63	91.8	96	91.4	97.3	61.8	60.4	34.5	35.0



Preferred Arm Position for Side-Stick Controllers

A second design issue is the stick force level that is possible and acceptable. This figure, from Reference 4, shows typical data available to the control system designer.



These graphs show the forces the pilots could develop at two elbow angles. They were instructed to apply the following levels of exertion:

(1) Operational force--chosen as the comfortable level for continuous control maneuvers;

(2) Maximum operational force--acceptable for short periods, applicable to any maneuver requiring maximum control capability;

(3) Maximum force--the greatest force pilots could exert in each grip position.

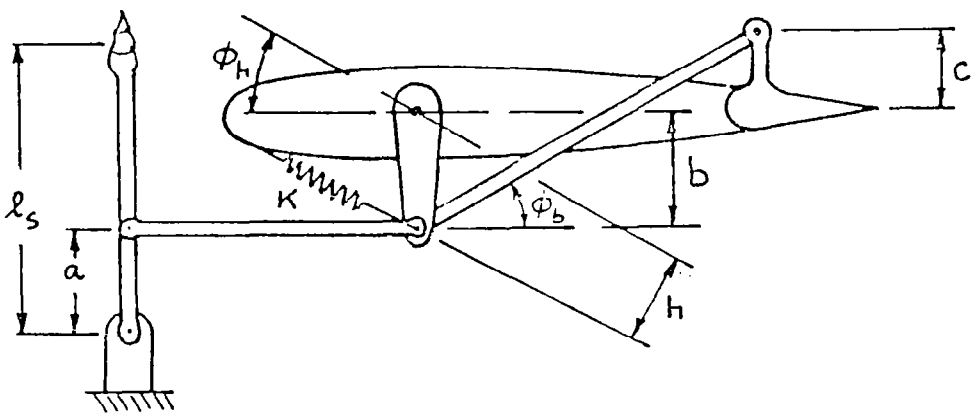
Average Torques Exerted on Side-Stick Controllers

The wheel, center stick, and Brolley handle mechanization all had sufficient mechanical advantage to permit the controller to be directly connected to the control surface. Because of the limits to stick force motion of the side-arm controller, it is probably not possible to use a direct link for all aircraft. Two other possibilities are direct link to a control surface tab, or a boost system. At this time, definitions of "small," "medium," and "large," as used below, are not well established.

SIDE-ARM CONTROLLER MECHANIZATION

"SMALL" AIRCRAFT	DIRECT MECHANICAL LINK
"MEDIUM" AIRCRAFT	MECHANICAL CONNECTION TO TAB
"LARGE" AIRCRAFT	BOOST SYSTEM REQUIRED

This figure, from Reference 3, shows a typical spring tab mechanization for the pitch axis. The aerodynamic gain in this mechanization can compensate for the relatively small value of the mechanical advantage (ℓ_s/a) typical of a side-arm controller.



(From ref. 3. Reprinted by permission of the author.)

A comparison of all controller mechanizations using the wheel as the standard shows that relative to the SPIFR criteria the side-arm controller offers an improvement in all categories.

COMPARISON* OF CONTROLLER OPTIONS

	CENTER STICK	BROLLEY HANDLE	SIDE-ARM
PANEL VISIBILITY	IMPROVED	IMPROVED	IMPROVED
REQUIRED SPACE BEHIND PANEL	LESS	EQUAL OR GREATER	LESS
COMPLEXITY	LESS	EQUAL OR GREATER	LESS
CONTROL SENSITIVITY	GREATER	EQUAL	GREATER

*WHEEL USED AS STANDARD.

To establish the feasibility of using side-arm controllers in future general aviation aircraft, two areas require further research.

FUTURE SIDE-ARM RESEARCH

- QUANTITATIVELY DEFINE "SMALL," "MEDIUM," AND "LARGE" AIRCRAFT FOR SIDE-ARM CONTROLLER APPLICATION.
- INVESTIGATE CONTROLLER SENSITIVITY.

REFERENCES

1. Deam, Dirk J., Michael J. See, Douglas B. Shane, "Pilot Controls and Single-Pilot IFR Flight: Description of Potential Control Devices and Assessment of Their Applicability in General Aviation Aircraft," NASA CR-165738, 1981.

2. Roskam, Jan, "On the Interaction Between Six Types of Cockpit Controllers, Pilots, and Control Surfaces," NASA CR-165755, 1981.

3. Roskam, J., "Methods for Estimating Stability and Control Derivatives of Conventional Subsonic Airplanes," published by the author, Lawrence, Kansas, 1971.

4. Black, G. T., and D. J. Moorhouse, "Flying Qualities Design Requirements for Sidestick Controllers," AFFDL-TR-79-3126, Air Force Flight Dynamics Laboratory, 1979.

ADVANCED SYMBOLOGY FOR GENERAL AVIATION APPROACH TO LANDING DISPLAYS

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NASA Langley Research Center

ABSTRACT

This presentation describes a set of flight tests designed to evaluate the relative utility of candidate displays with advanced symbology for general aviation terminal area IFR operations. The symbology was previously evaluated as part of the NASA Langley Research Center's Terminal Configured Vehicle Program for use in commercial airlines. The advanced symbology included vehicle track angle, flight path angle and a perspective representation of the runway. These symbols were selectively drawn on a CRT display along with the roll attitude, pitch attitude, localizer deviation and glideslope deviation. In addition to the CRT display, the instrument panel contained standard turn and bank, altimeter, rate of climb, airspeed, heading, and engine instruments. The symbology was evaluated using tracking performance and pilot subjective ratings for an ILS capture and tracking task.

OUTLINE

The sponsoring program for the display symbology work discussed here was the GATOR program which was outlined in the presentation, "Flight Test Validation of a Design Procedure for Digital Autopilots". The current presentation includes a short background stating the purpose of this work and how the experiment was designed. The three display options evaluated are then presented, and the tracking performances for two test subjects are given. The presentation ends with some conclusions and the status of this work.

O U T L I N E

- Background and Experiment Design
- Display Options
- Tracking Performance
- Conclusions and Status

EXPERIMENT PURPOSE AND DESIGN

The advantages of CRT displays in the cockpit have been demonstrated for the commercial airline class vehicle through such programs as NASA Langley's Terminal Configured Vehicle (TCV) program (Ref. 1). Further, the incorporation of electronic displays in the Boeing 757 and 767 is indicative of display hardware technology maturity. It is not clear how this technology can be best applied to general aviation aircraft with their more limited panel space and display system budget, and which are used by pilots with a broad skill range. For these reasons, the current study was initiated with the main objective of determining the relative merit of various symbology levels in the GA IFR approach to landing environment.

The display concepts are based on TCV developed formats and include the ability to selectivly draw a perspective representation of the runway, a measure of the current flight path angle, and presentation of a relative ground track angle. The tests were conducted in a GA aircraft (Princeton's Navion) using the NASA LaRC DARE package described in the companion autopilot presentation. The original intent was to use GA pilots, but actually two GA pilots and two NASA test pilots participated in the study. Two measures of symbology value were used: (1) a statistical analysis of localizer and glideslope tracking performance, and (2) pilot ratings and comments.

ADVANCE DISPLAY SYMBOLOGY RESEARCH

OBJECTIVE: DETERMINE THE VALUE OF ADVANCED SYMBOLOGY FOR GA IFR APPROACH AND LANDING

DISPLAY CONCEPTS

- MODIFIED COMMERCIAL AIRCRAFT SYMBOLOGY
  - PERSPECTIVE RUNWAY
  - FLIGHT PATH ANGLE
  - RELATIVE GROUND TRACK ANGLE

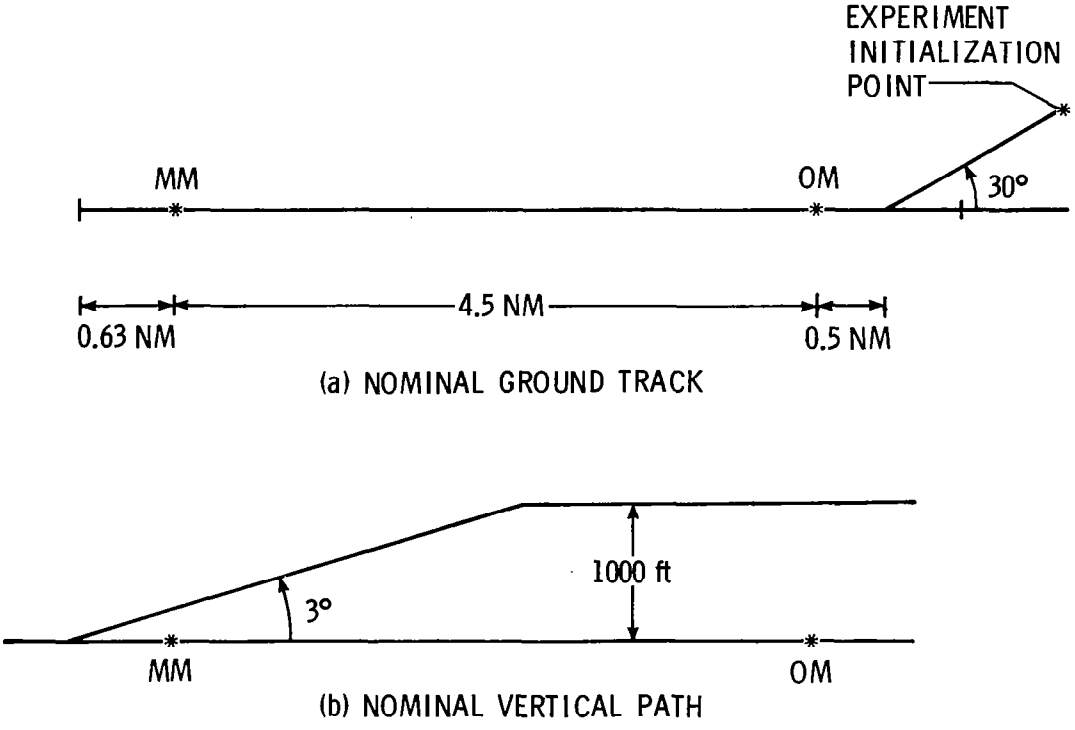
EXPERIMENT DESIGNS

- FLIGHT TEST USING GA PILOTS IN GA AIRCRAFT
- STATISTICAL ANALYSIS OF TRACKING PERFORMANCE
- SUBJECTIVE PILOT RATING

TEST RUN DESCRIPTION

The task required the interception and tracking of an ILS localizer and glideslope as shown in the figure. The safety pilot positioned the aircraft at the initialization point at approximately 1000 feet and 80 knots with the wheels down and the flaps up. The subject pilot was then given control of the aircraft and proceeded to "fly an 80 knot approach, tracking the localizer and glideslope as tightly as possible." The run ended at the CAT-1 ILS decision height of 200 feet. A data run from initialization to initialization required about 15 minutes; six approaches for a single display option could be completed in a 1-1/2 hour flight. Two approaches were used for training, and the remaining four were used for analysis. While the aircraft was returing to the initialization point, the pilot would relay subjective ratings and comments to ground observers.

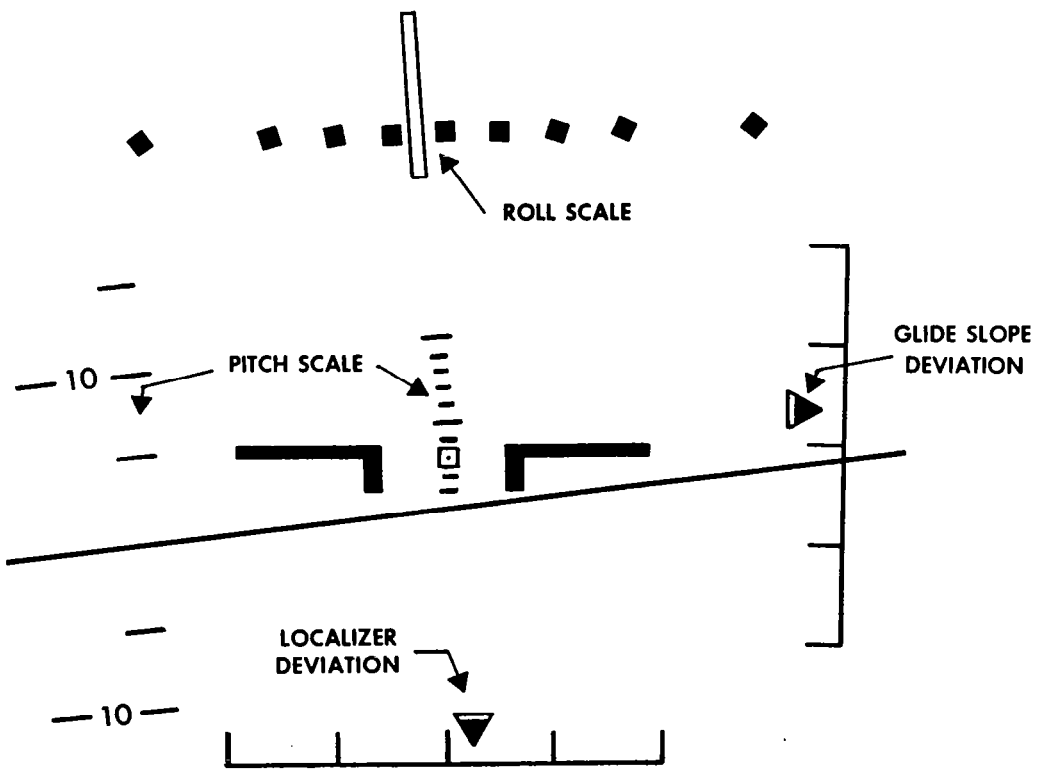
NOMINAL FLIGHT PATH



BASELINE DISPLAY

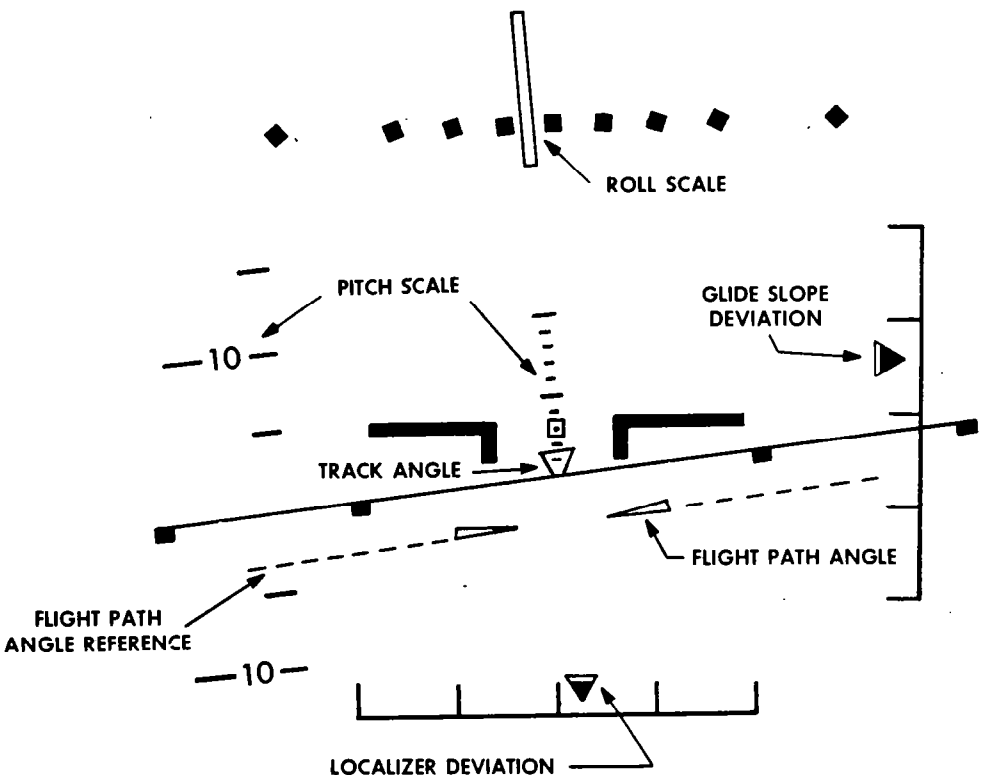
The baseline display shown here presented the information normally found on an attitude deviation indicator (an aircraft symbol, a horizon line, a pitch scale, and a roll scale). Added to this were localizer and glideslope deviations. The aircraft symbol was fixed relative to the CRT frame but could be adjusted up or down by the pilot in a manner similar to that found on an artificial horizon. The roll scale had marks at 15 degree intervals over a range of +-45 degrees. The pitch scale at the left shows a 25 degree range with numerical labels at 10 degree increments; the scale at the center has marks at +5 degree and +10 degree pitch attitude. The square in the center of the A/C symbol was programmed to blink at outer and middle marker passage.

The raw ILS deviations were displayed on linear scales with marks at 0, +-50%, and +-100%. Full scale readings corresponded to 2.5 degrees on localizer and 0.7 degrees for glideslope. None of the symbols was damped or smoothed.



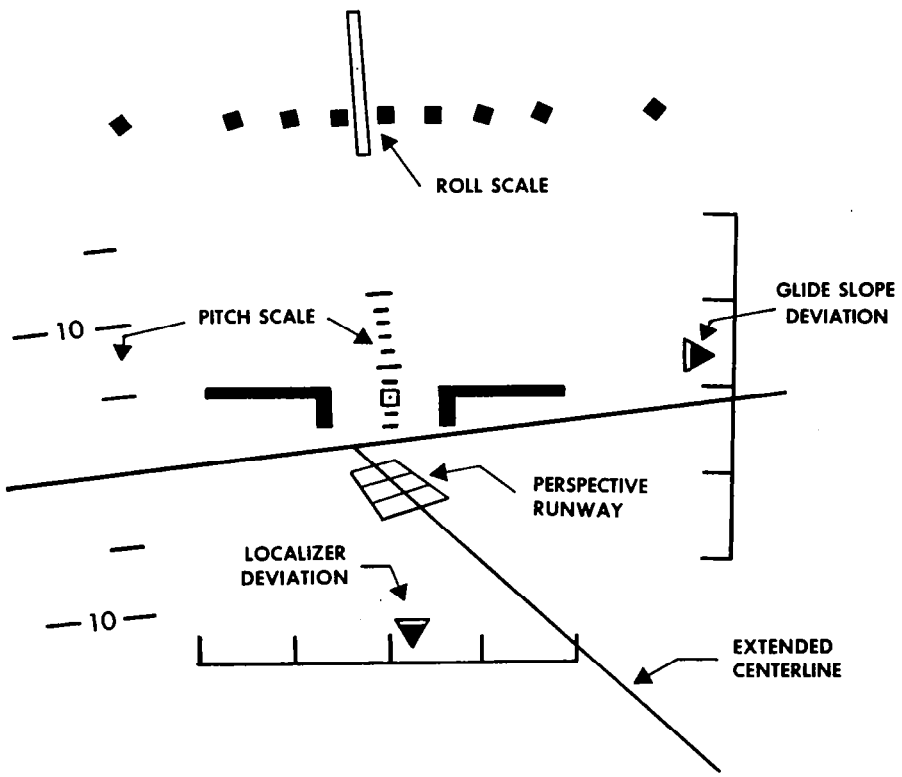
ADVANCED DISPLAY OPTION 1

Advanced Display Option 1 added to the baseline display two additional pieces of data: (1) a ground-referenced track angle, and (2) a ground-referenced flight path angle. A dashed line parallel to the horizon was added to represent the 3 degree nominal glideslope angle. The track angle is defined as the angle between the aircraft's ground-speed in the horizontal plane and the runway centerline, and is useful for localizer intercept and capture since it provides a measure of the localizer closure rate and includes the effect of wind. During localizer tracking, it gives a measure of departure rate due to crosswinds or changing wind conditions. The pilot has only to adjust the aircraft heading so that the track angle is zero to fly a ground track parallel to the runway centerline. If the localizer deviation is also zero, the pilot is flying a ground track directly on the localizer. This additional information can potentially reduce the workload associated with the iterative process of finding the crab angle which compensates for crosswinds.



ADVANCED DISPLAY OPTION 2

Advanced Display Option 2 augments the baseline display with a perspective image of the runway having an extended centerline. The runway image was formed by displacing it according to the vehicle's position and rotating it through the vehicle's pitch and roll angles and the ground track angle. The use of track angle rather than the more conventional heading was done for two reasons: (1) it made the runway and centerline image move more gradually, and (2) its use made the relative orientation of the runway provide a measure of the aircraft's track angle.



PILOTING EXPERIENCE OF SUBJECTS

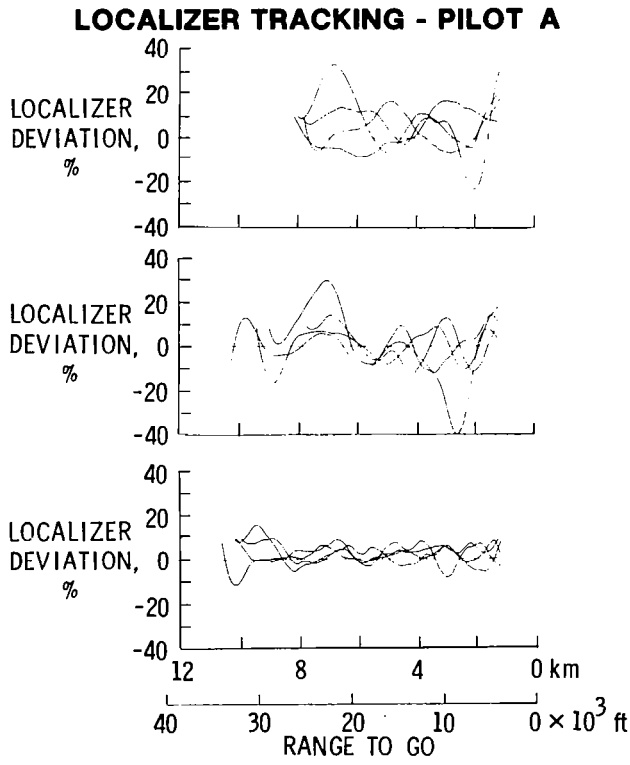
Data for two test subjects are presented here; Pilot A was a test pilot, and Pilot B was a GA pilot with an instrument rating.

SUBJECT PILOTS EXPERIENCE

	TOTAL HOURS	INSTRUMENT HOURS	RATINGS
PILOT A	7000	1000	ATP, CFI
PILOT B	526	60	PVT, INSTRUMENT RATING

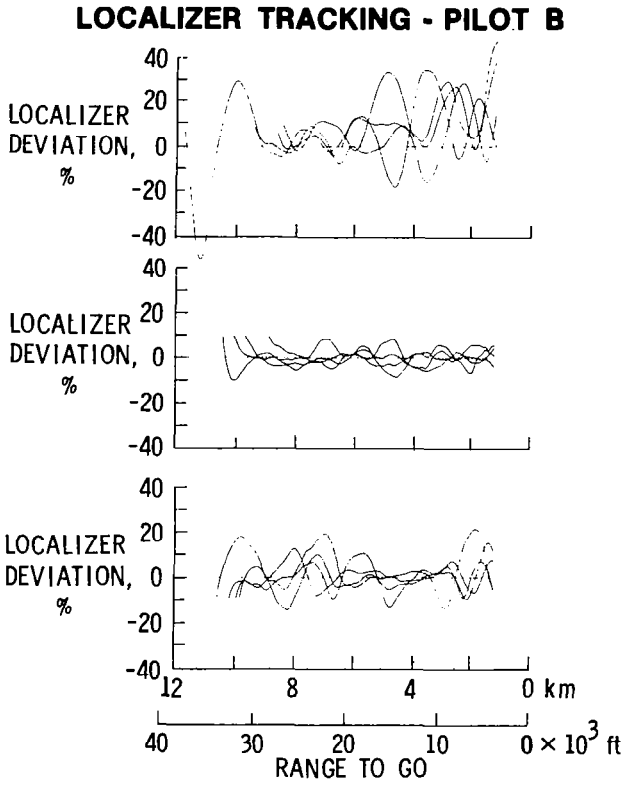
TRACKING PERFORMANCE DATA--TEST PILOT

Shown here is the localizer tracking performance for the test pilot for each of the three displays. The top plots represent the deviation in percent recorded during the four data runs for the baseline display; the center plots, Option 1; and the lower plots, Option 2. It can be seen from this data that the use of the Option 2 display resulted in a substantial improvement in localizer tracking for this subject, while there was essentially no improvement over the baseline with the use of Option 1. The next figure shows an interesting observation for the GA pilot.



TRACKING PERFORMANCE DATA--GA PILOT

The localizer tracking histories for the GA pilot data runs are given here, with the top, baseline; center, Option 1; and lower, Option 2. It can be seen that both Options 1 and 2 gave better tracking performance than the Baseline, with Option 2 clearly the better. This is not the same result noted with the test pilot in the previous chart. With the limited data developed to date, it is not clear whether this was a consequence of pilot experience, or simply pilot preference.



CONCLUSIONS & RECOMMENDATIONS

Based on data obtained from this experiment, it appears that the advanced symbology permits a more precise localizer and glideslope capture and tracking than does the baseline display. Because of the limited data developed so far, it is not possible to determine which symbology is "best." Pilot skill level and/or personal preference may be a factor. The pilot comments indicate, however, that even the baseline display is superior to conventional ADI and CDI presentations on separate instruments.

Also based largely on pilot comments, the recommendations below were derived.

CONCLUSIONS

- Advanced symbology permits more precise capture and tracking than does baseline.
- Data obtained thus far is inadequate to determine which advanced symbology is "best." Pilot skill level and/or personal preference may be a factor.
- Pilot comments indicate even baseline display is superior to conventional ADI and CDI presentations on separate instruments.

RECOMMENDATIONS

- Future experiments should:
  - use a side task to simulate an operational environment
  - use a "standard" electromechanical ADI and CDI as the baseline
  - evaluate new display options that combine symbology from the two advanced options
- More work is required to improve the sensitivity of the subjective rating scales.

EXPERIMENT STATUS

A total of four pilots (two GA, and two test pilots) have evaluated each of three display options. A presentation of preliminary results has been made at the AIAA Aircraft Systems and Technology Meeting in Dayton, OH, in August, 1981 (Ref. 2). This report included the data from only two of the test subjects, and the report will be revised to include the contributions of the remaining two pilots. After this revision, there is currently no future NASA work envisioned for this area.

STATUS

- Four pilots (2 GA, 2 Test) have evaluated each of the three displays.
- Preliminary results have been reported in at the AIAA Aircraft Systems and Technology Meeting in Dayton, OH in August, 1981.
- Preliminary report will be revised.
- No future NASA effort for this work is currently envisioned.

REFERENCES

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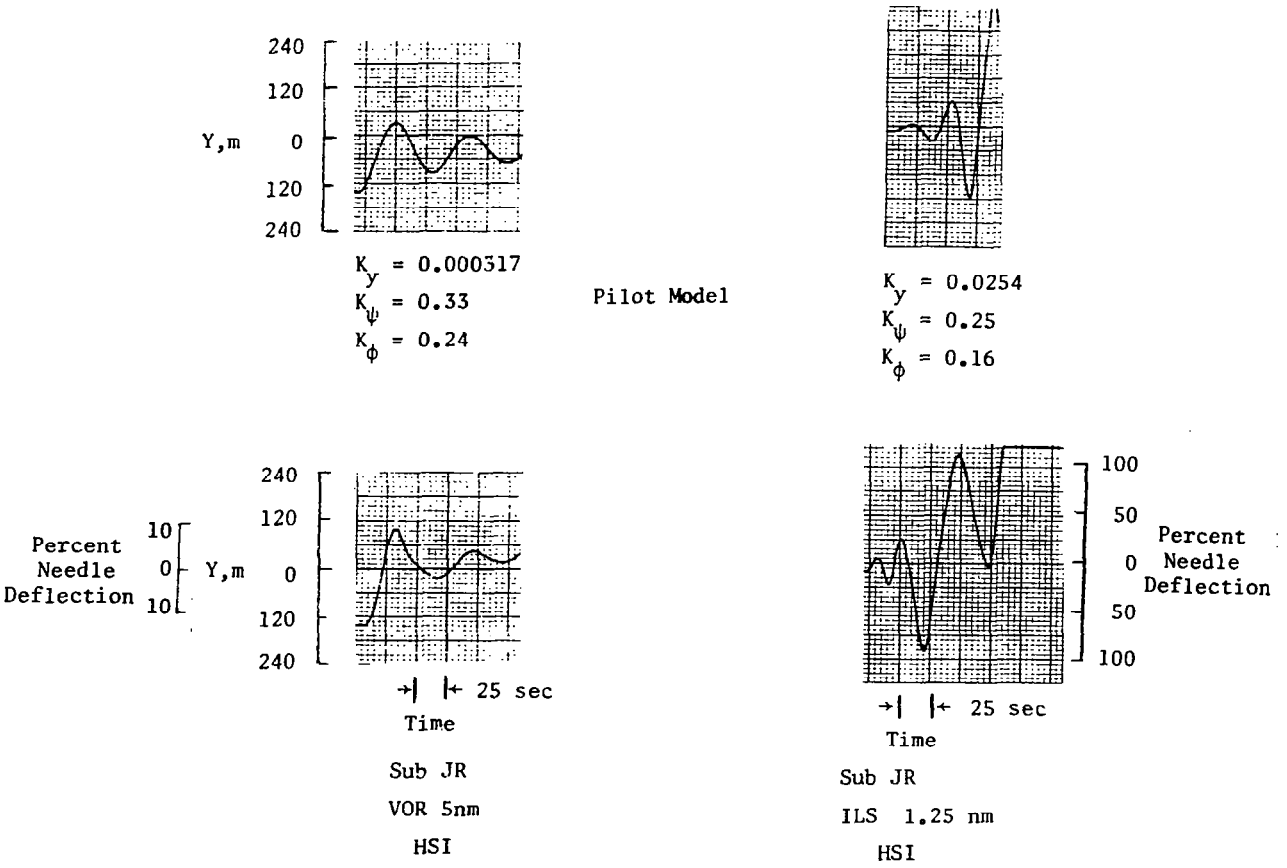
2. Downing, D. R.; Bryant, W. H.; and Yenni, K. R.: "Flight Test Evaluation of Advanced Symbology for General Aviation Approach to Landing Displays." Presented at the AIAA Aircraft Systems and Technology Meeting, Dayton, Ohio, August, 1981. Paper 81-1643.

PILOT RESPONSE WITH CONVENTIONAL DISPLAYS

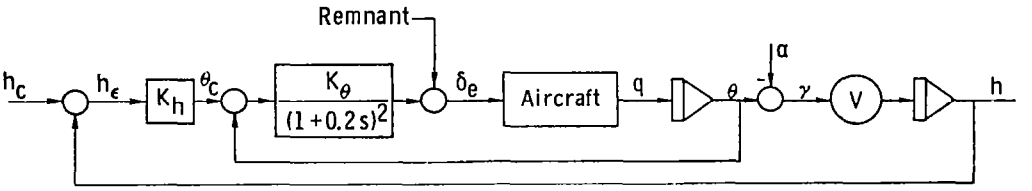
James J. Adams
NASA Langley Research Center

A critical examination of pilot-aircraft-display system response has been conducted for conventional displays. The study concentrated on determining the system frequency and damping both by visual examination of system responses to initial errors and by pilot model analysis. Examples of system response at two points in a flight are shown on the first figure. The long periods and the occasional loss of system damping in these responses are a matter of concern. These system characteristics can be duplicated with the pilot model shown on the pilot-model-aircraft system block diagram of the second figure. The responses obtained with the pilot model are also shown on the first figure, together with the pilot model gains used in obtaining these responses. The factors that determine what these gains will be are the requirements for system stability, the sensitivity of the displays, and the scanning required in looking at the displays. The effects of scanning on system response can be determined with the test set-up shown in the third figure. Using this test equipment, it was found that separating bank angle information from heading information caused a noticeable degradation in system response.

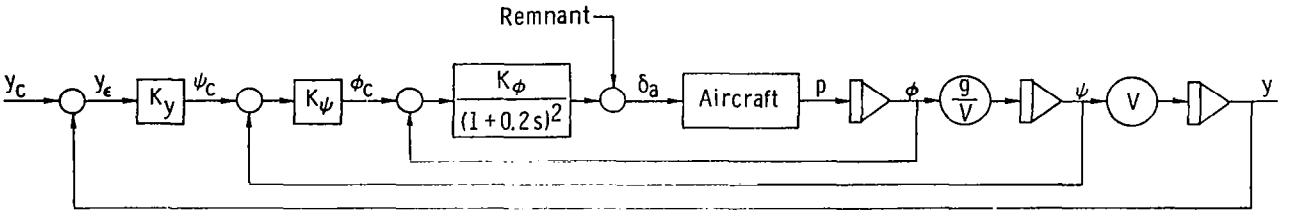
PILOT AIRCRAFT SYSTEM RESPONSE



Aircraft lateral position response obtained with subject JR and with a pilot model with the sensitivity of the HSI set at two different values corresponding to the condition noted.

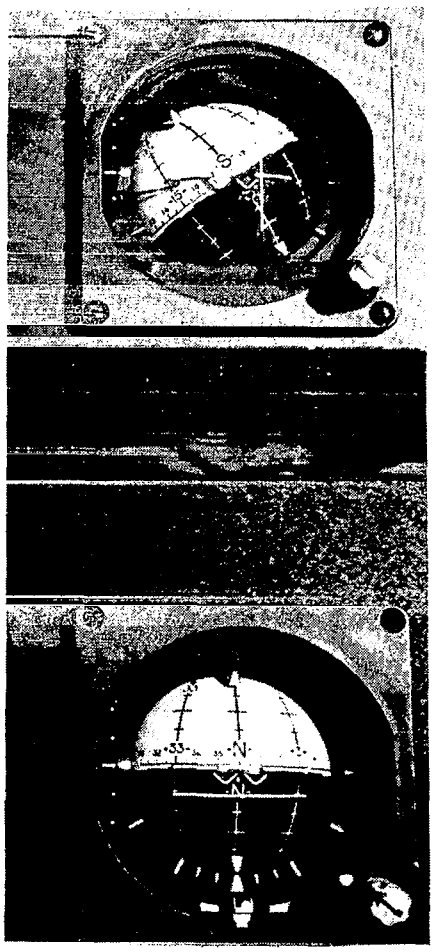


(a) longitudinal system



(b) lateral system

Pilot-model—aircraft system.



Test set-up for measuring effect of pilot scan.

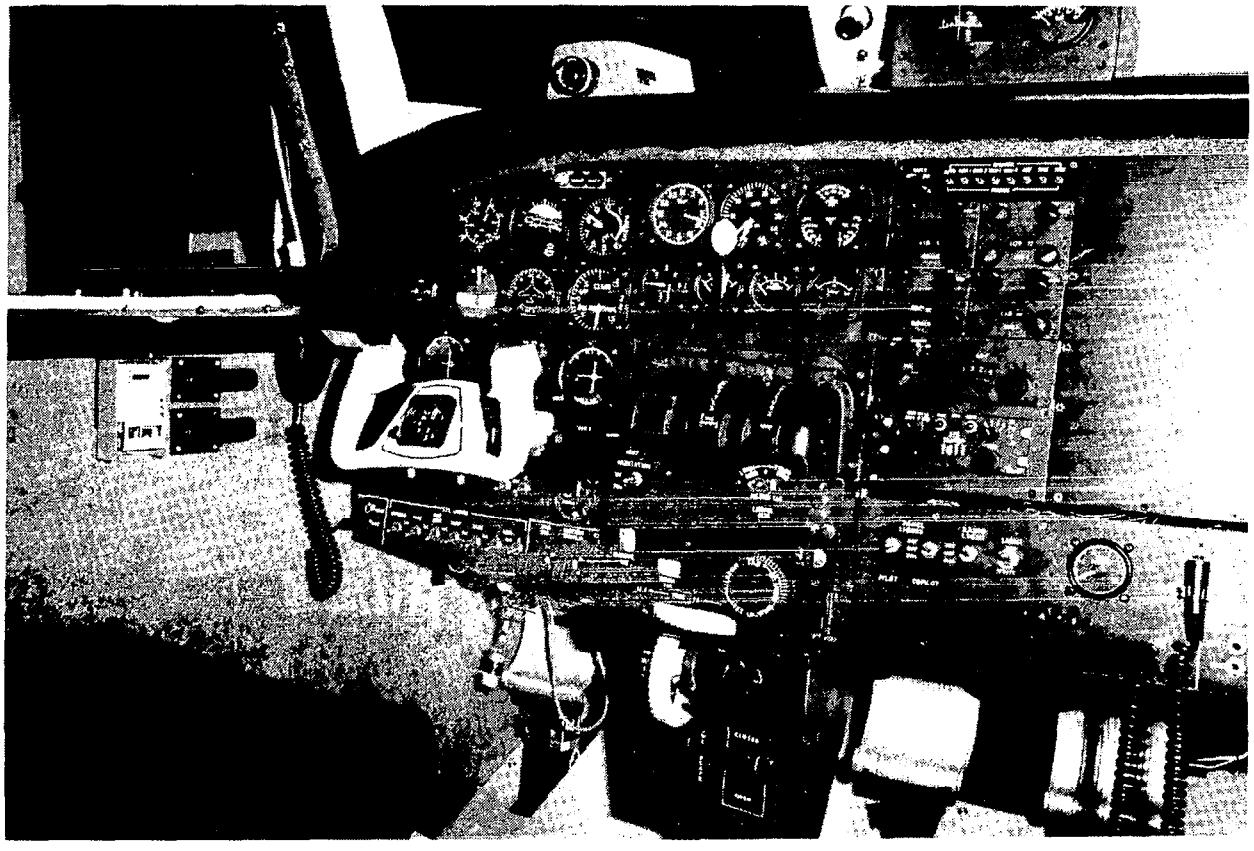
SINGLE PILOT SCANNING BEHAVIOR IN SIMULATED INSTRUMENT FLIGHT

Jack E. Pennington
NASA Langley Research Center

ABSTRACT

A major objective of research in avionics and controls is to reduce the pilot's workload and provide needed information in an optimal manner. This paper presents results from a simulation of general aviation instrument flight tasks in which the pilot's scan pattern and lookpoint were measured along with control inputs and state variables. The objective of the study was to provide a baseline for comparing results from later studies of advanced avionics. Some of scanning parameters measured are described, and conclusions from this and subsequent studies are presented.

This photograph shows the instrument panel in the simulator. The TV camera was mounted above the instrument panel. Shown to the right of the camera is an acoustic sensor which monitored the level of cockpit noise. The IR source and collection point for the oculometer was a small two-axis mirror assembly mounted to the left of the panel.



Three instrument-rated pilots flew the nine flight maneuvers shown below, with three replications. The tasks were chosen to represent those which might occur during parts of a flight, and which taken together could represent a flight profile. Task 9, an ILS approach, was divided into seven consecutive phases for analysis. Pilots flew all tasks manually and made callouts at the beginning of each phase.

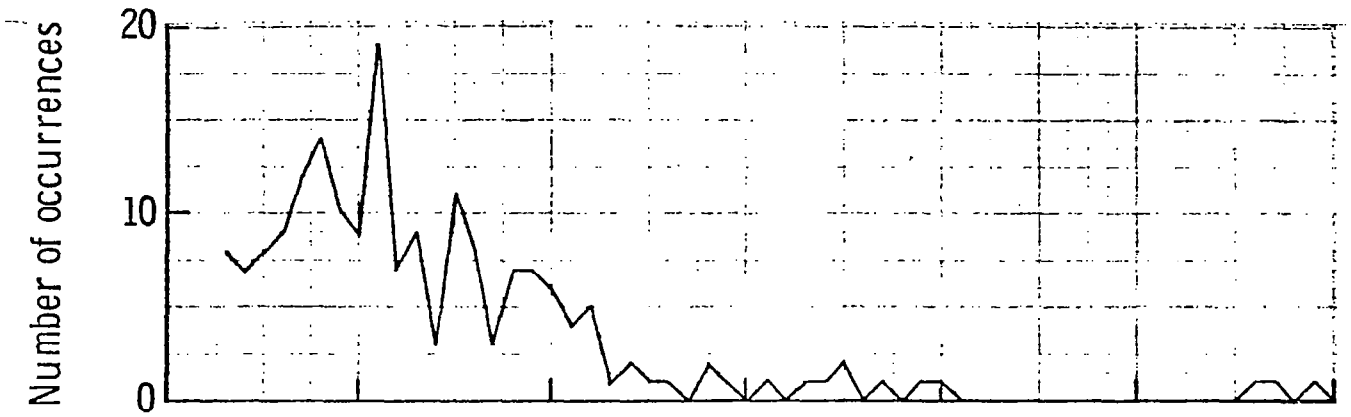
SIMULATED FLIGHT TASKS

RUN	DESCRIPTION
1.	STRAIGHT & LEVEL (1 MINUTE)
2.	CLIMB
3.	CLIMBING TURN
4.	LEVEL TURN
5.	DESCENT
6.	DESCENDING TURN
7.	INTERCEPT AND TRACK VOR
8.	HOLDING PATTERN
9.	INTERCEPT AND TRACK LOCALIZER INTERCEPT & ESTABLISH G.S. TO MM

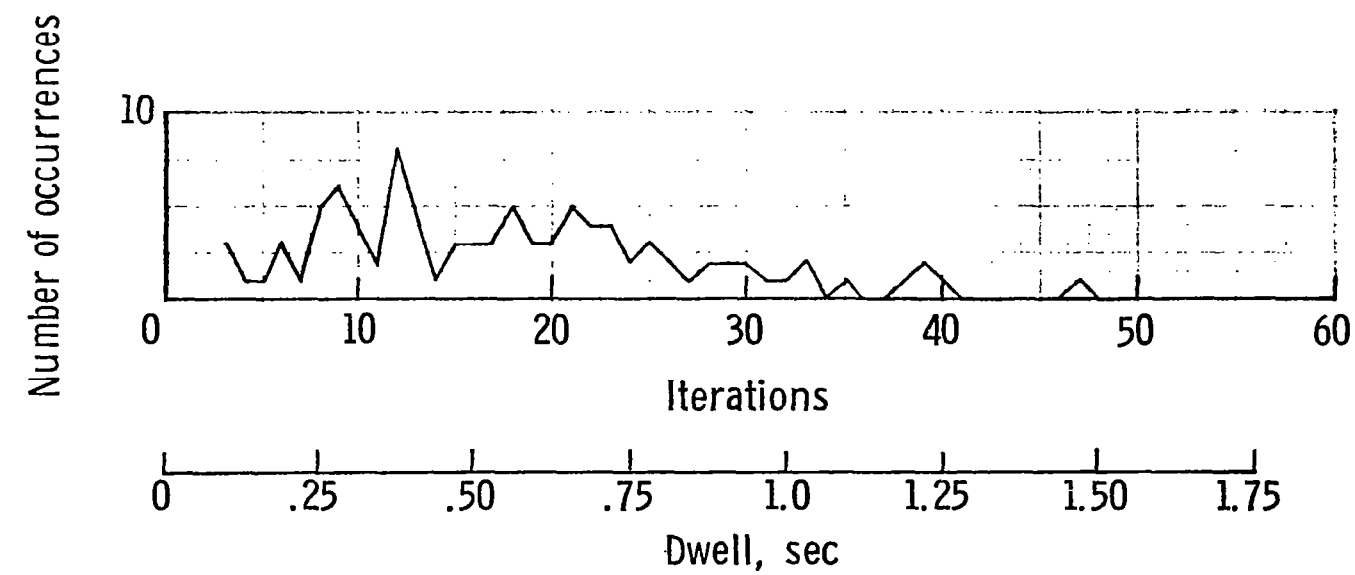
The dwell (fixation) time on each instrument and transitions between instruments were determined. This table shows the percent time on instruments for each of the simulated tasks. A dash signifies that no fixation occurred; a zero indicates that the percent of time on instrument was less than .05 percent.

Cockpit Instrument	Run Number (see previous page)								
	1	2	3	4	5	6	7	8	9
Tachometer	-	-	-	-	-	-	-	-	-
ADF	0	0.1	0.2	0.1	0.1	0	0	0	0.2
Marker Bcn.	0	0	-	2.4	0	0	0.1	0.1	0
Altimeter	10.6	9.4	4.1	6.7	9.2	3.9	8.1	6.1	3.2
Artificial Horizon	58.7	64.3	59.7	62.7	67.0	61.5	63.3	56.5	42.4
Airspeed	1.3	2.8	2.9	1.5	2.9	5.1	1.5	1.7	1.2
IVSI	1.7	2.8	1.3	0.4	2.1	2.5	1.9	1.6	1.2
Dir. Gyro.	25.4	19.7	17.6	11.9	17.9	13.7	18.9	18.9	31.7
Turn & Bank	0.9	0.8	14.0	14.3	0.6	12.8	0.8	4.3	0.5
VOR 1	0.1	0	-	0	0.1	0.3	4.9	4.6	17.0
DME	1.0	0.1	0	0	0.1	-	0.4	0.7	1.1
VOR 2	0.1	0	0.2	0.1	0	-	0.2	5.5	0
Window	-	0	-	-	-	-	-	0	1.6

The data analysis method only counted fixations of three iterations (.1 sec) or longer. This figure shows the distribution of dwell (fixation) time occurrences for the artificial horizon and VOR instrument in the final phases of the simulated approach. Most of the dwell times are .2 - .4 seconds. The artificial horizon, VOR indicator and directional gyro accounted for over 90% of the pilot's visual attention in this task.

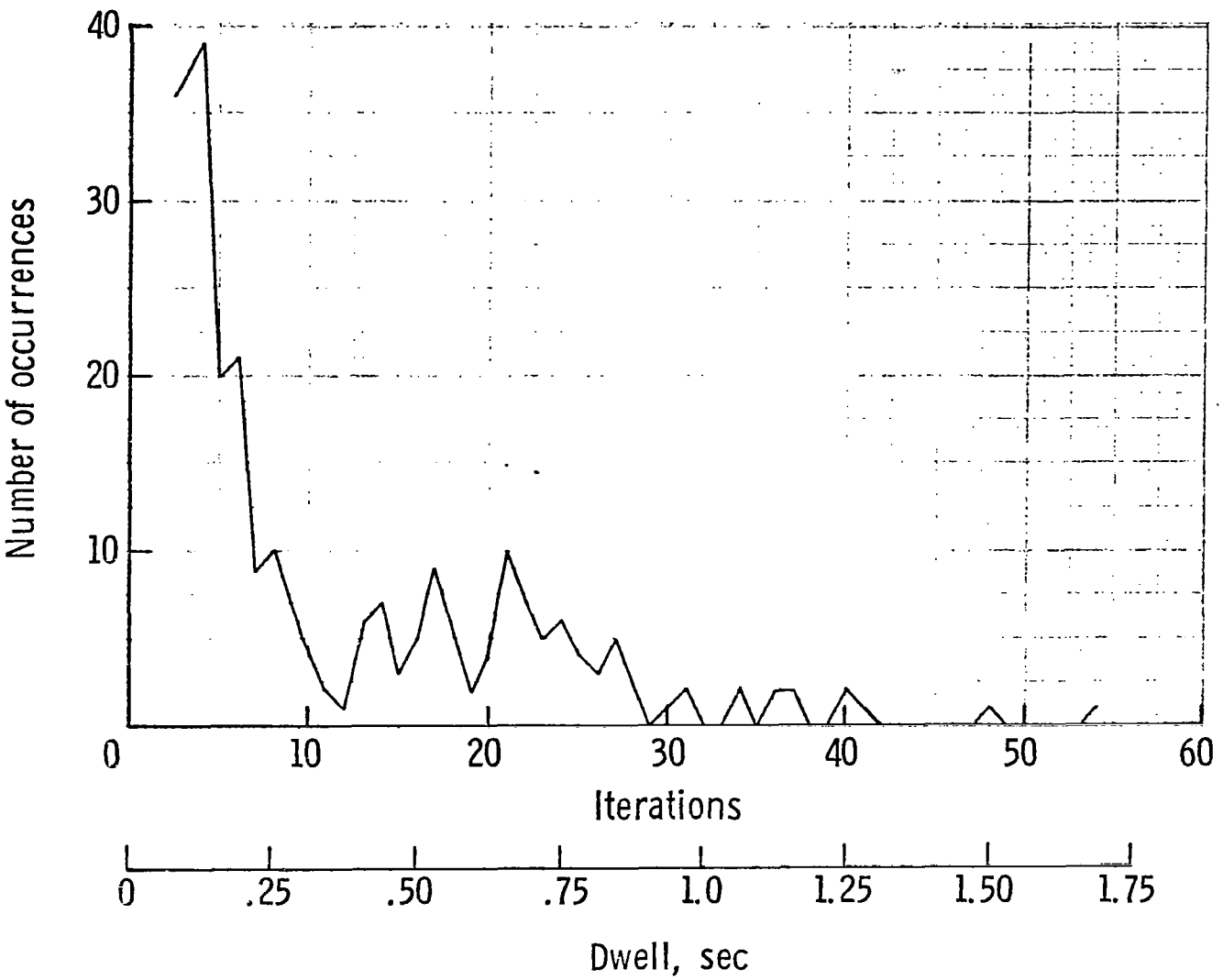


(a) Artificial horizon

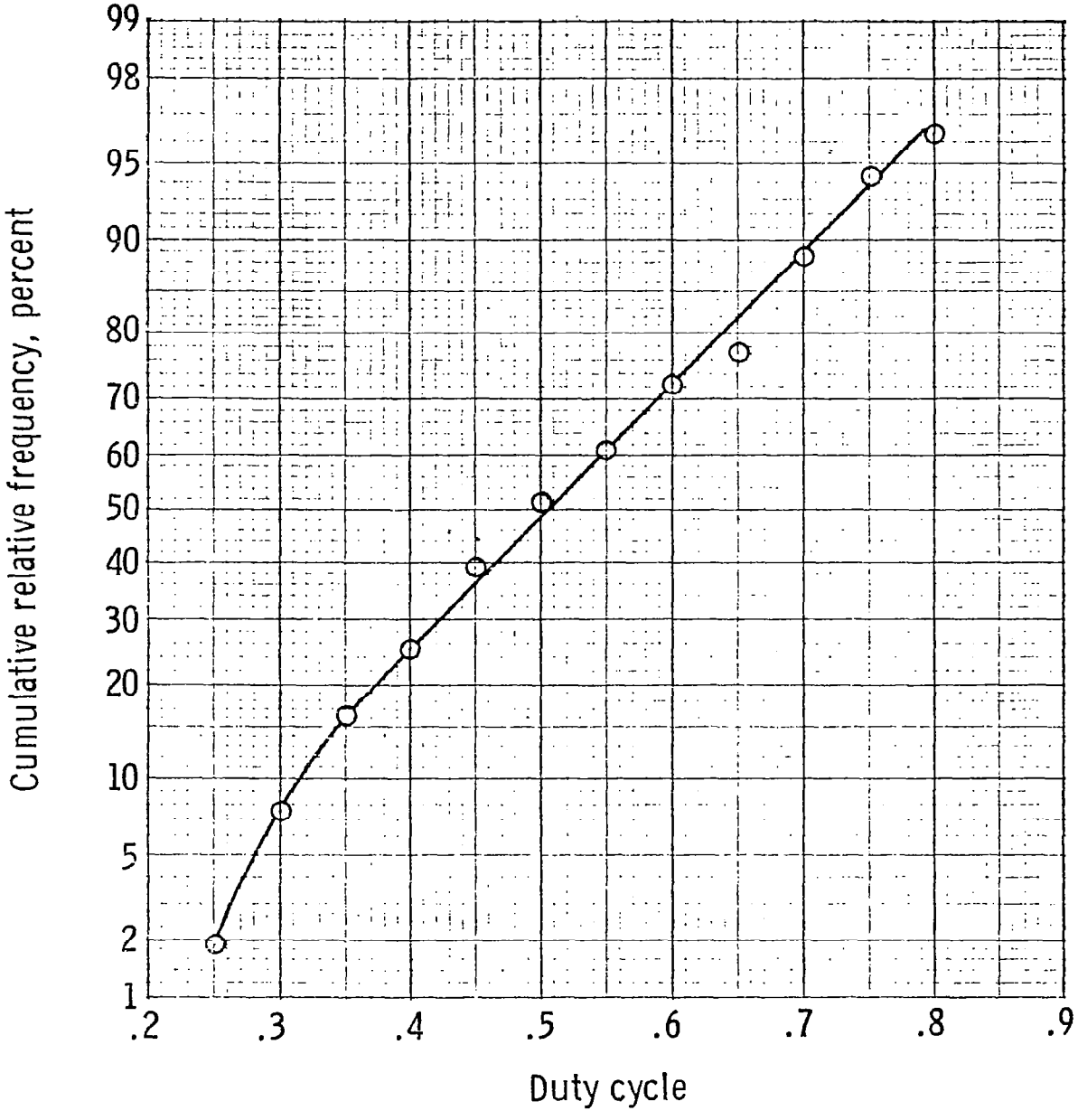


(b) VOR 1

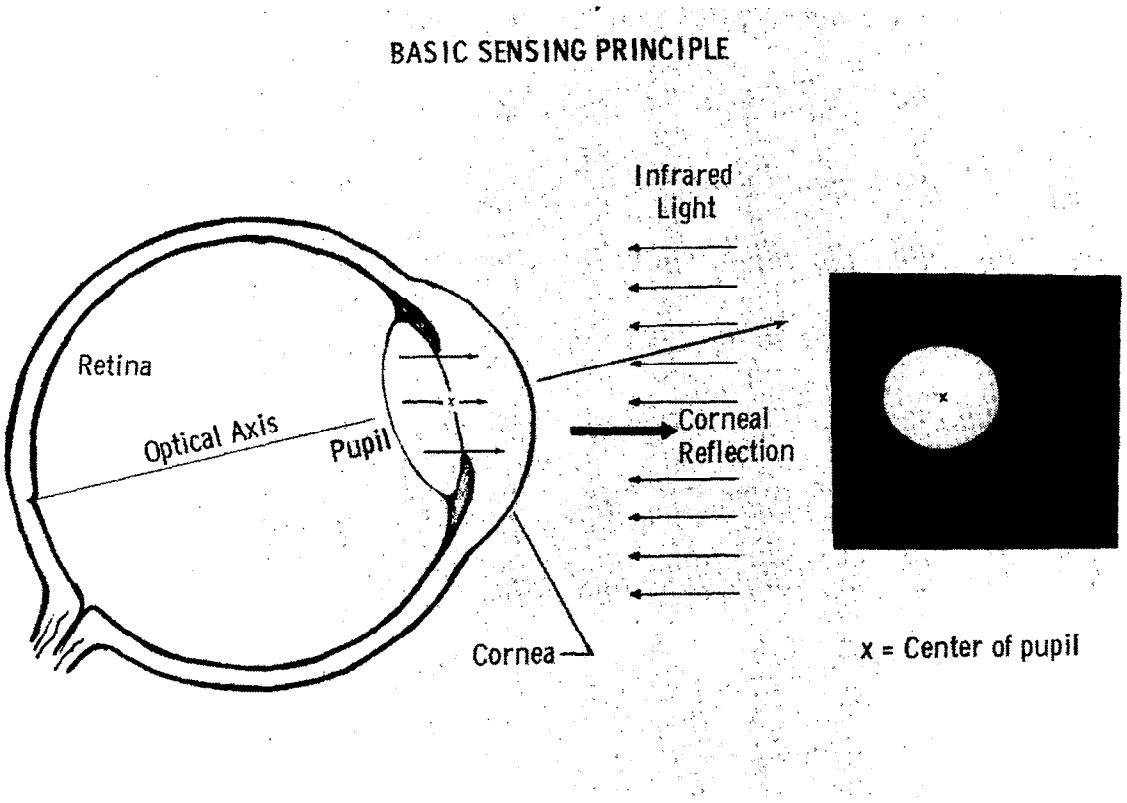
This figure shows the dwell time data for the directional gyro. The large number of very short dwell times (less than .25 sec) may have occurred because the instrument was located directly in front of the pilot, at the center of his scan pattern. The amount of information obtained in such short fixations is uncertain. A second mode appears to occur in the data at .5 - .8 seconds dwell time. This may be more indicative of the time required to assimilate the displayed data.



Another parameter investigated was duty cycle, defined as the dwell time divided by the sum of dwell time plus the time spent looking at other instruments before returning. The duty cycle data for the directional gyro in task 9 was found to resemble a normal distribution when fixations of less than .3 seconds were omitted. The cumulative frequency distribution for the directional gyro data, shown plotted on probability paper, confirms that the data appears to be normally distributed over much of its range. However, chi-square tests of duty cycle data for the artificial horizon and the VOR indicator were not consistent between pilots or tasks.

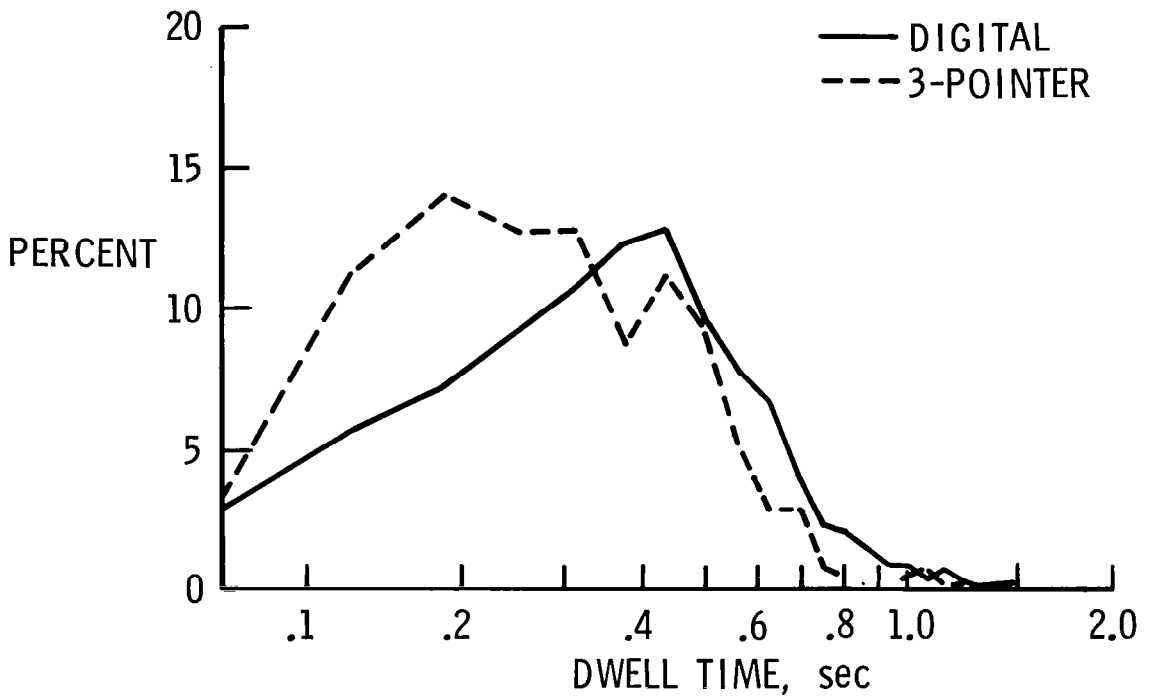


An oculometer was used to determine the pilot's lookpoint. This figure illustrates the basic sensing principle. The oculometer uses a low power infrared source to illuminate the pilot's eye. The high reflectivity of the retina causes an infrared-sensitive TV camera to see a backlighted pupil plus a small bright corneal reflection. A microcomputer processes the TV signal in real time to compute the angle of rotation of the eyeball with respect to the IR beam and the coordinates of the lookpoint on the instrument panel.



The value of visual scanning data in investigating display requirements is illustrated in this figure. In a subsequent study, Harris and Spady (ref. 1, 2) replaced the three-needle altimeter with an altimeter having only a digital read-out, and monitored the visual scanning behavior in a landing approach task. This figure shows the dwell time histograms for the two altimeters. The high percentage of short dwell times suggests that the analog altimeter provided the desired information in a more quickly assimilated form.

ALTIMETER MONITORING DWELL HISTOGRAM



This figure summarizes general findings on scanning behavior based on use of the oculometer in both GA and commercial transport studies. Scanning behavior is one tool in understanding the information needed by the pilot and determining how to present the information efficiently.

GENERAL FINDINGS OF SCANNING BEHAVIOR

- o SCANNING IS A SUBCONSCIOUS CONDITIONED ACTIVITY
  - o PILOTS DON'T KNOW HOW THEY SCAN
  - o CONSCIOUS THOUGHT DISRUPTS SCANNING BEHAVIOR
- o THE CONDITIONED ACTIVITY OF SCANNING IS
  - o DIFFERENT FOR EACH PILOT
  - o AFFECTED BY THE PILOT'S ROLE
  - o SENSITIVE TO THE DESIGN OF INSTRUMENTS
  - o AFFECTED BY DISPLAY-CONTROL SYSTEM COMPATABILITY
  - o MODIFIED WITH EXPERIENCE AND BETTER UNDERSTANDING

REFERENCES

1. Harris, Randall L., Sr.; and Christhilf, David M.: What Do Pilots See in Displays? Presented at the Annual Meeting of the Human Factors Society, Los Angeles, CA, October 13-17, 1980.

2. Spady, Amos A., Jr.; and Harris, Randall L., Sr.: How a Pilot Looks at Altitude. NASA Technical Memorandum 81967, April 1981.

A SIMULATOR EVALUATION OF A RATE-ENHANCED INSTRUMENT LANDING SYSTEM DISPLAY

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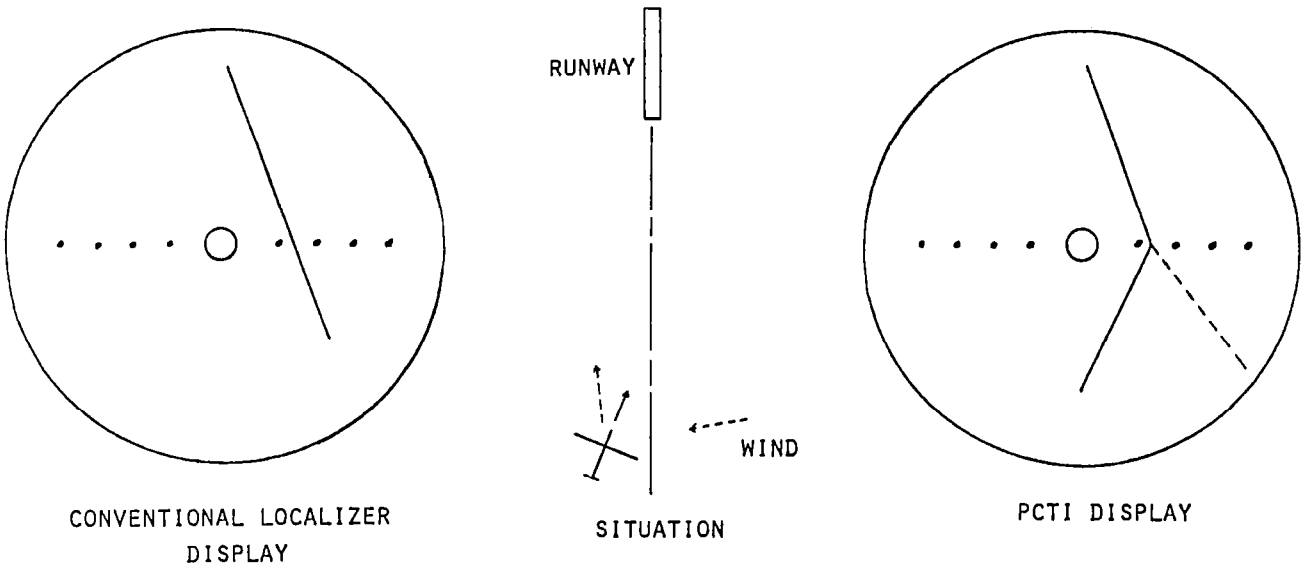
NASA Langley Research Center

ABSTRACT

A piloted simulation study was conducted to evaluate the effect on instrument landing system tracking performance of integrating localizer error rate information with the raw localizer error display. The resulting display was named the pseudo command tracking indicator (PCTI) because it provides an indication of any changes of heading required to track the localizer. Eight instrument-rated pilots each flew five instrument approaches with the PCTI and five instrument approaches with a conventional course deviation indicator. The results show good overall pilot acceptance of the PCTI and a significant reduction in localizer tracking error.

PSEUDO COMMAND TRACKING INDICATOR (PCTI)

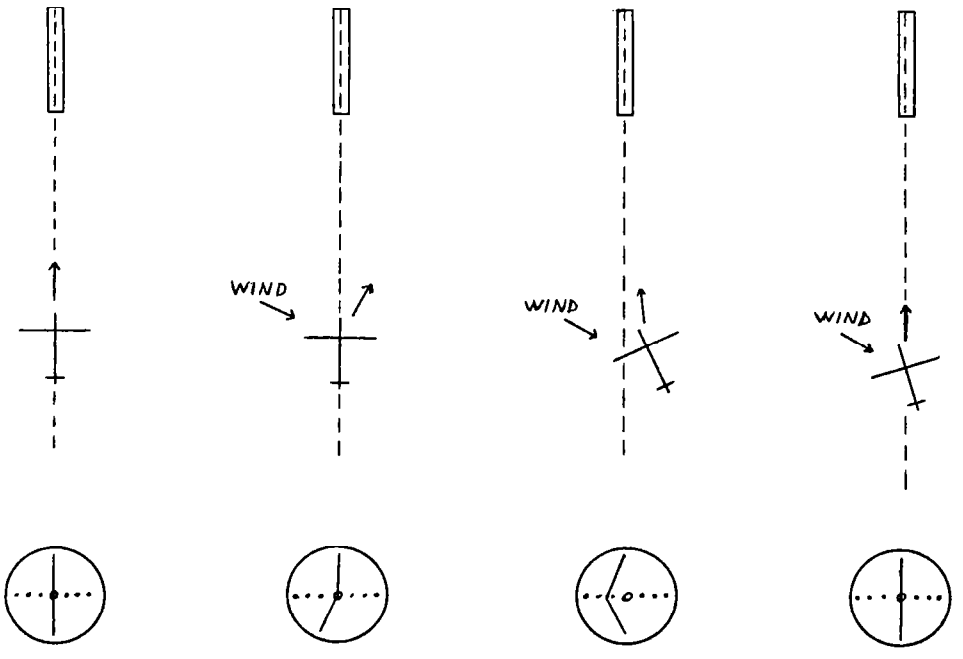
This figure compares the PCTI presentation and the conventional CDI presentation for two different flight situations. The PCTI consists of two needles joined at the horizontal centerline of the instrument. The upper needle presents the same raw localizer error information as is presented on the conventional display. The lower needle pivots from the upper needle and indicates localizer error rate. The PCTI in this figure depicts two situations. The airplane between the two displays is to the left of centerline and with no wind is returning to centerline (see solid flight path arrow). With a wind (see dashed wind vector arrow) the airplane is tracking away from centerline (dashed flight path arrow). The solid localizer error rate needle depicts the first situation. If the pilot turns the airplane to keep the tip of the rate needle centered, the result will be an asymptotic return to the centerline. The second situation is depicted by the dashed rate needle. The rate needle is deflected more than the localizer needle, indicating increasing error. If the localizer error rate were zero, then the two needles would form a straight line.



- DISPLAY LOCALIZER ERROR RATE ALONG WITH LOCALIZER ERROR
- PROVIDE TURN COMMANDS BY INTEGRATING THE TWO INDICATIONS
- "ON COURSE" INDICATION IS INDEPENDENT OF RUNWAY HEADING OR WIND CONDITION
- PROVIDES PILOT WITH LEAD INFORMATION

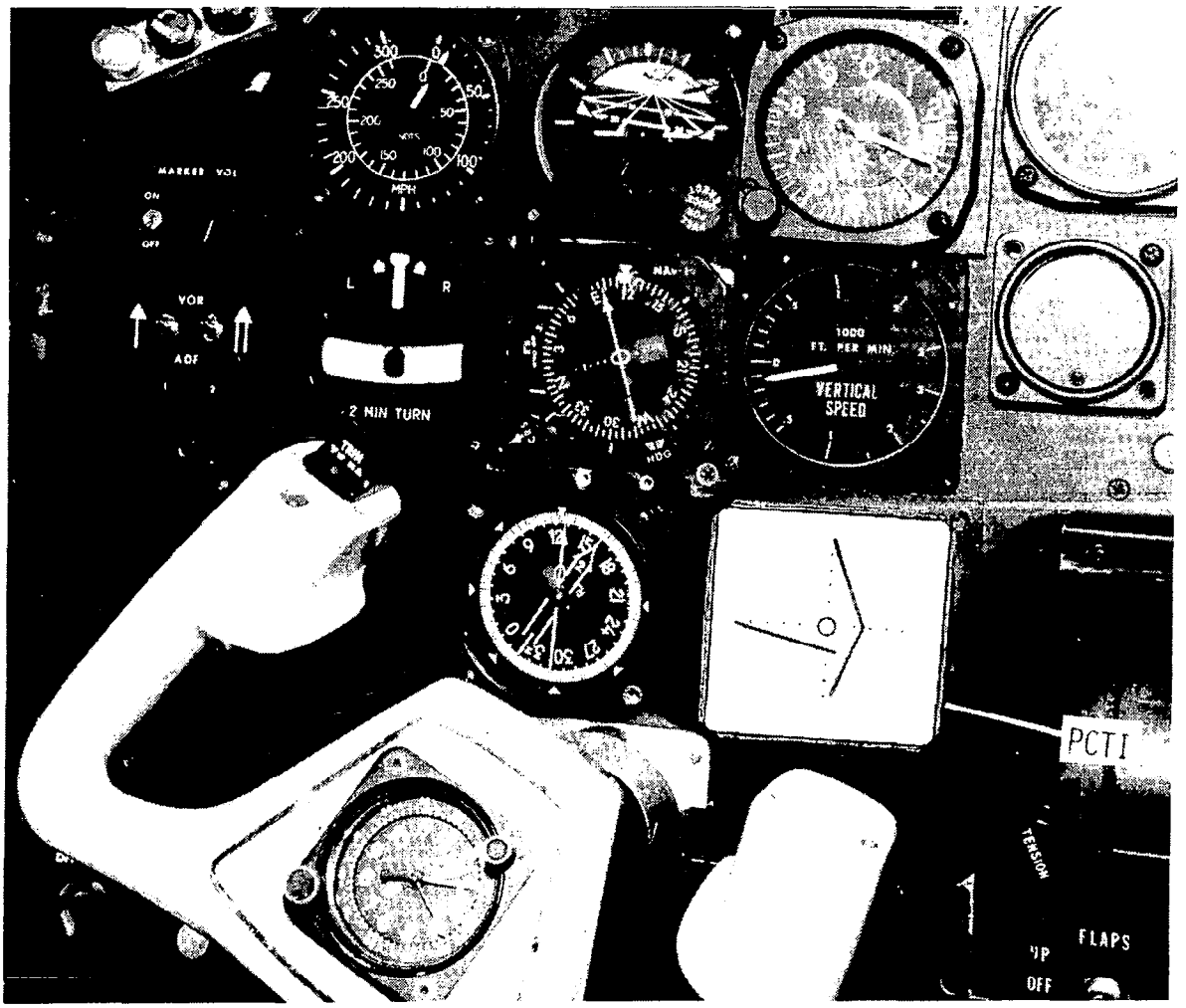
PCTI IN FOUR SITUATIONS

The diagram below shows an airplane in four situations and the corresponding PCTI displays. In the left-most figure the airplane is stabilized on the localizer centerline. Both needles of the PCTI are centered. In the next figure the airplane has begun to drift off centerline because of a wind. The localizer needle is still centered but the rate needle is deflected to the left, telling the pilot to turn to the left. The third figure shows the airplane to the right of the centerline on a flight path returning to the centerline. The localizer needle is deflected to the left and the rate needle is deflected back towards the center to indicate decreasing error. In the final figure the airplane is stabilized on centerline with a heading that compensates for the wind. Both PCTI needles are centered.



DISPLAY IMPLEMENTATION

The PCTI display was implemented in the NASA LaRC General Aviation (GA) Simulator. A 5-inch diagonal monochromatic CRT displayed the PCTI and CDI presentations. The CRT was located immediately to the right of the primary flight instruments in a typical GA instrument panel CDI location. The CRT presentation was chosen for the speed and ease of display implementation and does not imply that a CRT is necessary for a PCTI. Switching between CDI and PCTI presentation was accomplished by driving both needles as one needle with localizer error information when the CDI was desired. A conventional glideslope needle was also drawn on the CRT for the study.



TEST SUBJECTS AND DATA RUNS

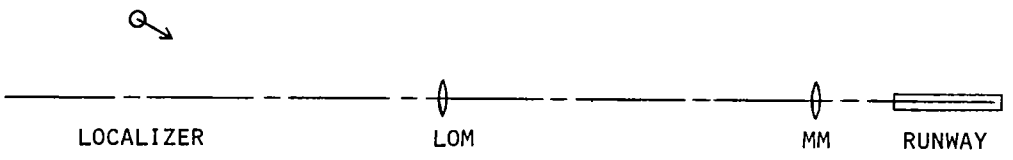
Data were collected from eight pilots. All of the pilots were instrument rated and their experience ranged from 250 hours to 6000 hours. Each of the pilots was given an explanation of the display and simulation task and was required to fly four practice approaches. More practice was allowed if requested.

Each pilot flew five data runs with the PCTI and five data runs with a conventional CDI. Since the run conditions were identical for each run, the runs were alternated between the CDI and PCTI to minimize learning effects.

- EIGHT SUBJECTS, ALL INSTRUMENT RATED, HOURS RANGE FROM 250 TO 6000
- EACH PILOT WAS GIVEN AN EXPLANATION OF DISPLAY AND RUN CONDITIONS AND FOUR PRACTICE RUNS
- DATA RUNS ALTERNATED BETWEEN CONVENTIONAL DISPLAY AND PCTI, FIVE RUNS WITH EACH DISPLAY PER PILOT

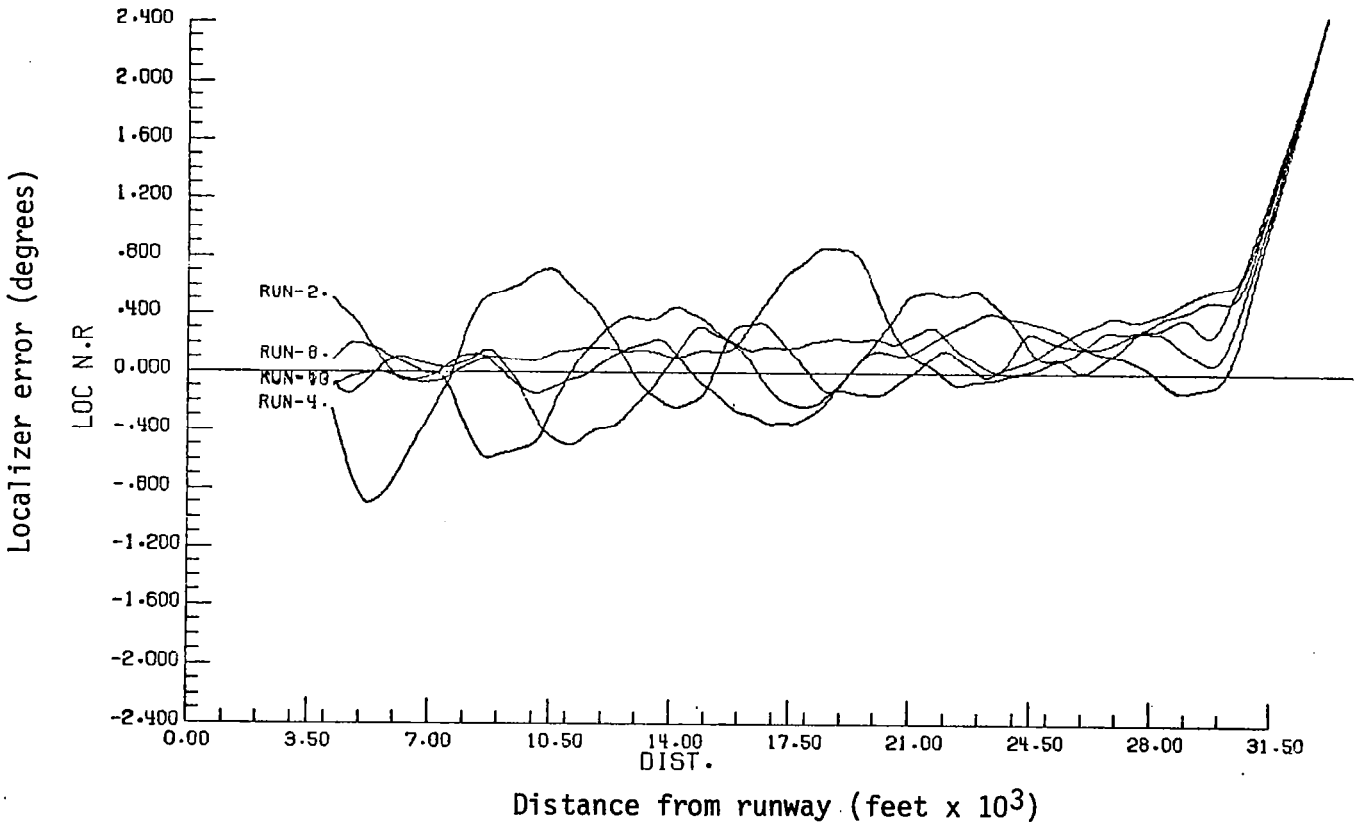
RUN CONDITIONS

Each data run began with the airplane 0.3 nautical miles left of the localizer centerline about 5.3 miles from the runway on a 30° intercept heading to the localizer as indicated by the circle and arrow in this figure. This situation resulted in a localizer intercept prior to reaching the outer marker or glideslope intercept. Identical weather conditions were used for each data run. At the initial altitude of 1000 feet above ground level a 24 knot wind from 12° right of localizer course was present. At the surface a 12 knot wind from 36° left of localizer course was present. Linear interpolation for both wind speed and direction was used at other altitudes. This provided a constantly changing wind as the airplane descended on the glideslope. Light turbulence was also present during each data run. Data runs were terminated with an automatic reset just prior to reaching decision height at the middle marker.



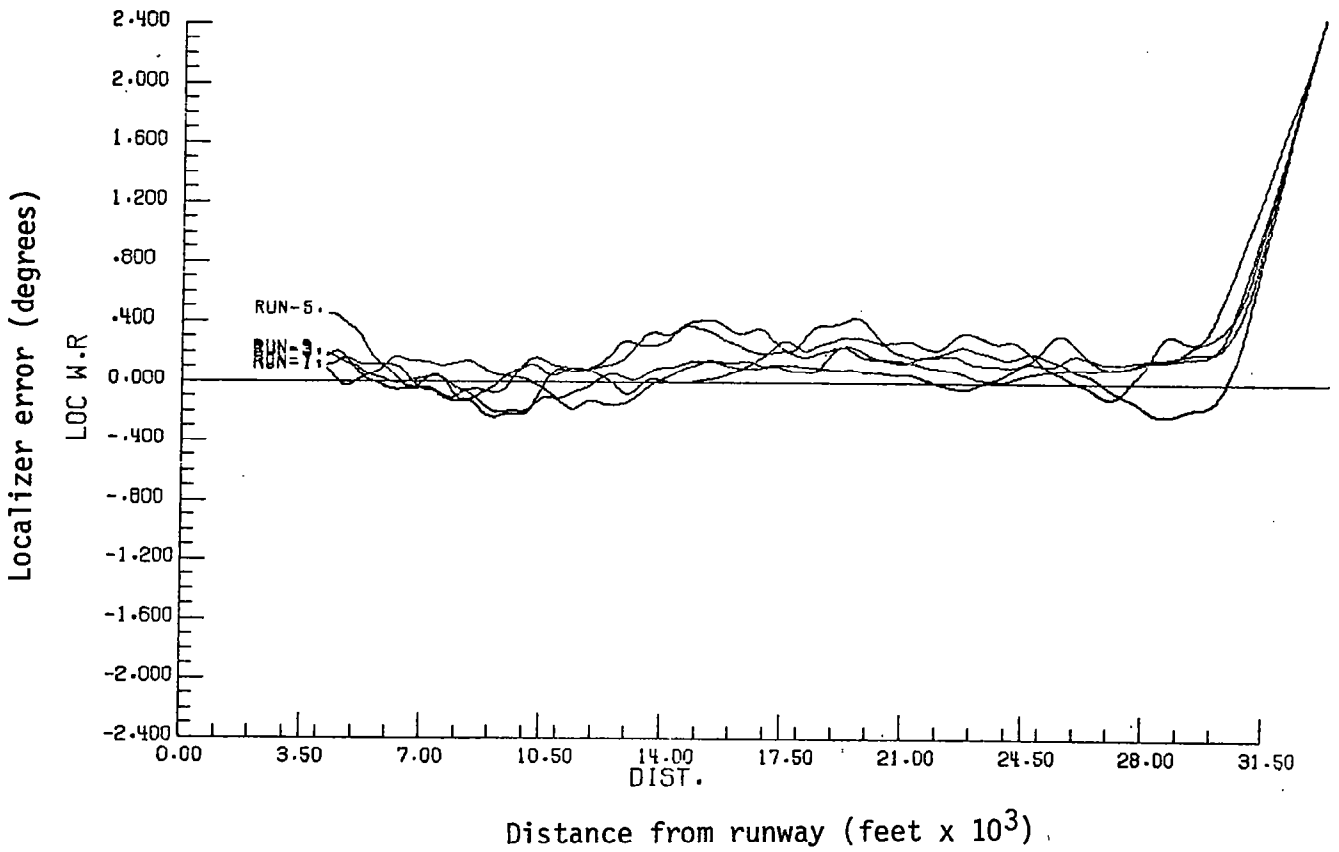
DATA RUN PLOT, CDI

This plot shows angular localizer error versus distance from the runway for all five CDI runs for one of the subject pilots. Localizer error in degrees is presented on the ordinate and distance from runway in thousands of feet is on the abscissa. Each run began with the airplane to the left of the localizer about 5.3 nautical miles from the runway (top right of plot). The airplane then intercepts the localizer about 5 miles from the runway and tracks inbound until an automatic reset occurs at a range of about 4000 feet. This plot is typical of each subject pilot.



DATA RUN PLOT, PCTI

This plot shows the five PCTI runs for the same pilot that flew the CDI runs in the previous plot. Higher system frequencies and smaller localizer errors are observed with the PCTI.



PILOT COMMENTS

Pilot comments indicate that the PCTI was easy to interpret and provided more useful information than the conventional CDI. In particular, the PCTI provided lead information on the localizer and solved the problem of finding the correct heading to compensate for wind. The pilots were less concerned with localizer error using the PCTI since keeping the rate needle centered automatically kept the localizer error near zero. When errors did develop, the pilots would bank the airplane into a turn until the localizer rate indicated a return to centerline. When the localizer error zeroed, the pilots would turn the airplane to zero the localizer error rate. Very little use of the directional gyro was reported by the pilots. The reduced scanning tended to lower reported pilot workload while the higher system frequencies tended to increase workload. The result was that reported workloads with the PCTI and the CDI were about the same.

- ABOUT THE SAME WORKLOAD, PCTI MEANS LESS SCANNING BUT TIGHTER CONTROL
- LESS LATERAL WORKLOAD AND MORE TIME FOR GLIDESLOPE
- PCTI EASY TO INTERPRET
- USED BANK ANGLE TO SET RATE NEEDLE IN GOOD POSITION THEN ROLL LEVEL AND WAIT FOR LOCALIZER TO CENTER, VERY LITTLE D.G. USE
- LESS CONCERNED WITH LOCALIZER, JUST KEEP RATE NEEDLE CENTERED
- IGNORE RATE DURING LARGE CORRECTIONS AND USE IT TO STAY ON LOCALIZER ONCE THERE
- SOLVED PROBLEM OF FINDING THE CORRECT HEADING
- PROVIDES LEAD INFORMATION ON LOCALIZER

CONCLUSIONS

The pseudo command tracking indicator (PCTI) was designed to aid pilots during ILS approaches. The PCTI display was evaluated in the General Aviation Simulator using eight instrument-rated pilots. The results showed a 42 percent reduction in localizer mean RMS error with the PCTI when compared with a conventional CDI display. The PCTI display aided the pilot in compensating for wind drift and in correcting for wind- and turbulence-induced deviations from centerline. No significant changes in pilot workload or glideslope RMS errors were noted.

- PCTI DISPLAY DESIGNED TO AID PILOT DURING ILS APPROACH
- DISPLAY EVALUATED IN GA SIMULATOR WITH EIGHT SUBJECT PILOTS
- FORTY-TWO PERCENT REDUCTION IN LOCALIZER MEAN RMS ERROR
- NONSIGNIFICANT CHANGES IN GLIDESLOPE TRACKING OR PILOT WORKLOAD
- KEEPING THE RATE NEEDLE CENTERED WILL AUTOMATICALLY KEEP THE LOCALIZER NEEDLE CENTERED
- SOLVES PROBLEM OF FINDING THE CORRECT HEADING IN WINDS

DISPLAY RESEARCH - PILOT RESPONSE WITH THE "FOLLOW-ME" BOX DISPLAY

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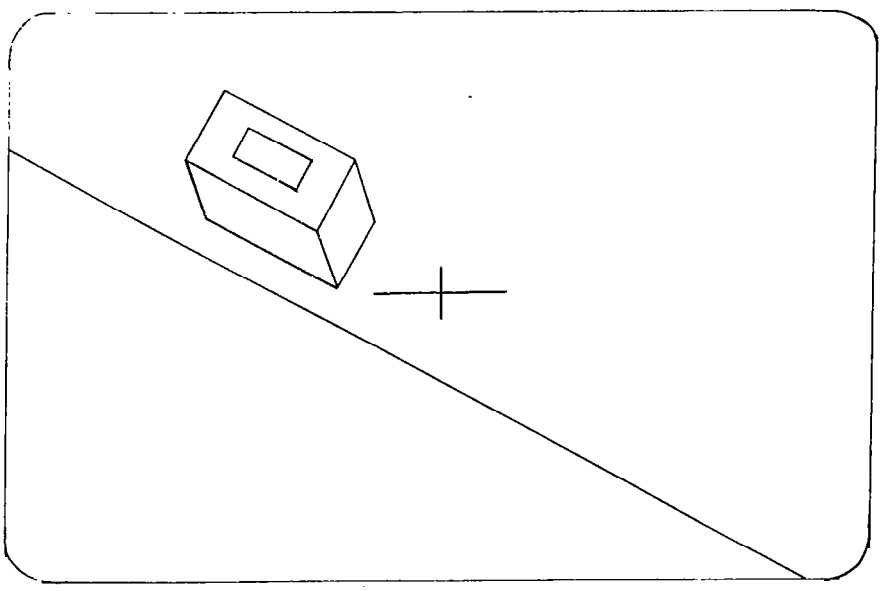
NASA Langley Research Center

Abstract

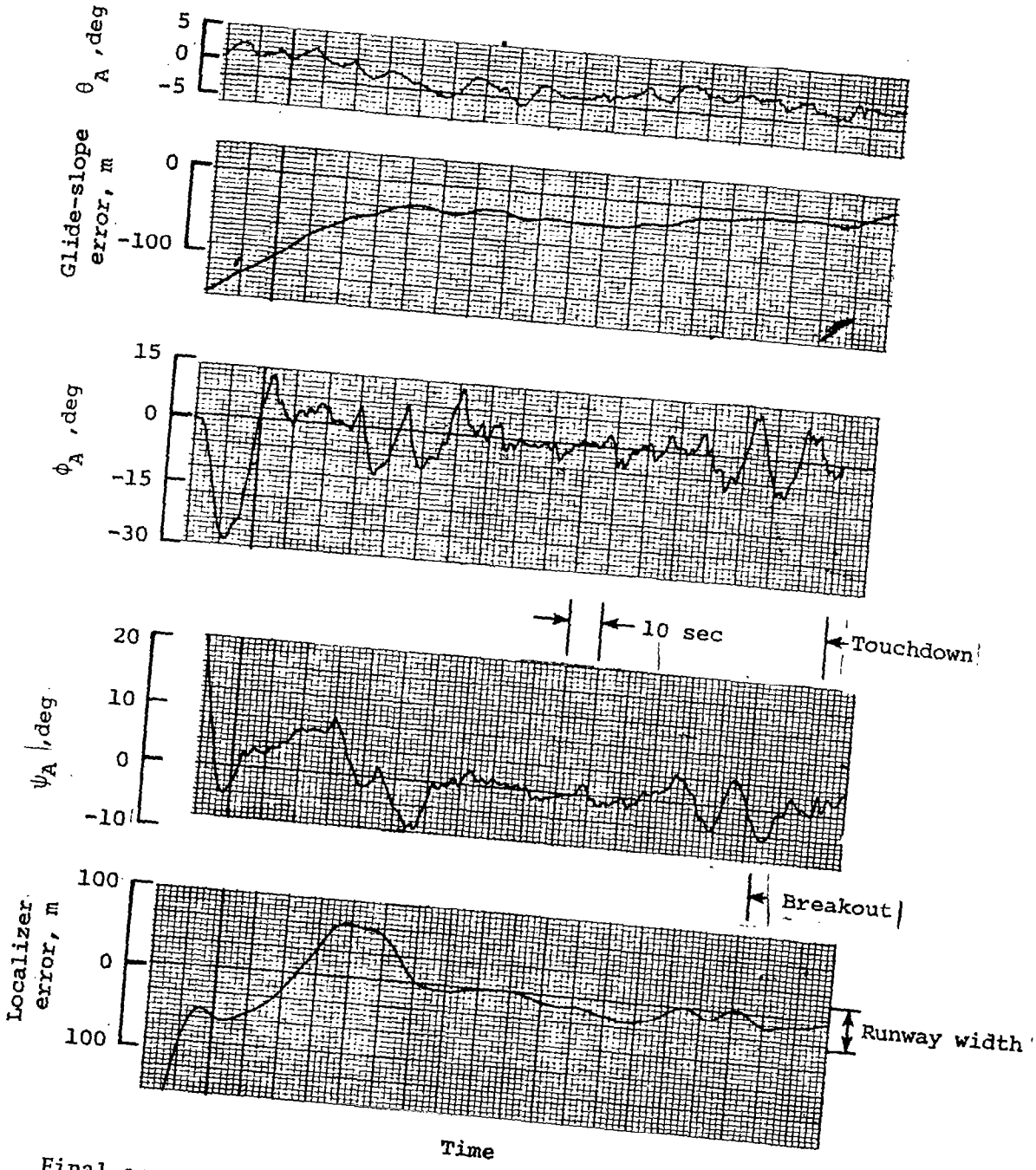
As a part of the Single Pilot Instrument Flight Rule program at Langley Research Center, a study of display configurations and their effect on pilot-aircraft system response has been undertaken. This investigation includes an examination of conventional displays to provide a set of data that can be used for comparison with advanced displays. The study also encompasses the examination of an advanced display design that includes the use of a digital computer and a cathode ray tube to provide a drawing of a three-dimensional box. The results of these studies, which show the improvement in system performance that can be obtained with the advanced display, will be presented. For the most part, these studies were conducted using the General Aviation Simulator, but verification of the results with the advanced display was also obtained from flight tests.

The "follow me" box display, shown in the first figure, combines all of the attitude, displacement and flight director information required to control the aircraft to a designated line in one symbol. As a result of this integration of information, a very high pilot-aircraft-display system frequency can be obtained. To illustrate the factors involved, consider the approach made using a conventional Horizontal Situation Indicator shown in the second figure. This time history shows the long periods obtained with the conventional display, and the loss of system damping that occurs when the aircraft is close to touch-down. These characteristics are depicted further in the third figure, which shows the system lateral frequency and damping both for conventional displays and for the box display. The system frequencies are quite low with the conventional displays, but are very high with the box display. The superior landing approaches that can be obtained with the box display are shown in the next three figures, which provide a comparison of results obtained with the box display and conventional displays.

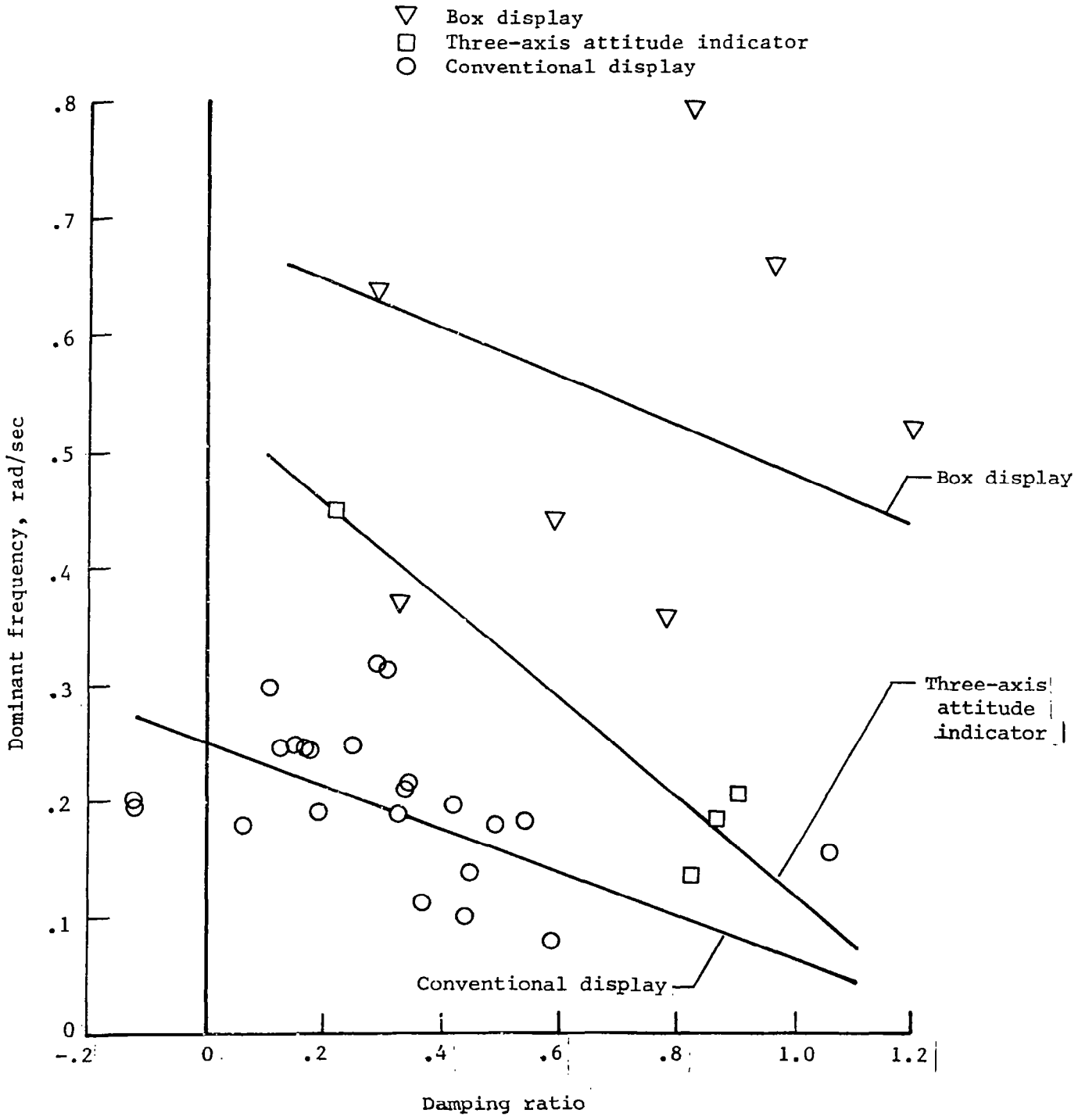
The ground tracks shown on the last figure illustrate other features that can be obtained with the box display. These are the enroute system response that is obtained with low pilot workload, the complex guidance in the terminal area, the short, curved, descending, precisely controlled final approach that can be obtained when the box display is combined with an MLS landing system, the go-around guidance, and the unique holding pattern guidance. These guidance features were obtained with the use of two boxes (so that the pilot could go from one to the next), a change in display sensitivity (by a factor of 20) between the enroute segment and the final approach, and, in addition to the sliding boxes, the use of stationary boxes at certain waypoints.



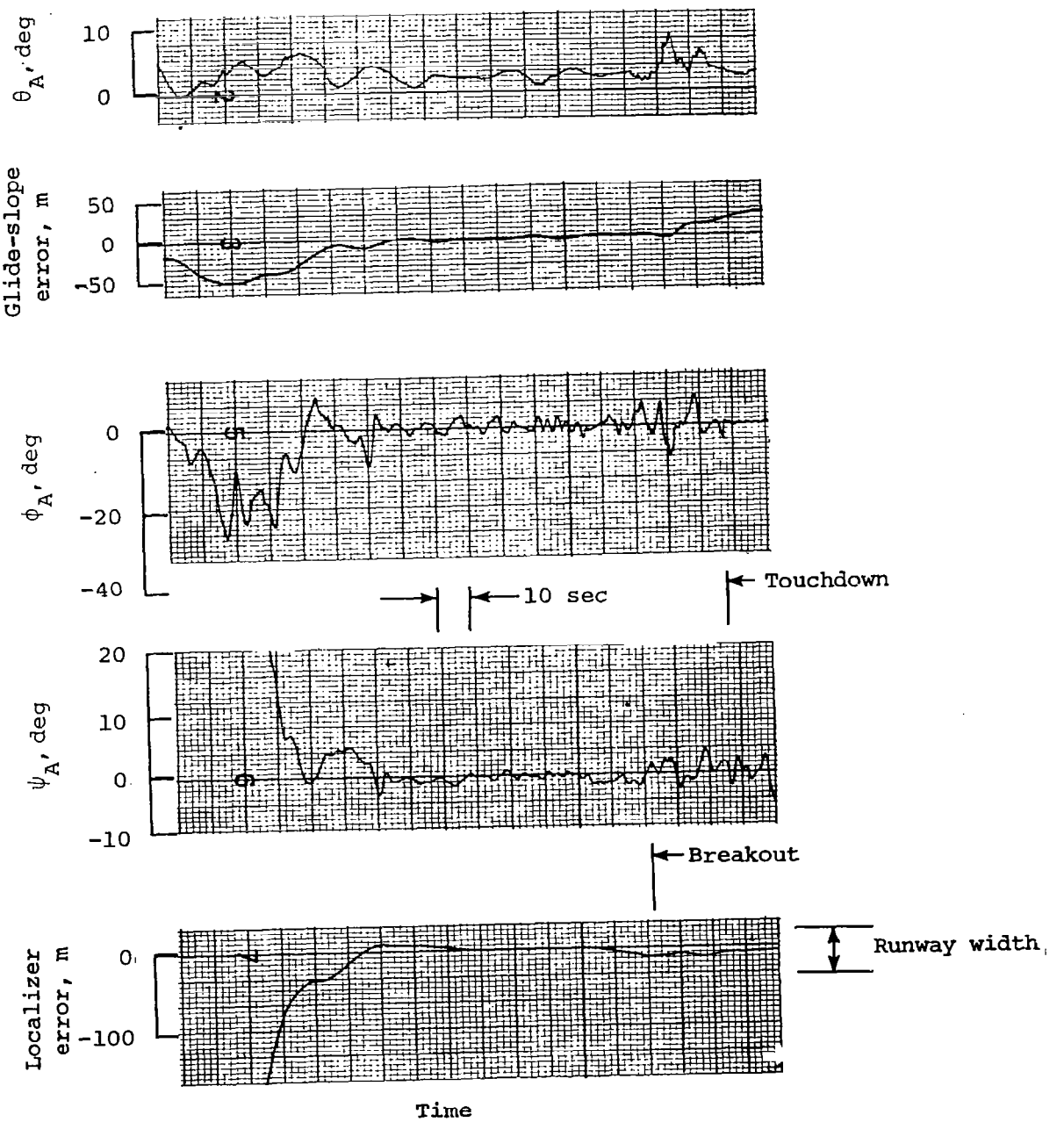
"Follow me" box display. The aircraft is below and to the right of the desired path, and is climbing and banked to the left so as to get behind the box.



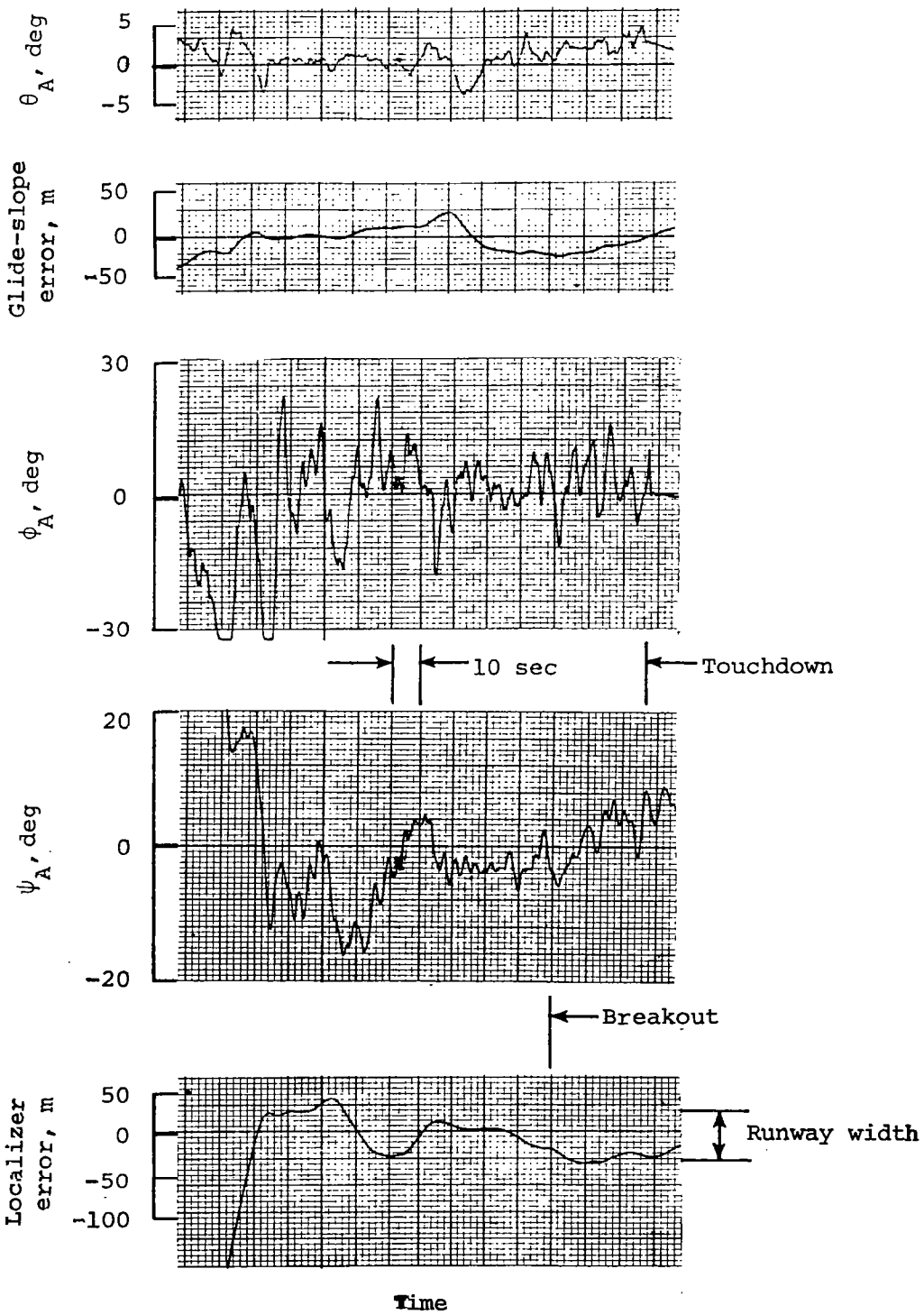
Final approach using conventional Horizontal Situation Indicator by subject 8; no winds.



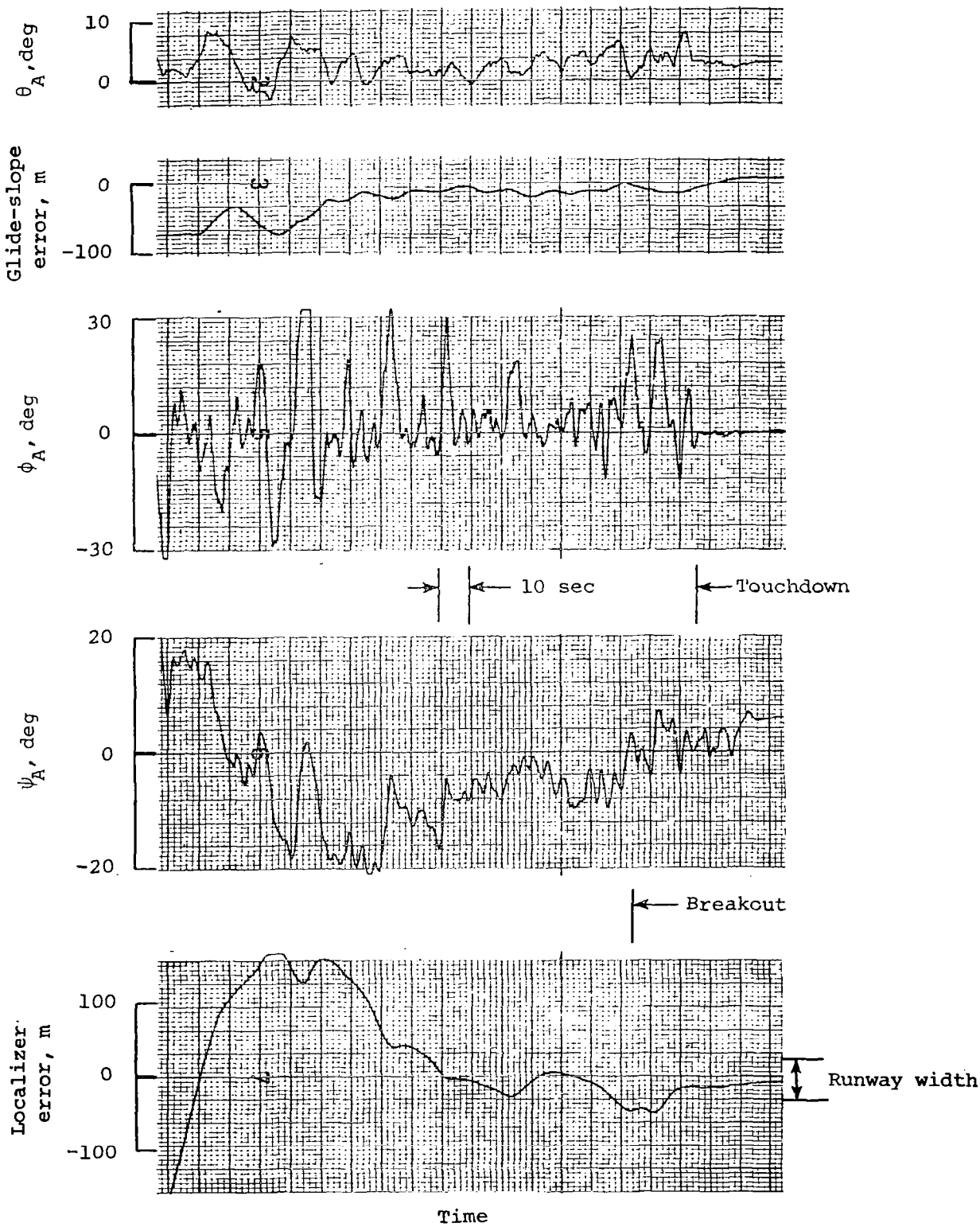
Dominant frequency and damping ratio of pilot-aircraft-instrument system.



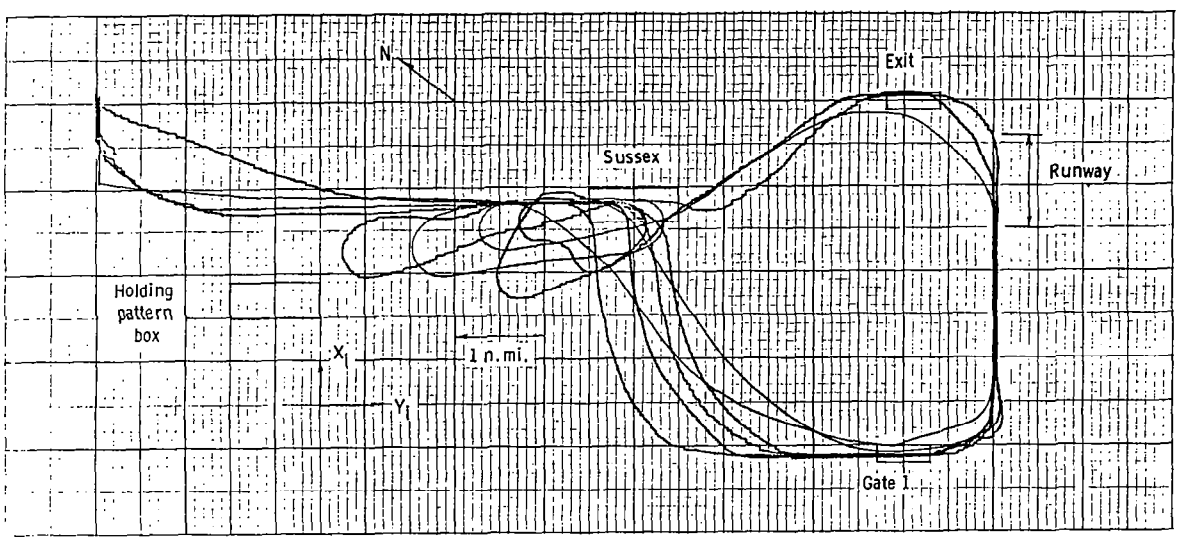
Final approach using box display by subject 4; no winds.



Final approach using box display by subject 4; thunderstorm wind shear condition.



Final approach using conventional Horizontal Situation Indicator by subject 4; thunderstorm wind shear condition.



Ground tracks of complete flight for three subjects.

CONTROL/DISPLAY TRADE-OFF STUDY FOR SINGLE-PILOT INSTRUMENT FLIGHT RULE OPERATIONS

Roger Hoh
Systems Technology, Inc.
Milco International

CONTROL DISPLAY TRADE-OFF STUDY FOR SINGLE PILOT IFR OPERATIONS

Objectives

- Determine minimum autopilot functions and displays required to keep pilot workload at an acceptable level
- Determine what constitutes an acceptable level of workload
- Identify critical tasks
- Suggest specific experiments required to refine conclusions

Examples of critical tasks are: revised clearances in terminal area, transition from cruise to terminal area, last minute holding clearances, requirements to read charts and tune radios in turbulence or under poor lightning conditions.

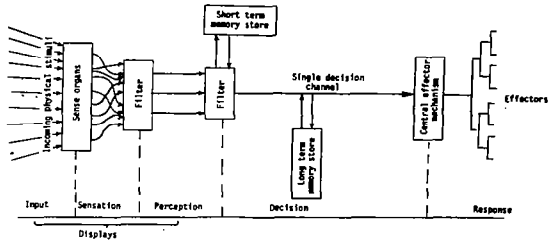
Specific experiments are discussed in more detail later in this presentation.

KEY ELEMENTS OF SPIFR PILOT WORKLOAD

- Mental Orientation
- Instrument Scan
- Mental Distractions
  - Malfunctioning Equipment
  - Weather (Clouds, Turb, Ice)
  - Communications

The key elements of SPIFR pilot workload are listed above. Later experimental work has revealed that the pilot interface with the controls and displays should be included in this list.

KEY ELEMENTS OF HUMAN INFORMATION PROCESSING



- Human operator can attend to only one thing at a time
- Simultaneous inputs held in short term memory
- Scanning behavior is guided by long term memory

A model is required to provide the basis for a systematic analysis of the single pilot IFR workload problem. The above model was used as a starting point (ref. 1). Examples of incoming physical stimuli are:

- Avionics and autopilot control settings
- Instrument readings
- Clearances from ATC
- Weather data
- Navigation information
  - Approach plates, enroute charts, STARs, SIDS
- Turbulence
- Malfunctions

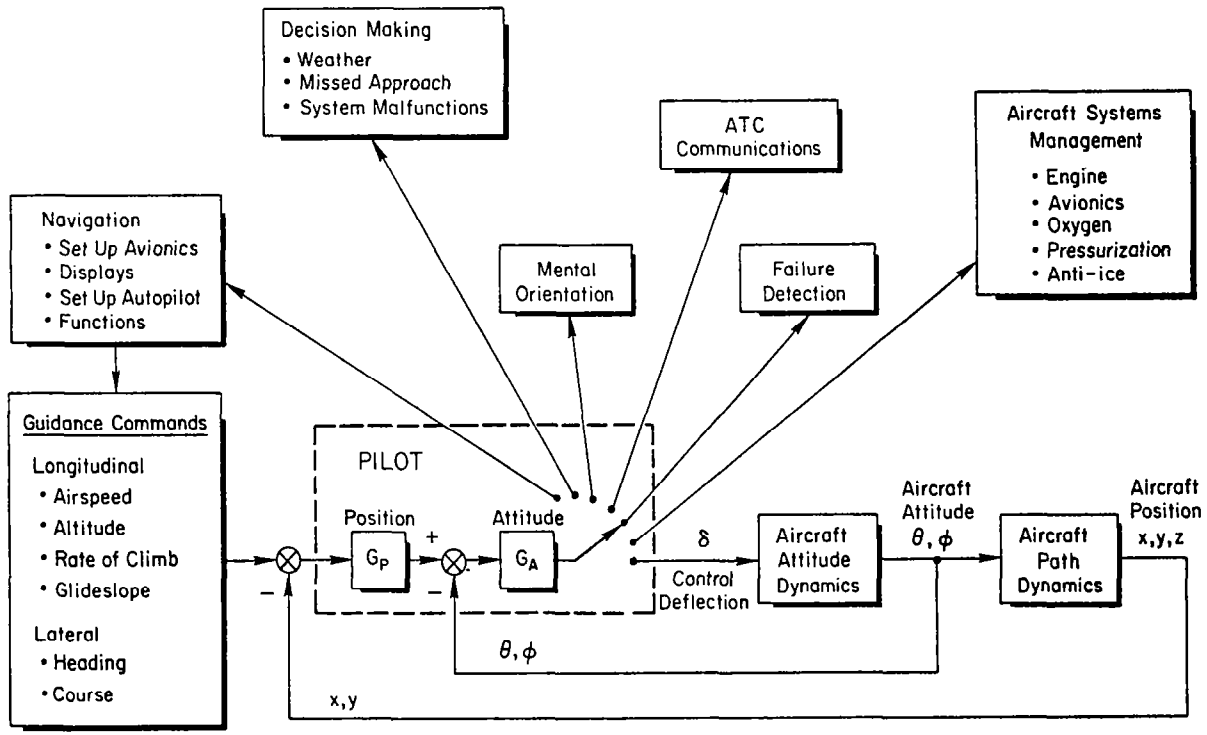
The following observations can be made about short term memory

- It is prone to errors which arise as a result of false hypotheses.
- All but one piece of incoming data (physical stimuli) are stored in short term memory. Note that the data is "filtered" by the human operator to delete useless information.
- Much of the data in short term memory is wiped out if an overridingly important piece of information is received.
- One objective of the displays and controls should be to reduce the requirements on short term memory.

The following observations can be made about the long term memory.

- It sets priorities on which items in short term memory get acted upon.
- It sets the scanning behavior.
- Its efficiency is strongly associated with IFR proficiency.

PILOT WORKLOAD MODEL FOR SPIFR OPERATION



This SPIFR pilot model was developed using the basic concepts of the more general model on the previous slide. Of particular importance is the fundamental concept that a human operator can only process one item of information at a time. The resulting "switching behavior" in the model is presumed to be guided by long term memory. Efficiency of the long term memory is a function of training and recent proficiency.

PILOT WORKLOAD RATINGS FOR TRANSITION FROM ENROUTE CRUISE TO FINAL APPROACH FIX IN HIGH DENSITY TERMINAL AREA

	Partial Panel	Attitude and Heading	Flight Director	Moving Map Display	Integrated Data Control Center
Basic Stability Augmentation	4	3	3	3	3
Wing Leveler	4	2½	2½	2	2
Heading Hold	3	2	2	1½	1½
Course Tracking	3	1½	1½	1½	1½
Altitude Hold	3	1½	1½	1	1
Airspeed Hold	3	1½	1½	1	1

Workload Ratings

1. Satisfactory
2. Acceptable
3. Tolerable Without Failures
4. Emergency Only

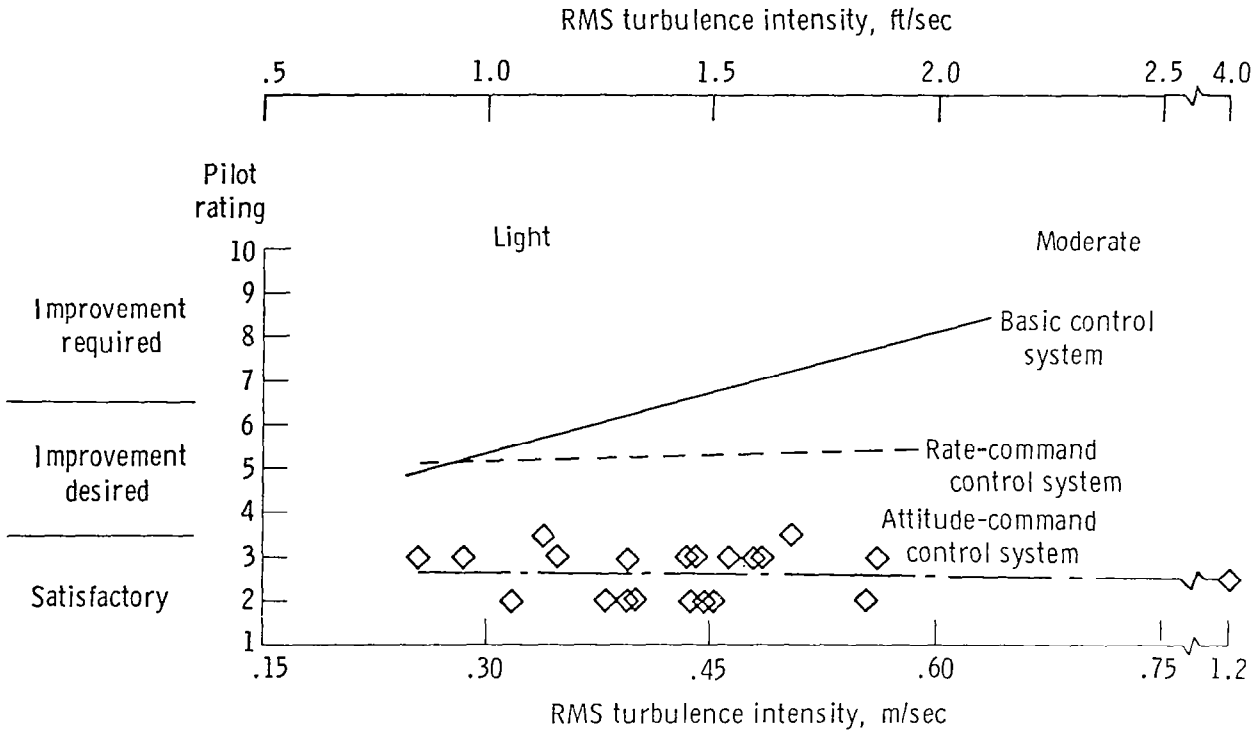
This is an example of how the results of the control/display trade-off are expected to look. The experimental matrix shall be based on this format.

DATA FOR CONTROL/DISPLAY TRADE-OFF

- Simulator Studies at LRC
  - Autopilot Complexity
  - ATAS
  - Follow me box
- Flight Tests at Dryden
- Demonstration Advanced Avionics System
- Princeton Navion
- Pilot Jury
- Aviation Safety Reporting System

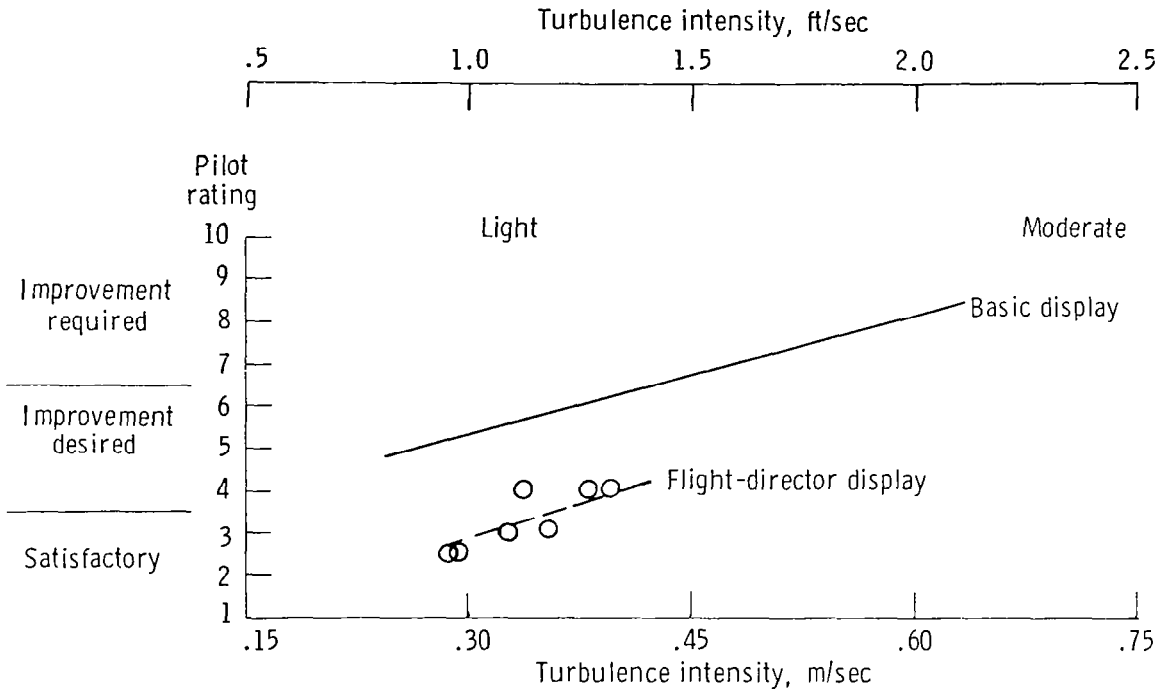
Data which exists and is being utilized in the current research is summarized above. The "pilot jury" was a concept wherein several pilots would hypothesize a level of workload for a given IFR scenario. Since the workshop, we have been fortunate enough to have been able to conduct a flight test program at NASA Langley in lieu of the pilot jury.

ILS APPROACH TASK — EFFECT OF AUGMENTATION



These are typical results from an in-flight experiment conducted at NASA Dryden Flight Research Center. They show that pitch attitude augmentation significantly improves pilot opinion for an instrument task in turbulence.

ILS APPROACH TASK — NO AUGMENTATION



These results from the NASA Dryden experiment show that displays are not as effective as augmentation in improving the piloting task in increasing levels of turbulence.

TENTATIVE CONCLUSIONS TO DATE

- Primary workload relief is derived from basic stability augmentation
- Complex autopilots can induce serious blunders -- Problem seems related to
  - Mind set
  - False hypothesis
  - Pilot interface with autopilot functions
- Need Displays to
  - Enhance positional awareness
  - Minimize likelihood of false hypothesis
- Need Experimental Data
  - Simulation
  - DAAS

An experiment has been conducted at NASA Langley utilizing three aircraft, a simulator, and four pilots. The results of this experiment are currently being analyzed and will be discussed in detail in the final report.

REFERENCE

1. Hurst, Ronald (Ed.): Pilot Error: A Professional Study of Contributory Factors. Crosby, Lockwood, Staples: London, 1976.

WEATHER DATA COMMUNICATION AND UTILIZATION

Richard H. McFarland, James D. Nickum, and Daryl L. McCall
Avionics Engineering Center
Ohio University

Following is a description of some of the technical work performed by the Avionics Engineering Center as a part of the Department of Electrical Engineering at Ohio University, Athens. The general title of the work is the communication of weather data and the utilization of these data in improving general aviation aircraft safety. The participants in this work have been principally Dr. Richard H. McFarland, Mr. James D. Nickum, and Mr. Daryl L. McCall. Mr. McCall served in 1981 as an intern at the Langley Research Center under a special program.

One of the basic interests in communications involving weather data is how to accomplish it efficiently. (See Figure 1.) If we are talking about weather data, in particular, we can envision great quantities of data being available and only a limited amount of capability to transfer this via radio link to an aircraft. Further, the pilot, of course, will be limited in the amount of time he has to peruse the data and excess data may actually be a detriment to safety. It is, therefore, important to be able to select appropriate information and transfer it in a very efficient manner. Earlier research indicated that the radio communications technique is the only practical means of accomplishing this. Two options appear to be available in the radio spectrum. One is to use an aeronautical radio communication channel designated by the FCC, or use a navigation channel with subcarriers imposed on it. The VOR, in particular, is a good candidate, and use of low-frequency beacons offers some possibility especially for non-line-of-sight transmission, perhaps to ground-based users for flight planning purposes. The use of subcarriers, vertical intervals on the television channels and portions of the FM band are not acceptable to the Federal Communications Commission. The possibility of obtaining some of the military channel authorizations for use for civil purposes also seems to be out of the question based on information obtained during this investigation.

Approaching the problem of providing efficient transfer, considerations such as development of coding schemes to reduce the redundancy of the information being transmitted are important. For example, providing line packing, which means that the amount of information transmitted for each line is reduced by having knowledge that certain pixels are repeated, goes a long way in saving time in transmitting a weather radar picture.

The information to be transferred can be broken into two categories. One is graphics information which includes such items as weather radar reflectivity patterns, severe weather maps, icing, synoptic weather patterns, possibly satellite pictures, sferics information, and information contained in the National Weather Service AFOS System. (See Figures 2 and 3.) The other is text items such as sequences, forecasts, altimeter settings, pilot reports, and NOTAMs. These are easily transmitted through data links and when properly screened provide excellent information for the pilot.

One of the concerns that we as researchers should have concerning the use of uplink data is how it will and can be used. An important means for determining this will be through simulation. Accordingly, Ohio University

has produced some weather radar sequences on magnetic tapes which are being put into form to be applicable with the NASA Cyber computer. The intent will be to place weather information, assuming it to be derived from an uplink, in front of the pilot in the simulator and allow him to proceed to manipulate his aircraft in performing deviations and other maneuvers to avoid the serious weather threats. The safety of the flight can be examined by the observer pilot and determination will be made of how well the pilot can handle the information and in what form it can best be handled.

As a part of the display work, it is necessary to place the aircraft in the weather picture, so to speak, and to move the weather picture consistent with the heading and course of the airplane. In other words, in a good simulation the pilot may very well imagine himself to be flying behind an airborne weather radar but with greater synoptic coverage. The challenge at the present has been to place the aircraft in the weather picture and rotate and translate the weather picture according to heading and speed of the aircraft. This work is in progress at the present time. Figures 4, 5 and 6 show the equipment that has been used by Ohio University for demonstrating some of the rudimentary aspects in developing the algorithms for translating and rotating the weather picture. The weather data has been obtained by courtesy of the National Weather Service, Columbus, Ohio. Results are shown in Figures 7 and 8.

Additional hardware is shown in Figure 9 which allows for the transfer of the sferics information obtained from a Ryan Stormscope over a radio link to an aircraft type receiver. Although this demonstration has not been performed with an aircraft in flight, it has been completely simulated using the transmitter and receiver terminals connected only by the radio link. If requested by NASA, this uplink can be implemented in flight over an aeronautical radio communications channel which has been authorized by the Federal Communications Commission.

This work involving the radio uplink for the sferics information and the preparation of the weather information for inclusion in the NASA simulation has been accomplished under NASA Grant NAG-1-124.

The bibliography relevant to this weather uplink study that is dedicated to developing better capabilities of interfacing the pilot to available information and equipment in the aircraft is documented in the following publications.

McFarland, Richard H., "Midterm Report of an Investigation of Methods for Efficient Transfer of Weather Information to the Pilot", OU/AEC/EER 53-1, Avionics Engineering Center, Ohio University, prepared for NASA Langley Research Center, July 1981.

McFarland, Richard H., "A Delineation of Critical Weather Factors Concerning General Aviation", OU/AEC/EER 53-3, Avionics Engineering

Center, Ohio University, Athens, Ohio, prepared for NASA Langley Research Center, November 1981.

Fischer, Joseph P., "An Investigation of Techniques for Coding and Transmitting Weather and Flight Related Information to an Aircraft", Avionics Engineering Center, Ohio University, Athens, Ohio, Interim Report OU/AEC/EER 53-4, prepared for NASA Langley Research Center, December 1981.

McFarland, Richard H., "Precipitation Area Detection Data", TM W-1, Avionics Engineering Center, Ohio University, prepared for NASA Langley Research Center, March 1982.

McFarland, Richard H., "Efficient Transfer of Weather Information to the Pilot in Flight", NASA Contract NAG-1-124, NASA Contractor Report 165889, Avionics Engineering Center, Ohio University, Athens, Ohio, April 1982.

Lilley, Robert W., "Creation and Demonstration of a Weather-Radar Simulation Data Base", TM W-2, Avionics Engineering Center, Ohio University, Athens, Ohio, prepared for NASA Langley Research Center, May 1982.

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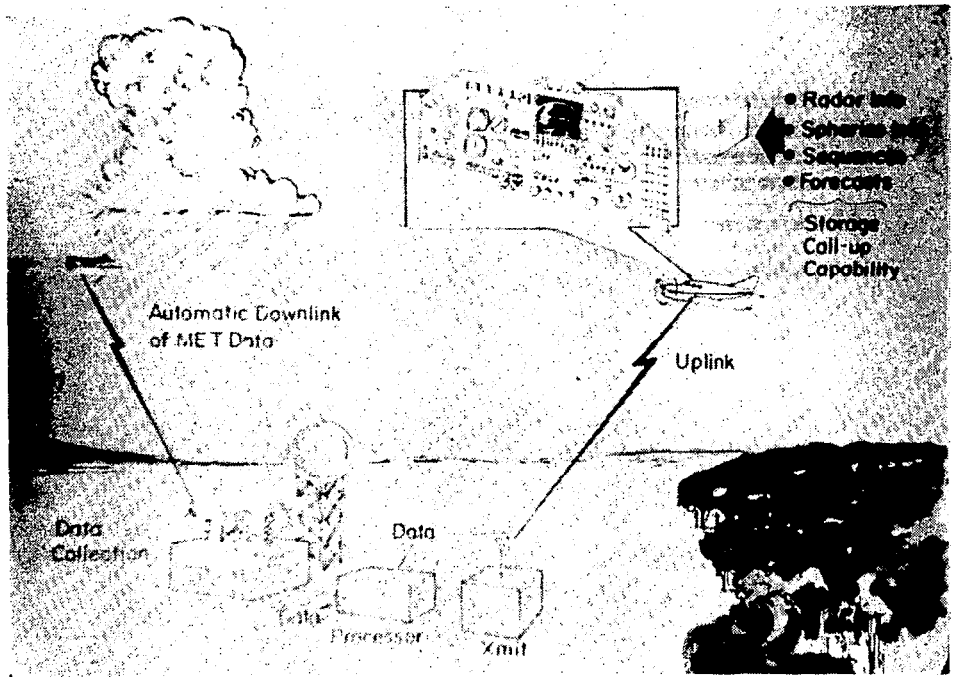

Radar Info
Forecasts
Storage
Call-up
Capability
Automatic Downlink
of MET Data
Uplink
Data
Collection
Data
Processor
Xmit

Figure 1

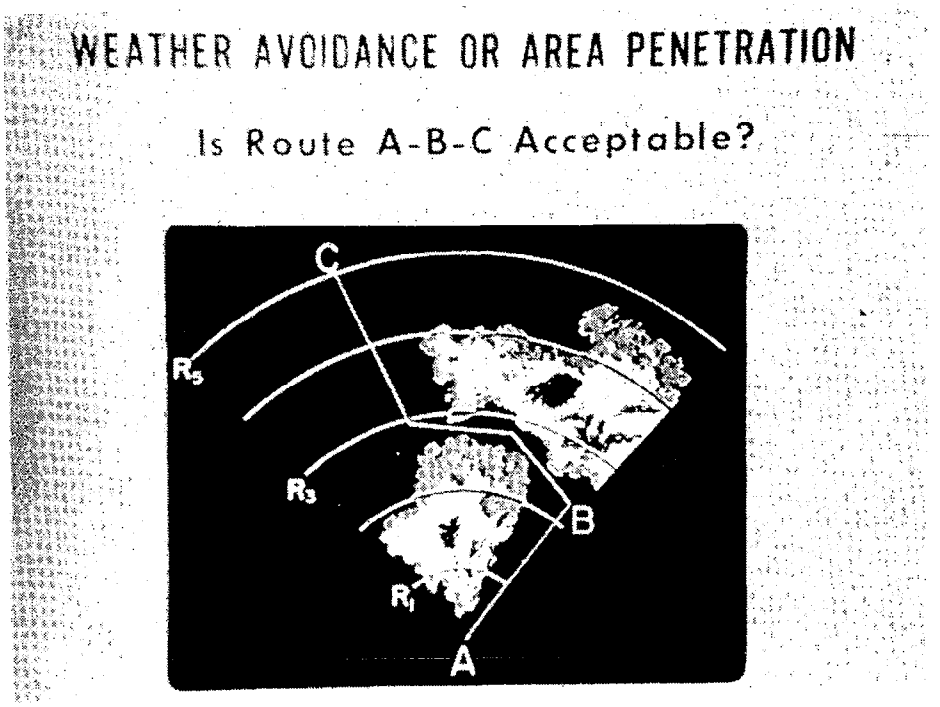


Figure 2

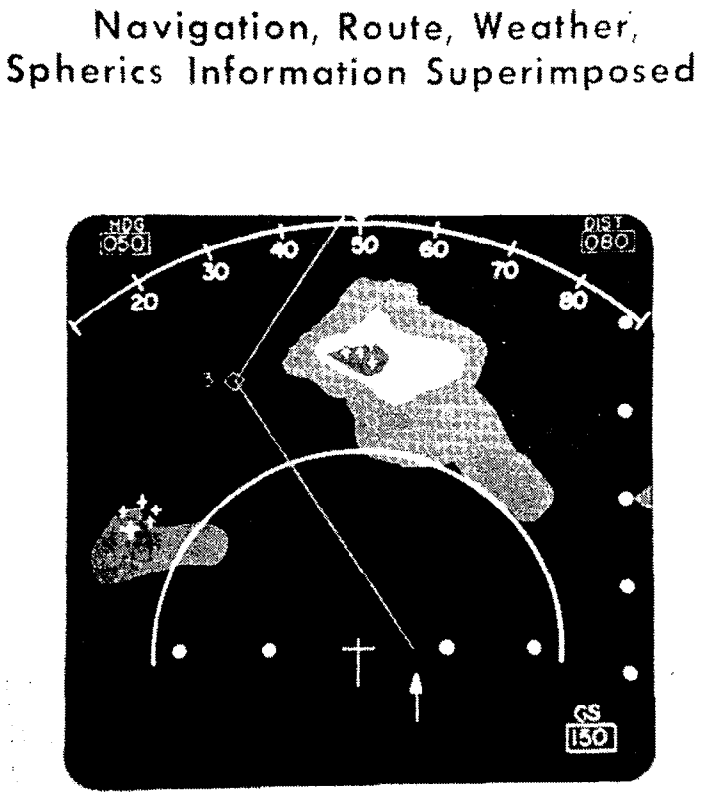


Figure 3

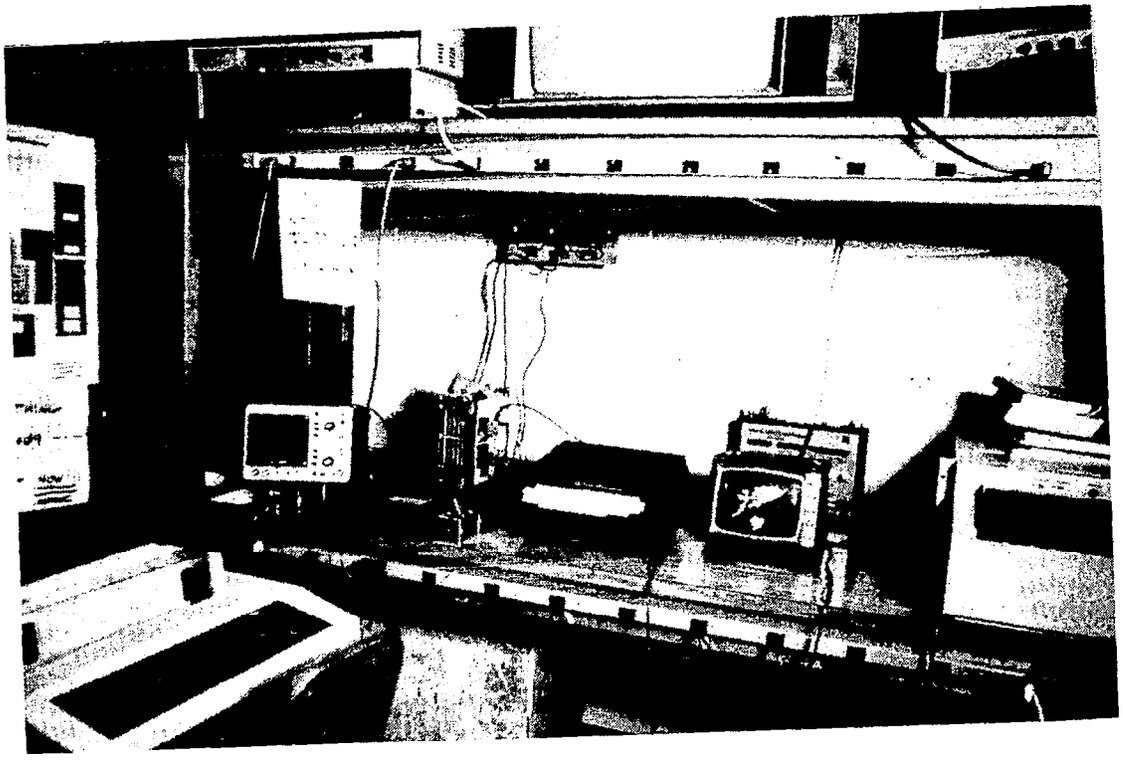


Figure 4

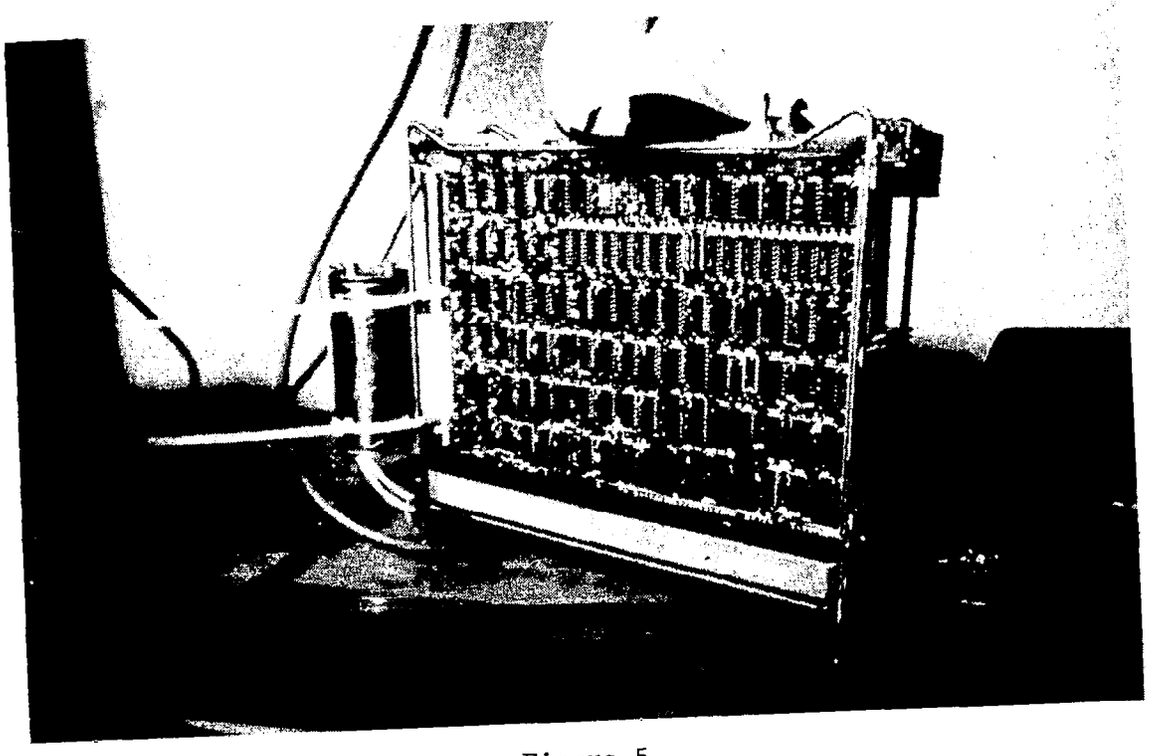


Figure 5

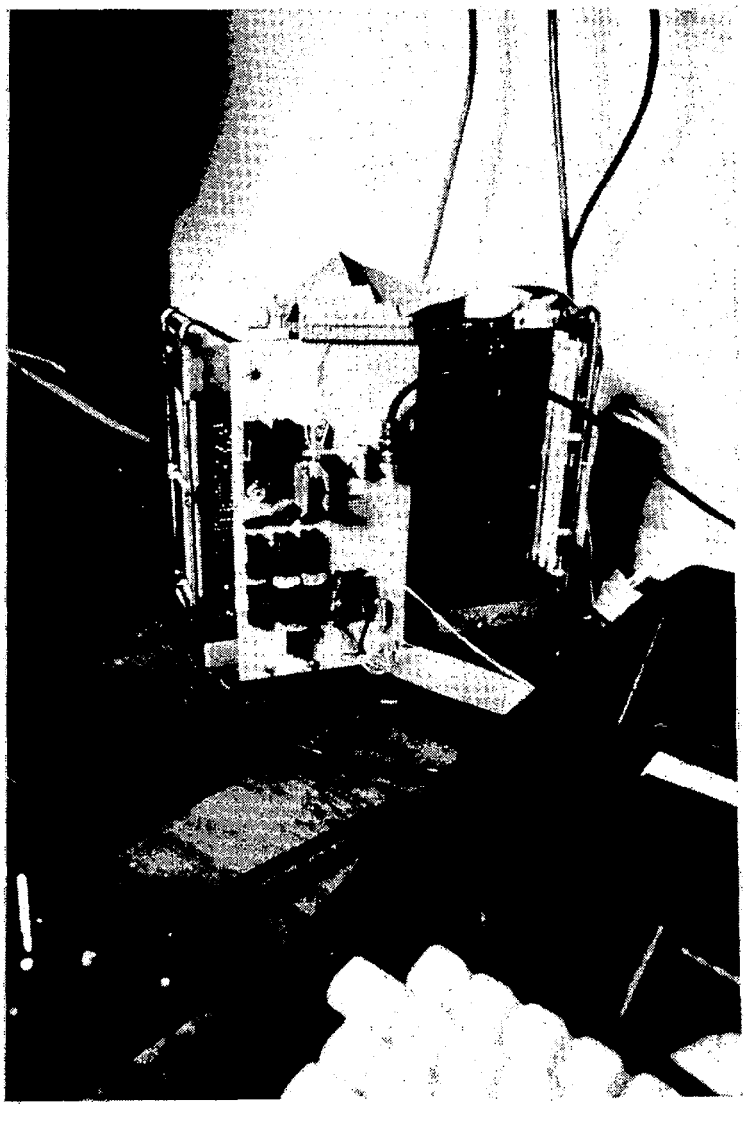


Figure 6

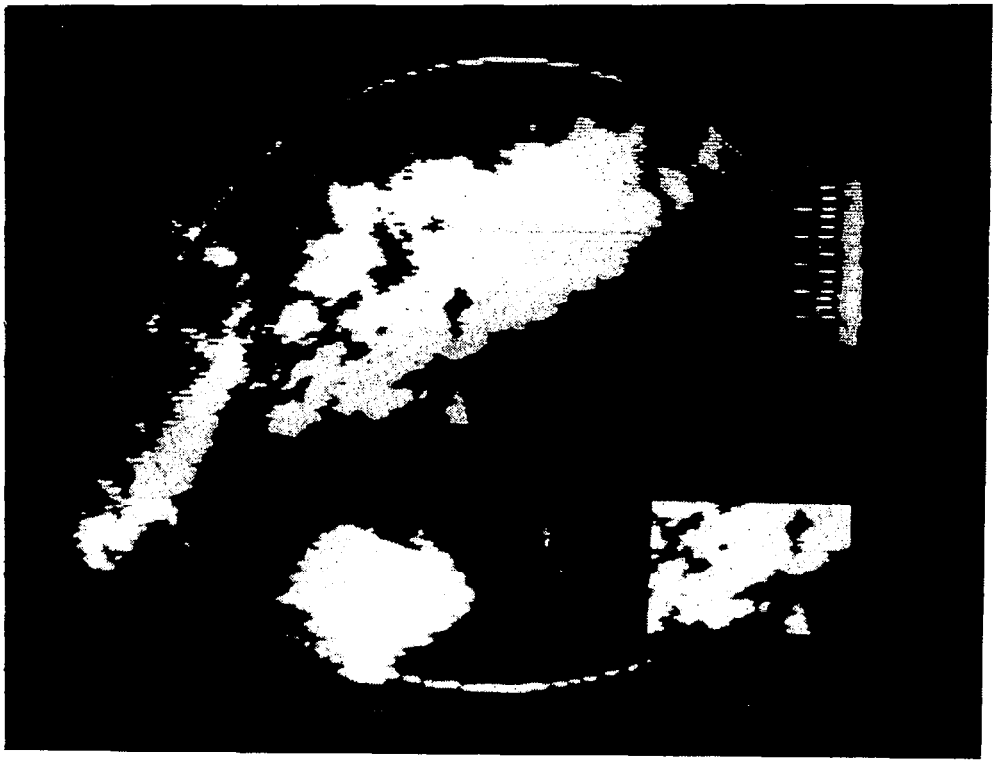


Figure 7

Figure 8

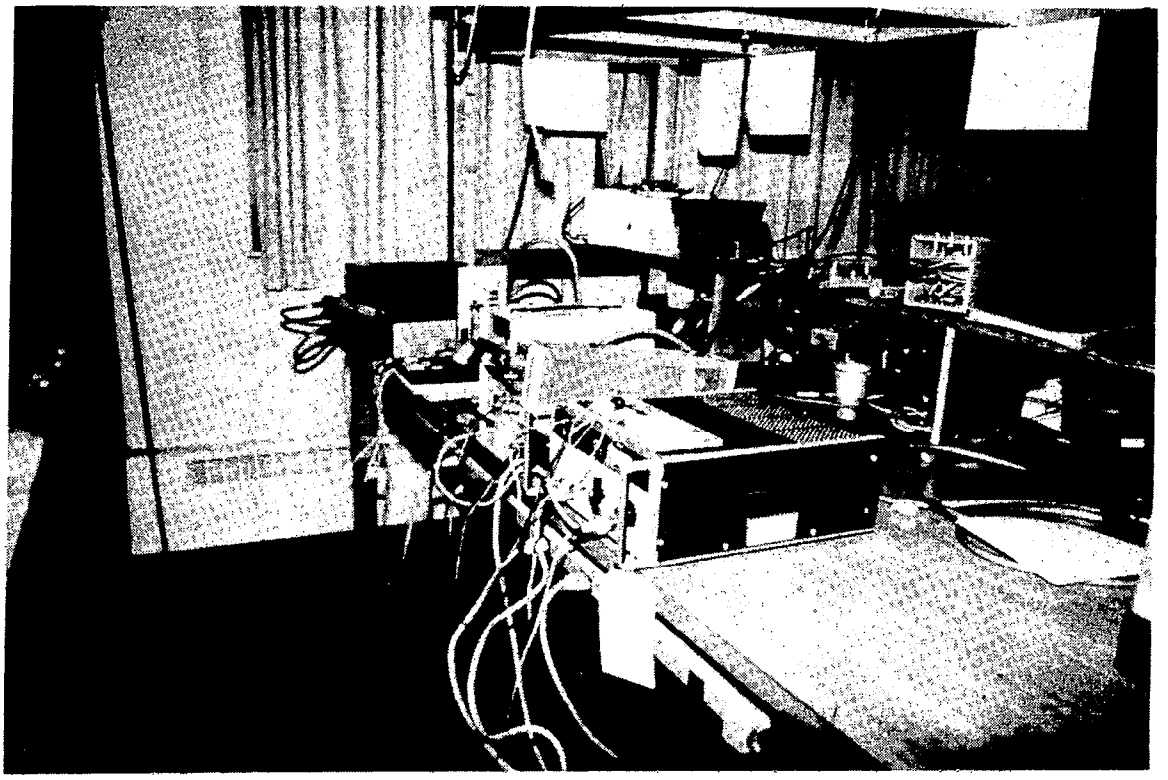


Figure 9

A FLIGHT INVESTIGATION OF SIMULATED DATA LINK COMMUNICATIONS DURING SINGLE-PILOT IFR FLIGHT

J. F. Parker, J. W. Duffy, and D. G. Christensen
BioTechnology, Inc.

ABSTRACT

A Flight Data Console (FDC) was developed to allow simulation of a digital communications link to replace the current voice communication system used in Air Traffic Control. The voice system requires manipulation of radio equipment, read-back of clearances, and mental storage of critical information items, all contributing to high workload, particularly during single-pilot operations. This was an inflight study to determine how a digital communications system might reduce cockpit workload, improve flight proficiency, and be accepted by general aviation pilots.

Results show that instrument flight, including approach and landing, can be accomplished quite effectively using a digital data link system for ATC communications. All pilots expressed a need for a back-up voice channel. When included, this channel was used sparingly and principally to confirm any item of information about which there might be uncertainty. Workload for single-pilot flight, using the FDC, matched that found when a qualified copilot was present. Comments by subject pilots identified a number of human factors issues (placement, size, message format, etc.) which influence the acceptance of a data link system.

PROJECT OBJECTIVES

The safety record of general aviation is not excellent, with 1200 to 1500 fatalities occurring regularly each year. In general aviation, single-pilot instrument flight operations are known to be very demanding, with cockpit data management (information processing) representing a key issue.

The objective of this project was to study data management during single-pilot IFR. The initial project period was spent in developing an item of cockpit instrumentation, the Flight Data Console (FDC), which could be used to simulate use of a digital data link to replace the current voice communications system used in ATC. In the second project period, an inflight evaluation was conducted using the FDC. Results led to a number of recommendations for improvements in cockpit data management in general aviation.

- **STUDY PROBLEMS OF DATA MANAGEMENT DURING GA SINGLE-PILOT IFR FLIGHT**
- **DESIGN AND CONSTRUCT A COCKPIT FLIGHT DATA CONSOLE (FDC)**
  - **PRESENT ATC REFERENCE AND COMMAND DATA**
  - **REMOVE PILOT FROM ATC VOICE LOOP**
- **CONDUCT AN INFLIGHT EVALUATION**
- **PREPARE RECOMMENDATIONS ON**
  - **IMPROVED COCKPIT DATA MANAGEMENT**
  - **USE OF AN FDC–TYPE SYSTEM IN A FUTURE ATC ENVIRONMENT**

FLIGHT EVALUATION PLAN

The flight evaluations were conducted in two phases. Phase 1 used only terminal area approaches to airports in the Washington, DC area. In this phase, four kinds of flight were flown:

Copilot - In this flight, which provided baseline data, the subject pilot flew with an instrument-rated copilot and was free to use the copilot in any way desired. This flight was considered optimum in terms of reducing workload and making the flight as proficient and safe as possible.

Flight Data Console/Memory - Here the subject pilot used the FDC as an electronic data storage system (memory aid) solely to assist during each instrument approach.

Single-Pilot IFR - This is the customary single-pilot instrument flight. A safety pilot was present but did not participate in any way. The FDC was not used.

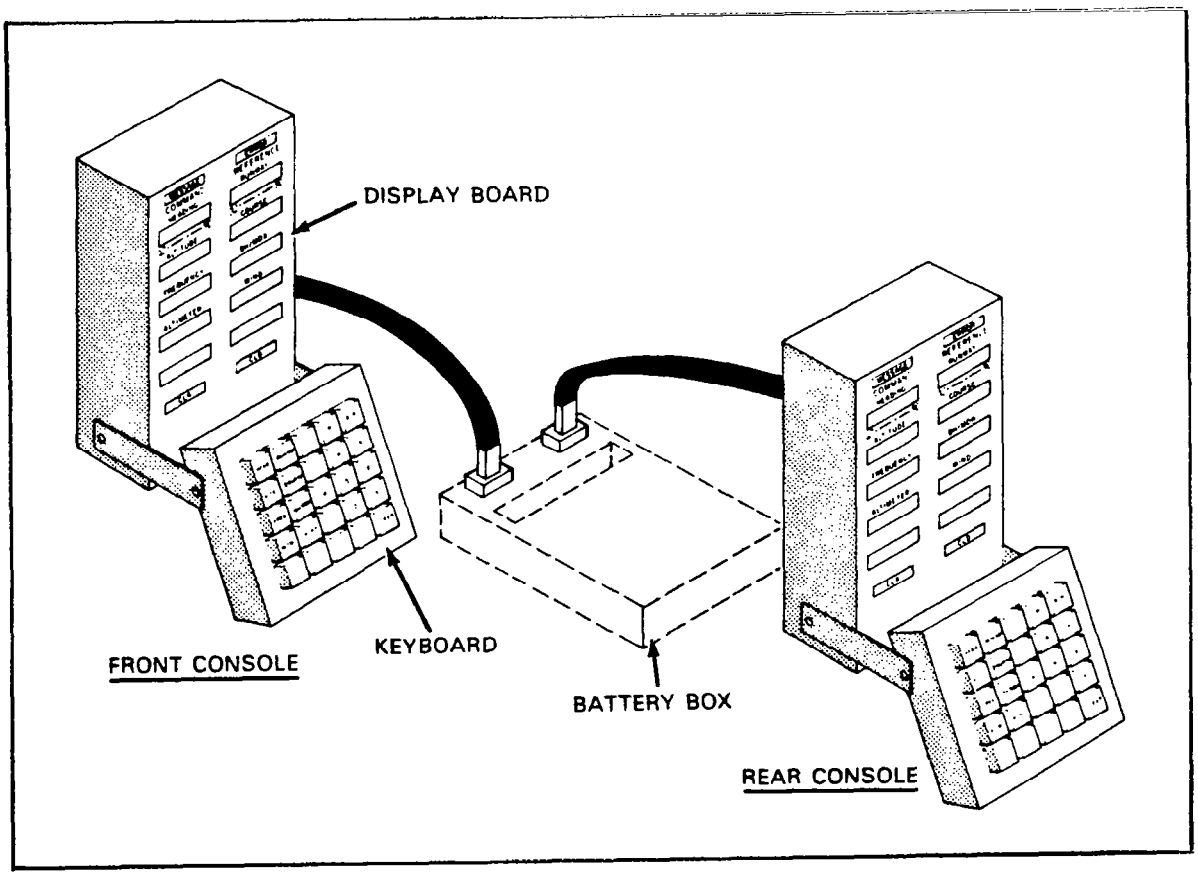
Flight Data Console/ATC - In this flight, all approaches were flown using Air Traffic Control information provided through the Flight Data Console.

FLIGHT EVALUATION PLAN

PHASE 1	NO. OF SUBJECTS
● TERMINAL AREA APPROACHES	8
– CO-PILOT	
– FLIGHT DATA CONSOLE / MEMORY	
– SINGLE-PILOT IFR	
– FLIGHT DATA CONSOLE / ATC	
PHASE 2	
● TERMINAL AREA APPROACHES	9
– FLIGHT DATA CONSOLE / ATC (VOICE BACK-UP)	
● ENROUTE (250 n.mi., FULL IFR)	4
– SINGLE-PILOT IFR	
– FLIGHT DATA CONSOLE / ATC (VOICE BACK-UP)	

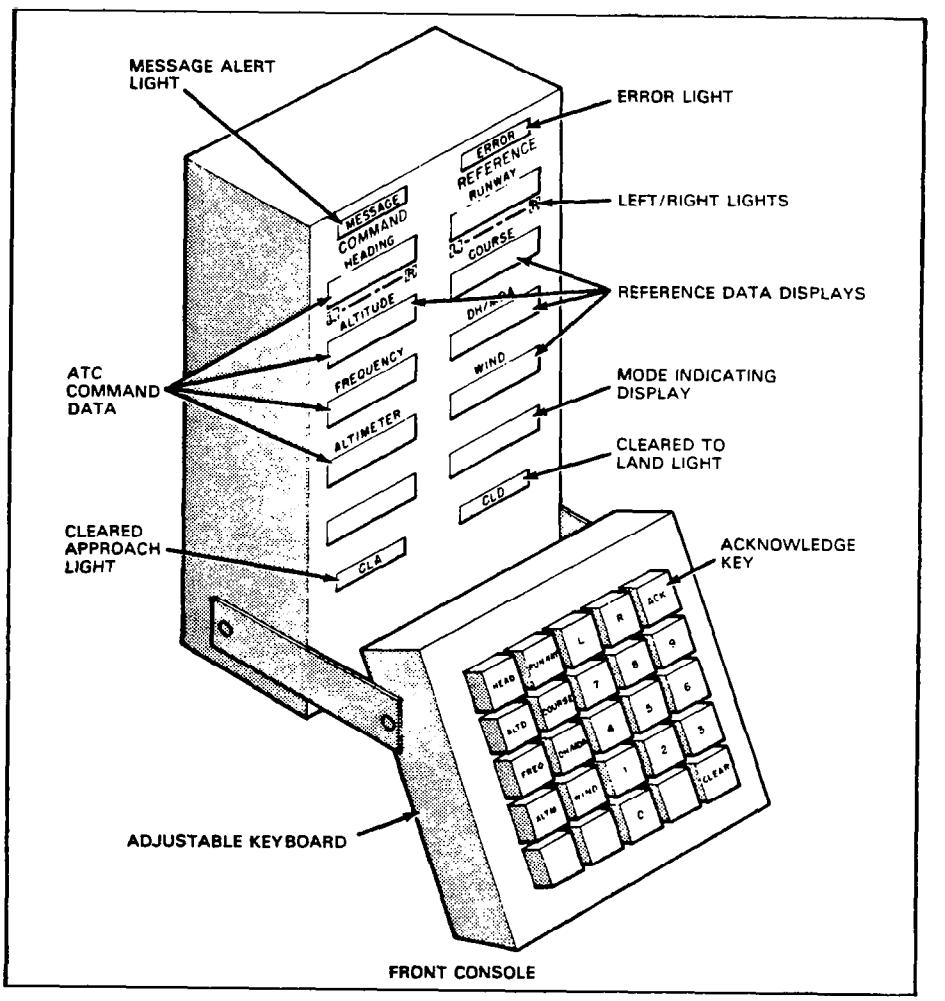
COMPONENTS OF FLIGHT DATA CONSOLE

The Flight Data Console is made up of three principal parts: a front seat display and data entry panel for use by the pilot, a rear seat display and data entry panel whereby a console operator serves as a transducer for ATC instructions (entering ATC commands and immediately transmitting these commands to the front seat display), and a battery power unit which makes the system independent of the aircraft.



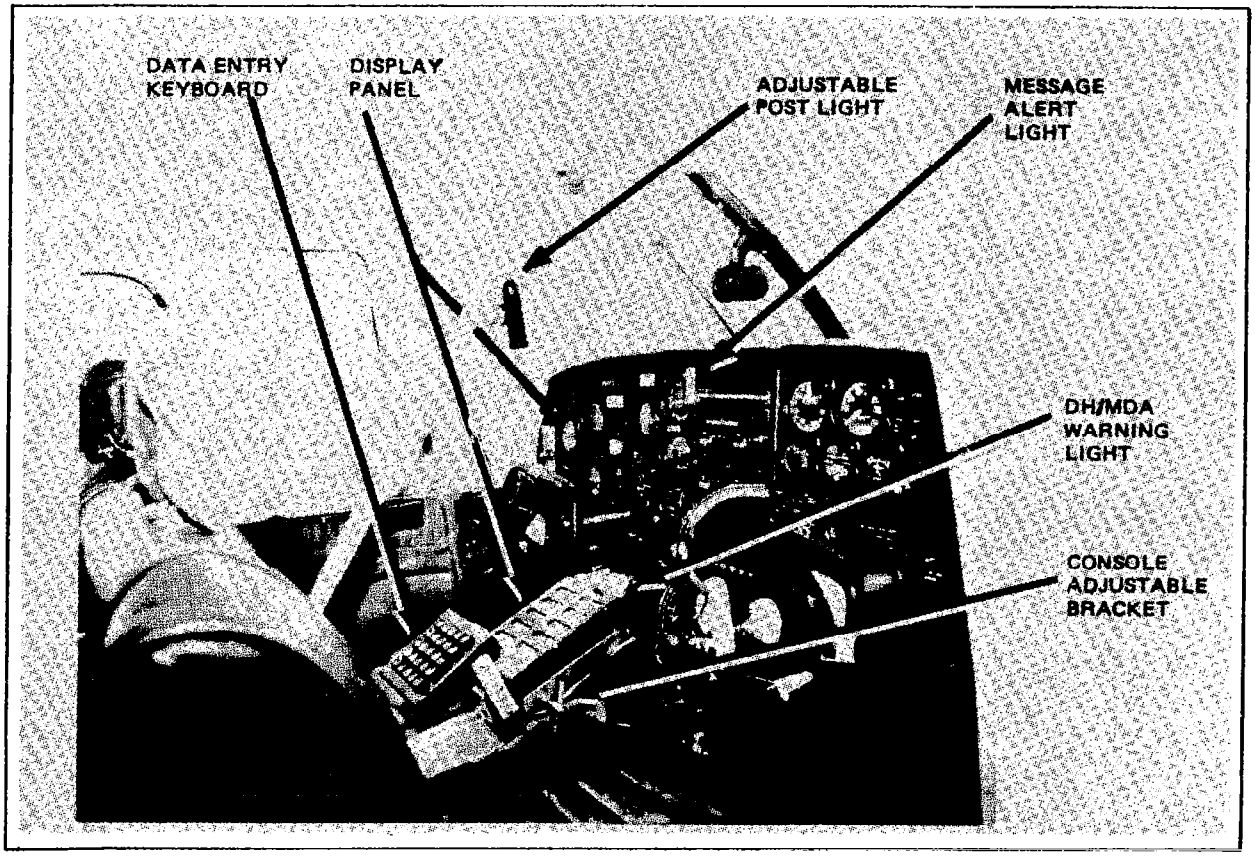
PILOT'S DISPLAY AND KEYBOARD

The unit which presents ATC information uses liquid crystal displays, each of which can present up to eight digits. The right column presents and stores flight data items as entered by the pilot. Using this capability, the FDC can serve as a memory aid and, in essence, take the place of a paper and pencil kneepad. The left column presents command information from Air Traffic Control. This includes instructions for changes in heading (including direction of turn), changes in altitude, new frequencies, updated altimeter settings, and, as shown in the bottom two display windows, "Cleared for Approach" and "Cleared to Land" instructions. When the pilot receives this information from ATC, he depresses the acknowledge key, completes the instruction, and presses another key to indicate completion.



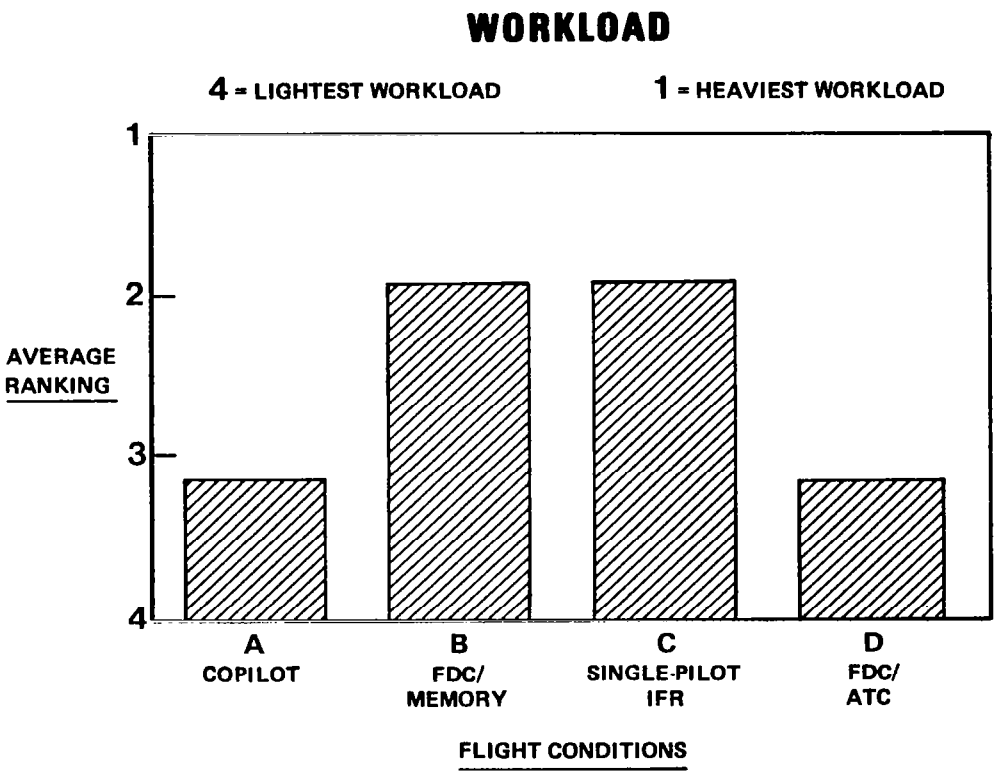
INSTALLATION OF FLIGHT DATA CONSOLE

The Flight Data Console was installed in a twin-engine Piper Aztec aircraft used for all flight evaluations. Because the system could not be permanently installed, the FDC display was positioned just behind the throttle quadrant with the data entry keyboard just right of the pilot's elbow position. This installation proved workable although far from optimal in terms of ease of viewing and operation.



WORKLOAD

At the completion of all terminal area approaches, subject pilots ranked the four flight conditions in terms of workload imposed. Based on these rankings, the presentation of ATC instructions through the Flight Data Console results in a cockpit workload equal to that found when flying with a fully qualified instrument copilot. Workload is substantially heavier both for the single-pilot IFR condition and for those flights in which the FDC is used simply as an electronic memory aid.



ACCEPTANCE OF FLIGHT DATA CONSOLE

(Positive)

One project objective was to determine the extent to which a data link communications system would be accepted by general aviation pilots. Many comments and recommendations were received. It was found that the Flight Data Console was well received, with its acceptance seeming to involve three basic dimensions. These are (1) communications effectiveness, (2) workload reduction, and (3) an improvement in cockpit conditions.

ACCEPTANCE COMMENTS ON FLIGHT DATA CONSOLE

ACCEPTANCE

- COMMUNICATIONS EFFECTIVENESS

  "NO MIXUP ON WHO THE INSTRUCTION IS FOR"
  "NO MISUNDERSTANDING OR FORGETTING NUMBERS"
  "DON'T MISS CALLS"

- WORKLOAD REDUCTION

  "NO FUMBLING WITH PENCIL, KNEEBOARD, MIKE OR VOLUME CONTROL"

- COCKPIT CONDITIONS

  "LIKE THE QUIET OF THE RADIO-FREE ENVIRONMENT"

ACCEPTANCE OF FLIGHT DATA CONSOLE

(Negative)

A number of problems were identified with use of the Flight Data Console. Many of these were a function of it being a temporary installation. The human engineering aspects were far from optimum. This means that a number of human factors issues must be addressed if a data link system is to achieve its potential. Care must be taken in placing the system in the cockpit. Message content must be matched to pilot needs, instrument scan must be considered, and display complexity should not be great.

A second negative comment deals with the information restriction imposed through use of a data link system. In some measure, these comments were relieved by the incorporation of a backup voice channel for later project flights.

ACCEPTANCE COMMENTS ON FLIGHT DATA CONSOLE

NON-ACCEPTANCE

- **HUMAN ENGINEERING**
  - "POSITION OF FDC DETRACTS FROM SCAN"
  - "EVERY TIME I USED IT, I HAD TO SCREW MY BODY INTO A WIERD CONTORTION"
  - "DIFFICULT TO READ IN DAYLIGHT"
- **INFORMATION RESTRICTION**
  - "VOICE SECURITY BLANKET IS SIGNIFICANT"
  - "FDC TENDS TO FORCE GREATER RELIANCE ON ATC THAN I'M READY TO GIVE"
  - "NOT ABLE TO QUESTION ATC"

VOICE CHANNEL

The consensus of pilots who flew in the Phase I program was that a backup voice channel was needed with the Flight Data Console. This backup system was included in the Phase II flights. During the terminal area evaluations, the voice channel was used sparingly and principally to obtain confirmation of flight data provided through the Air Traffic Control system.

USE OF BACK-UP VOICE CHANNEL IN TERMINAL AREA OPERATIONS

NUMBER OF USES	INFORMATION
4	REQUESTED ATIS INFORMATION
4	VERIFIED TYPE OF APPROACH
3	CHECKED WIND CONDITIONS
1	CONFIRMED ALTITUDE AND VECTOR COMMANDS
1	VERIFIED MINIMUM ALTITUDE
1	VERIFIED CLEARANCE

Four pilots flew IFR missions under full instrument weather conditions over routes on the order of 250 nautical miles. The purpose was to develop a typical flight scenario as an aid in studying problems of pilot workload and information acquisition.

The performance ratings given the subject pilots by the safety pilot, who was a qualified instrument flight instructor, ranged from eight (quite a good score) to one (marginally above unsatisfactory). The number of unsafe occurrences noted, each of which would have been disqualifying in a flight test, ranged from zero to eleven. The differences in the evaluation data among the four pilots were considerable; a much wider disparity than expected. In an attempt to account for this, several variables were examined, principally dealing with flight time. The correlation between "rating by safety pilot" and "instrument time - last six months" was quite high. Since this measure of time ranged from eight to 40 hours, it is apparent that maintenance of instrument proficiency requires that one fly quite frequently under instrument conditions.

COMPARISON OF PERFORMANCE AND EXPERIENCE FOR SUBJECT PILOTS (ENROUTE FLIGHTS)

	SUBJECT PILOTS (N = 4)
RATING BY SAFETY PILOT[1]	1 - 8
TOTAL TIME (HRS.)	425 - 2000
TOTAL INSTRUMENT TIME	30 - 250
INSTRUMENT TIME-LAST SIX MONTHS	8 - 40
UNSAFE OCCURRENCES (NO.)	0 - 11

[1] 10 = EXCELLENT, 0 = UNSATISFACTORY

SINGLE-PILOT IFR VERSUS FDC WITH VOICE

The performance of the four pilots who flew IFR missions under full instrument weather conditions with no aid (FDC or copilot) was compared to their performance in four comparable flights over different routes using the Flight Data Console with the backup voice channel. In all, a measure of improvement was seen when the FDC was used. Performance ratings improved on the low end from a rating of one to three. The number of unsafe occurrences noted in any one flight decreased from 11 to five.

ENROUTE FLIGHT PERFORMANCE COMPARING FLIGHT DATA CONSOLE WITH VOICE AGAINST SINGLE-PILOT IFR

	SUBJECT PILOTS (N = 4)		
SINGLE-PILOT IFR			
PERFORMANCE RATING BY SAFETY PILOT[1]	1	-	8
UNSAFE OCCURRENCES (No.)	0	-	11
FDC WITH VOICE			
PERFORMANCE RATING BY SAFETY PILOT	3	-	8
UNSAFE OCCURRENCES (No.)	1	-	5

[1] 10 = EXCELLENT, 0 = UNSATISFACTORY

COMPARISON OF THREE FLIGHT CONDITIONS

At the completion of the final full-mission flight, the four subject pilots were asked to rank the three flight conditions, shown in this Table, along the three dimensions of safety, workload, and pilot preference. Some caution must be expressed with respect to the validity of these relative rankings. Subjects were asked to compare flight conditions for which their recency of experience varied greatly. In one case, they had just completed a certain flight condition (Flight Data Console/Voice) and could judge it with some validity. With the other two conditions, the evaluation was based on long-term memory and is open to some question. In any event, the results did show that the flight condition represented by the use of the Flight Data Console with a backup voice channel was considered to be safest, to impose the lightest workload, and to be most preferred by these pilots.

RANKINGS OF THREE FLIGHT CONDITIONS FOLLOWING FULL-MISSION IFR FLIGHTS

FLIGHT CONDITION	SAFETY	WORKLOAD	PREFERENCE
FLIGHT DATA CONSOLE / VOICE	3.0	1.3	3.0
FLIGHT DATA CONSOLE	1.5	2.0	1.5
SINGLE-PILOT IFR	1.5	2.8	1.5

SAFETY: 3 = MOST, 1 = LEAST
WORKLOAD: 3 = HEAVIEST, 1 = LIGHTEST
PREFERENCE: 3 = MOST, 1 = LEAST

CONCLUSIONS

The current voice communications system used in Air Traffic Control requires manipulation of radio equipment, read-back of clearances, and mental storage of critical information items, all of which contributes to high workload and an excessive error rate, particularly during single-pilot operations. This study indicates that use of a data link communications system has considerable potential for alleviating these problems and improving cockpit data management during general aviation operations. The specific conclusions of this project are presented in succinct form below.

DATA LINK COMMUNICATIONS

- WELL RECEIVED AND USED BY GA PILOTS
- SHOULD IMPROVE PROFICIENCY OF SINGLE-PILOT IFR SIGNIFICANTLY
- REQUIRES BACK-UP VOICE CHANNEL
- RESEARCH NEEDS
  - HUMAN ENGINEERING
  - INFORMATION SELECTION AND FORMATTING

SINGLE-PILOT IFR

- WORKLOAD HEAVIEST DURING LANDING APPROACH
- DIFFICULT TO ACCOMPLISH SAFELY WITHOUT CONSIDERABLE PROFICIENCY FLYING

PROPOSED STUDY TO DETERMINE POTENTIAL FLIGHT APPLICATIONS AND HUMAN FACTORS DESIGN GUIDELINES OF VOICE RECOGNITION/SYNTHESIS SYSTEMS

Hugh P. Bergeron
NASA Langley Research Center

ABSTRACT

This study will evaluate the human factors aspects and potential of voice recognition/synthesis techniques and the application of present and near-future (5 years) voice recognition/synthesis systems as a pilot/aircraft cockpit interface capability in an operational environment. The analysis shall emphasize applications for single pilot IFR operations but shall also include applications for other categories of aircraft with various levels of complexity.

The study will concentrate on the pilot/aircraft cockpit interface and on how this interface integrates into the total aircraft system from an operational human factors point of view. The study will encompass all aircraft categories including both single- and multi-crew operations, but will emphasize single-pilot operations in the ATC IFR environment. It is expected that applications for this more demanding type of operation will also be applicable to most of the multi-crew operational requirements.

Applications in the cockpit will include the independent use of voice recognition and voice synthesis techniques as well as the integration of the two in solving problems, performing functions, or meeting any other requirement for interfacing with aircraft systems.

SCOPE: THE STUDY WILL:

- o CONCENTRATE ON THE PILOT/AIRCRAFT COCKPIT INTERFACE AND ON HOW THIS INTERFACE INTEGRATES INTO THE TOTAL AIRCRAFT SYSTEM FROM AN OPERATIONAL HUMAN FACTORS POINT OF VIEW
- o ENCOMPASS ALL AIRCRAFT CATEGORIES INCLUDING BOTH SINGLE- AND MULTI-CREW OPERATIONS, BUT WILL EMPHASIZE SINGLE-PILOT OPERATIONS IN THE ATC IFR ENVIRONMENT
- o INCLUDE THE INDEPENDENT USE OF VOICE RECOGNITION AND VOICE SYNTHESIS TECHNIQUES AS WELL AS THE INTEGRATION OF THE TWO IN SOLVING PROBLEMS, PERFORMING FUNCTIONS, OR MEETING ANY OTHER REQUIREMENT FOR INTERFACING WITH AIRCRAFT SYSTEMS
- o ONE YEAR EFFORT (WINTER 83 - WINTER 84)

This study will investigate human factors aspects and the potential for using voice recognition/synthesis techniques in the cockpit environment for reducing workload, increasing safety, and increasing aircraft utility. More specifically, the study will: 1) review the state of the art of voice recognition/synthesis and the projection of this technology five years into the future, 2) define and analyze the potential of the technology for control of flight systems and for information transfer applications in the aircraft cockpit environment, 3) determine the suitability of the above applications in an operational environment, and 4) identify and recommend, through a hierarchy of benefits, specific applications.

OBJECTIVE: TO INVESTIGATE HUMAN FACTORS ASPECTS AND THE POTENTIAL FOR USING VOICE RECOGNITION/SYNTHESIS TECHNIQUES IN THE COCKPIT ENVIRONMENT FOR REDUCING WORKLOAD, INCREASING SAFETY, AND INCREASING AIRCRAFT UTILITY.

METHOD:

- o REVIEW THE STATE OF THE ART OF VOICE RECOGNITION/SYNTHESIS AND THE PROJECTION OF THIS TECHNOLOGY FIVE YEARS INTO THE FUTURE.
- o DEFINE AND ANALYZE THE POTENTIAL OF THE TECHNOLOGY FOR CONTROL OF FLIGHT SYSTEMS AND FOR INFORMATION TRANSFER APPLICATIONS IN THE COCKPIT ENVIRONMENT.
- O DETERMINE THE SUITABILITY OF THE ABOVE APPLICATIONS IN AN OPERATIONAL ENVIRONMENT.
- O IDENTIFY AND RECOMMEND, THROUGH A HIERARCHY OF BENEFITS, SPECIFIC APPLICATIONS.

NASA DEMONSTRATION ADVANCED AVIONICS SYSTEM

(DAAS)

ERIC M. PETERSON

HONEYWELL, INC.

The Demonstration Advanced Avionics System (DAAS) integrates a comprehensive set of general aviation avionics functions into an advanced system architecture for demonstration in a Cessna 402 aircraft. This paper presents a cursory functional description of the DAAS complex.

Several years ago the NASA Ames Research Center initiated a program to improve avionics for general aviation by applying, whenever possible, new developments in computing and sensing devices. The overall objective was to improve the safety and dependability (schedule adherence) of general aviation IFR operations without increasing the required pilot training/ experience by exploiting advanced technology in computers, displays and system design. Earlier studies in the program provided a data base in computer technology potential, air traffic control environment, and system configuration possibilities. These studies also indicated that to bring advanced avionics benefits to general aviation at an affordable price, changes should not merely be those of improving existing devices and adding a few new "aids" to an already crowded cockpit, but should take the form of a rather sweeping change in the approach to combining sensors, computers and displays into systems which will meet the overall objective. The current Demonstration AdvancedAvionics System (DAAS) is the culmination of this effort and is intended to demonstrate the feasibility of the approach by designing, building, and flying a set of demonstration equipment.

DEMONSTRATION ADVANCED AVIONICS SYSTEM

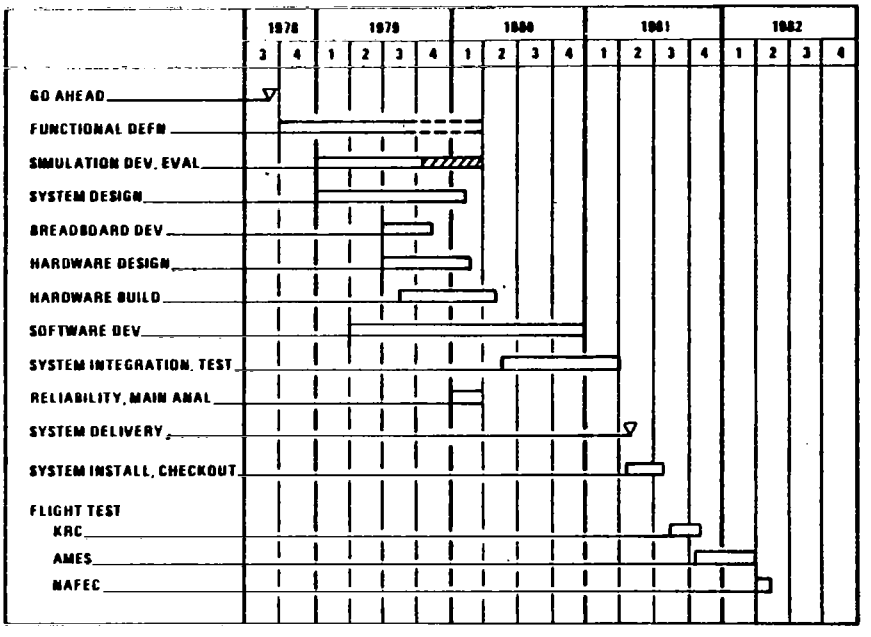
DAAS PROGRAM

- PROGRAM OBJECTIVES
  - PROVIDE CRITICAL INFORMATION FOR THE DESIGN OF INTEGRATED AVIONICS FOR GENERAL AVIATION
  - USE DATA BUSSING, DISTRIBUTED MICROPROCESSORS, SHARED ELECTRONIC DISPLAYS
  - PROVIDE IMPROVED FUNCTIONAL CAPABILITY
- DESIGN CONSIDERATIONS
  - COST
  - RELIABILITY
  - MAINTAINABILITY
  - MODULARITY

The DAAS program go ahead was awarded to Honeywell, Inc. and King Radio Corp. in August 1978. The system was installed in the Cessna 402 aircraft in June of 1981. Flight testing begun in July 1981 and concluded with NASA acceptance in October of 1981.

NASA
DEMONSTRATION ADVANCED AVIONICS SYSTEM

DAAS PROGRAM SCHEDULE



The DAAS is an integrated system. It performs a broad range of general aviation avionics functions using one computer system and shared controls and displays.

The DAAS system also has the capability of simulating navigation and aircraft sensor signals on the ground. This provides the pilot with the ability to demonstrate, test or train using the navigation and flight control features of the system without flying the aircraft.

DEMONSTRATION ADVANCED AVIONICS SYSTEM

DAAS FUNCTIONS

- AUTOPILOT/FLIGHT DIRECTOR
- NAVIGATION/FLIGHT PLANNING
- FLIGHT WARNING SYSTEM
- GMT CLOCK
- FUEL TOTALIZER
- WEIGHT AND BALANCE
- PERFORMANCE COMPUTATIONS
- DISCRETE ADDRESS BEACON SYSTEM
- BUILT-IN TEST
- NORMAL, EMERGENCY CHECKLISTS

INTEGRATED --COMMON COMPUTER SYSTEM, SHARED CONTROLS AND DISPLAYS

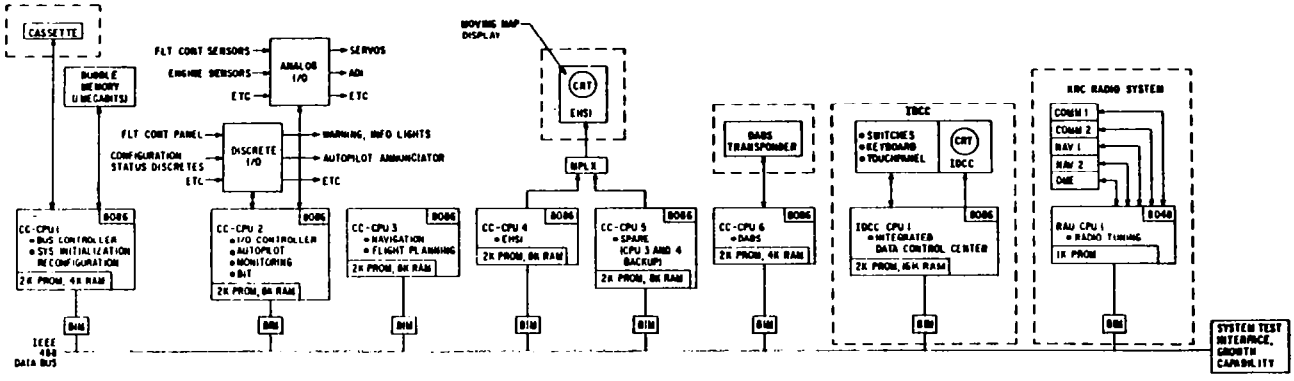
The DAAS architecture is characterized by a modular computer system structure; ie., multimicroprocessor interconnected by an IEEE 488 data bus. Each processor, except for the radio system, represents an Intel 8086 16-bit microprocessor, 2Kx16 PROM memory and 4Kx16 to 16Kx16 RAM memory. The radio system uses the Intel 8048 8-bit microprocessor.

Each processor performs a function and interfaces directly with the subsystems associated with that function. At power on, the bus controller central computer (CC) CPU-1 takes functional programs from the non-volatile EEPROM memory, and subsequently loads each processor. CC-CPU-5 is a spare processor used to demonstrate reconfiguration capability. If processor CC-CPU-3 or CC-CPU-4 fail, the bus controller will load the appropriate software into the spare which will then take over the function of the failed processor.

Six processors are contained in the DAAS central computer unit. One processor is contained in the IDCC, and one processor is contained in the Radio Adaptor Unit.

DEMONSTRATION ADVANCED AVIONICS SYSTEM

DAAS ARCHITECTURE



The DAAS system employs multifunction controls and displays including an Integrated Data Control Center (IDCC) and Electronic Horizontal Situation Indicator (EHSI).

DEMONSTRATION ADVANCED AVIONICS SYSTEM

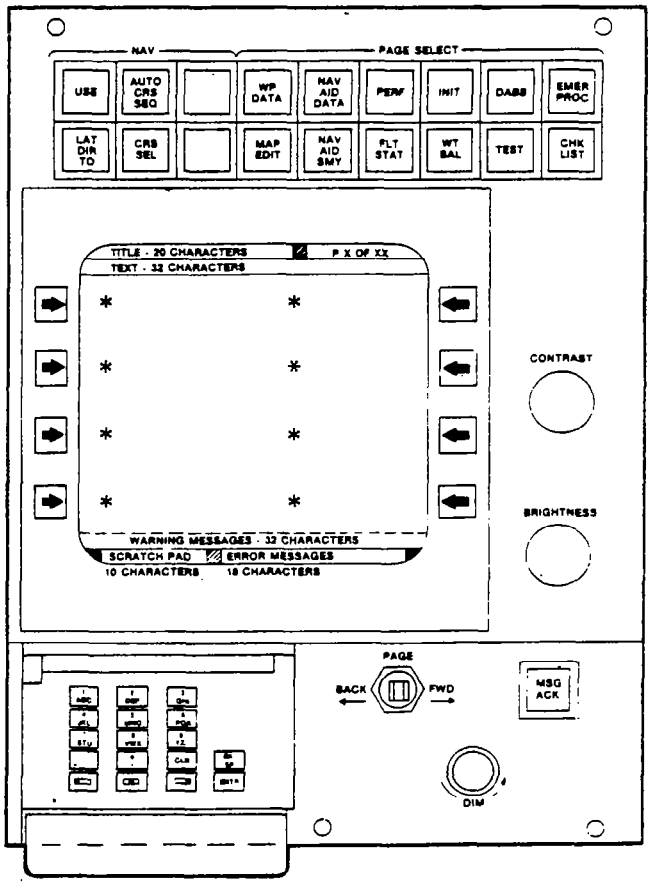
MULTIFUNCTION DISPLAYS AND CONTROLS

- INTEGRATED DATA CONTROL CENTER (IDCC)
- ELECTRONIC HORIZONTAL SITUATION INDICATOR (EHSI)

The IDCC is the pilot's primary means of interacting with the DAAS. Included are a keyboard at the bottom of the unit and a set of function buttons to control navigation and page selection along the top. The IDCC is implemented with menu select buttons (touchpoints) along each side of the CRT.

DEMONSTRATION ADVANCED AVIONICS SYSTEM

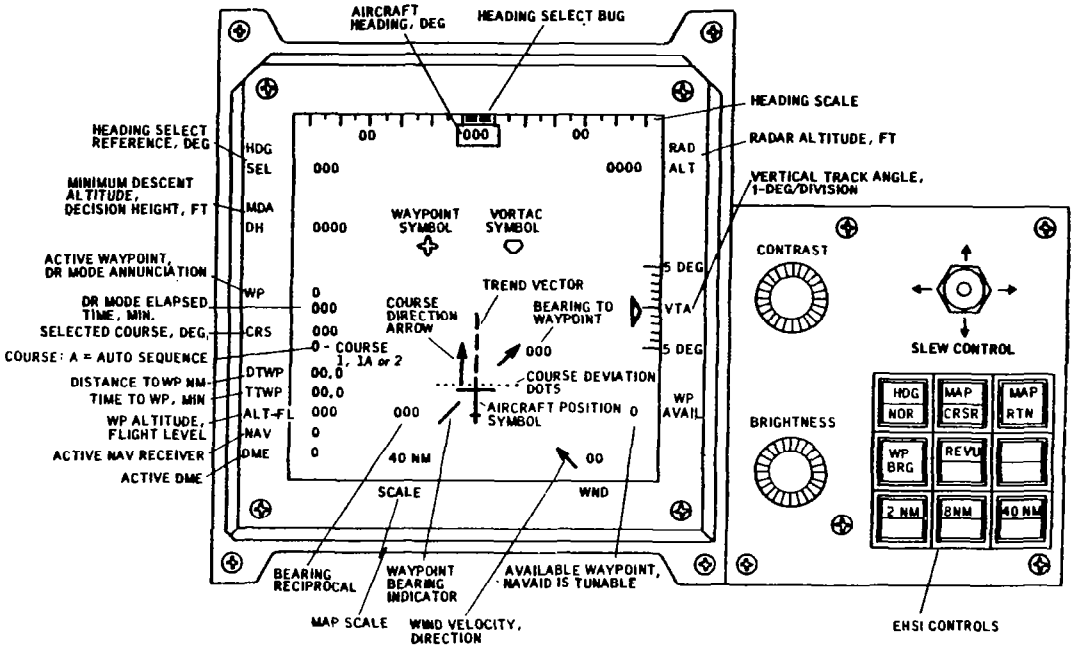
MULTIFUNCTION DISPLAY – INTEGRATED DATA CONTROL CENTER



The EHSI is the primary output of DAAS system information. It presents a moving map display showing aircraft position with respect to course, along with other flight status information. The EHSI is controlled by functional control buttons and a map slew controller.

DEMONSTRATION ADVANCED AVIONICS SYSTEM

MULTIFUNCTION DISPLAY – ELECTRONIC HORIZONTAL SITUATION DISPLAY



The DAAS autopilot is a digital version of the King Radio KFC 200 modified for compatibility with DAAS.

DEMONSTRATION ADVANCED AVIONICS SYSTEM

AUTOPILOT/FLIGHT DIRECTOR FUNCTIONS

- PITCH ATTITUDE HOLD
- GO-AROUND
- CONTROL WHEEL STEERING (CWS)
- ALTITUDE
  - ALTITUDE HOLD
  - ALTITUDE SELECT
- VERTICAL NAVIGATION (VNAV)
- WINGS LEVEL
- HEADING HOLD
- HEADING SELECT
- NAVIGATION (NAV)
- APPROACH
  - GLIDESLOPE
  - LATERAL BEAM FOLLOWING

The navigation/flight planning function computes aircraft position with respect to an entered flight plan and data from the automatically tuned VOR/DME radio receivers. In the event of radio failure, dead-reckoning position (as determined from airspeed and heading) is estimated with respect to the entered flight plan.

DEMONSTRATION ADVANCED AVIONICS SYSTEM

NAVIGATION/FLIGHT PLANNING

- VOR/DME
- 10 WAYPOINT, 10 NAVAID STORAGE
- MOVING MAP DISPLAY
- PRESENT POSITION DIRECT TO DESTINATION CAPABILITY

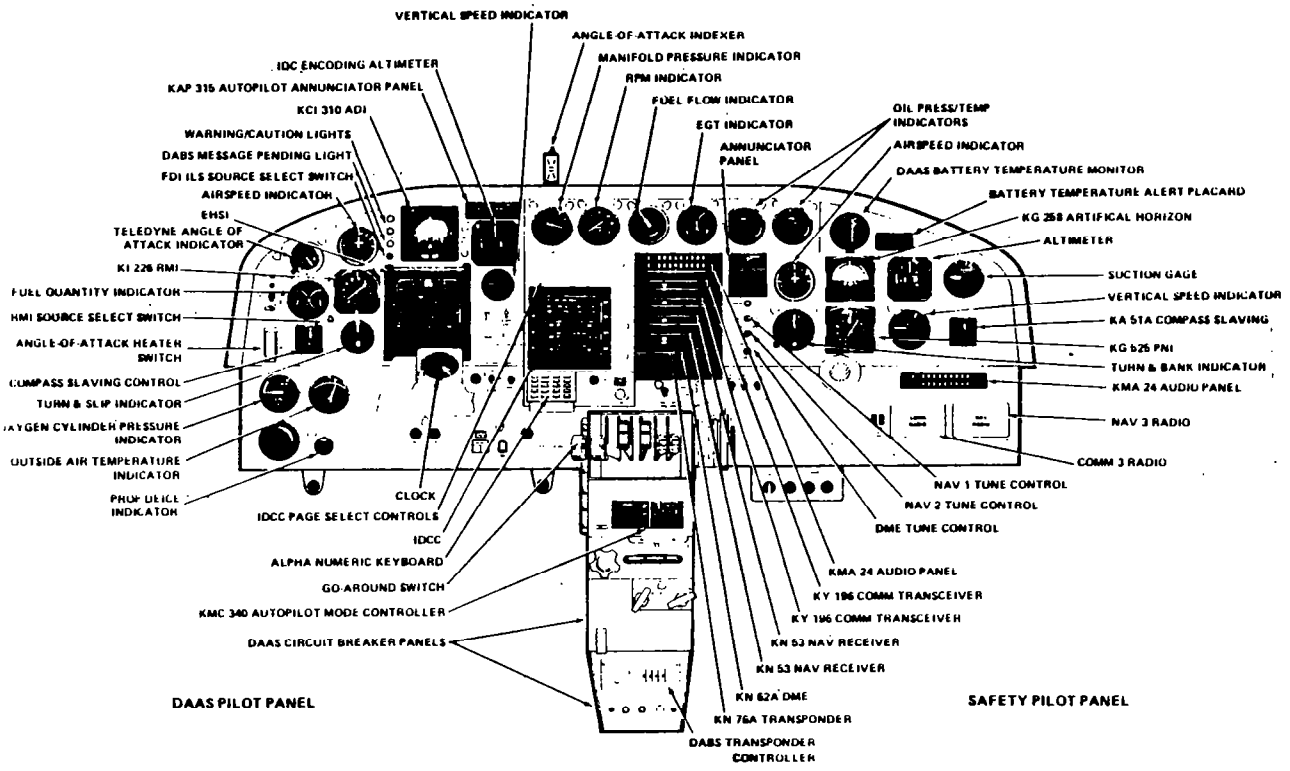
DAAS includes extensive monitoring, with warning capability. For example, the DAAS system monitors engine parameters (MAP, RPM), aircraft configuration (door open, gear retracted) with respect to flight condition and ground proximity and informs the pilot of undesirable situations.

DEMONSTRATION ADVANCED AVIONICS SYSTEM

ELEMENTS FLIGHT WARNING/ADVISORY FUNCTION

- ENGINE PARAMETER MONITORING, WARNING
- AIRCRAFT CONFIGURATION MONITORING, WARNING
- GROUND PROXIMITY MONITORING, WARNING
- AIRSPEED AND STALL MONITORING, WARNING
- ALTITUDE ADVISORY FUNCTION
- NAVAID IDENTIFICATION MONITORING, WARNING
- BUILT IN TEST, BIT
- AUTOPILOT/FLIGHT DIRECTOR MONITORING, WARNING
- OTHER

Shown below is the DAAS EHSI and IDCC, as well as other system components, as they appear in the Cessna 402 cockpit. The safety pilot instrument set is independent of the DAAS instruments and is adequate for safe flight with DAAS inoperative.



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Demonstration Advanced Avionics System (DAAS) Final Report. NASA CR-166281, January 1982.

AN OVERVIEW OF THE DEMONSTRATION ADVANCED AVIONICS SYSTEM GUEST PILOT EVALUATION CONDUCTED AT AMES RESEARCH CENTER

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NASA Ames Research Center
Moffett Field, California

ABSTRACT

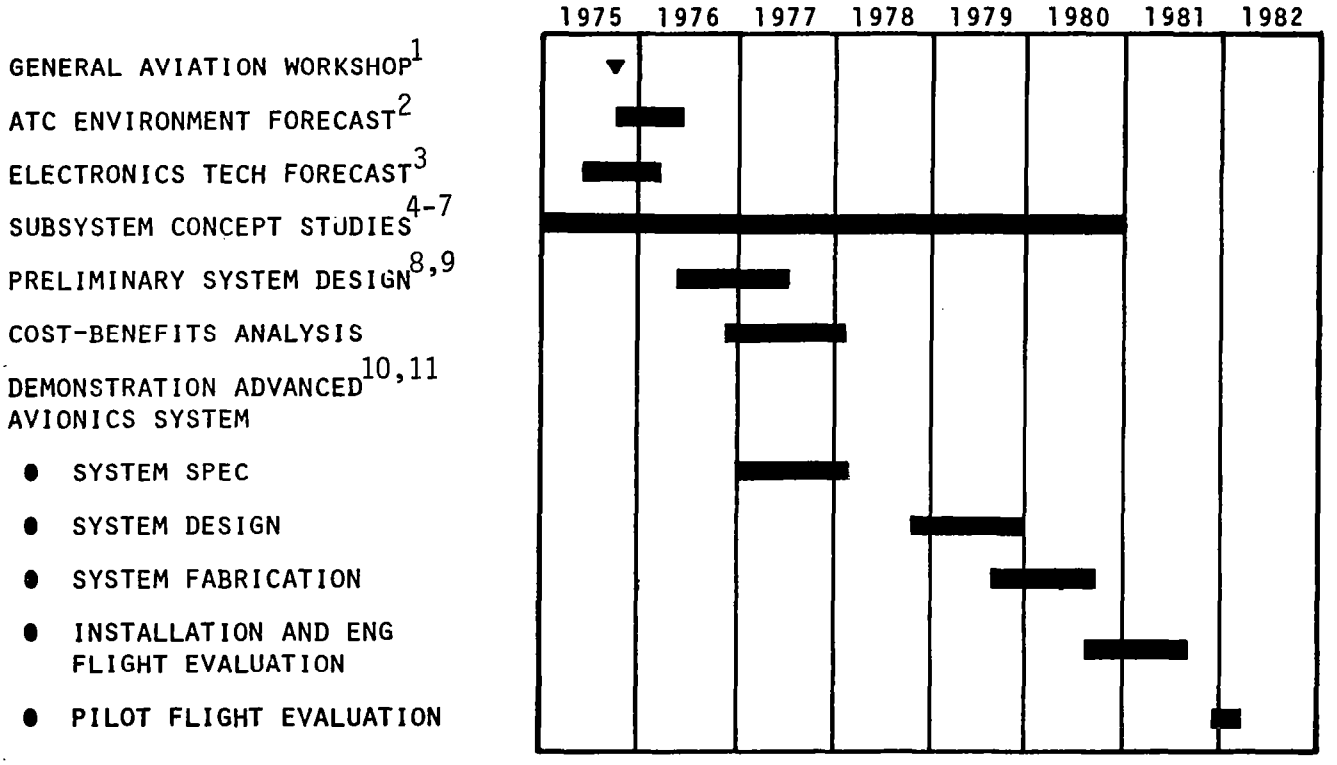
The Ames Research Center has recently completed a program which led to the development and flight evaluation in a Cessna 402 of a fully integrated, microprocessor based, digital avionics system referred to as DAAS. The program was initiated in 1975 in anticipation of an increasing dependence by general aviation on avionics and the supposition that the corresponding increase in their cost and complexity could potentially be offset by the introduction of fully integrated systems. The program objective was to provide information required for the design of reliable integrated avionics that would enhance the utility and safety of general aviation at a cost commensurate with the general aviation market.

DAAS integrates most general aviation present and projected avionic requirements into a single system. It includes the basic flight control and navigation functions as well as more novel capabilities such as flight planning; computerized performance and weight and balance functions; stored checklists; engine and aircraft configuration monitoring and warning capabilities; built-in test; and a simulation mode for pilot training. The DAAS system utilizes a distributed microprocessor architecture with shared electronic displays, and a complete set of navigation and aircraft sensors. All processing, display, and sensor resources are interconnected by a standard bus to enhance overall system effectiveness, modularity, reliability, and maintainability.

This paper describes the guest pilot flight evaluation of the DAAS. The results are based on the fifty-nine questionnaires that were completed by the participants.

PROGRAM OVERVIEW

The major elements of the General Aviation Advanced Avionics Systems Technology Program are contained in the program overview chart. The program was initiated in 1975 and completed in April 1982. Reports resulting from each of these elements are listed in the references. The program culminated in the design and flight test of the Demonstration Advanced Avionics System (DAAS). In this presentation, the results of the pilot flight evaluation are summarized.



PILOT FLIGHT EVALUATION

The primary purpose of the pilot evaluation was to expose the Demonstration Advanced Avionics System to the various segments of the general aviation community and solicit comments in order to determine the effectiveness of integrated avionics for general aviation. The figure lists the segments of the community that were represented in the evaluation. A total of sixty-four (64) flights were conducted in which one hundred and seventeen (117) pilots and observers participated.

GUEST PILOT EVALUATION PARTICIPANTS

- AIRFRAME COMPANIES
- AVIONICS COMPANIES
- FIXED BASE OPERATORS
- UNIVERSITIES
- MAGAZINE EDITORS
- GOVERNMENT ORGANIZATIONS (NASA-FAA-DOD)

64 EVALUATION FLIGHTS

117 PILOTS AND OBSERVERS

FLIGHT EVALUATION AGENDA

A typical flight evaluation included a review of the DAAS that lasted two to three hours, an hour-long simulation in the DAAS aircraft exercising the DAAS functions and reviewing the flight scenario, a 75-minute flight, and a debriefing usually lasting about one hour. At the conclusion of the debriefing the subject was given a questionnaire that was to be completed at a later time and returned. The results presented in this paper are from the fifty-nine questionnaires that were returned.

• REVIEW OF THE DAAS FUNCTION	≈ 2 HOURS
• GROUND DEMONSTRATION/SIMULATION	1 HOUR
• EVALUATION FLIGHT	1 HOUR 15 MINUTES
• POST FLIGHT DEBRIEFING	≈ 1 HOUR
• QUESTIONNAIRE	

FLIGHT SCENARIO

The flights originated at Moffett Field which is at the south end of the San Francisco Bay and proceeded to Salinas which is located in the Salinas Valley about 12 miles from Monterey Bay. The standard instrument departure was followed leaving Moffett Field, and except for take-off and landing the DAAS provided all of the steering commands for the entire flight.

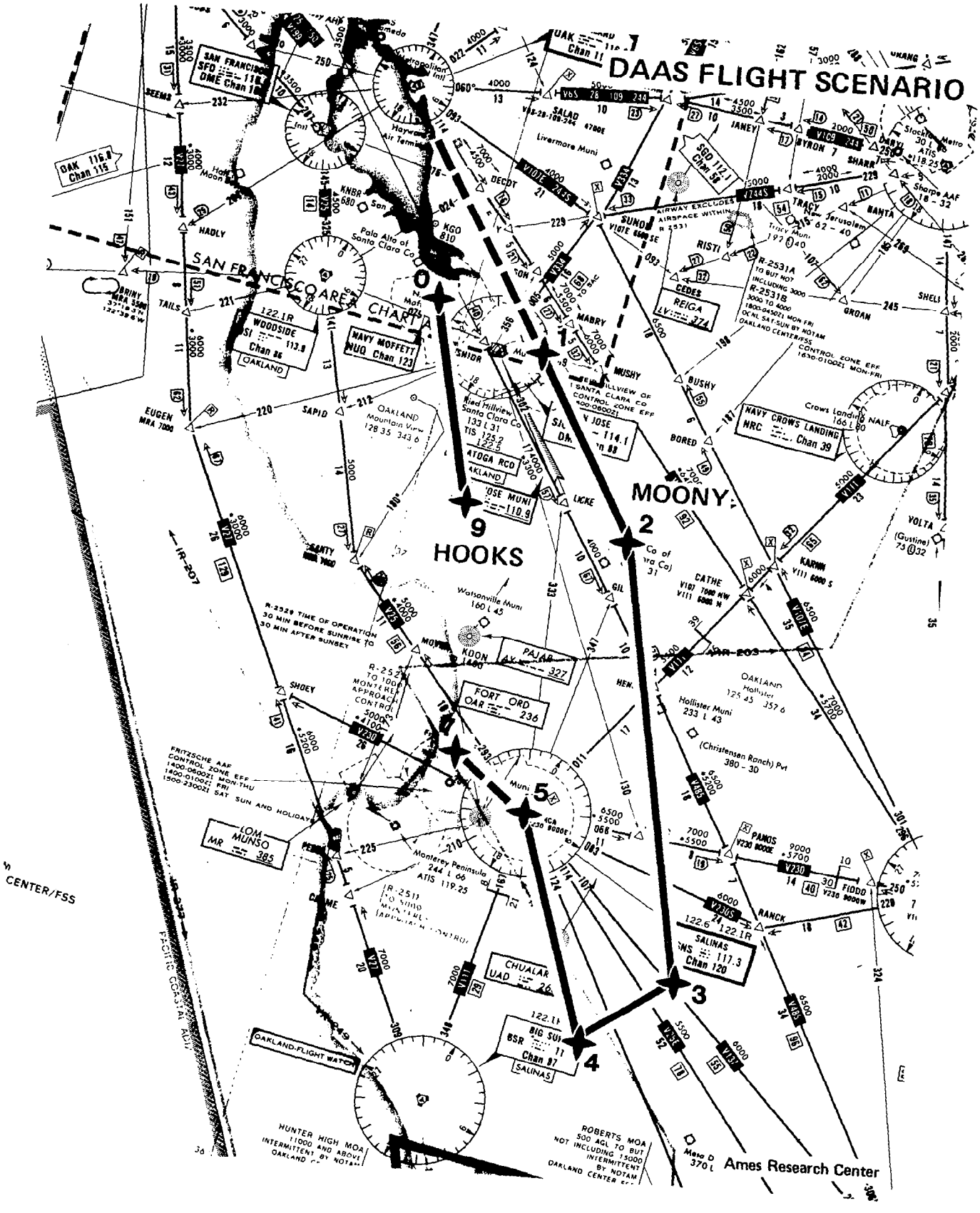
The waypoints were defined at key intersections enroute to Salinas and back to Moffett. Waypoints 6 and 8 are not labeled on the map. Waypoint 6 (WP6) is the Salinas ILS which is marked on the map by the Salinas VOR which was stored as WP5. WP8 was left blank in the flight plan so that the waypoint generate feature of the map edit page could be exercised. The long leg between WP2 and WP3 allowed the pilot ample time to exercise the flight planning and performance functions. The leg between WP3 and WP4 was used to set up the intercept to the Salinas ILS in order to demonstrate the EHSI display in the ILS mode as well as the autopilot/flight director performance during the missed approach at Salinas.

After the missed approach and before reaching the missed approach point, WP7, two additional map edit features were demonstrated. The first was the "waypoint present position" which moved WP7 under the aircraft, and the second was the "waypoint generate" feature which inserted WP8 between waypoints 7 and 9.

Once WP8 was defined, the map cursor feature was used to move it to the left several miles to avoid a simulated storm cell that could be shown on the EHSI had a radar system been included as part of the DAAS.

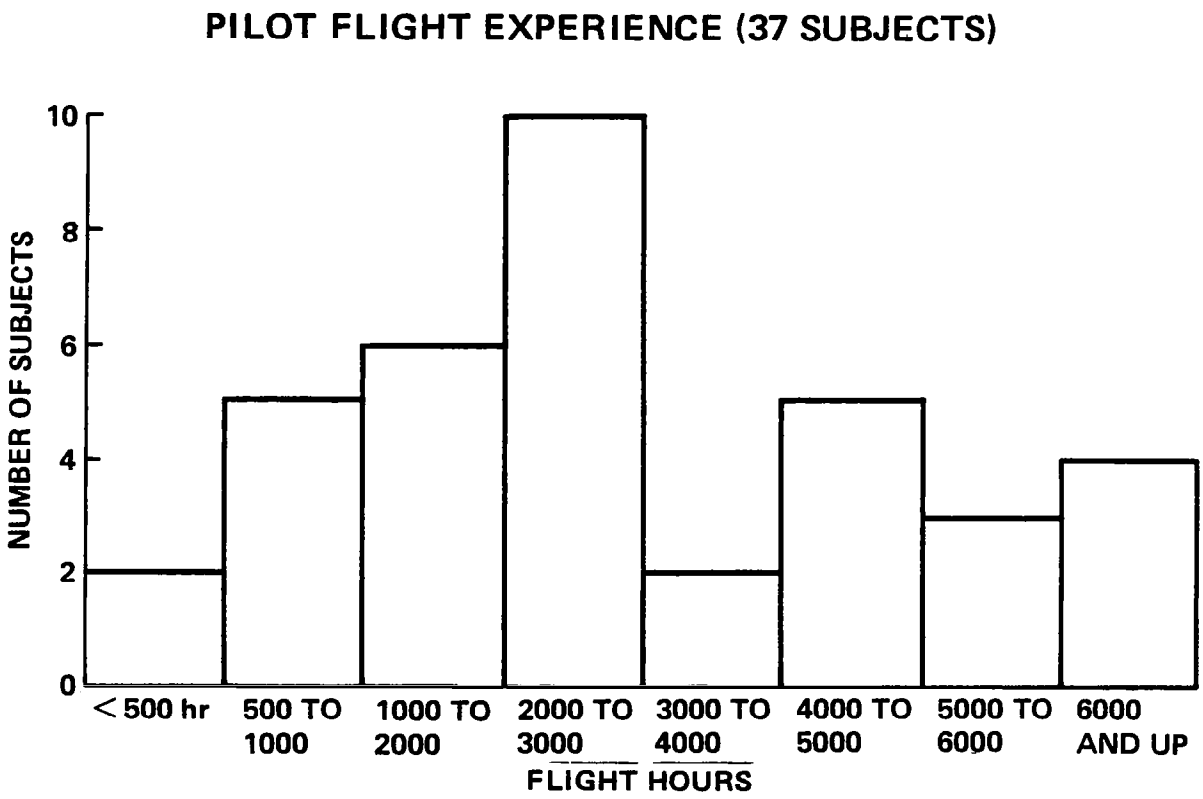
At WP9 the vertical navigation feature of the autopilot was demonstrated by making a coupled VNAV approach into Moffett. After landing and before system shutdown, the DAAS reconfiguration feature was demonstrated.

The DAAS flight scenario was designed to demonstrate most of the key flight functions. Those functions not used in flight, such as the Built-In Test function, or the Discrete Address Beacon System (DABS or Mode S), were demonstrated using the simulation function.


DAAS FLIGHT SCENARIO
SAN FRANCISCO AREA CHART
0
1
2
3
4
5
9
HOOKS
MOONY
Ames Research Center

PILOT FLIGHT EXPERIENCE

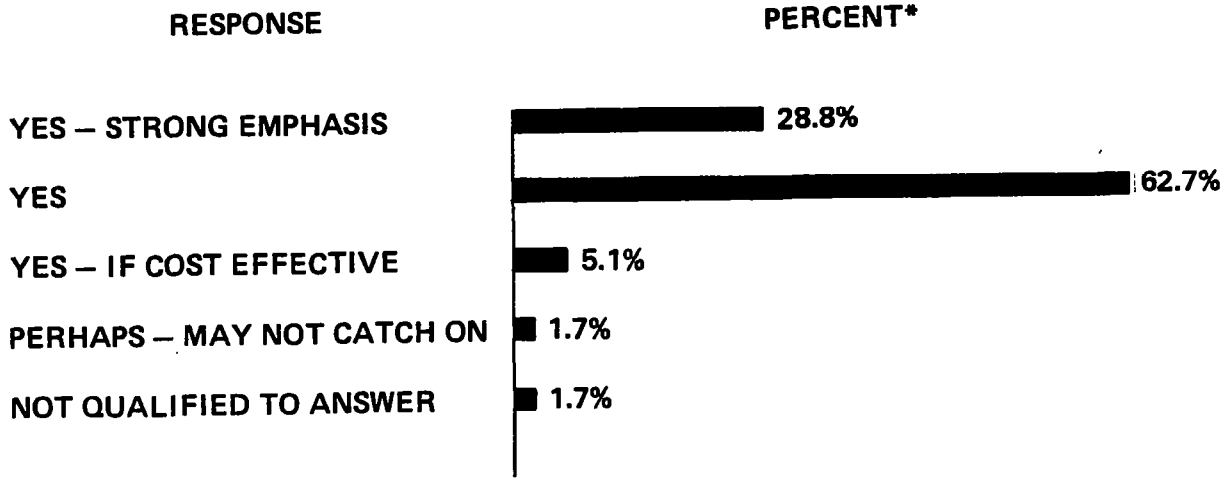
The experience levels of the pilots who participated in the test are summarized below. Of the 37 respondents who listed their experience, 28 had more than 50 hours of instrument experience.



QUESTIONNAIRE RESPONSE

QUESTION 1: DO YOU FEEL THE DAAS CONCEPT REPRESENTS THE DIRECTION THAT FUTURE GUIDANCE, NAVIGATION AND FLIGHT MANAGEMENT SYSTEMS WILL EVOLVE?

The responses to the question are ordered with the highest level of agreement at the top decending to the lowest level with (in this case) one subject (1.7%) at the bottom who felt unqualified to answer. The responses given in the left column summarize the questionnaire responses of the 59 subjects. The results indicate that nearly everyone thought that the DAAS concept or something similar is the direction of future general aviation systems. Three subjects were concerned with the cost effectiveness.

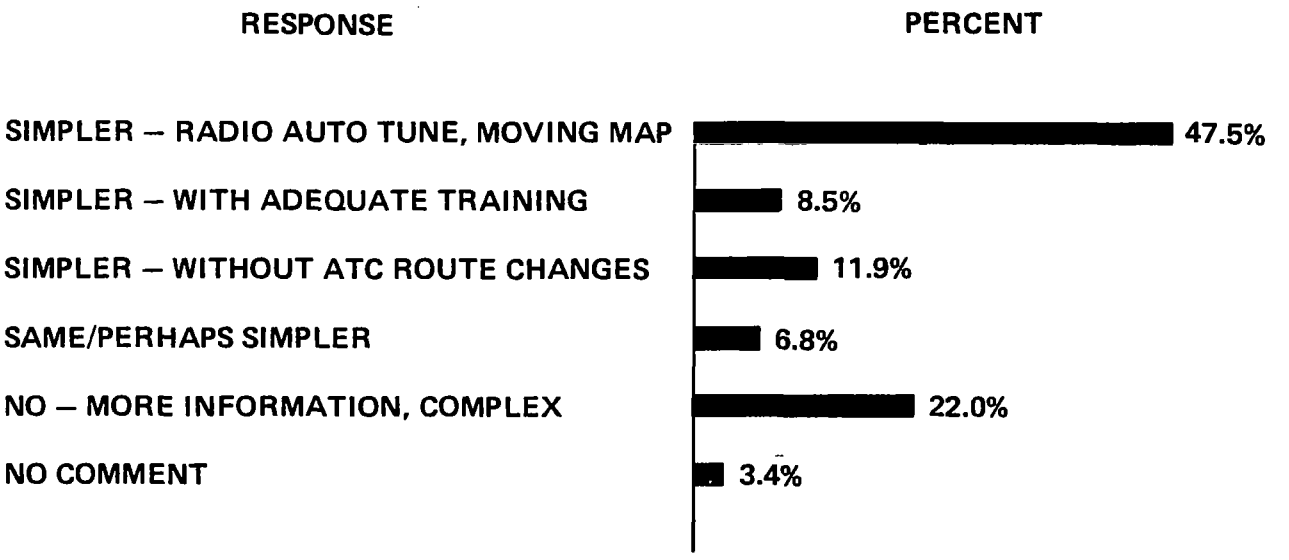


*RESULTS FROM 59 QUESTIONNAIRES

QUESTIONNAIRE RESPONSE

QUESTION 2: DO YOU FEEL THAT WITH ADEQUATE TRAINING THE DAAS SYSTEM WOULD BE SIMPLER OR LESS COMPLEX TO USE THAN THE CONVENTIONAL SUITE OF AVIONICS FOR IFR FLIGHT?

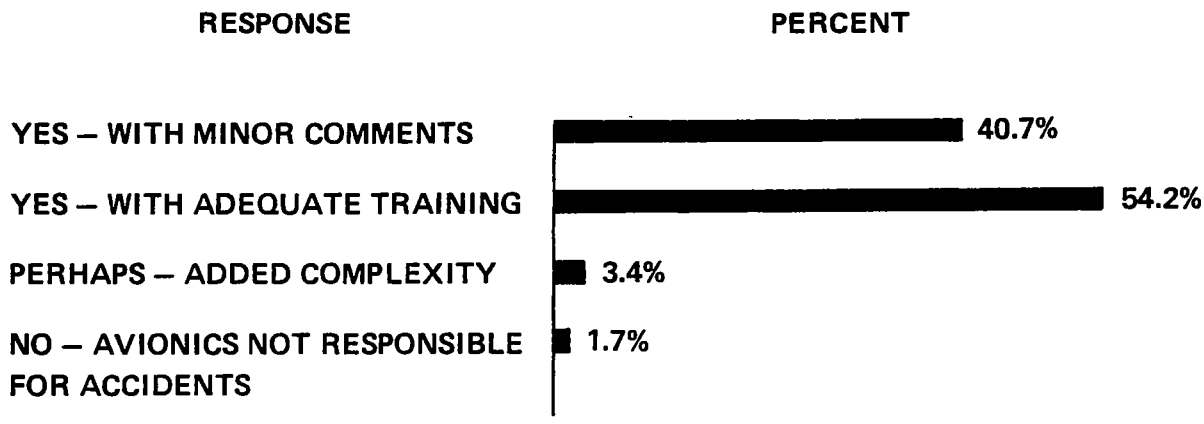
Nearly half the subjects responded with "simpler" or "simpler with some particular feature such as radio auto tune or the map display being primarily responsible". These subjects were followed by about 9% who had concerns about training level. Twelve percent thought the system would be simpler as long as there were no ATC route changes. Over 20% felt that it would be less simple or more complex because of the greater amount of information and modes available to the pilot.



QUESTIONNAIRE RESPONSE

QUESTION 3: DO YOU FEEL THE FUNCTIONAL CAPABILITY PROVIDED BY DAAS COULD ENHANCE SAFETY?

About 40% of the subjects responded "yes" because of certain features such as the map, the weight and balance function, the check-lists, the performance and flight status functions, or the built-in test function. Over 50% thought adequate training was a prerequisite. Two subjects (3.4%) were neutral, feeling that the added complexity might override the other system advantages. One subject felt that avionic systems were not responsible for most accidents and therefore would have a minimal impact on safety.

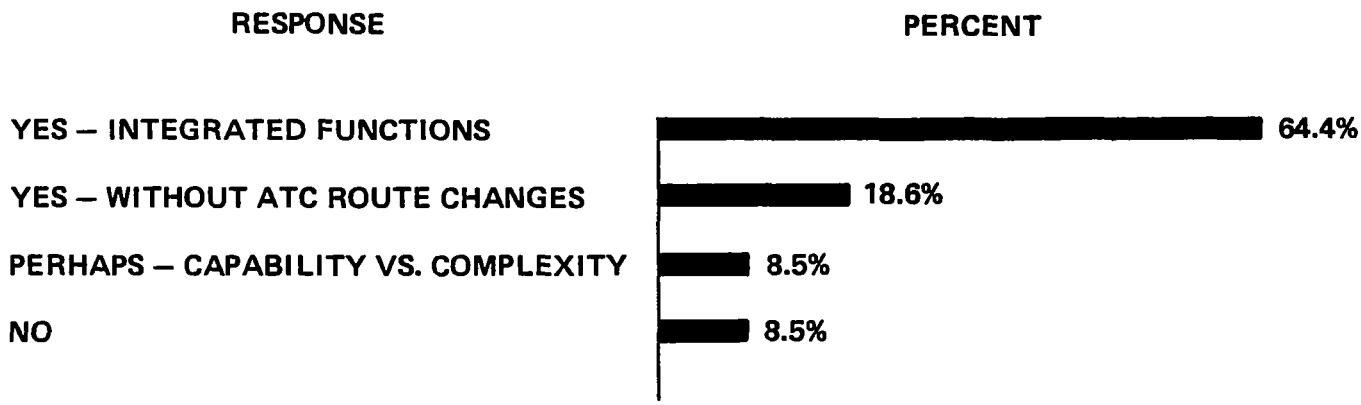


QUESTIONNAIRE RESPONSE

QUESTION 4: DO YOU FEEL THAT THE FUNCTIONAL CAPABILITY PROVIDED BY DAAS WOULD REDUCE PILOT WORKLOAD IN HIGH DENSITY IFR CONDITIONS?

About 65% of the subjects responded "yes" and indicated the feature that in their opinion reduced the workload. Typical were the map, the flight status and the flight warning functions. About 19% responded "yes" provided there were no ATC route changes. Five subjects (8.5%) felt the added capability might be offset by the increased complexity, and another 5 subjects responded "no" either because the configuration was cumbersome or because the existing avionics have been optimized for the present ATC system.

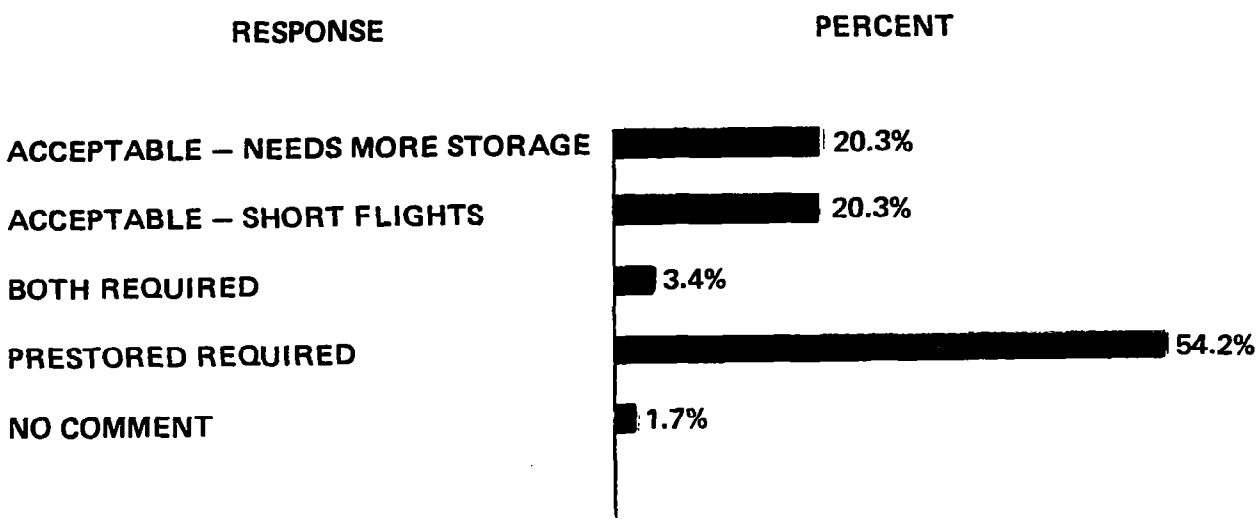
One function that was not mentioned in the questionnaire was the Discrete Address Beacon System (DABS) function. There was almost universal agreement that a data link system will significantly reduce pilot workload especially when used in conjunction with an integrated system such as DAAS. During the debriefings several subjects suggested that the DABS data link could provide the capability to transfer an ATC clearance directly from the DABS receiver into the navigation/flight planning function.



QUESTIONNAIRE RESPONSE

QUESTION 5: DO YOU FEEL THAT MANUAL ENTRY OF THE NAV-AID DATA IS ACCEPTABLE OR IS A PRESTORED DATA BASE REQUIRED?

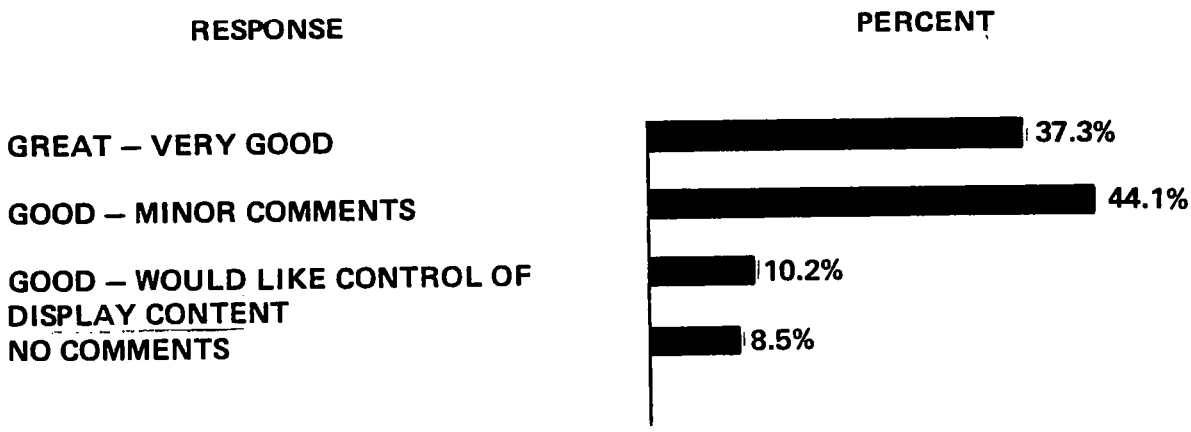
Nearly 40% of the responses indicated it was "acceptable", but preferred that the system have more NAV-AID and WP storage capability. About 55% (32 subjects) felt that an automated entry of NAV-AID data through a tape or disk would be preferred.



QUESTIONNAIRE RESPONSE

QUESTION 6a: WHAT COMMENTS DO YOU HAVE REGARDING THE HORIZONTAL SITUATION INDICATOR, EHSI?

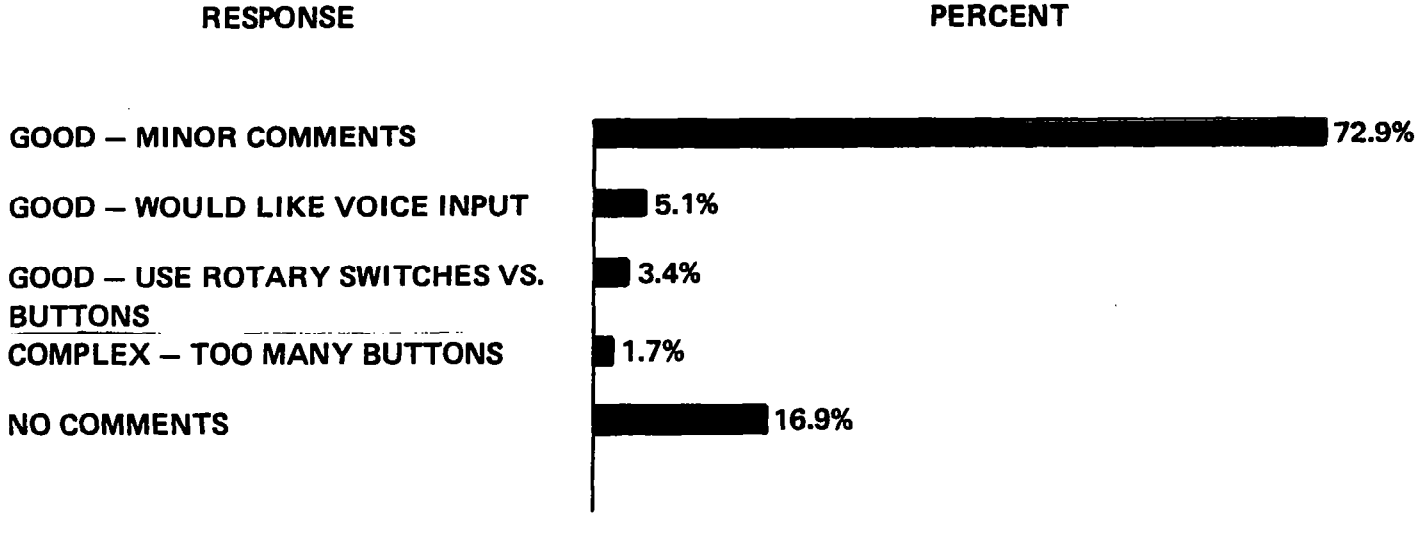
Nearly 40% gave it an unqualified "great or very good" while 44% (26 subjects) felt it was good but needed improvements such as color, better ILS presentation, different map scales, etc. Ten percent would like to control the display format with, for example, a declutter mode. Five subjects (8.5%) made no comments.



QUESTIONNAIRE RESPONSE

QUESTION 6b: WHAT COMMENTS DO YOU HAVE REGARDING THE INTEGRATED DATA CONTROL CENTER, IDCC?

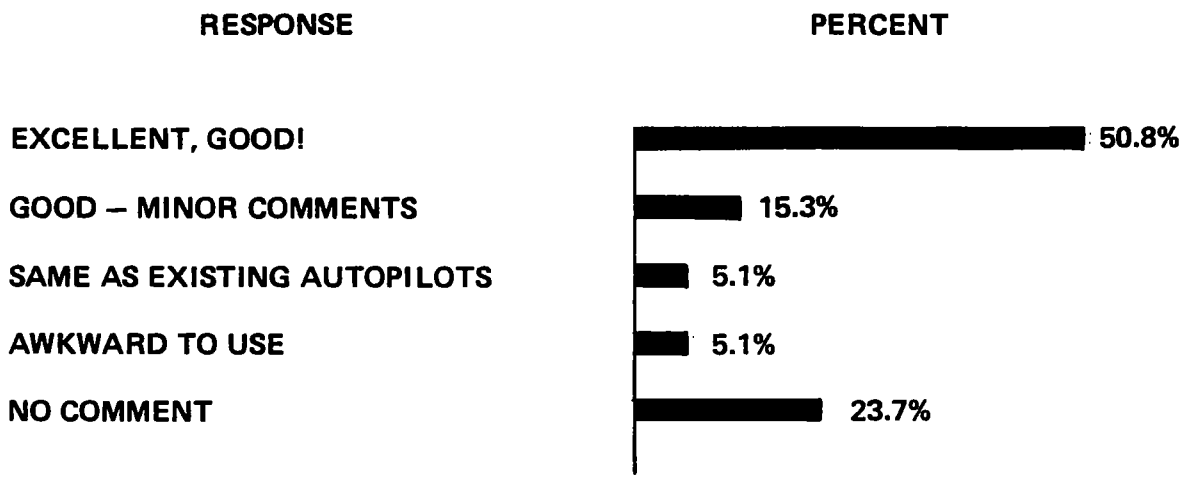
The first response group, 73%, felt it was good but needed some improvements. Some of the comments included: "needs better tactile feel on buttons", "color might help", "reduce parallax", etc. Three subjects (5.1%) suggested voice input while two subjects (3.1%) felt rotary switches would be better than push buttons. One subject felt there were far too many buttons while 10 subjects (16.9%) made no comments.



QUESTIONNAIRE RESPONSE

QUESTION 6c: WHAT COMMENTS DO YOU HAVE REGARDING THE AUTOPILOT FUNCTIONS?

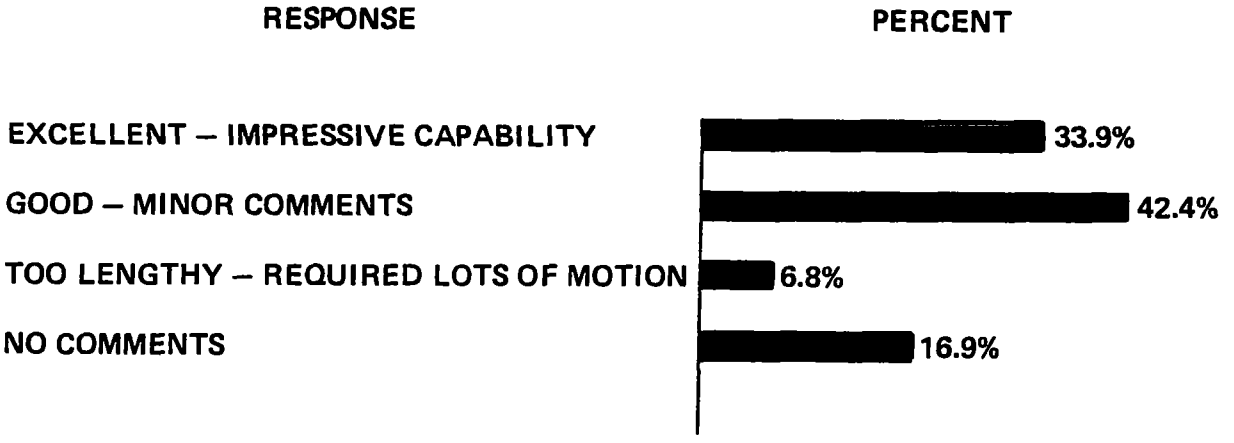
The first two response groups, nearly 66%, felt it was "Excellent" or "Good", listing some minor comment. Three subjects (5.1%) felt it was similar to existing autopilots, and another three subjects felt it was awkward to use principally because the mode enunciation was remote from the mode select keys. Fourteen subjects (24%) made no comments.



QUESTIONNAIRE RESPONSE

QUESTION 6d: WHAT COMMENTS DO YOU HAVE REGARDING THE NAVIGATION/FLIGHT PLANNING FUNCTION?

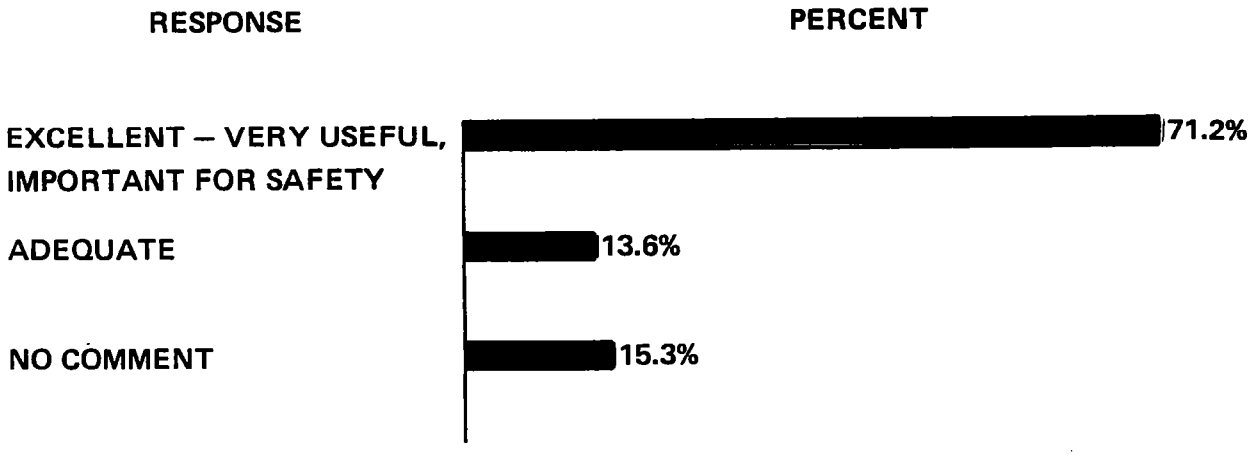
The first response group, nearly 34%, felt that it was "Excellent" and gave the pilot an impressive capability. The second group, nearly 42%, felt it was good but suggested changes such as a dedicated altitude preselect display, an automatic data base, etc. Four subjects (6.8%) felt the function was too lengthy or required excessive motion. Ten subjects (16.9%) made no comments.



QUESTIONNAIRE RESPONSE

QUESTION 6e: WHAT COMMENTS DO YOU HAVE REGARDING THE WEIGHT AND BALANCE FUNCTION?

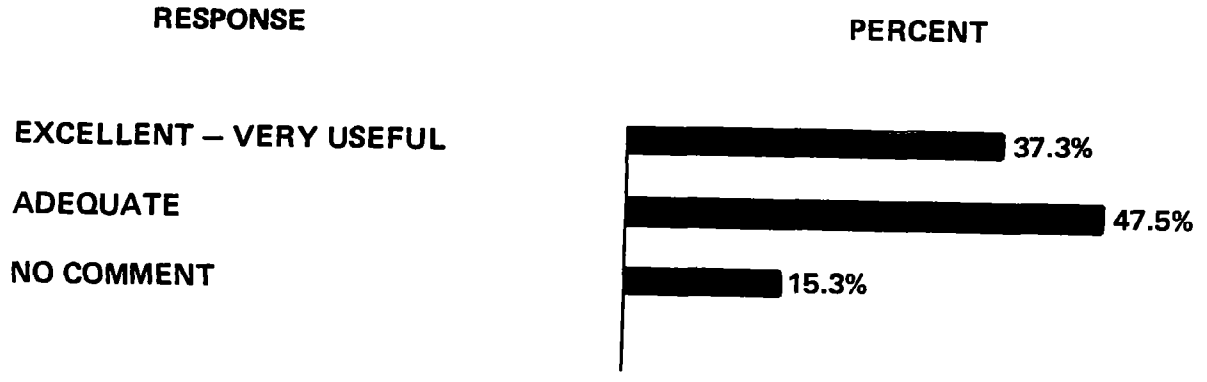
Everyone who responded felt positive about this function. Nine subjects (15.3%) made no comment.



QUESTIONNAIRE RESPONSE

QUESTION 6f: WHAT COMMENTS DO YOU HAVE REGARDING THE PERFORMANCE FUNCTIONS?

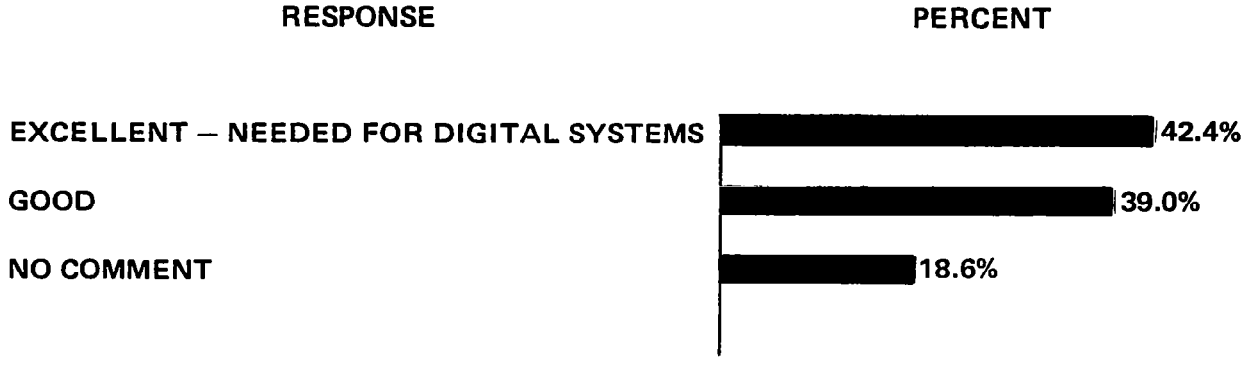
Nearly 40% responded with an "excellent" and commented that it was "very useful". About 48% felt that the function was "adequate" or a "nice" feature. Nine subjects (15.3%) made no comments.



QUESTIONNAIRE RESPONSE

QUESTION 6g: WHAT COMMENTS DO YOU HAVE REGARDING THE BUILT-IN TEST (BIT) FUNCTION?

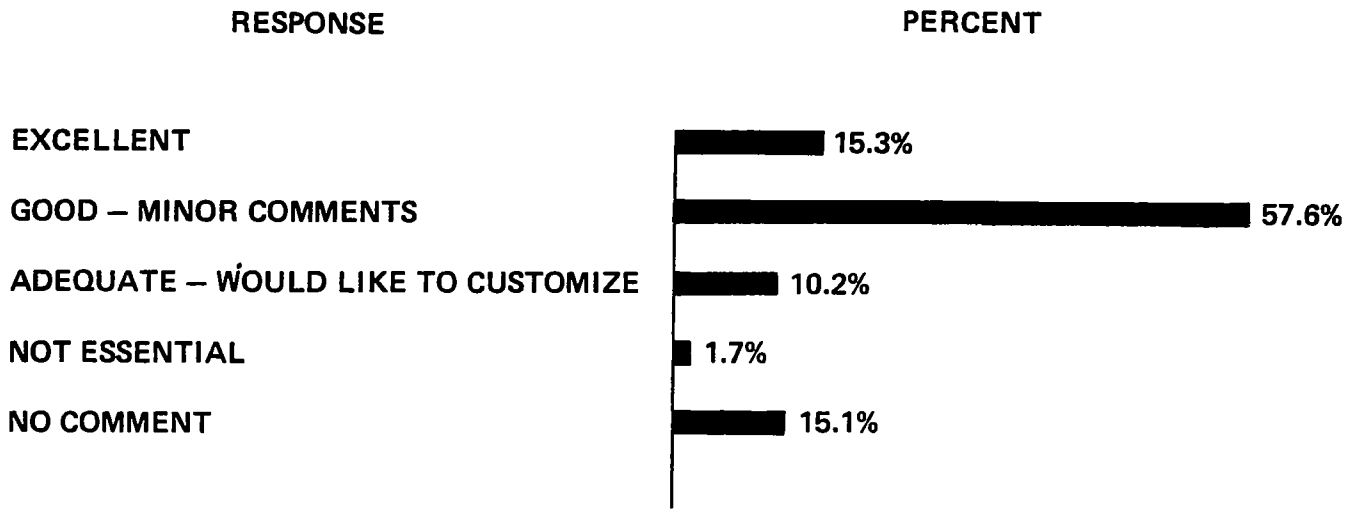
Over 40% responded with an "Excellent" and indicated that BIT was needed in a digital system. Nearly 40% felt that it was "Good", "Complete", or "OK". Eleven subjects made no comment.



QUESTIONNAIRE RESPONSE

QUESTION 6h: WHAT COMMENTS DO YOU HAVE REGARDING THE CHECK-LIST FUNCTION?

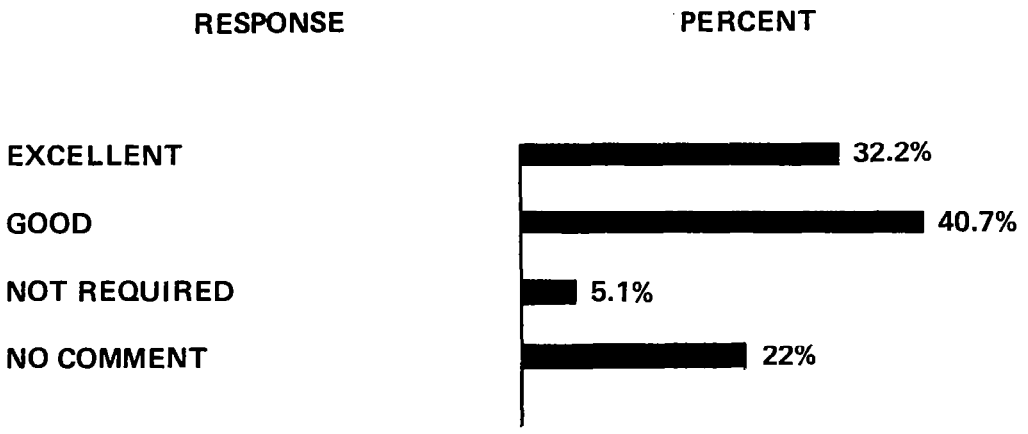
The first three response groups, nearly 50%, responded positively. Six subjects, about 10%, would like to customize the check-list, and one subject (1.7%) felt check-lists were not essential. Nine subjects (15.1%) made no comment.



QUESTIONNAIRE RESPONSE

QUESTION 6i: WHAT COMMENTS DO YOU HAVE REGARDING THE GROUND SIMULATION FUNCTION?

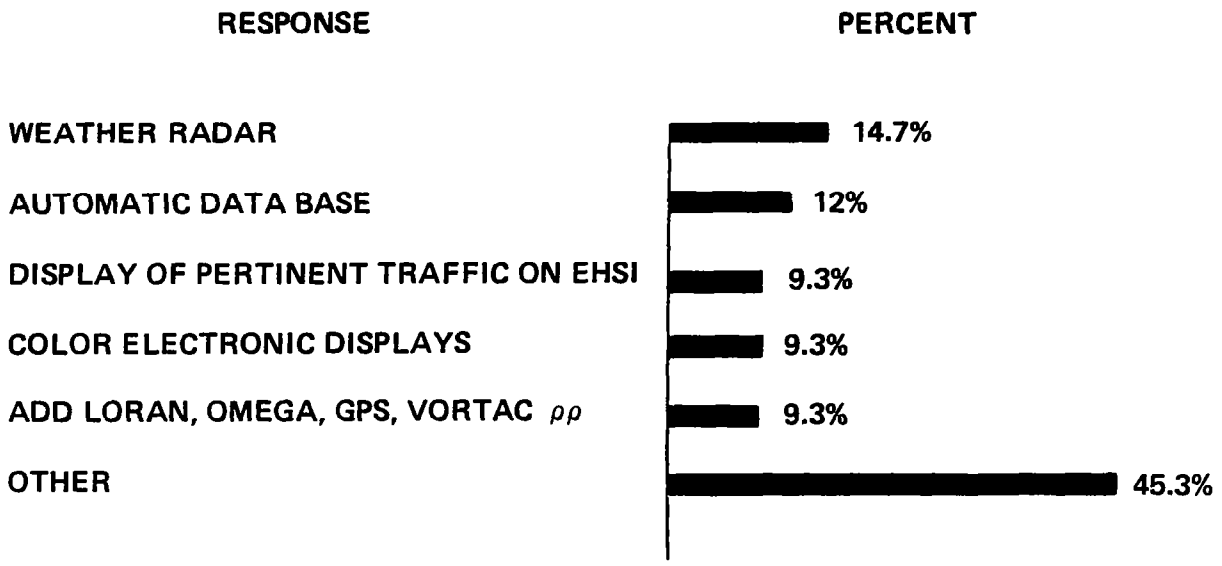
Nearly 73% responded with either "Excellent" or "Good". Some felt that this function should be part of a product system and others felt it could satisfy currency requirements for IFR flight and be cost effective. Three subjects (5.1%) felt the function was not required and 13 subjects (22%) made no comment.



QUESTIONNAIRE RESPONSE

QUESTION 7: DO YOU FEEL THERE ARE ANY OTHER CAPABILITIES THAT SHOULD BE INCLUDE IN A DAAS TYPE SYSTEM TO IMPROVE THE OVERALL SYSTEM EFFECTIVENESS?

In 59 questionnaires there were seventy-five responses with 27 different ideas. The 5 most common suggestions are summarized below. The most popular response (15%) felt the addition of weather radar on the EHSI was most desirable, while 12% felt that the automatic data base would improve system effectiveness. The next three response groups each had 4 subjects (9.3%) and felt that the display of pertinent traffic on the EHSI, color electronic displays, or the addition navigational receivers for LORAN, OMEGA, GPS or VORTAC, would improve system effectiveness. Of the remaining 45% of the suggestions, no one function was mentioned by more than three subjects.



PILOT EVALUATION CONCLUSIONS

The Demonstration Advanced Avionics System Program objectives were accomplished. Most of the responses from the questionnaire indicated that future systems will resemble the DAAS. The DAAS architecture and functions were adequate to demonstrate the benefits of integration. The integrated functions could reduce pilot workload and enhance safety. The elements or functions the respondents felt most useful were: (1) the electronic map, EHSI, (2) the autopilot, (3) the Navigation/Flight Planning Function, (4) the Weight and Balance Function, (5) the Built In Test (BIT) Function and (6) the Discrete Address Beacon System (Mode S Transponder).

The questionnaire responses indicated that the functional capability provided in the DAAS was adequate to demonstrate the program objectives and that the implementation was satisfactory for nearly all of the functions. It was felt that additional human engineering in the mechanical design would be required in a production system.

DAAS OBJECTIVES ACCOMPLISHED

- **RESPONDENTS FELT FUTURE SYSTEMS WILL RESEMBLE DAAS**
- **DAAS ARCHITECTURE AND FUNCTIONS WERE ADEQUATE TO DEMONSTRATE THE BENEFITS OF INTEGRATION**
- **DAAS INTEGRATED FUNCTIONS COULD REDUCE PILOT WORKLOAD AND ENHANCE SAFETY**
  - **ELECTRONIC MAP, EHSI**
  - **AUTO PILOT**
  - **NAVIGATION/FLIGHT PLANNING FUNCTION**
  - **WEIGHT AND BALANCE FUNCTION**
  - **BUILT-IN TEST FUNCTION, BIT**
  - **DISCRETE ADDRESS BEACON SYSTEM, (MODE S) FUNCTION**

RECOMMENDATIONS

It was felt that the exposure each subject had with the DAAS was too short to adequately assess the training requirements, pilot workload, and the reconfiguration concept of the DAAS. It is recommended that an operational evaluation of the DAAS be made to assess: (1) the training requirements for varying experience levels, (2) the pilot workload in the ATC environment with unplanned route changes, and (3) the viability of the reconfiguration concept for failures of the EHSI during various phases of flight.

OPERATIONAL EVALUATION OF DAAS TO ASSESS

- TRAINING REQUIREMENTS FOR VARYING EXPERIENCE LEVELS
- PILOT WORKLOAD IN ATC ENVIRONMENT REQUIRING ROUTE CHANGES
- RECONFIGURATION CONCEPT

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APPENDIX B

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APPENDIX C

ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

A/C	aircraft
ADF	automatic direction finder
ADI	attitude indicator
AFOS	automation of field operation and services
AIAA	American Institute of Aeronautics and Astronautics
APPR	approach
ASRS	Aviation Safety Reporting System
ATAS	Automatic Terminal Approach System
ATC	Air Traffic Control
ATIS	Automatic Terminal Information Service
ATP	Air Transport Pilot
BC	back course
BIT	built-in test
CC	central computer
CDI	Course Deviation Indicator
CIRC	circle
CFI	Commercial Flight Instructor
Comm	communication
CRT	cathode ray tube
CTOL	conventional takeoff and landing
CWS	control wheel streering
C-402	Cessna 402 aircraft
DAAS	Demonstration Advanced Avionics System/Digital Advanced Avionics System
DABS	Discrete Address Beacon System (Mode S)
DARE	Digital Avionics Research Equipment
DATCOM	data compendium
deg	degree
DIST	distance
DC	District of Columbia
DME	Distance Measuring Equipment

DoD	Department of Defense
DOF	degrees of freedom
DP	dual pilot
DPIFR	dual pilot IFR
EGT	exhaust gas temperature
EHSI	Electronic Horizontal Situation Indicator
FAA	Federal Aviation Administration
FAR	Federal Air Regulation
FBO	Fixed Base Operator
FCC	Federal Communication Commission
FDC	flight data console
FM	frequency modulation
FSS	flight service station
ft	feet
FY	fiscal year
GA	general aviation
GATOR	General Aviation Terminal Operations Research
GMT	Greenwich Meridian Time
GPS	Global Positioning Satellite
GS	glide slope
HAC	heading select with lateral nav coupler and altitude hold with vertical nav coupler
HC	heading select with lateral nav coupler
HM	hinge moment
HRS	hours
HS	heading select
HSI	Horizontal Situation Indicator
IA	Intelligent Autopilot
IDCC	Integrated Data Control Center
IFR	instrument flight rules
ILS	Instrument Landing System
IMC	instrument meteorological conditions
IR	infrared
IVSI	instantaneous vertical situation information
KIAS	knots indicated airspeed
KRC	King Radio Corporation

kts	knots
LaRC, LRC	Langley Research Center
LF	low frequency
Loc	localizer
Loc N.R.	localizer no rate
Loc W.R.	localizer with rate
LOM	locator outer marker
LORAN	long range navigation
m	meters
MAP	manifold air pressure
MDA	minimum decision altitude
MIN	minimums/minutes
MM	middle marker
Mode S	FAA data link
MVFR	marginal visual flight rules
NA	no autopilot
NASA	National Aeronautics and Space Administration
NAV	navigation/navigational
NDB	non-directional radio beacon
nm/n.mi./NM	nautical miles
NOTAM	notice to airmen
NTSB	National Transportation Safety Board
OM	outer marker
OMEGA	low-frequency radio range
PCTI	Pseudo Command Tracking Indicator
PIF	proportional-integral-filtered
PVT	private
rad	radians
RHO	VOR bearing angle
RMI	Radio Magnetic Indicator
RMS	root mean square
RNAV	area navigation
RND	around
RPM	revolutions per minute

SE	single engine
sec	seconds
SIDS	standard instrument departures
SP	single pilot
SPIFR	single pilot IFR
STAR	standard terminal arrival
STD	standard
Sub	subject
SVFR	special visual flight rule
TCA	Terminal Control Area
TCHDWN	touch down
TCV	Terminal Configured Vehicle
TE	trailing edge
Turb	turbulence
VLDS	Visual Landing Display System
VFR	visual flight rules
VNAV	vertical navigation
VOR	very high frequency omni range
VORTAC	VOR with tactical air navigation (TACAN)
VTOL	vertical takeoff and landing
Wx	weather
WL	wing leveler
WP	way point

SYMBOLS

a	dimensional constant
b	dimensional variable/constant
C_h	hinge moment coefficient
c	dimensional constant
$\bar{c}$	chord
d	dimensional constant
e	dimensional constant
F_s	stick force
G	gear ratio/gravitational force
g	dimensional constant/gravity
h	dimensional variable/altitude, m

K	spring constant
K_h, K_Y	pilot model gains, rad/m
K_θ, K_ϕ, K_ψ	pilot model gains, constant
ℓ_s	dimensional constant
p, q	pitch and roll angular rates, rad/sec
$\bar{q}$	dynamic pressure, psi
S	area of control surface
s	Laplace operator, per sec
V	velocity, m/sec
X_i, Y_i	inertial axes
Y	lateral distance, m
σ	angle of attack, rad
γ	flight path angle, rad
δ_e	elevator deflection, rad
θ, ϕ, ψ	Eulerian angles, rad
θ_A	pitch angle, deg
ϕ_b, ϕ_h	dimensional variables
ϕ_A	roll angle, deg
ψ_A	heading angle, deg

Subscripts:

A	aircraft
C	command
E	error

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16. Abstract

A workshop on controls, displays and information transfer for general aviation IFR operations, sponsored by NASA Langley, was held in Hampton, Virginia, August 30-31, 1982. The purpose of the workshop was to review and evaluate the work performed under the NASA Single Pilot IFR (SPIFR) program, to highlight and disseminate major research findings, and to provide a forum for industry, universities, and Government to interact and discuss the future thrust of research in the SPIFR program.

The first day consisted of selected presentations by NASA personnel on in-house studies and by industry and university personnel on work performed under contract or grant to NASA. The presentations represent key elements of the SPIFR program. These elements are classified in five disciplinary areas: problem definition; controls; displays; information transfer; and research simulation facilities. A forum, held on the second day, consisted of a general discussion of the research performed to date and the future thrust of the NASA SPIFR program.

A summary of the forum and copies of the materials used in the presentations are presented in this report.

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