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General Aviation IFR Operational Problems

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ABSTRACT

A detailed study of the operational problems of general aviation IFR operators (particularly single pilot operators) was performed. Several statistical bases were assembled and utilized to identify the more serious problems and to demonstrate their magnitude. These bases include official activity projections, historical accident data and delay data, among others. The GA operating environment and cockpit environment were analyzed in detail. Solutions to each of the problem areas identified are proposed which are based on direct consideration of currently planned enhancements to the ATC system, and on a realistic assessment of the present and future limitations of general aviation avionics. A coordinated set of research programs are suggested which would provide the developments necessary to implement the proposed solutions.

FOREWORD

This report presents the results of the study performed by Systems Control, Inc. (Vt), Champlain Technology Industries Division, under NASA Contract NAS1-15313. The study addresses the operational problems which face general aviation operators both now and in the future. The Technical Representative of the Contracting Officer is Mr. John Garren. The principal investigator for Systems Control was Mr. Eric H. Bolz. Ms. Janice E. Eisele provided analytical services in the areas of detailed flight event analysis and the evaluation of pilot workload and the GA cockpit environment.

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ABBREVIATIONS AND ACCRONYMS

A/C	Aircraft
ADF	Automatic Radio Direction Finding Equipment
AERA	Automated Enroute ATC
A/G	Air-to-Ground
AIM	Airmen's Information Manual
ARTCC	Air Route Traffic Control Center
ARTS	Automated Radar Terminal System
ASDE	Airport Surface Detection Equipment
ASTC	Airport Surface Traffic Control
ATARS	Automated Traffic Advisory and Resolution Service
ATIS	Automatic Terminal Information Service
ATC	Air Traffic Control
ATCRBS	Air Traffic Control Radar Beacon System
ATS	Automated Terminal Service
AWADS	Aviation Weather and Aeronautical Data System
AWES	Aviation Weather System
BCAS	Beacon Collision Avoidance System
CAS	Collision Avoidance System
CDTI	Cockpit Displayed Traffic Information
CFCF	Central Flow Control Facility
CIFRR	Common IFR Room (New York)
CMA	Control Message Automation
CONUS	Conterminous United States
CRT	Cathode Ray Tube
CW	Continuous Wave
DABS	Discrete Address Beacon System
DME	Distance Measuring Equipment
E&D	Engineering and Development
ETABS	Electronic Tabular Display System
FAA	Federal Aviation Administration
F&E	Facilities and Equipment
FAME	Final Approach Monitoring Equipment
FSS	Flight Service Station
G/A	Ground-to-Air
GA	General Aviation
GPS	Global Positioning System
HUD	Head-up Display
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
IPC	Intermittent Positive Control
LOC	Localizer
Loran-C	Long Range Navigation (version C)
M&S	Metering and Spacing
MEA	Minimum Enroute Altitude
MLS	Microwave Landing System
MSAW	Minimum Safe Altitude Warning
MTD	Moving Target Detection
NADIN	National Airspace Data Interchange Network

ABBREVIATIONS AND ACCRONYMS
(Continued)

NAFEC	National Aviation Facilities Experimental Center (FAA)
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NAVSTAR	Navigation Satellite Timing and Ranging GPS
NDB	Non-Directional Beacon
NTSB	National Transportation Safety Board
NWS	National Weather Service
OBS	Omni-Bearing Selector
OMEGA	A VLF Navigation System
OSEM	Office of Systems Engineering Management (FAA)
PIREP	Pilot Report
PSBT	Pilot Self Briefing Terminal
PWI	Proximity Warning Indicator
R&D	Research and Development
RNAV	Area Navigation
RVR	Runway Visual Range
RWD	Remote Weather Display
SCC	System Command Center (FAA)
SID	Standard Instrument Departure
SPIFR	Single Pilot IFR
STAR	Standard Terminal Arrival Route
TAGS	Tower Automated Ground Surveillance
TCA	Terminal Control Area
TIPS	Terminal Information Processing System
TIS	Terminal Information Service
TRACON	Terminal Radar Control
TRSB	Time-Referenced Scanning Beam MLS
TSD	Traffic Situation Display
T-VASI	"Tee" Visual Approach Slope Indicator
UG3RD	Upgraded Third Generation System
UHF	Ultra-High Frequency
UNICOM	Universal Communications Frequency
VASI	Visual Approach Slope Indicator
VFR	Visual Flight Rules
VHF	Very High Frequency
VICON	Visual Confirmation
VLF	Very low Frequency
VOR	VHF Omnidirectional Range
VORTAC	VOR/TACAN (Tactical Air Navigation)
WVAS	Wake Vortex Avoidance System

1.0 EXECUTIVE SUMMARY

1.1 INTRODUCTION

This report presents the results of a study of general aviation IFR operators, particularly single pilot operators. The study was concerned with the operational problems these operators face, both now and in the next ten to twenty years. The most serious and pressing problems have been identified, and are substantiated either using official statistics and projections, or through the use of detailed analysis of typical operations. Solutions to these operational problems have been identified. These solutions have been chosen from a pragmatic viewpoint, and each solution has been thoroughly analyzed to determine what factors stand in the way of its implementation. These factors are typically in the following categories:

- Lack the required technology
- Require development of new procedures
- Require refinement of methods and techniques
- Require that projected benefits be proven
- Are too expensive

The end product of this study is a defined set of research areas which must be pursued in order that the problem solutions may be implemented. The following sections present the organization and overall results of this study.

1.2 STUDY BACKGROUND

Sections 2 and 3 present the background material for the study. Section 2 presents the problems of GA IFR operators in the general sense, discussing:

- The parameters of GA IFR operators (Aircraft uses, aircraft types, avionics complements, the magnitude and projected growth of IFR flying, fleet growth).

- The operating environment of GA IFR operators
  (Terminal and enroute ATC, approach procedures, weather problems, delays encountered, concentration in metropolitan areas)
- The cockpit environment of GA IFR aircraft
  (Information requirements, control functions, avionics and instruments, workload and stress)
- The limitations of present avionics
  (Technology, ground and airborne system cost, operational limitations)

Section 3 presents the improvements to ATC and to other aspects of the National Aviation System which are planned or under study by the FAA. These include the now-classic "Upgraded Third Generation System" improvements as well as more recently developed ideas. Each of these features is introduced in some detail, but the objective of this section is to determine what, if any, effects, both positive and negative, these features will have in solving the operational problems of GA IFR operators. Each feature is examined in detail in Section 3.4 from this point of view; the findings served as direct inputs to the analysis of operational problems and development of solutions in the ensuing sections.

1.3 STUDY RESULTS

Section 4 presents results which were derived from detailed analyses of six typical single pilot IFR operations, or were derived from investigations of available statistics and projections. These data sources supported the selection of the twenty-one GA IFR operational problem areas, listed below, as being foremost in importance to GA IFR operators. These problem areas have been organized in four groups for convenience of discussion. As with all such groupings, there is a degree of overlap which is unavoidable. No particular order of priority is associated with the groupings themselves or within the groupings.

Table 1.1 GA IFR Operational Problem Areas

PILOT FACTORS:	SAFETY:
IFR Training Inadequacies	Maintaining Required Separation
High Workload in Critical Flight Phases	Weather-Related Accidents
High Workload in High Density Environments	Growing Airborne Alert Environment Complexity
Future Traffic Growth Rate in High Density Areas	Final Approach Accidents
Potential Workload Impacts of New ATC Features	COMMUNICATIONS:
Growing Vehicle Control Complexity	Communications Channel Congestion
MISSION RELIABILITY AND EFFICIENCY:	Communications Errors, Omissions and Dropouts
Flight Planning/Information Availability	Lack of Tower or Off-Hours Services
High Delays in Dense Terminal Areas	Access to Evolving Ground Data Bases
Lengthy Delays/Diversions in IMC	
Limited Availability of Landing Aids	
Routing Inefficiencies	
Enroute Weather Avoidance Delays	
Low Density Area Delays Due to lack of Tower	

It is apparent from a review of this list that it does not contain every conceivable GA operational problem. This stems from the attempt within this study to isolate the most important problem areas from the point of view of the typical GA IFR operator, especially those areas which can reasonably be expected to become worse over the next ten to twenty years.

In response to the problem areas identified, a set of twelve broad solution areas have been identified. These solutions have been selected in a process influenced by several basic factors:

- The ability (and shortcommings) of the planned enhancements to the ATC system to solve the GA operator's operational problems were directly considered.
- The eventual impact on user costs and overall "implementability" of a concept was seriously considered.
- No solution was rejected simply because one or more segments of the aviation community opposes its use; if a solution concept has merit, part of the problem of implementing it is to prove its value to all concerned.
- No solution was rejected due to apparent technical complexity if it appeared that the application of R&D resources to reduce the cost to the aircraft operator sufficiently constituted a reasonable risk.

Most of these solution areas are quite broad in scope. Specific hardware/software or procedures realizations within these areas are discussed in Section 5.1. The solution areas are as follows:

Table 1.2 Candidate Solution Areas

- Promote Aircraft/Powerplant Configuration Control and Display Integration
- Promote the Development of Collision Avoidance (CAS) and Proximity Warning Indicator (PWI) Systems
- Develop Concepts for the Distributed Management of Air Traffic Control and Associated Traffic Situation Display Devices
- Develop Concepts for Remote Cockpit Display of Ground-Derived Graphic Weather Data
- Assess the General Aviation Avionics Requirements to Support Ground/Air Data Link Functions
- Determine the Functional and Operational Requirements of Automated and Remote Air Traffic Control Towers
- Promote Development of Alternative, Low Cost Precision Landing Aids for General Aviation Airport Applications
- Foster the Usage of Wide Area Coverage Navigation Systems for Use as the Primary Aid for Non-Precision Approach Procedures
- Advance the Development of Head-up Displays (HUD), Visual Approach Slope Indicators (VASI) and Approach Monitor Concepts in General Aviation Operations
- Determine Methods to Enhance the Ability of the IFR Training Process to Prepare Pilots for Safer and More Expeditious Flight
- Develop Innovative Methods for Reorganizing and Improving Air/Ground Communications Procedures to Reduce Errors and Omissions and Pilot Workload
- Develop Methods for the Efficient Reorganization of Route Structures Including the Application of RNAV Techniques

Pursuant to the implementation of these solutions to the GA IFR operational problems, a set of sixteen research, simulation and test task areas have been identified which, if executed, would provide the technological basis for their successful implementation. These research areas are listed below in Table 1.3. They are explained in detail in Section 5.2. The relationships between the problems, solutions and research areas are illustrated in Table 1.4 (which is Table 5.1 repeated). The letters in that table correspond to the sixteen research areas in Table 1.3. As a

Table 1.3 Recommended Research Areas

A. Development of Technology for Integrated Configuration Control and Data Display Systems and for Multifunction Graphics Devices

B. Evaluation of Sensor Instrumentation and Display Factors Influencing the Design of Integrated Alert Systems or Subsystems

C. Identification of Operational Procedures or Automated Techniques for Resolving Conflicting Data Sources, Such as ATARS and CAS, in the Future Cockpit Environment

D. Development of Methods for Reorganizing Tasks Between the Pilot and the Controller, Particularly Considering an Environment with Traffic Situation Display and Other Enhancements

E. Determination of the Information, Data Rate, Format and Human Factors Requirements for General Aviation TSD-type Systems, and the Resulting Impact of TSD Design Parameters on Pilot Workload

F. Conduct of Operational Evaluations of Remote Weather Display and TSD Concepts

G. Investigation of Data Link Performance, Hardware Requirements and Technology Alternatives such That Remote Weather Display and Traffic Situation Display Systems may Properly Serve Pilot Information Needs

H. Reevaluation of the Role of Communications Data Links in the ATC Environment in Terms of Service Provided to GA Pilots and Impact on Frequency Congestion, Pilot and ATC Procedures, and Pilot Workload

I. Determination of Information Content and Communications Format Requirements of Automatic and Remote Towered Airports for Serving GA Operators and Resulting Impact on Procedures

J. Investigation of Candidate Alternative Low Cost Precision Approach Aids for Eventual Widespread Implementation at GA Airports

K. Assessment of Approach Monitor System Concepts and Determination of Human Perception Aspects and Required Characteristics of External Stimulus-Based Approach Monitor Systems

Table 1.3 Recommended Research Areas (Continued)

L.	Assessment of Functional Performance Requirements of Area Coverage Navigation Systems for Use as Non-Precision Landing Aids to Significantly Expand the Number of IFR-Capable Airports
M.	Establishment of Design and Performance Characteristics of GA HUD Systems
N.	Comprehensive Review of Pilot Training Requirements
O.	Redefinition of Cockpit and ATC Procedures Aimed at Communications Improvements and Pilot Workload Optimization During Critical Flight Phases
P.	Formulation of an Approach to Promote Travel Efficiency Through Route Structure Reorganization and Application of RNAV Techniques

summary of the types of research involved, Table 1.5 (Table 5.2 repeated) lists the tasks and the research tools involved in each task:

- Analysis
- Cockpit Simulation
- ATC Simulation
- Flight Test

1.4 SUMMARY OF CONCLUSIONS

Section 6 presents the general conclusions of this study. Due to the nature of this study, the specific conclusions and recommendations are actually the study results as expressed in Section 5. The major findings of this study relate to the seriousness of the GA IFR operator's problems and the effects that rapidly growing traffic demand, the planned enhancements to the ATC system, and potentially more restrictive airspace policies will have on mission reliability, safety and operational efficiency. The problems of either the aircraft operator or the low density airport operator in providing avionics and ATC improvements which would improve the situation while remaining economically feasible using today's technology and concepts are discussed. The final conclusion recommends that a comprehensive, well-planned attack on GA IFR operational problems should be executed in order to address the conceptual, technology and procedures issues.

2.0 STATEMENT OF THE PROBLEM

2.1 PARAMETERS OF GA IFR OPERATORS

The intent of this study is to address the problems of single-pilot IFR operators in the National Airspace System. It is instructive to establish a baseline set of parameters which describe these operators, the equipment they use and the purposes behind the operations of interest. Subsequent subsections will deal with the environment in which they operate, both internal and external to the cockpit, and the limitations of the ATC system (including related avionics) regarding their operational needs.

General aviation operators who are IFR-certified and regularly (but not always) file IFR flight plans are, in general, flying with a purpose other than the pleasure or challenge of the flight itself. Mission purposes include the following categories:

- Recreation (at the destination)
- Proficiency or Training
- Business
- Corporate Transport
- Transport for Hire

A major motivation towards becoming IFR-certified is to increase the reliability of being able to complete the objective of the mission (including return trip) in the alloted time. This is obviously important for the business, corporate and for-hire operator since the objective of the mission is typically to keep an appointment of some sort. Even for the recreational IFR operator, the ability to complete the flight and return within a time constraint is quite important, since only specific segments of time are available for recreational purposes. The concept of mission reliability is central to this study for two reasons. First, it is conceived by IFR operators as the most significant factor (other than safety) affecting the success of any given mission. Second, nearly all of the common operational and ATC problems typically encountered, directly impact reliability as manifested in delays, diversions and cancellations.

The ability to fly IFR greatly increases mission reliability over the VFR-only situation. However, many technical, operational and ATC related factors still limit the degree of mission reliability available. These factors are identified in sections which follow.

General aviation operators select their aircraft based on many criteria, the most important of which are load carrying capability and seating, cruise speed, IFR range, climb performance and cruise altitudes, field length requirements, lease or purchase cost and operating economy. Generally a compromise is struck between carrying capacity, speed, range and cost factors. Operators seeking greater speed, range and safety can elect retractable gear, twin engines, turbo-prop or turbo-jet capabilities (in order of increasing cost). Enhanced mission reliability may be obtained through selection of more complete avionics packages and de-icing boots, for example. Each one of these factors involves a very significant cost differential. In general, the difference in IFR capabilities and mission reliability between a well equipped turbine aircraft and a minimally-IFR single engine aircraft is quite significant. The scope of this study includes both the low and high ends of the GA cost/capability spectrum. However, primary attention is focused on the lower end (single engine and light twin) since their present capabilities are the most limited, their numbers are far greater, and improvements for them typically also improve the lot of the higher capability users.

2.1.1 Avionics Capabilities of GA Aircraft

The distribution of avionics capabilities among the basic types of aircraft and classes of operators is of interest here since it demonstrates the wide disparity in IFR capabilities, depending on the availability of funds for avionics. Funding availability can be measured (very roughly) in terms of basic aircraft value (single, twin, turboprop, turbojet) and primary usage (personal, business, executive, air taxi). Data is available from FAA aircraft registration files describing the avionics complement and primary usage of each aircraft, as reported by the owner. While the data is problematic in that avionics are sometimes inaccurately reported and owners often report multiple aircraft use categories, it has been found to be quite useful in other studies of avionics capabilities and requirements [1]. The avionics survey used in reference 1 has been reviewed and is summarized in the following figures.

Figure 2.1 illustrates the avionics breakdown for each basic class of aircraft: turbojet, turboprop, twin engine and single engine. (The multiple engine case includes light and medium twins -- heavy twins and four engine prop aircraft were excluded since their operations and usages are so unlike the light and medium twins, and since most are older aircraft which are being obsoleted by turbine aircraft.) To simplify the presentation, three broad avionics categories have been defined:

VFR:	Not equipped with the minimum avionics complement required for IFR flight.
Minimum IFR:	Equipped with VHF nav and comm capability. There is no indication in the registration data whether an aircraft is actually used in IFR operations, so many VFR craft are unavoidably included in this category.
IFR:	Equipped with greater than the minimum requirements, indicating a high probability of usage in IFR operations.

The last category (IFR) includes multiple VOR, VOR and DME, ADF, glideslope or long range navigation capability in addition to the basic nav and comm capability. The figure shows that the typical avionics complement of an aircraft is highly dependent on aircraft class. Virtually all turbojet and most turboprop aircraft are fully IFR-equipped. Even of the twins, 80% are IFR and and 16% more meet minimum IFR requirements. Only 4.5% fail to meet minimum IFR requirements. As would be expected, the percentage of single engine aircraft meeting the full IFR requirement is only 16.7%. However, the significant factor here is that since there are so many single engine aircraft, the number which are IFR (21271) actually <u>exceeds</u> the total of all twin and turbine aircraft which are likewise equipped (19172). The data from which these values (and the figures) are derived are listed in Table 2.1. While single engine IFR operations do not comprise the majority of IFR GA flying (see Table 2.2), their numbers are still significant. As shown in that table (for FY'71, reference 2), a total of 9523 IFR flights were conducted on the peak day in single or light and medium twin aircraft, or 83% of all GA IFR flights (26% of all IFR departures including air carrier).

Figure 2.1 also shows that an additional 58.2% of single engine aircraft are potentially capable of IFR operations, leaving only 25.1% which are definitely limited to VFR operations.

It is also instructive to examine the GA fleet from the point of view of primary use of each aircraft. As previously stated, this data is somewhat problematic since many owners report multiple use categories, although double counting was removed from the data base whenever possible. Figure 2.2 illustrates the breakdown of each aircraft class by use, and the results are not unexpected. Jet and turboprop aircraft are dominated by executive and business operations, while light and medium twins are used mainly (54%) for business purposes with the three remaining uses (executive, air taxi and personal use) tied at about

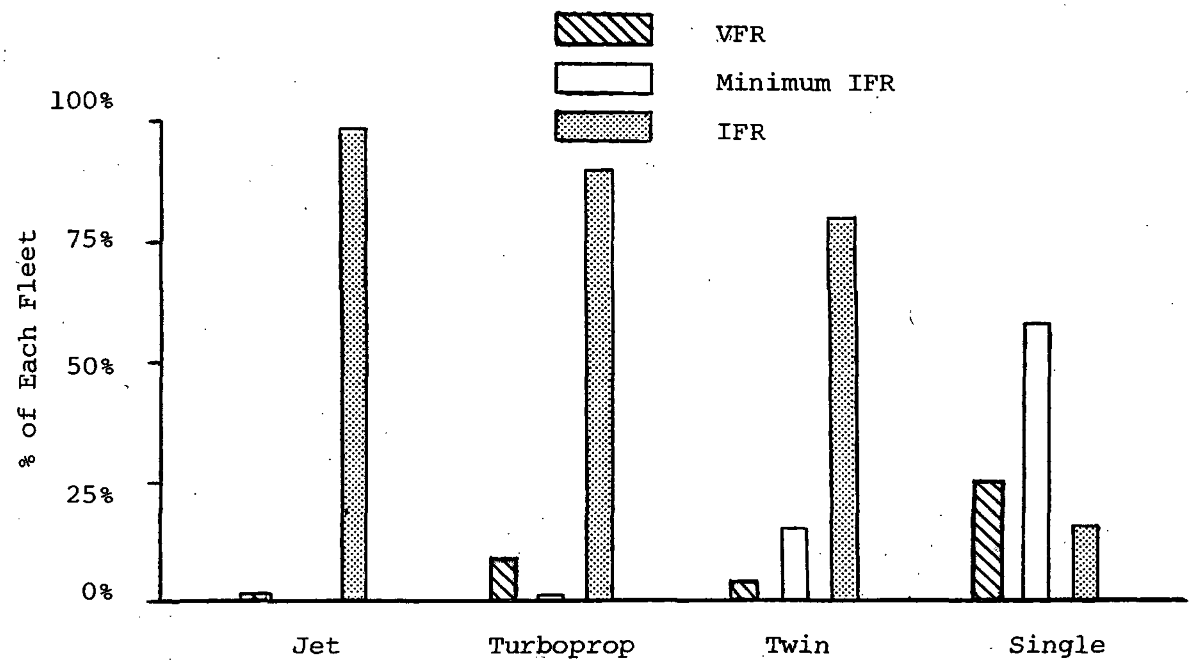


Figure 2.1 Basic Avionics Complement by Class of Aircraft

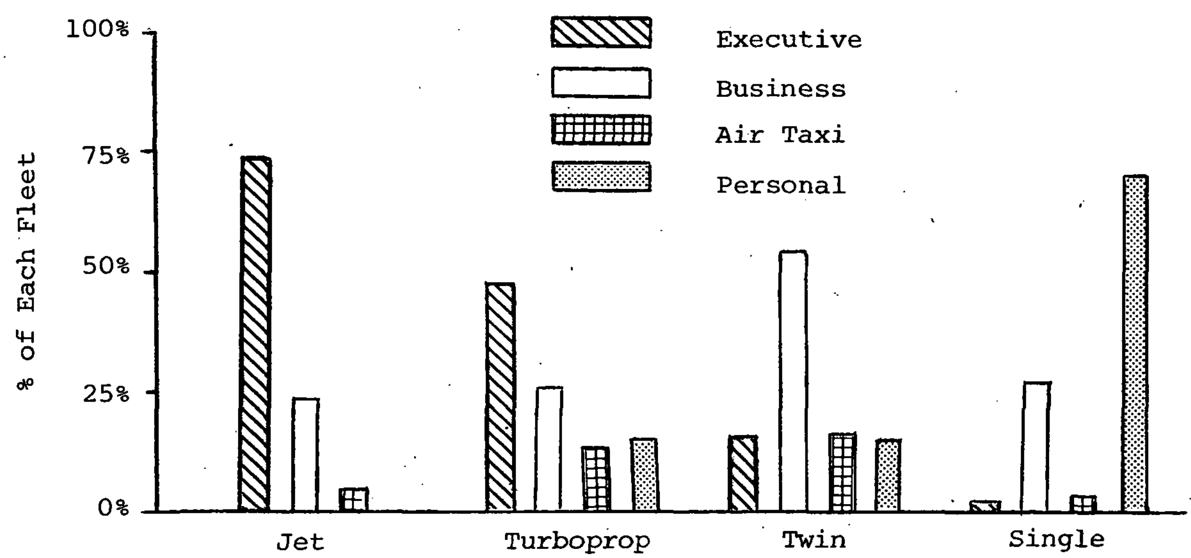


Figure 2.2 Primary Use by Class of Aircraft

Table 2.1 GA Fleet By Aircraft Type, Primary Use and Avionics

Primary Use	Jet	Turboprop	Twin	Single
Executive (Total)	1141	1179	2869	1088
IFR	1141	1133	2533	566
Minimum IFR	0	0	224	385
VFR	0	46	112	137
Business (Total)	358	651	10391	34089
IFR	336	651	8618	10025
Minimum IFR	0	0	1350	19518
VFR	22	0	423	4546
Air Taxi (Total)	67	322	3200	3651
IFR	67	322	2330	573
Minimum IFR	0	0	589	2828
VFR	0	0	281	250
Personal (Total)	0	357	2870	88047
IFR	0	161	1880	10107
Minimum IFR	0	29	934	51055
VFR	0	167	56	26885
Total	1566	2509	19330	126875

Table 2.2 Peak Day IFR Flight From Centers and Towers (FY1971)

Total	Single Engine		Multi-Engine		Turbine		Other
	1-3 Places	>4 Places	≤12,500 #	>12,500 #	Prop	Jet	
36479	339	2565	6619	1954	5744	19099	159

15% each. As would be expected, single engine aircraft usage is dominated by personal or pleasure usage, although a very significant portion, 26.9%, of owners report business uses (this amounts to 34,089 aircraft). Many of these aircraft are probably only used part-time for business purposes. The important factor here is that of those 34,089 aircraft reporting business use, 29.4% (10025) meet the IFR criteria, and another 57.3% (19518) meet the minimum IFR avionics criteria. Only 13.3% are definitely VFR-only. Figure 2.3 illustrates the sharp distinction of avionics capabilities between pleasure use and business use single engine GA aircraft. While the percentage meeting the minimum IFR criteria remains the same (58%), the percentage meeting the IFR criteria is almost three times as much in the business category (29.4%) as in the pleasure category (11.5%). This trend clearly indicates the more stringent operational reliability requirement of the business-use operator.

2.1.2 GA IFR Growth

The dimension of the GA IFR problem is growing rapidly -- much more rapidly than that experienced by the air carrier population. Figure 2.4 graphs the projected numbers of general aviation and air carrier IFR departures from 1975 to 2000 based on FAA projections [3]. GA IFR departures in 1975 ran at an annual rate of 3.2 million, as opposed to 4.8 million air carrier IFR departures, constituting 33% of all IFR departures (including military). In 1983, GA IFR departures will have reached parity with air carriers at 6.2 million (44% of total). The astronomical growth rate is projected to continue through the year 2000, when the annual GA IFR departure rate will have reached 17.4 million, as compared to 9.1 million air carrier IFR departures, constituting 62% of all IFR departures. Thus, GA IFR departures will have increased 444% while air carrier departures will have increased only 90% (substantial increases in average seating capacity and load factor will result in a far larger increase in revenue passenger miles of 269%). The FAA aircraft fleet projections [3] track the IFR departure projections as expected.

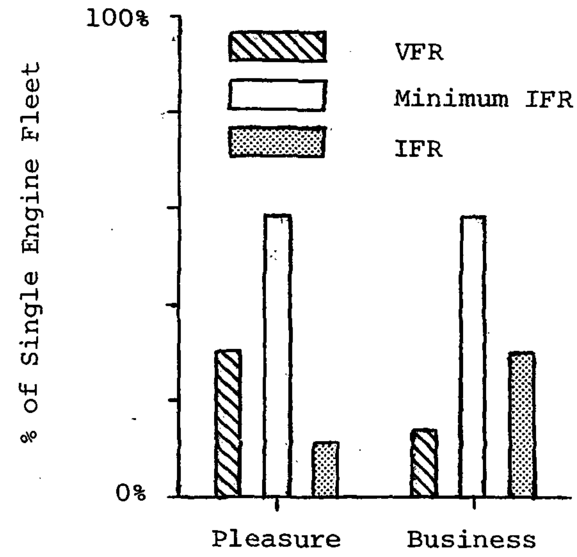


Figure 2.3 Avionics Complement, Single Engine GA Aircraft, by Primary Use

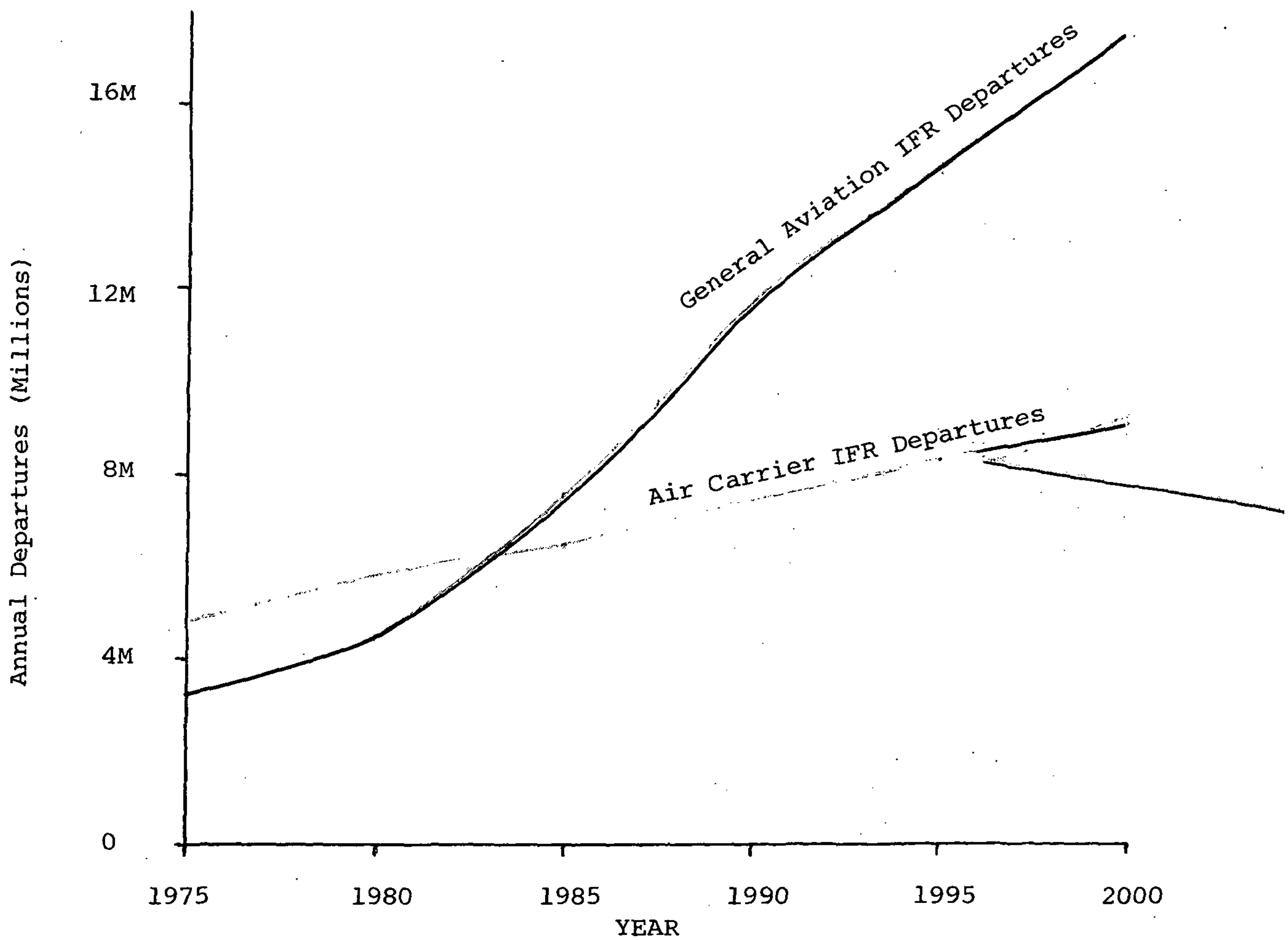


Figure 2.4 Projected GA and Air Carrier Annual IFR Departures

As shown in Figure 2.5, the air carrier fleet is projected to grow by 84% from 1975 to 2000, at approximately the same rate as the growth in air carrier IFR departures. Growth in the GA fleet is considerably faster, as would be expected from the projected growth in IFR departures. However, as shown in Figure 2.5, the growth rate is highest for the predominently-IFR aircraft types--turbine and multi-engine aircraft--as opposed to the single-engine category. The projected turbine-powered growth is a phenomenal 633% by year 2000, with multi-engine piston growth at 294% and single-engine piston growth at 158%. Even the single-engine aircraft growth rate far exceeds the air carrier case.

All of these statistics are intended to point out the fact that while general aviation IFR operations are a very important factor today, they will eventually

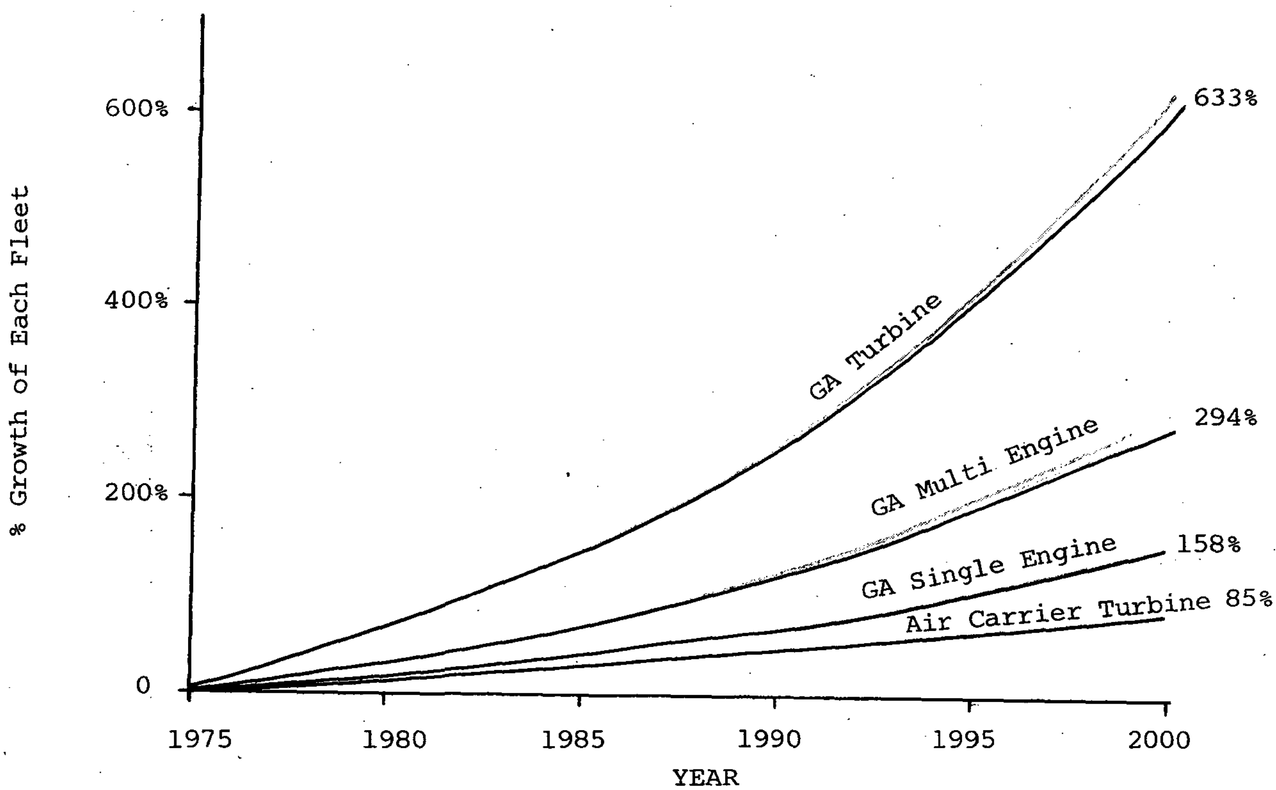


Figure 2.5 Air Carrier and GA Fleet Growth Projections

far exceed the air carriers in terms of demand on services from the ATC system. A series of conclusions are in order here:

- GA IFR operators will eventually dominate the NAS in terms of demand for services.
- The primary units of measure of the "quality of service" obtained from the NAS are mission reliability and safety. Mission reliability is essentially a measure of the expediency with which the desired operation is conducted. Even safety may be conceived in mission reliability terms since avoidance of potentially unsafe situations derogates expediency.
- While the turbine aircraft category population is growing rapidly, the single-engine and light/medium twin-engine categories will continue to dominate GA IFR operations in terms of sheer numbers.
- The single and twin-engine categories are primarily operated by one pilot, but are the least-blessed in terms of avionics equipment and flight control systems for enhancing safety and mission reliability and for reducing workload. This results in a critical situation for the single-pilot IFR operator.
- Research and development effort in the areas of enhancing single-pilot IFR mission reliability, safety and workload is clearly needed.

The remainder of Section 2 will complete the general evaluation of GA IFR operational problems. As stated in the summary, Section 3 evaluates current plans for NAS enhancement from the GA point of view, while Section 4 presents a detailed analysis of specific problems and needs. Section 5 then evaluates these needs and suggests solutions and approaches to their realization.

2.2 GA IFR OPERATING ENVIRONMENT

Technically, GA IFR operators are unlimited with respect to the areas of the U.S. in which they may operate. However, practical and, in some cases, regulatory restrictions limit the areas where IFR flight can actually be conducted. Curiously, more restrictions are encountered at the highest and lowest density airports, with fewer difficulties encountered at intermediate density airports.

2.2.1 Low Density Terminal Environment

Low density airports, and intermediate density airports situated in low density enroute environments, suffer from three problems which tend to limit their usefulness under IFR conditions:

- No instrument approach procedure, or only a non-precision approach procedure.
- Lack of radar coverage for monitoring an instrument approach procedure.
- Marginal facilities for clearing snow and ice.

In the first case, while the flight may be conducted IFR to the airport, the visibility must be above VFR minimums to make a landing. Even if a non-precision instrument procedure is available, the approach may be made down to non-precision minimums, which are much higher than minimums associated with a precision approach. In the second case, the absense of radar monitoring does not usually affect the approach procedure or the minimums, but lowers the pilot's confidence since no monitoring is available to advise him of (1) deviations from the specified procedure, and (2) unexpected traffic in potential conflict. Lack of radar coverage also has another serious drawback during time periods of significant traffic demand: it limits arrival and departure capacity. During IFR conditions the controller must reserve a block of airspace around the airport until radar contact is established, allowing only one arriving or departing aircraft in that block at a time. In certain circumstances, non-radar separation procedures can be used but this involves much larger separation between aircraft and, hence, low capacity. The impact of the third case, regarding snow and ice removal facilities, is self-evident.

There are other factors which tend to limit the usefulness of low density airports without control towers in IFR conditions, such as indequate runway lighting and the absence of local meteorological observations. Inaccurate weather observations are undesirable for two reasons: If visibility is reported as being worse than actual, the pilot may be required to proceed directly to an alternate, unnecessarily inconveniencing him. If the opposite is true, he may elect to attempt the approach in visibility conditions which are well below minimums. Inadequate runway lighting can lead to confusion and difficulty in completing the approach. These factors all tend to diminish <u>mission reliability</u>.

While not mentioned specifically, several of the above factors also tend to complicate the IFR departure situation. In particular, snow and ice removal and radar coverage gaps are obstacles to departure operations. Another factor which tends to impact departure operations even more than arrivals is the absence of communications coverage at an airport. If no radio channel is available for communication with center or FSS prior to takeoff, arrangements must be made when filing the clearance (by telephone) to provide a departure time slot and a clearance cancellation time so that center can reserve the required airspace. This is obviously quite cumbersome and restricts airport capacity.

2.2.2 High Density Airports

Very high density airports offer highly advanced ATC and landing facilities, but are also quite problematic for the single pilot IFR operator during periods of high traffic demand. One of most serious problems facing a single-pilot IFR operator, particularly in the terminal area arrival phase, is the overall complexity of the routes, procedures, communications and the terminal environment in general. This complexity leads to high workload, confusion and disorientation. The use of radar vectors rather than cockpit navigated routings can contribute to pilot disorientation. Furthermore, since the communications channels are in a state of near-saturation, clearances are easily missed and the pilot finds it difficult to initiate requests for clarifications. The pilot is also requested to perform activities which he may not be accustomed to or which deviate from normal flying procedures, such as holding at arrival fixes for delays and flying at a high velocity on final approach in order to keep up with air carrier traffic.

At several of the busier terminals in the U.S., arrival and departure delays have become routine during most of the daylight and early evening hours. This problem has been in existence for many years and has been the subject of many investigations by the FAA, by municipalities and airport commissions, and by the airlines. In recent years joint (federal, municipal and airline) task forces have been set up to examine the delay problem and seek solutions through improved facilities, airspace reorganization, runway reassignments and traffic structuring. Those efforts have met with some success, most notably at Chicago O'Hare. The FAA has been keeping accurate records of operations counts and delays at several high delay airports recently under their Performance Measurement System program [4]. Currently, daily data is collected for O'Hare, Atlanta, Washington National, Kennedy and LaGuardia airports and reported monthly in "Monthly High Density Airport Performance/ Utilization Report(s)" [5]. This process is being further automated and enhanced. Delays are logged and causes are noted in detail for later review. This has greatly helped the process of understanding the delay causes and effects of remedial efforts far better than earlier delay data collection efforts which relied on airline voluntary record-keeping [6,7].

Arrival delays in particular are problematic for GA IFR operators. Besides being a problem of themselves in terms of lengthening the trip and wasting fuel and personal time, they precipitate additional problems. When delays are longer than anticipated they can force an aircraft to divert to an alternate to refuel just to maintain IFR reserves. While this is also true for air carriers, they are usually in a better position to predict the delays to be expected at airports they routinely serve than the GA operator who only occasionally uses a given airport.

The complicating factors of high density terminal areas, in particular the ATC procedures involved, occur at precisely the most inopportune time for the arriving GA single pilot IFR operator. The arrival and approach phases of flight are by nature the highest workload periods of the entire flight. Activities include maneuvering the aircraft, navigation, communications, configuration changes, chart and approach plate reading, and conducting the approach. It is during this period of high workload when the maximum effects of ATC are felt, including reroutings, holding patterns, radar vectors (which are easy to execute but tend to lead to disorientation), active runway changes, and communications saturation.

2.2.3 Satellite Airports in High and Medium Density Environments

A third, and quite common, operating environment of GA IFR operators is the satellite GA airport in a medium or high density terminal area. These satellite airports are usually preferable to GA operators since delays are usually low and there is little competition with air carriers, yet they are convenient to urban areas.

GA IFR operators encounter some significant operational problems in these higher density operating environments. In particular, arriving and departing aircraft must deal with the highly structured ATC environment with extremely busy controllers and communications channels, even though most of this activity is related to traffic for the nearby higher density air carrier airports rather than the satellite airport used by the GA operator. This leads to difficulty in obtaining clearances, extensive radar vectoring, extraneous delays due to circuitous routings and holds, and, in Terminal Control Areas (TCA's), specific avionics requirements (Mode C Transponder). In such an environment there is a greater tendency for pilot confusion or disorientation, in comparison to a low density environment where navigation is done autonomously and communications requirements are minimal. An additional problem associated with IFR operation in medium and high density terminal areas is the common situation where landing aids are better (lower minimums) at the primary air carrier airport than at the GA satellite airports. Commonly, the GA operators will be able to file the air carrier airport as the alternate destination. When weather goes below minimums at the satellite airports the GA traffic converges on the already overburdened air carrier airport, creating intolerable delays for many operators. Often these GA operators must find new alternates in order to avoid holding beyond their IFR minimum fuel requirements. Besides leading to potentially unsafe situations, these resulting delays diminish mission reliability.

Satellite airports in dense terminal areas carry a large share of the GA traffic serving those areas. Most of this traffic is itinerant and requires extensive interchange with ATC either because it is IFR or because it involves operations within a TCA. A case in point is the New York area. Statistics and projections for the three major air carrier terminals in the New York area and for the thirteen major GA airports within 50 nmi of New York have been reviewed. Since direct projections of IFR operations at each of those airports were not available, the next best indicator, itinerant operations, was used. Thirteen GA airports were selected on the basis of proximity to New York and level of current (or projected) itinerant operations. They are listed in Table 2.3.

In 1975 the three primary air carrier airports logged a total of 674,000 air carrier operations, and only 191,000 itinerant operations. In contrast, the thirteen GA airports reported 27,000 air carrier operations and 1,009,000 GA itinerant operations. Even today GA itinerant operations exceed air carrier operations at these sixteen New York airports by 71%. Projections show, as indicated in Figures 2.6 and 2.7, that by the year 2000 the air carrier operations at the three primary airports will increase only 78%, to 1,203,000 annually. GA operations at these airports remain essentially constant (growing 35% to 257,000), However, virtually unbridled growth in GA itinerant operations is projected at the remaining thirteen airports: 245% to 3,477,000 operations annually. At that time GA itinerant operations will dominate the area, exceeding air carrier operations by 297% overall.

Table 2.3 New York Area Airports

City	Airport	State	Code
New York	John F. Kennedy	NY	JFK
New York	LaGuardia	NY	LGA
Newark	Newark Int'l	NJ	EWR
Farmingdale	Republic	NY	FRG
Flushing	Flushing	NY	FLU
Islip	MacArthur	NY	ISP
Newburgh	Stewart	NY	SWF
Poughkeepsie	Dutchess Co.	NY	POU
Shirley	Brookhaven	NY	1N1
White Plains	Westchester Co.	NY	HPN
Caldwell	Caldwell Wright	NJ	CDW
Morristown	Morristown Muni	NJ	MMU
Teterboro	Teterboro	NJ	TEB
Trenton	Mercer Co.	NJ	TTN
Belmar	Monmouth Co.	NJ	BLM
Linden	Linden	NJ	LDJ

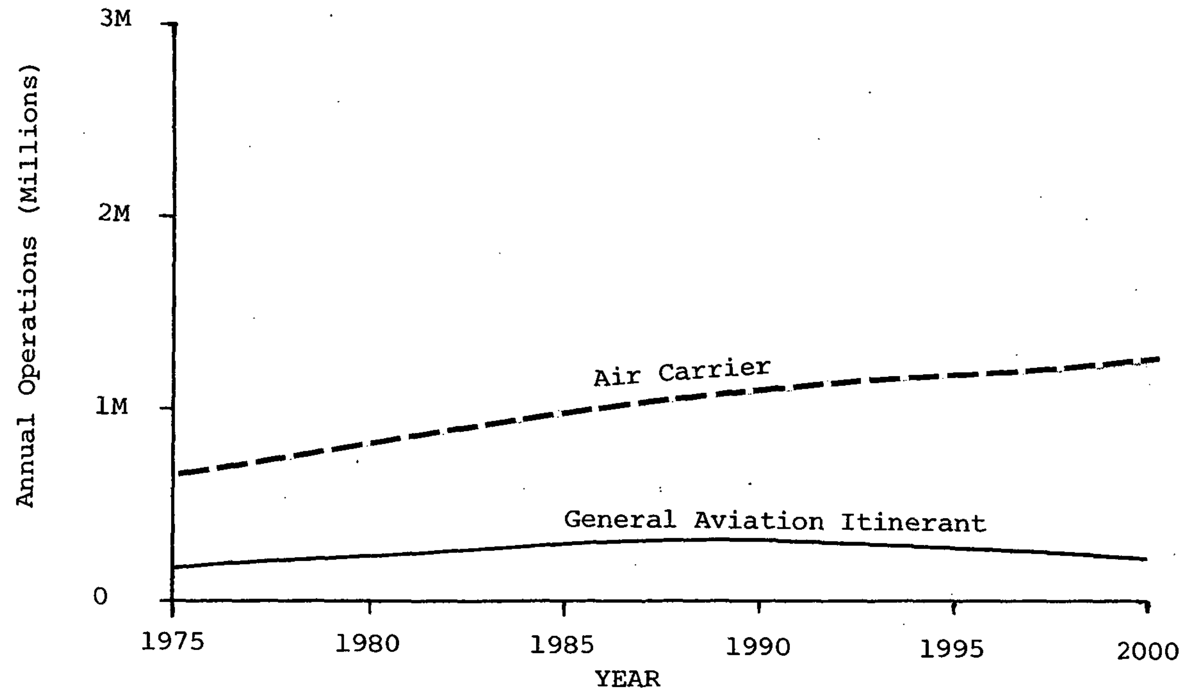


Figure 2.6 Annual Itinerant Operations -- JFK, LGA, EWR

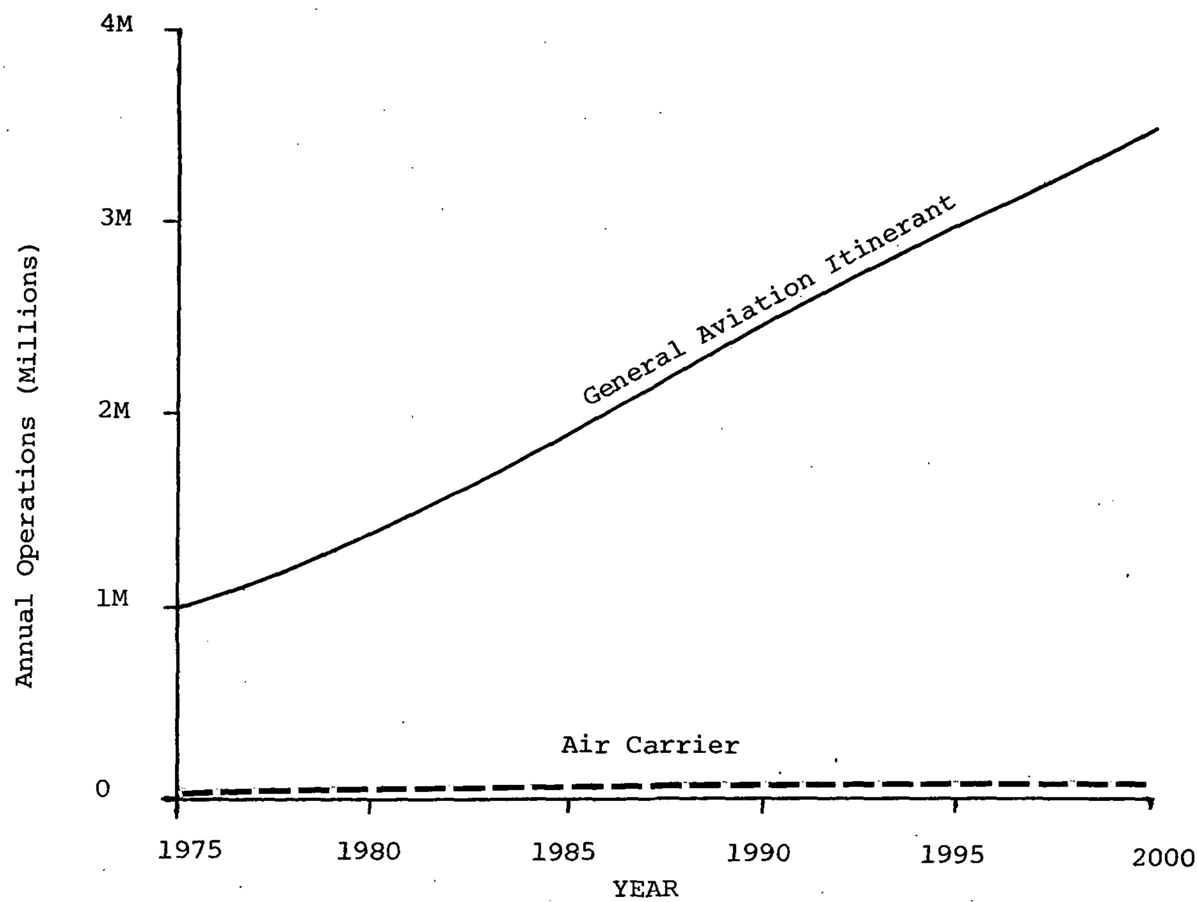


Figure 2.7 Annual Itinerant Operations -- Remaining 13 NY Airports

Further indications of the emerging preeminence of general aviation IFR operations, in the New York area in this example, are available by examining the projections for instrument operations handled by the area TRACONS: New York CIFRR, Islip and White Plains. These statistics also include some "over" traffic as well as operators at area airports. In 1975 a total of 1,093,000 instrument operations were reported, of which 701,000 were air carrier arrivals and departures. This leaves 392,000 as general aviation IFR operations (and miscellaneous military operations). In the year 2000 these figures are projected to climb to 3,569,000 instrument operations, of which 1,258,000 are air carrier arrivals and departures. This will leave 2,311,000 GA instrument operations, an increase of 490% over 1975 figures. These data are shown in Figure 2.8. At that time general aviation will constitute 65% of all New York area instrument operations. These results are indicative of the degree to which GA will dominate the attention of ATC, and of the need to provide services and capabilities oriented toward GA IFR operators. This tremendous growth in traffic levels will tax the capabilities of the ATC system and the airports involved, contributing to delays and inefficiency. If suitable instrument approach facilities are not made available at these satellite airports, the satellite airport problems discussed above will become greatly magnified during periods of poor visibility.

2.3 GA IFR COCKPIT ENVIRONMENT

In this section the cockpit environment of GA single pilot IFR operators is addressed. The pilot's information requirements and the degree to which they are satisfied are briefly reviewed, periods of high workload are analyzed and impacts on safety are discussed.

2.3.1 Pilot Information Requirements

The typical GA aircraft cockpit is relatively simple and uncluttered due to the effects of the common economic limitations of private aircraft ownership and the range of avionics equipments which can be purchased. Of course, most of

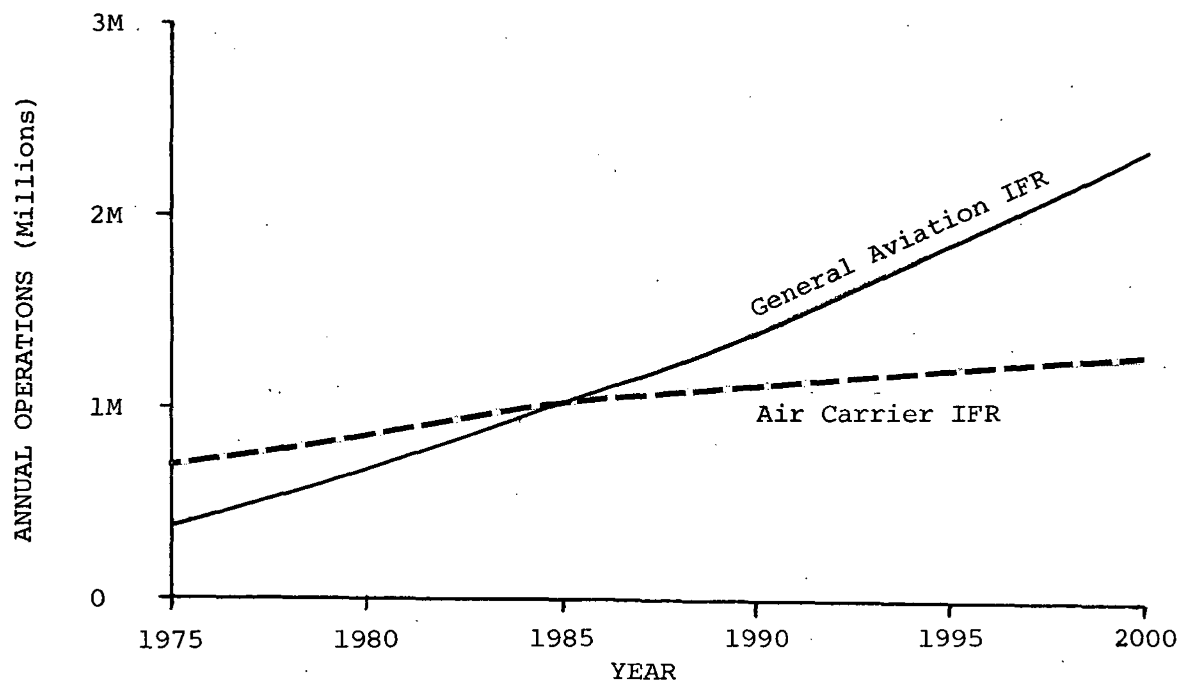


Figure 2.8 Annual New York Area IFR Operations

the more expensive, usually corporate-owned aircraft are equipped with much more complex instrumentation. This leads to a far more complex cockpit environment; however, the benefits which these systems (radar, flight directors and autopilots, long-range nav systems, etc.) provide strongly outweigh the minor penalty of greater complexity associated with their use. While the cockpit of typical GA IFR aircraft may be relatively simple, the information requirements for conducting IFR flight are quite extensive. Cockpit information may be organized in the following set of functionally-related categories:

1) Power Plant Operation and Monitoring
2) Aircraft Flight Controls Operation
3) IFR Flight Instrumentation
4) Communications Information
5) Weather Information
6) Route and Approach Information
7) ATC, Navigation and Guidance Instrumentation

Each of these involves unique types of information, and the requirements change for each flight phase. Information content within the powerplant operation and monitoring category include (for reciprocating engines):

- Throttle, mixture and prop controls
- Fuel management (tank select, level monitor)
- Carb heat, fuel boost pumps
- Engine instruments (tachometer, manifold pressure, cylinder head temperature, fuel flow, etc.)
- Ignition system (magneto select, amperage)

The aircraft flight controls operation category can include the following elements:

- Stick and rudder
- Trim tabs and flaps, approach/takeoff flap settings
- Landing gear operation and verification indicators
- Pitot heat and de-icing boots

IFR flight instrumentation will include the following items:

- Airspeed
- Altimeter
- Stall Warning
- Rate of Climb
- Attitude Gyros, Turn and Bank Indicator
- Directional Gyro
- Magnetic Compass

Communications information categories include those information elements required to initiate and carry on communications with ATC, FSS and UNICOM.

- Clearance Delivery, Ground Control, Departure Control frequencies for origin point

- Enroute Center Frequencies, Approach Control and Tower frequencies for destination and alternate
- FSS, weather and UNICOM frequencies, where required
- Types of required reports
- Expected message information content (downlink, uplink)
- Phraseology

Weather data categories include the following types of information:

- Enroute weather including icing conditions, thunderstorms and winds aloft
- Visibility, winds and runway conditions and runway in use at the destination and alternate
- Present conditions and predicted conditions ±3 hours of ETA

Route and approach information can be quite extensive and complex, due mainly to the variety of approach procedures and the large amount of data associated with each approach:

- Route of flight; potential approach procedures
- Navaid frequencies, route bearings, MEA's, cleared altitude
- Fix names, stations used in their formation
- Enroute charts, SIDs and STARs, area charts, approach plates, runway/taxiway diagrams, sectional charts
- Approach minimums, decision heights, approach course, landing aid frequencies, descent initiation points, altitude profile, outer and middle markers, etc.

Of course the list above is far from exhaustive. The final category, ATC navigation and guidance instrumentation includes the following items:

- ATC transponder, four digit code, ident feature, mode A/C
- Navigation aid control heads, VOR/DME/LOC frequencies, NDB frequencies, radials, ident codes, probable coverage limits

- Guidance instrument displays, lateral and vertical deviations, flags, course bearings, bearings to stations, rate of climb and altitude displays

Even though the above lists of information elements may be incomplete, they demonstrate both the variety and sheer magnitude of information which the pilot must have at hand and deal with. It becomes especially critical during those periods of aircraft operation when stress and workload are at their highest level.

2.3.2 Workload, Stress and Safety Aspects

The most critical phases of flight from the point of view of stress and workload, either as induced by required activities or by a requirement to be prepared for imminent emergency procedures are:

- Takeoff
- Terminal area arrival
- Instrument approach and landing

The takeoff is critical mainly due to the requirement to anticipate an engine failure. This includes multi-engine operations where immediate, precise action is required to maintain control of the aircraft. The terminal area arrival phase is critical in dense terminal areas due to the high communications workload and complex procedures. However, in any environment this is the time where preparations for the approach must be made. The approach and landing phase is of course critical due to the precision aircraft control required, the need to carefully monitor critical instruments, the need to visually acquire the runway, and the need to transition from instrument to visual guidance.

In all of the critical flight phases the GA single pilot IFR operator is at a distinct disadvantage since no one is available to take over workload-critical functions. Major functions often taken over by a copilot include handling communications, calling out checklists, speeds and altitudes, monitoring engine instruments, and visually acquiring the runway while the pilot concentrates on the instrument approach. While this oversimplifies the division of tasks between pilot and copilot, it is useful to generalize that tasks are divided in such a manner as to allow a higher level of concentration with fewer distractions for each. The single pilot IFR operator, however, must contend with all of these tasks, leading to distraction, confusion and a possible derogation of safety.

The specific effects on safety are particularly felt during the high workload phases of flight, such as the terminal arrival and approach and landing phases. In the arrival phase two effects are common: misinterpretation of communications, and inability to keep up with events ("getting behind the aircraft"). Both of these can result in unplanned deviations from the intended flight path (horizontally and vertically), possibly into someone else's airspace, can lead to initiation of the approach procedure in a confused state, and can even result in loss of control of the aircraft due to distractions from the primary flight instruments. Any of these effects can also occur on final approach. In addition the approach plate may be misinterpreted or workload/confusion may result in erroneous execution of the procedure. This can result in early descent, descent below authorized altitude, deviation from approach path, distraction from airspeed, etc. instruments, misinterpretation of visual cues, errors in tracking time, and late initiation of the missed approach procedure.

Unfortunately, the structure of the airspace and ATC system does nothing to actively encourage a confused pilot to go around and try again. In contrast, each pilot is expected to be able to perform competently in the given environment, and tends to become a disturbance to the system when he abandons an apparently - executable approach.

2.4 AVIONICS LIMITATIONS AND TRADEOFFS

This section concentrates on those avionics systems which relate the operator to the ATC environment: Navigation, communications and surveillance systems. The present level of technology widely implemented throughout the ATC system provides short-range, localized type service. Surveillance is conducted with radar installations having range limited to 50 to 100 miles. Navigation and communications are conducted in the VHF band and at power levels which are purposely designed to have limited range thereby reducing interference with other facilities using the same frequencies. As a result of this, air traffic control has evolved as a very localized function. This is also of advantage to the human controllers who can then break the problem down into smaller segments of manageable dimensions. There are distinct advantages of this approach to ATC system design for GA aircraft operators. With reference to the VORTAC network, navigation becomes <u>easy</u> and <u>cheap</u>. Navigation along airways consists simply of flying from station to station switching frequencies and OBS settings. Receivers are designed using mature VHF technology which is quite inexpensive to implement and utilizes inexpensive antennas. Furthermore these systems are rather simple to install <u>and they work</u>. VHF communications has the same cost/performance advantages. The most common disadvantage is the incessant switching of frequencies in dense environments. Even ATC transponders, although they use L-band microwave technology, have become relatively inexpensive and function reasonably well.

All of these benefits are derived at a price, however. That price is that highly distributed ground support systems have been expensive to install and maintain. For example, it would be far cheaper for the FAA to install and maintain a Loran-C net across CONUS than it has been to install and maintain the VORTAC system [1]. However, the economically - constrained GA operator, which includes nearly all single-engine and light/medium twin operators, cannot afford the suitable Loran set required to operate in such an environment. Even new technology Loran navigators [8], which represent a breakthrough in terms of performance/ price ratio, cost on the order of three times the price of low-cost VOR receivers.

Other methods of reducing the ground-based cost of providing necessary ATC functions and services typically put a greater complexity or technology burden on the airborne equipment as a direct consequence. This results in higher user costs and can also be more difficult to operate from the user's standpoint. For example, in the Loran example cited above, the operator must input waypoint coordinates, etc. for each charted point on the route, which is more difficult than simply dialing in VOR frequencies and OBS settings.

Another problem associated with the implementation of a system to replace an existing nav, comm or surveillance system is the required implementation period, and the compatibility or coexistence problem which results. For example, the DABS (Discrete Address Beacon System) system which is intended to replace the existing ATCRBS secondary radar will be implemented in an evolutionary manner over a number of years. Full compatibility has been designed into the DABS system; i.e., DABS ground sites will track ATCRBS transponders and DABS transponders will respond to ATCRBS interrogations. Therefore, operators may use their existing ATCRBS unit over its useful economic life before replacing it with the DABS unit. In contrast, it would be difficult to design a VOR-compatible NAVSTAR GPS system. Therefore, if such a system were to be implemented to replace VOR, both systems would have to coexist over an extended time period before requiring users to replace their existing equipment. This creates considerable additional expense for the FAA since dual systems must be maintained over an extended time period.

Many of the future system concepts (not necessarily those of the Upgraded Third Generation ATC System -- UG3RD) for improved nav, comm. and surveillance systems depart from the traditional localized coverage techniques in use to date. These include surveillance techniques using surveillance satellites or based on data-linked navigation data, navigation techniques such as OMEGA, LORAN, NAVSTAR and VOR/DME RNAV, and communications techniques based on satellites. If any of these systems are to totally replace any existing systems, a long implementation and coexistence time period would be required to successfully achieve a transition.

3.0 PLANNED IMPROVEMENTS TO THE ATC SYSTEM

The FAA has undertaken a major program to enhance the capabilities of the ATC system. There are two motivating factors behind this program:

1) To improve the performance of the ATC system
   - Improve all-weather landing capabilities
   - Improve runway acceptance rates (and reduce delays)
   - Improve weather sensing and reporting
   - Improve safety level for IFR and VFR aircraft
   - Improve the reliability of the various ATC subsystems
2) To reduce facilities, equipment, operating and maintenance costs
   - Improve controller productivity through automation
   - Centralize the Flight Service System
   - Modernize navigation facilities
   - Modernize communications facilities
   - Allow more economical deployment of category I landing systems

As conceived by the Air Traffic Control Advisory Committee in 1968 [9], this set of ATC enhancements was titled the "Upgraded Third Generation System (UG3RD)" since it was conceived as a set of improvements to, rather than replacements of, the components of the then-emerging Third Generation ATC System. The major changes which differentiated the Third Generation system were primarily the introduction of automation to the traffic control environment and the exploitation of secondary radar (Mode A/C transponders). The "classic" UG3RD improvements to the Third Generation system will be briefly reviewed here. The next section will introduce other current FAA programs and changes to the UG3RD plan, as well as the decline in usage of the term "Upgraded Third" in favor of the more general terms "ATC enhancements" or "future ATC system".

The primary objective of this entire section is to evaluate the ATC enhancement plans of the FAA from the viewpoint of the general aviation single pilot IFR operator in order to determine the extent to which these improvements will solve the many operational problems of the GA IFR operator. This analysis is then carried out in detail in Section 4, where detailed flight scenario analyses of IFR flights in typical environments (with and without the ATC enhancements) have been conducted in order to demonstrate exactly where these improvements will impact the GA operator's procedures.

3.1 UPGRADED THIRD GENERATION FEATURES

The features of the Upgraded Third Generation Systems (UG3RD) are expounded in three documents written by the Office of Systems Engineering Management (OSEM) within the FAA (References 10 , 11 , and 12) . In essence, nine programs or features were proposed. Eight pertain to CONUS operations. They are introduced, along with their rationalizations, in the paragraphs which follow.

Discrete Address Beacon System (DABS): The DABS program was proposed in order to provide three enhancements to the secondary radar (ATCRBS) system:

- Improved tracking accuracy
- High tracking reliability through elimination of synchronous garble interference
- A/G and G/A data link capability

The first enhancement can be applied to the present standard ATCRBS secondary radar: the primary improvement being the addition of direct azimuth measurement using monopulse techniques. The second enhancement can only be realized through discrete addressing techniques. The third enhancement, data link, is achievable by many techniques, including UHF or VHF radio channels. However, once having established a discrete addressing transponder scheme, addition of data link field to the message format provides an efficient, low incremental cost and high capacity data link system.

The major driving requirement behind the DABS/Data Link system is to support advanced automation functions, such as Control Message Automation (discussed below). These functions require surveillance data which is highly reliable and which does not become garbled when two aircraft are very close to one another. They also require an efficient data link for communicating the automated control messages to the affected aircraft. The data link feature will also be used to provide a variety of other routine and optional functions, such as providing terminal information and confirming clearances for aircraft equipped with some form of alphanumeric data display.

Intermittent Positive Control (IPC): This feature is designed to provide proximity warning information (PWI) and conflict avoidance commands, primarily for VFR aircraft in VFR and mixed VFR/IFR environments. The PWI and collision avoidance command decisions would be based on ground-derived measurements of position and estimates of future position based on tracking data. When critical situations are detected, the following sequence of events are executed. On first detecting proximity of two aircraft, the PWI messages are uplinked over the DABS link. If the situation deteriorates and a conflict is imminent, conflict resolution messages are uplinked to both aircraft. If one or both aircraft are on IFR clearances, the appropriate controller is also notified. When a conflict message is required, the VFR aircraft involved would temporarily be under positive control, hence the name IPC. More recently the name has been changed to Automatic Traffic Advisory and Resolution Service (ATARS), reflecting a change in approach within FAA from that of positive control to one of provision of a service.

This capability depends on DABS transponder equipage both for tracking purposes and for the data link function.

Microwave Landing System (MLS): MLS is designed to be the successor to ILS as the primary precision landing aid. Development of MLS was motivated by several deficiencies in the ILS concept which have prevented its full potential benefits from being realized. Foremost among these problems is the great expense, or total impracticality, associated with installing ILS at many sites due to site preparation problems. Being a continuous wave (CW) system, multipath propagation problems directly affect accuracy, causing "bends" in the approach guidance or rendering it useless. Furthermore, these same factors prevent proliferation of ICAO Category II or III ILS installations since the associated accuracy and reliability requirements for Cat II/III are more stringent. Category II ILS has been installed at some major hubs. The MLS concept is based on a pulsed time-referenced scanning beam (TRSB) technique which minimizes the multipath effect. The system is designed to be installed with minimal site preparation requirements and can be implemented in several levels of cost and capability starting with a basic small-community airport Category I configuration all the way to an area coverage Category II/III system with DME. This will allow precision MLS guidance to be installed at a large number of airports for which ILS is infeasible due to cost or technical problems. Also, it will allow Category II or III capability to be installed at the many larger airports where that level of capability is needed. Other capabilities which MLS provides which is unavailable from ILS include a much larger selection of channels (200) to avoid interference and the capability in installations which provide wide area coverage (40° or greater) and DME to support complex segmented approach procedures.

Flight Service Station Modernization: This program is oriented toward improving certain services provided to pilots, mainly weather observation, communications and briefing services, and toward cutting operating costs through a major reorganization and automation program. Original objectives of the FSS program included the complete centralization of FSS personnel and systems into the twenty ARTC Centers (or other suitable quarters) and replacing the field stations with automated facilities by which pilots could obtain briefings and file flight plans. These facilities, called Pilot Self-Briefing Terminals (PSBT), were to be installed in many convenient locations such as the offices of Fixed Base Operators, according to original plans. More recently, the PSBT concept has been deemphasized due to difficulty of operation of the terminals and cost factors. In its place telephone service to trained specialists with direct computer access would be substituted. Also, pre-recorded briefings and computer-generated briefings are to be emphasized. Current plans call for eventual centralization of the many FSS facilities, although it is unclear when that centralization process may commence.

The improvements projected in weather observation include automated observation and data link capabilities. These will allow more up to date observations at airports where observations are presently recorded, reduced manpower costs, and observations at unmanned stations where weather data is currently unavailable. Concepts including automatic creation of recorded messages for VHF broadcast are being explored.

Wake Vortex Avoidance System (WVAS): The intent of this program is to develop sensors and systems which will in the near term predict when conditions will, and will not, result in potentially hazardous wake vortex encounters. In the long term actual measurement of wake vortex trajectories is planned.

The objective is to determine when potential hazards will and will not exist, and to adjust in-trail aircraft spacing on approach in response to that information.

Airport Surface Traffic Control (ASTC): The ASTC program is being carried out in order to provide improved ground traffic surveillance and control capabilities during low visibility conditions. These development efforts include both improved surveillance sensors and automated enhancements to traffic displays. The sensors include a new, solid state radar, the ASDE-3 (Airport Surface Detection Equipment), to replace some ASDE-2 installations, and a beacon-based secondary radar surveillance system, TAGS (Tower Automated Ground Surveillance). Automated aids would include generation of a display with identification tags attached to each target, etc., similar in form to an ARTS III display.

Automation Enhancements: Automation enhancements are planned for both the enroute NAS Stage A and terminal ARTS systems. The enhancements include both hardware improvements and new software packages. Two of these planned enhancements are either fully implemented or are in the advanced implementation stage: Minimum Safe Altitude Warning (MSAW) and Conflict Alert. This applies to both enroute and terminal systems. Other enroute system software enhancements include Flight Plan Probe, which would strive to produce conflict-free clearances, Local Enroute Flow Control, which would help to prevent enroute congestion on a sector by sector basis, and Enroute Metering, which would automate the process of metering arriving aircraft to high density terminal areas in order to avoid undue terminal area congestion.

The major intermediate-term hardware enhancement to the enroute system will be the implementation of the Electronic Tabular Display System (ETABS) which will automate the functions of the flight data controller position through provision of data communications, management and display hardware. The long-term development of major significance is the Control Message Automation program, now referred to as the Automated Enroute Air Traffic Control (AERA) program. This will include both automated control decision making and control message data link capabilities, which will change the human controller's role to more of a management capacity.

In addition to automation enhancements within enroute centers, the Central Flow Control Facility (CFCF) within the ATC System Command Center (SCC) is also being improved in order to better predict peak demands and temporary capacity restrictions such that delayed takeoffs and other measures may be invoked in order to more efficiently absorb the inevitable delays which will result.

Near-term enhancements to the ARTS III systems will include hardware and software changes to increase the capacity of the systems. Intermediate-term hardware enhancements include TIPS (Terminal Information Processing System), which (like ETABS) automates the flight data function. The major software enhancement under development is Metering and Spacing (M&S). This system will automate the sequencing and spacing control decision logic presently executed by human controllers. The objective is to gain an improvement in interarrival control spacing, on a statistical basis, such that an improvement to arrival capacity would result. Control Message Automation (CMA), the far term software objective, would automatically data link the M&S messages as well as generating routine control and conflict avoidance messages.

In addition to the ARTS III system, ARTS II is being implemented at many of the smaller hubs. This low-cost system will provide basic automation service to controllers, such as digitized secondary radar and digital target display with alphanumeric data tags.

Area Navigation: The objective of the area navigation (RNAV) feature is to improve the efficiency of NAS operations and to return more responsibility for navigation to the cockpit. The major benefits to be derived from RNAV equipage include reduced enroute route length, more efficient terminal area routings, improvements to air traffic controller workload and improvements to terminal area arrival capacity. In addition, RNAV systems can provide vertical guidance, which may be used for optimizing descent procedures, and time control guidance, which can be used to enhance Metering and Spacing system performance. Deriving maximum benefit from RNAV operations requires extensive support and participation from ATC, particularly in the terminal area.

3.2 UG3RD STATUS, AND OTHER CURRENT FAA EVALUATION OR E&D PROGRAMS

In the ten years which have passed since the initiation of the Air Traffic Control Advisory Committee, there have been several changes and refinements to the UG3RD program, plus other programs have been initiated in the interim. Some of the more significant developments are reviewed in this section.

The DABS development program is progressing generally in the manner originally prescribed for it. A draft U.S. National Standard for DABS (reference 13) has been issued recently. The signal format now being considered is somewhat more complex than original concepts due to the fact that the Syncro-DABS feature and Beacon Collision Avoidance (BCAS) features are accommodated in the format. Synchro-DABS is a concept which allows direct one-way range measurements to be made between aircraft, forming the basis of a collision avoidance system. It is not currently supported as a formal FAA development program. BCAS concepts are currently under evaluation by FAA, and are discussed later in this section.

The data link feature of DABS is also being developed in concert with original plans. Two types of data fields are supported; the standard message format, which is embedded within a standard beacon interrogation or reply format structure, and the extended length message, which dispenses with the surveillance format structure in order to more efficiently transmit long messages. DABS message development efforts have concentrated on development of useful data link applications for nearer term applications. Ideas being explored at present include:

- ATARS
- Real-time airport surface winds
- Wind shear information
- Takeoff clearance confirmation
- Runway visual range
- MSAW advisory
- Altitude clearance confirmation
- Selected routine weather (surface observations, terminal forecasts, PIREPS)
- ATIS

In addition various cockpit data link terminals are under study.

The Flight Service System modernization program has met with obstacles which have caused some changes in plans or timing. A request for Proposals for the Flight Service Automation System has been issued and a contractor should be selected shortly. Original FSS modernization plans called for extensive centralization and widespread usage of Pilot Self Briefing Terminals (PSBT). However, the PSBT concept has proven to be rather difficult for pilots to use, given the diversity of information and services which must be provided. Also, the move towards centralization of the several hundred flight service stations into the twenty centers has proven to be politically unpopular.

The ATARS program, formerly known as Intermittent Positive Control, has shifted from a concept of providing control instructions to pilots involved in hazardous conflict situations to a concept where more detailed information describing the nature of the conflict is provided such that the pilot can formulate a sound plan of action. This is especially true of high level GA and air carrier aircraft which would probably be equipped with more complex displays. Low cost units would still be limited to PWI-type data and suggested maneuvers.

The MLS program has progressed essentially as planned. The Time Reference Scanning Beam (TRSB) technique has been adopted as the standard signal format. Extensive prototype flight testing has verified system performance. Current efforts are focused on setting avionics system standards and resolving implementation issues.

The Airport Surface Traffic Control program originally emphasized the beacon-based TAGS system as well as primary radar systems such as ASDE-3. TAGS, which selectively elicits responses from individual ATCRBS transponders on the airport surface and presents the tracking data on a synthetic CRT display, has proven to be technically feasible but quite expensive relative to the cost of the ASDE-3 system. Therefore, at present, primary emphasis is placed on ASDE radar development.

Extensive R&D work has been performed to resolve technical, operational, ATC and economic issues concerning area navigation which has resulted in several FAA publications [14 , 15, 16 , 17 , 18]. At present, work is progressing within the RTCA towards producing a Minimum Operational Performance Standard for VOR/DME-based RNAV systems. The FAA has no current plans, however, for implementing RNAV routes and procedures beyond the present point unless specifically requested by major user groups, notably the airlines. As a result it is impossible to predict at this time when RNAV may come into prevalent usage as the primary enroute and terminal navigation system.

The Central Flow Control Facility program has resulted in expansion of CFCF capabilities through the implementation of a new automation facility at Jacksonville ARTCC based on a 9020A computer system. This system is linked to all twenty centers and the System Command Center facility in Washington. The system is serving as a data collection and experimental evaluation facility as well as being the basis of the operational CFCF system.

Development of Metering and Spacing logic has met with several difficulties. Software compatible with ARTS III has been under development by two contractors since 1970, and has finally resulted in a working system installed at NAFEC. It is currently undergoing test and evaluation. Original plans were to include testing at an operational ARTS site; i.e. Denver. However, these plans have been changed with further simulation and evaluation to be performed at NAFEC. The current version of M&S is generally referred to as the "basic" capability. Only arrivals are sequenced, and only one runway may be accommodated. Future versions will be designed to accommodate more complex environments.

The control message automation program has always been conceived as a long term objective since it depends on three necessary factors: implementation of DABS ground equipment at appropriate sites, adoption of DABS transponder and data link capability by a majority of affected users, and development of the advanced hardware and software capabilities necessary to implement the automated decision-making and data link capabilities. If operational implementation of M&S is successful, CMA may find its first use in conjunction with M&S, since all the necessary components for CMA would be available earliest at those terminal areas, and required changes to M&S would be less extensive than would be expected for CMA in general since the control decision-making logic is integral to the M&S process.

The ETABS program has progressed to the point where an experimental facility has been built, and a contract for an engineering model will be let shortly. The system will not only process and display all enroute flight plan data, but also meteorological and other operational data as well. The TIPS program is also to the stage where contract award for fabrication of two functional prototype systems will be made shortly. While the primary interfaces of TIPS will be to the ARTS and NAS computers, plans call for eventual interfacing with the Aviation Weather and Aeronautical Data System (AWADS), the National Airspace Data Interchange Network (NADIN), ASTC, WVAS, Flight Service Stations and DABS Data Link.

Two automation programs have been conducted on a high priority basis and are in the process of being implemented ahead of original schedule. Terminal area Minimum Safe Altitude Warning (MSAW) has been implemented, as has enroute Conflict Alert in the higher altitudes. Terminal Conflict Alert has been in operation experimentally at some ARTS facilities for several months. Implementation of the enroute MSAW function is still about a year in the future due to the greater complexity of the enroute problem.

There are, of course, many other evaluation or E&D programs being conducted within the FAA at the present time. They are too numerous to list exhaustively; some of the more important programs are the following:

- Digital remoting for air traffic control terminal areas -- this involves providing ARTS data services to remote control towers and other ATC users using inexpensive, low data rate data channels.

- Visual Confirmation (VICON) of voice takeoff clearance -- this is a system intended to enhance safety by providing a system of lights which would signal to a pilot a confirmation of his clearance to take off.
- Beacon Collision Avoidance System (BCAS) -- this category encompasses several techniques of deriving collision avoidance data (Active BCAS, Passive BCAS, Single Site BCAS) utilizing the ATCRBS (or DABS) transponders aboard aircraft within a BCAS - equipped aircraft's area as sources of data for deriving collision threat information. The primary advantage of BCAS over independent CAS techniques is usage of existing transponder capabilities (ATCRBS or DABS), thus protecting BCAS aircraft from all aircraft which are so equipped.
- Wind Shear Program -- Development efforts have progressed regarding both ground based and airborne wind shear detection or prediction systems. The airborne sensor systems in general involve comparing airspeed with an accurate ground-speed reference, such as INS or specialized DME equipment. This, unfortunately, only detects shears as they are occurring. Ground based sensors showing promise include anemometer arrays, laser radars and acoustic radars. At present, anemometer arrays are installed at several airports, with plans for further installations.
- Cockpit Displayed Traffic Information Program -- The CDTI program is the latest effort in the area of Traffic Situation Displays (TSD). This program is being pursued with the

support of NASA. It is primarily oriented towards the air carrier user, and would provide data concerning surrounding traffic as derived by ATCRBS, which would then be displayed on a cockpit CRT. It could be useful for controlling interarrival spacing, for collision avoidance purposes, and for flight crew orientation with the present traffic situation. This could be quite important when the Control Message Automation feature is eventually implemented and the VHF "party line" communications channel is no longer routinely used.

- Moving Target Detection (MTD) -- This is a program to develop an improved radar clutter processor for enroute and terminal radars in order to enhance the ability to detect small aircraft.
- National Airspace Data Interchange Network (NADIN) for aeronautical operations -- This integrated data network is intended to replace present low-performance networks, such as the Service B, and parts of the Service A, teletype systems and to carry air traffic control operational data.
- Voice Switching and Control System for FAA Voice Communications -- This is a research program to investigate improved methods for providing air/ground and ground/ground voice channels and channel switching.
- Automated Terminal Service (ATS) -- This is an automated aid designed to be implemented at terminals which qualify for air traffic control towers, but for which funds are unavailable. A computerized secondary radar system provides basic control services to transponder-equipped VFR and IFR aircraft.

- T-VASI -- This is an Australian VASI concept which provides glideslope deviation data in 0.1° increments, compatible with the ILS glideslope, through a system of lights. It is under operational evaluation at NAFEC and MIA.
- Final Approach Monitoring Equipment (FAME) -- This is a system designed to prevent air carrier duck-under accidents. Aircraft glideslope is monitored using special secondary radar tracking, and excessive deviations are enunciated through a system of high-intensity lights.
- Application of NAVSTAR/GPS for navigation, approach and landing -- This program is analyzing the potential applicability of GPS for civil usage.
- LORAN-C/OMEGA development programs -- These are for the same purposes as the GPS program.
- Air Transport Cockpit Alert/Warning Studies -- These studies are oriented towards reducing the proliferation of alerts and warnings in the cockpit environment through a more systematic, integrated approach to the alert problem.
- Evaluation of Head-Up Displays (HUD) for Civil Aviation -- This study is oriented towards evaluating the contribution of HUD to flight safety and their applicability in the large turbojet aircraft cockpit environment.
- Helicopter Development Program -- These studies are intended to develop improved capabilities within NAS for serving helicopter operations.

In addition to these programs there are several more in the areas of environmental regulations, noise research, crashworthiness, fire hazard reduction, digital flight controls and control configured vehicles.

3.3 PROBABLE ATC ENHANCEMENT IMPLEMENTATION SCHEDULE

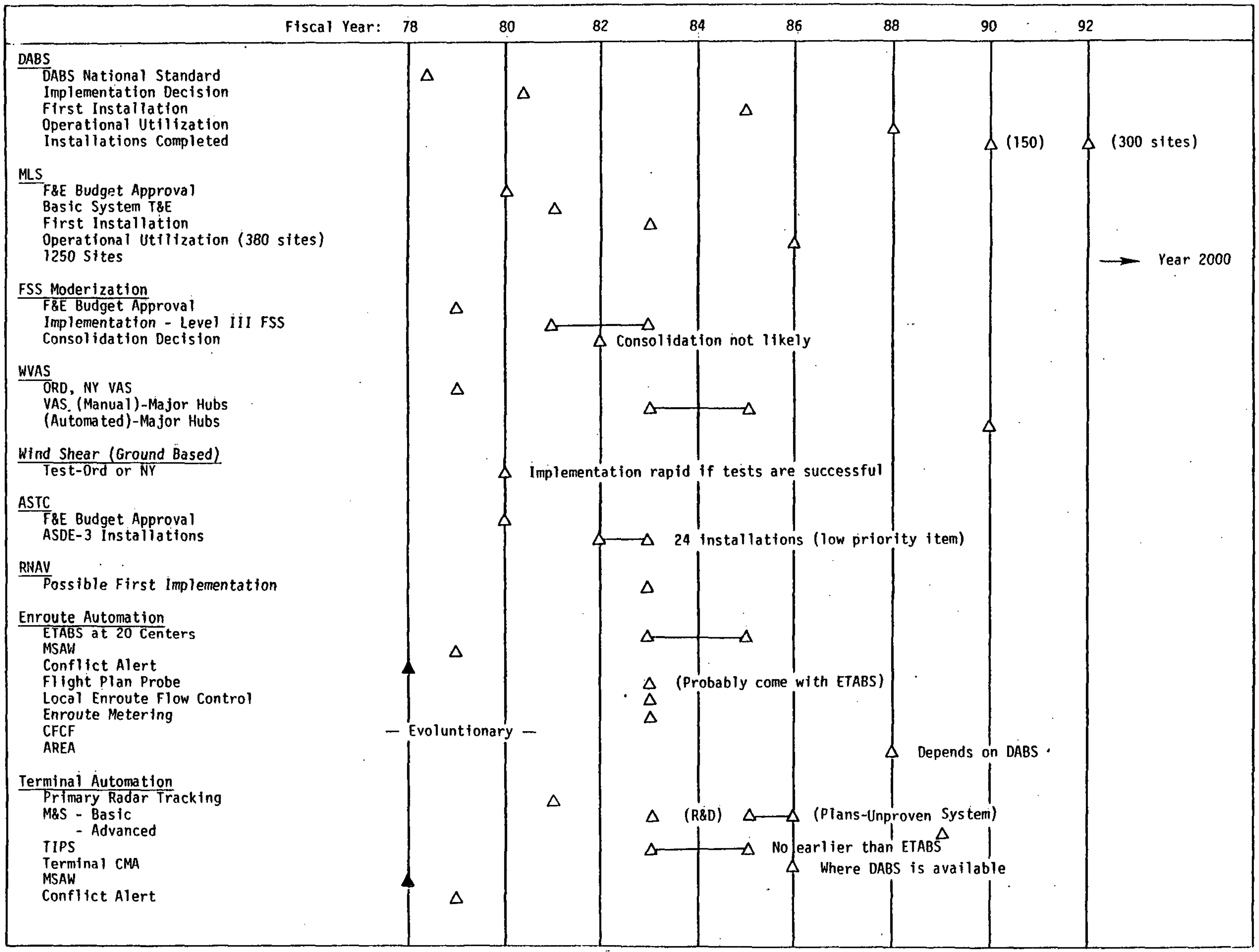
While most of the programs discussed above are under intensive development by FAA, a firm implementation decision has been made within FAA for only a very few. As a result it is difficult to establish firm timetables for the implementation of these features. Table 3.1 exhibits reasonably probable implementation schedules for some of the major features for which implementation is definitely being considered at this time. Many programs are experimental in nature, and so it would be premature to ascribe potential implementation dates.

The data from which Table 3.1 was developed was taken primarily from the SRDS Progress Report [19], the unpublished 1977 NAS Plan [20], and discussions with personnel in the Office of Aviation System Plans [21].

The most obvious observation of specific interest to the GA operator that can be made regarding Table 3.1 is that very few of the programs are to be implemented in the near term. Most of the major programs which may offer potential advantages to GA operators, such as DABS, ATARS, MLS, WVAS and RNAV, will reach the operational utilization stage in the 1985 to 1988 time frame and beyond. One of the potentially most useful enhancements, MLS, will not result in improvements to GA operations until a significant number of small community systems are installed at locations where no ILS currently exists. This could occur quite late in the UG3RD implementation time frame.

One enhancement which will affect GA operations in the nearer term is the Flight Service moderization program, which will be implemented in the 1982 time frame. However, other than some improvements in weather reporting and currency, it is unclear whether the planned FSS automation efforts will actually improve services, as is discussed further below.

Table 3.1 Probable ATC Enhancement Implementation Schedule



3.4 EFFECTS OF ATC IMPROVEMENTS ON GA OPERATIONS

In this section FAA ATC enhancement programs, including the major UG3RD programs or their derivatives and more recently initiated programs, are evaluated in terms their impact on GA operations and procedures and avionics requirements. Table 3.2 lists the major (primarily UG3RD) programs and outlines their projected impacts on GA operations in each operating environment: high density terminal, low density terminal, and enroute. Also identified are the new avionics equipments which will either be a specified requisite for operation in high density airspace, or which must be obtained in order to realize the functional improvements listed. Most of these features and their functions have been discussed in the earlier sections, so this section will concentrate on the operational impact and avionics requirements.

The impact of the DABS surveillance, data link and ATARS functions is highly dependent on the operating environment. DABS and associated data link services will eventually be universally available in high and medium density terminal areas and most regions of the enroute environment. However, low density terminal areas will in general not be covered at low altitudes, and certainly not on the surface. Therefore, a departing aircraft at a low density terminal would not have available any of the DABS informational services, such as weather and TIS, prior to takeoff and climbout. Furthermore, flight plan cancellations for arrivals at these airports would be effected as they are today (telephone or radio relay) since surveillance would be lost prior to landing. Also, since secondary radar coverage will not be much more widespread at low altitudes than at present, nothing can be done to improve arrival and departure capacity at the lower density airports where blocked airspace must be reserved in IFR conditions when radar coverage is unavailable. This problem is even more severe when A/G communications coverage is also

Table 3.2 FAA ATC Enhancements -- Functional Improvements and GA Impact

ATC ENHANCEMENT	FUNCTION (OR IMPROVEMENT)	GA IMPACT			
		High Density Terminal:	Enroute:	Low Density Terminal:	Avionics:
DABS Surveillance	Accurate, garble-free surveillance	Req'd for advanced terminal & enroute automation	(Same)	None	DABS Transponder
DABS Data Link	Discrete digital A/G Comm.	Provide routine data, control messages & ATARS	(Same)	None	DABS Data Link Display
ATARS (VFR/IFR)	Ground-derived traffic advisories	Protection from beacon-equipped AC	(Same)	None	ATARS Display
MLS	Accurate (Cat I, II, III) Site independent, 200 channels Precision area coverage	More Cat. II available Selectable gradients Noise-abatement appr.	None	More precision rwys.	MLS Receiver. DME, Cat. II and complex appr. optional
FSS Modernization	Automated Wx reporting Better, current Wx data Faster specialist response More phone, area data service	Aid to GA IFR & VFR operators Briefing terminals at some FBO's	(Same) (Same)	(Same) (Same)	None
	Eventual centralization	Centralization may degrade service	(Same)	(Same)	
WVAS	Improve arrival separations	Improve capacity	None	None	None
Wind Shear	Detect dangerous shear cond.	Improve Safety	None	None	None
ASTC	ASDE-3 (No TAGS)	Improve Cat. II capacity	None	None	None
RNAV	Improved route structure direct routes, arbitary routes terminal self-navigation	Fuel savings, reduced controller workload, terminal capacity improvement, orientation	(Same)	Airport-finding, Approach procedures	RNAV
	VNAV	Descent fuel savings (JET)	(Same)	(Same)	VNAV
	4D RNAV	Terminal capacity improvement	None	None	4D
ENROUTE AUTOMATION					
ETABS	Auto. flight plan data mgmt.	None	None	None	None
MSAW	Mode C/Terrain check	None	Impact avoidance	None	Mode C
Conflict Alert	Project conflict situations	None	Controller backup	None	None
Flight Plan Probe	Conflict-free clearances	None	Fewer diversions	None	None
Local Enroute Flow	Congestion Avoidance	None	Fewer holds	None	None
Enroute Metering	Metering to terminal area	None	Prevent arr. congestion	None	None
CFCF	Manage demand/capacity	None	Prevent enroute congestion	None	None
AERA	Automate control tasks	None	ATC message display	None	DABS Data Link
TERMINAL AUTOMATION					
M&S	Control arr. & dep. seq. & spacing	Higher capacity	None	None	None
TIPS	Auto. flight plan data mgmt.	None	None	None	None
CMA	Automate control tasks	ATC message display	None	None	DABS Data Link
MSAW	Mode C/Terrain check	Impact avoidance	None	None	Mode C
Conflict Alert	Project conflict situations	Controller backup	None	None	None

nonexistent at these airports and telephone service must be relied upon to grant and cancel clearances.

Another consequence of the loss of coverage at low altitudes at low density airports is the fact that ATARS services would no longer be available.

Where DABS coverage is to exist, a variety of new informational services will be available: real time airport surface winds and RVR, MSAW advisories and wind shear information, terminal information service (TIS), takeoff and altitude reclearance confirmations and selected routine enroute and terminal weather data. These are in addition to the ATARS function.

DABS also provides a unique function which has been heretofore unavailable: real time confirmation of radar contact. In order for the "DABS Mode" indicator on the transponder to light, the discretely-addressed transponder must be acquired by a DABS sensor and instructed to switch to DABS mode, and then be periodically refreshed to remain in DABS mode. Furthermore, the DABS sensor provides real time verification of a correctly functioning link to the cockpit by adding local barometric correction to the air-to-ground linked encoding altimeter data and transmitting the corrected altitude back to the cockpit for display. This "Altitude Echo" should agree with the pilot's altimeter, and if so verifies a properly functioning link. These features serve to verify to the pilot that, if he is in contact with ATC by radio, he is also under radar contact and has been identified uniquely with a data tag on the controller's scope. This is in sharp contrast to the present situation where disasters have occurred when the pilot thought he was being observed on radar and assumed his craft was positively identified, while he was actually under non-radar control procedures. Under non-radar control procedures one or two misunderstandings can result in sharp deviations from the actual intent of the controller's instructions without that controller's knowledge, and is particularly dangerous if the pilot believes he is being followed on radar.

The Microwave Landing System is designed to have several significant operational impacts on the aviation community: widespread implementation of Cateogry II and III capability at major terminal areas, precision area navigation capability on approach for complex approach procedures, more widespread implementation of precision landing aids at small community airports where no ILS can be economically installed, reductions in the multipath propagation problem, and selectable approach gradients. However, regarding the typical single engine and light twin IFR operator whose avionics budget precludes anything but basic precision approach capability, the following benefits are probably not available for economic reasons:

- Category II & III Operations
- Complex approach procedures (RNAV function)

The only benefit of any real significance to these operators is the wider proliferation of precision capability at lower density airports. Due to the extended implementation schedule of MLS, running from 1983 to 2000, it is going to be a long time before any substantial benefit in this category is realized.

The Flight Service Station Modernization program is an area where almost any changes produce a direct impact on GA operators, since the FSS system is so intimately involved with the GA operator in the preflight planning and flight plan filing process, as well as in the enroute and terminal environments. Since present plans call for provision of automated data base management and access aids for use by the flight service specialists, as well as improved weather observation, reporting and communications services, the quality and timeliness of the resulting flight services should improve. However, if plans to consolidate all flight services within the twenty ARTCC facilities are carried out, the ability of a pilot to be briefed in person will be sharply diminished. This may impair his ability to have access to graphic weather presentations, and so he would have to rely on the specialist's interpretations of such weather data.

The Wake Vortex Avoidance System requires no specific changes to aircraft avionics. It may indeed appear totally transparent to the arriving and departing aircraft since primarily it will be used by ATC to set interarrival spacings. Unless they are operating in a CDTI or 4D RNAV type of environment, the pilots involved may have no idea what spacings are in use at any given time. This may eventually change if an advanced WVAS is to be linked through the DABS channel to a cockpit display. In this configuration the WVAS could provide warning information to pilots on final approach when adverse wake vortex situations are detected.

Wind shear detection systems are at present based on anemometer arrays which are connected to a computerized display in the ATC Tower. Shear conditions are detected as differences in wind conditions between different parts of the airport. Information concerning potential dangerous shear conditions is relayed to the IFR room, which then takes appropriate action (change runways or temporarily suspend operations). Thus, airborne avionics and procedures are not affected by the present techniques. As direct wind shear sensing systems are developed (such as acoustic radar) and implemented, the resulting warnings could conceivably be uplinked to involved aircraft through DABS in a manner similar to the WVAS technique.

The Airport Surface Traffic Control program as presently conceived has no direct impact on cockpit avionics or procedures since present efforts are aimed primarily at improving the ground controller's surveillance information. If taxiway guidance or intersection controller systems requiring cooperative cockpit displays are eventually deployed, then there could be some impact on GA operations in low visibility conditions.

The Area Navigation capability is based totally on air-derived information and so involves additional avionics equipments. The degree of benefit an operator derives from his RNAV capability depends on the extent to which RNAV procedures are integrated into the structure of the ATC system, and the degree of cooperation ATC is able to provide on a given day. At present the greatest benefit RNAV provides is thorugh direct routings, which avoid the existing "dog-leg" route structure. The significant [14] benefits which RNAV can provide in terminal area procedures will not be available until ATC adopts RNAV terminal route structures at major hub airports. When this occurs, the extensive usage of parallel offset, direct-to-waypoint, extended downwind and impromptu waypoint clearances will become part of ATC procedures. The 4D RNAV capability can make an important contribution to arrival capacity in an M&S environment, but these benefits cannot be realized unless RNAV operations are fully integrated in the terminal environment first. Also, any such integrated RNAV/M&S environment would, by necessity, have to accommodate non-RNAV users, and thus adverse impacts on non-RNAV GA operators would not be expected.

With the exception of the eventual control automation capabilities (AERA, CMA), and the Enroute Metering, M&S and MSAW functions, none of the enroute and terminal automation enhancements will impact cockpit procedures or avionics requirements. MSAW presents a need for Mode C or DABS capability; without that capability MSAW services can not be provided. AERA and CMA will affect avionics (DABS and Data Link Display) and procedures through the introduction of textual control messages. Enroute Metering and M&S will impact cockpit procedures to a minor extent, but no unique procedures will be involved until RNAV is integrated with M&S.

The impacts of each of these ATC enhancement features on cockpit procedures is summarized in Table 3.3. This table lists probable cockpit procedure impacts in each of three environments: high density terminal, low density terminal, and enroute. These results are limited to that impact expected for typical GA IFR operators. Therefore, for example, Category II/III MLS procedures are not to be found on that list.

3.5 LIMITATIONS OF THE ATC ENHANCEMENT PROGRAM

This section highlights the areas where the plans for upgrading the ATC system do not contribute to a resolution of GA IFR operational problems. It should be emphasized at the outset that while ATC upgrading plans may not solve all of the problems of the GA IFR operator, this does not imply that the FAA has not given due consideration to the general aviation community in developing these plans. Their first and primary responsibility is to provide air traffic control services to <u>all</u> IFR users, and so the emphasis of their plans rests understandably on making air traffic control service more efficient and less costly per unit of service rendered, a difficult task in the face of sharply increasing IFR traffic levels. It is important for purposes of this study to identify those areas where ATC enhancement plans are lacking in serving the specific needs of GA IFR operators, or where these plans include new responsibilities, facilities, or services for GA operators.

Table 3.4 summarizes the probable impact of each of the major ATC enhancement programs on air carriers, on GA operators and on the ATC system. Both cost and benefit impacts are listed (in qualitative terms). In terms of user cost, many entries are listed as "No direct cost", which means that no avionics, etc. purchases are required. However, increased costs in terms of fuel taxes, registration fees, etc. might in actuality be eventually

Table 3.3 GA Cockpit Procedures Impact

ATC ENHANCEMENT	ENVIRONMENT High Density Terminal:	Enroute:	Low Density Terminal:
DABS Surveillance	None	None	None
DABS Data Link	Clearances, TIS, vectors weather advisories	Clearances, Vectors weather, baroset	None(without ATS)
ATARS	PWI commands	Same	None
MLS	Steep gradients,	None	Precision approaches
FSS Modernization	Area Wx services	Area Wx incl. winds aloft, fronts, etc.	Call-up for Wx
WVAS	No direct impact	None	None
Wind Shear	Shear anticipation, missed approach	None	None
ASTC	None	None	None
RNAV	SID/STARS, offsets, direct-to-WP, RNAV IAP's, RNAV M&S	RNAV route data, direct routes, offsets, direct-to-WP, descent initiation	RNAV approaches airport finding
ENROUTE AUTOMATION			
ETABS	None	None	None
MSAW	None	Terrain Alert	None
Conflict Alert	None	None	None
Flight Plan Probe	None	None	None
Local Enroute Flow	None	Re-routings	None
Enroute Metering	None	Holds/slow-downs	None
CFCF	None	Re-routings, holds	None
AERA	None	Data link control msgs.	None
TERMINAL AUTOMATION			
M&S	None(except RNAV, 4D)	None	None
TIPS	None	None	None
CMA	Data link control msgs.	None	None
Conflict Alert	None	None	None
MSAW	Terrain Alert	None	None

Table 3.4 ATC System Performance Impacts of Planned Enhancements

ATC ENHANCEMENT	AIR CARRIER	GENERAL AVIATION	ATC SYSTEM
DABS Surveillance	Costs: Retrofit cost	Retrofit cost; might be "price-of-entry" item	Devel/Impl. costs
	Benef: Possible safety benefit	Same	Possible capacity impact
DABS Data Link	Costs: Display Cost Benef: Timely Wx data TIS, etc. services reduced voice comm.	Display Cost Same (Note: might also be "price-of-entry item)	Automation Development Reduce comm. channel demand; eliminate ATIS, much FSS voice (other benef. req. CMA)
ATARS	Costs: (Included above)	Incremental	ATARS mechanization including NAS/ARTS interface
	Benef: Marginal safety benefit	Considerable safety bene.	None
MLS	Costs: Retrofit cost	Retrofit cost; possible "price-of-entry" item	Devel/Impl. costs
	Benef: Expanded Cat. II/III Expanded Cat. I avail. Integration with M&S	Expanded Cat. I avail. (Cat. II for those equipped)	Reduced noise sens. Airport capacity thru advanced procedures
FSS Modernization	Costs: No direct cost Benef: Better Wx data	No direct cost Better Wx data Improved area-type services	Wx data/automation costs Eventual manpower reduction
WVAS	Costs: None Benef: Reduced arrival delays	None Reduced arrival delays	Devel/Impl. costs Airport capacity incr.
Wind Shear (ground based)	Costs: None Benef: Safety	None Safety	Devel/Impl. costs None
ASTC Improvements	Costs: None Benef: Reduced low vis. ground delays	None Reduced delays if Cat. II	Devel/Impl. costs Improved Ground Cap.
RNAV	Costs: Retrofit cost Benef: Reduced enroute time Reduced terminal time Reduced arr. delays VNAV fuel savings 4D M&S impact Non-precision approaches	Retrofit cost Reduced enroute time Night VFR capabilities Non-precision approaches Reduced terminal time Reduced arr. delays 4D M&S Impact VNAV fuel savings (jet)	RNAV routes, procedures Reduced controller wkld Airport arr. capacity Route flexibility VORTAC savings
ENROUTE AUTOMATION	Costs: None	None	Facilities & Software
ETABS	Benef: None	None	Staffing reductions
MSAW	Safety	Safety	None
Conflict Alert	Safety	Safety	None
Flight Plan Probe	None	None	Reduced workload
Local Enroute Flow	Reduced enroute delays	Reduced enroute delays	Reduced workload
Enroute Metering	Fuel Savings	Fuel Savings(major term.)	Workload shift
CFCF	Reduced airborne delay	Same (major terminals)	Workload shift
AERA	None	None	Reduced workload
TERMINAL AUTOMATION	Costs: None	None	Facilities & Software
M&S	Benef: Reduced Delays	Reduced Delays(major term)	Possible wkld. red.
TIPS	None	None	Reduced workload
CMA	None	None	Reduced workload
Conflict Alert	Safety	Safety	None
MSAW	Safety	Safety	None

charged to users. In the paragraphs below the relative costs and benefits of each feature for GA operators, as compared to air carriers, are reviewed.

The DABS feature provides two capabilities: enhanced surveillance performance and data link. The surveillance function provides no direct benefit to either user class, although it should improve the overall quality of ATC services, since it will allow enhancements to the capabilities of the ground system. Even though no direct benefits to users will result, costs will be incurred since the DABS feature may become a price of entry item for certain airspace, just as Mode C ATCRBS capability is at present for operations in TCA's.

There are further limitations to the DABS surveillance capability that affect primarily GA operations. These result from the fact that DABS is a ground-based radar surveillance technique (rather than a space-borne radar or ground based data link surveillance technique). The problem stems from line of sight limitations which:

1) Limit coverage in low altitude regions at remote airports, and
2) Limit coverage in areas of adverse terrain.

Unfortunately, both of these environments are widely used in GA IFR operations. Expected limitations to DABS coverage are analyzed in reference 22.

The DABS data link feature will provide useful services for all airspace users since it will

1) Serve as a conduit for the ATARS collision avoidance feature.
2) Provide a wide variety of informational services conveniently and without requiring controller or flight service specialist intervention.
3) Eventually allow automated control message transmittal.
4) Serve as a conduit for private data interchange.

Only the first three services are of interest to GA. It is important to realize that the primary motivations behind the DABS features are to allow advanced ATC automation capabilities to be developed, not the provision of new services to the cockpit.

Data-linked informational services will be very useful to GA pilots. A particularly useful feature will be that terminal information and enroute weather downstream will be available while enroute, still far away from the destination airport. Availability of these services will depend on equipage with necessary data link device options in addition to the basic DABS transponder. Certainly devices will be available in all cost ranges, but really useful ones will probably need some form of keyboard data entry along with the data display.

A major drawback of these DABS informational services regarding GA operators is that they, like DABS coverage itself, are not available to departing aircraft on the ground except at airports with on-site DABS antennas, or with antennas close enough to provide coverage. Thus the typical GA aircraft departing a more remote airport receives no service until the enroute coverage altitude is reached.

Another limitation of current DABS concepts is that it really does little to simplify operations in dense terminal areas since standard control procedures (even when automated) are not affected. In fact the situation becomes worse when control message automation is introduced, since the VHF "party-line" is lost and each pilot has no way of creating a mental picture of the surrounding traffic. This is a major argument for establishment of a traffic situation display (TSD) concept, such as CDTI, for example.

The ATARS concept is a good approach towards solving the collision avoidance problem using ground-based techniques. Its advantage is that it will use the DABS transponder for both position determination and data link, rather than some other dedicated piece of equipment. This results in an overall savings to users and maximizes the degree of implementation. One drawback is that DABS equipage will not be universal, and so users will not be protected against all aircraft. Other minor disadvantages are that the pilot is given no indication by ATARS how to return to his original course once he has deviated to avoid a conflict, possibly resulting in disorientation, and that the ground derived collision avoidance directives may not be consistent with air-derived CAS directives in aircraft which are so equipped with BCAS or alternative CAS aids.

The major drawback of the ATARS concept regarding GA operations is a result of the DABS coverage limitations discussed above. At remote airports in the lower altitudes no ATARS services will be available. Since common channels are used for ATC surveillance and ATARS, when one is lost, both are lost.

The Microwave Landing System represents a significant advancement in the technology of instrument approach aids as compared to ILS. MLS provides a solution to the signal multipath effect which has always plagued ILS, and has prevented many ILS installations from being attempted and has seriously increased the cost of many others. Furthermore, MLS allows flexibility to be built into an approach procedure, in that approach gradient and track angle may be selected by the aircraft operator. Even full area coverage data will be available at installations which will include DME capability. Low cost versions with more limited capabilities will be available such that precision approaches will be available at a wider range of airports. For the single pilot IFR operator, however, the advantages of MLS will be much less dramatic. First, after acquiring the MLS receiver he must retain and maintain his localizer/glideslope receivers for a very long time due to the protracted MLS implementation time frame. Second, cost considerations will allow acquisition of only the simplest type of MLS receiver. Therefore, he will not be able to execute the complex approach procedures which may be in use at some airports. This may prevent him from interfacing with the flow of airline traffic at these airports and result in substantial inconvenience or delay. Furthermore, while MLS will be available at all major airports, coverage may not be provided for the GA runways (where separate runways are so provided). This will further compound his inconvenience.

The major problem with MLS as opposed to ILS is that, while it offers significant benefits for airline operators, it raises the GA operators operational capability level only marginally. He cannot take advantage of the Cat II capability, he cannot navigate complex approaches, and he still has no precision approach aid at the vast number of small airports where he operates which will not qualify for even the Small Community version of MLS. The only benefit available to the typical GA operator will be the availability of precision approach capability at those airports which are not presently ILS-equipped but which will eventually qualify for the Small Community version of MLS.

Most aspects of the Flight Service Station modernization program will result in improvements to services rendered to GA operators. The only significant potential disadvantage would be experienced if the Flight Service Stations were consolidated into twenty central stations. This would only be disadvantageous if the substitute communications facilities for obtaining briefings and filing flight plans are inadequate.

The Wake Vortex Avoidance System, Wind Shear and Airport Surface Traffic Control Improvement programs all offer improvements which will be useful to

GA operators, particularly from a safety standpoint. The ASTC and WVAS programs should also yield capacity improvements. However, these programs are only slated for the major airports, and so no improvements at low density airports would be expected. The only facility of real usefulness at those airports would be WVAS (only where jet transports operate) and wind shear detection (any airport). From the capacity standpoint WVAS and ASTC would not be very useful at low density airports since airport capacity is typically not a limiting factor even in IFR conditions.

The Area Navigation capability offers several advantages to GA users. The fact that 15,000 of these systems have been sold to date [23] to GA operators testifies to this fact. RNAV is particularly useful for creating direct routes, for conducting non-precision approaches and for night VFR flying. World coverage systems (VLF/OMEGA) are extremely useful for oceanic and South American flying. Present FAA policy [24] regards RNAV as potentially beneficial to users and ATC, but does not consider RNAV to be pursued except upon specific request of user groups. Thus, RNAV terminal routes and procedures will not be implemented unless airline users actively campaign for them. The same holds for high altitude routes. Specific route requests will be considered, but under current plans no attempt to create a comprehensive high or low altitude route structure will be made. As for approach procedures, they will be granted upon specific request but, again, no comprehensive effort to initiate RNAV procedures wherever appropriate is being pursued. Also, since terminal routes and procedures are not being developed, the potential benefits of 4D RNAV integrated with M&S cannot be realized (unless MLS is used for this function). The basic drawback of the RNAV program from the GA point of view results not from the program itself, but from the fact that it is being implemented so slowly.

Of all of the enroute and terminal automation enhancements, none except the M&S feature and redundancy enhancements will resolve any GA IFR operational problems. The M&S feature will reduce delays at high density terminals, and therefore reduce delays for GA operators at those airports. The redundancy enhancements will result in an improved overall level of service since fewer ARTS and NAS service interruptions will be experienced. In addition, some positive safety benefit may result from the MSAW and Conflict Alert features currently being implemented.

In Table 3.5 a summary of the limitations of the ATC enhancement program of the FAA relative to GA IFR operational problems is presented, taken from the above discussions. It is apparent from this table that, due to the basic motivations behind the planned ATC enhancements, the major operational problems of GA IFR operators are largely unaddressed. Section 4, which follows, identifies the problems in detail and provides documentation as to their severity, while in Section 5 candidate research programs which could potentially resolve the problems are identified.

Table 3.5 UG3RD Limitations Relative to Single Pilot IFR

ATC ENHANCEMENT	LIMITATIONS
DABS Surveillance	Generally, no coverage in low altitude regions around small airports Incomplete coverage in areas of terrain Requirement for new transponder Transponder may be "price-of-entry" to some terminal areas
DABS Data Link	Limited message display capability in low cost system With AERA/CMA, the pilot will lose the traffic "picture" gained from party-line comm. Does little or nothing to resolve small airport operational problems Does little to simplify operations in high density terminal areas
ATARS	Depends on near-universal equipage with DABS or ATCRBS (70% to present) May be inconsistent with air-derived CAS indications No provision for return to normal navigation
MLS	Will require ILS & MLS equipment for protracted period Will not be installed at small GA airports Minimum avionics configurations may not allow interface with airline traffic (no complex approach capability) GA runways at major airports may not even have minimal MLS capability
FSS Modernization	Centralization may make access to some services more difficult
WVAS	Only at certain high density airports
Wind Shear	Only at certain high density airports
ASTC Improvements	Only at certain high density airports
RNAV	At present there is little impetus to implement RNAV No current plans to take advantage of 4D capability
ENROUTE AUTOMATION	MSAW and Conflict Alert will enhance safety. Other features provide no direct benefit to single pilot IFR case
TERMINAL AUTOMATION M&S	As above, except for M&S at major terminals

4.0 GA IFR OPERATIONS AND PROBLEMS

4.1 EVENT ANALYSES OF GA IFR OPERATIONS

4.1.1 Introduction

There are several analysis techniques which can be applied to the assessment of the problems of general aviation single pilot IFR (SPIFR) operations. The two techniques which were selected as most applicable to this study were the event analysis, or single thread technique, and statistical review and examination. Problems identified and supported by growth/forecast delay analyses and accident statistic examinations will be discussed in Section 4.3.

The successful completion of this study required the performance of the event analyses as a means of identifying SPIFR problems, assessing their relative impacts, and suggesting possible solutions. This process involves the following four steps:

1) Discovery of operator needs or problems.
2) Statement of the problems in their simplest terms.
3) Observation of relevant factors in the context of each problem.
4) Establishment of hypotheses suggested by these observations.

Through these steps of the event analyses, the performance of the general aviation, single pilot IFR system is constructed and formatted in a way which allows determination of how pilot performance might be improved through system redesign.

4.1.2 Assumptions and Constraints

Certain characteristics, assumptions, and constraints were established to create a definition for the event analyses which was appropriate for the program schedule and resources as well as responsive to the program objectives.

Table 4.1 presents the characteristics, assumptions, and constraints which constitute the analyses' definition. The first characteristic of the event analyses is that they reflect a general aviation cockpit orientation. The focus is on the pilot's point-of-view, to illustrate how the pilot perceives his/her role in the system and how the rest of the system impacts the pilot's performance of his/her activities. Secondly, all of the analyses can be characterized as reflecting normal system operation. In both of the ATC environments examined, 1978 and the mid-1980's, those events which would typically occur, or are considered likely to occur on an IFR flight are selected as part of the single thread. Pertinent alternate events, which illustrate some atypical or less probable events and how they would impact each single thread of events, are noted. Each of the 1978 event analyses presents a possible chain of events that would likely occur on a flight of that nature. Each of the three analyses for the mid-1980's corresponds to one of the present day scenarios, and presents another possible series of events.

The assumptions and constraints listed in Table 4.1 further define what the event analyses are and are not. The fundamental assumption is that these analyses were not intended to yield quantitative workload measures. The technique was used to construct system performance as a single thread of events, which simplifies analysis of that performance for information requirements, sources, and system communications. Through this breakdown of the pilot/ATC/aircraft system performance, the problems facing single pilot IFR operations can be more easily identified and assessed. Including a rough estimate of time to accomplish certain groups of events in the analysis provides another measure for comparing the relative efficiency or effectiveness of the systems. No quantitative workload evaluation was performed, and interpretation of the results of the event analyses as a formal workload assessment would have limited validity.

Table 4.1 Event Analysis Assumptions and Constraints

- PILOT CHARACTERISTICS
  - Instrument Rated
  - Current Instrument Proficiency Biennial Flight Review
  - Experienced in Instrument Flight Rules, Federal Aviation Regulations
  - Experienced in Aircraft Type and Model
  - No Co-pilot
- INSTRUMENT FLIGHT RULES PROCEDURES ARE FOLLOWED
- MARGINAL AND/OR INSTRUMENT METEROLOGICAL CONDITIONS ARE PRESUMED TO EXIST
- AIRCRAFT CHARACTERISTICS
  - Well Maintained
  - Functioning Normally
  - Equipped with "Typical" Avionics Package Appropriate to the Aircraft Type
- CHARACTERISTICS OF ATC SYSTEM AND EVENTS OF FLIGHT ARE NORMAL FOR IFR OPERATIONS
- VEHICLE CONTROL AND VEHICLE CONFIGURATION MANAGEMENT WAS NOT ANALYZED

Since the objective of the analyses was to assess SPIFR problems in the context of the present and mid-1980's general aviation ATC environments, the type of event included in the single thread was constrained. The analyses focus on events concerning navigation, communication, and other activities requiring pilot/aircraft interactions with the ATC system. Information requirements and sources were not determined for perceptual motor activities. Vehicle control and vehicle configuration management activities were not included as events. Aircraft malfunctions and system failures, such as inoperative landing gear or hydraulic system failures were not included as typical occurrences. It was assumed that the aircraft was well maintained, functioning properly, and certified for IFR operation.

Since the objective of this analysis was to determine problems facing the single pilot during IFR operations, the events studied covered the planning and accomplishment of IFR flights. However, many of the problems of the general aviation community are related to airport departure under marginal visual meterological conditions, and to flight through airspace containing both VFR and IFR traffic. Therefore, the six flights, though constrained to instrument flight rules, are not always flown under instrument meterological conditions.

Perhaps the most important set of assumptions are those which define the characteristics of the three pilots from whose viewpoints the events, and thus the analyses, are developed. It was desirable to have a definition of a pilot which would be representative of a majority of FAA certified IFR pilots. Using average, typical pilots as the bases for the event analyses, the problems assessed by the technique are likely to be those faced by a majority of the pilot population. In addition, a few of the problems stem from characteristics of the pilot such as his/her level of proficiency, type of training received, judgment, and experience. The pilots modelled for this study can be described by four basic characteristics. First, they are instrument rated, according to the present FAA standards. Second, each pilot has recently passed an instrument biennial flight review. Each is current, experienced and competent in the aircraft type and model flown in the event analyses, and last, all are knowledgeable in Instrument Flight Rules and the Federal Air Regulations. Knowledge of the rules and regulations, however, does not assure a high level of competence, skill, or good judgment in instrument flying, or even that the pilot conducts the flight in accordance with them. In fact, an assumption was made that the pilots possess certain characteristics and habits which support less than cautious respect, good judgment and conscientious obeyance of the principles and rules of IFR flight.

4.1.3 Major Variables of the Event Analyses

The impact of two major variables of the pilot/aircraft/ATC system on SPIFR problems was of interest. The first variable, the level of automation of the ATC environment, has previously been discussed. The two environments analysed, chosen for their relevance to problem assessment, are the present ATC system and a modified environment incorporating features of the Upgraded Third Generation system, representing the currently planned, mid-1980's modernized ATC system. DABS, data link, ATARS, Metering and Spacing, Enroute Metering, MLS, and Flight Service Station modernization were the features selected for the mid-1980's environment, on the basis of FAA projections of implementation coverages and schedules.

The second variable impacting SPIFR operations is airport complexity. Three types of airport terminal areas were chosen which represent the full range of airport complexity or density which a general aviation pilot is likely to encounter. The highest level of complexity characterizes the congested hub, air carrier airport. To represent an intermediate level of system activity, a satellite airport within the area of the congested hub was chosen. The strictly general aviation airport in a remote location typifies the lowest level of airport complexity or density. Two specific airports were selected to serve as examples of each of these three types of airport areas. Each pair served as the origin and destination airports in two event analyses.

A third variable in the problem analyses, aircraft complexity, was derived from the type of aviation operations under study and from the two major variables. Examples of aircraft flown by the general aviation community under Instrument Flight Rules were varied with level of airport complexity and ATC environment. Each of the two aircraft types represented were equipped with compatible avionics packages. FAA statistics on current aircraft registration, instrumentation, and projections of future general aviation aircraft and avionics were examined to assure that the examples selected represent typical aircraft and avionics capabilities. The three variables in the event analyses, the levels of each and the specific airport and aircraft selected to serve as examples are shown in Table 4.2. Avionics packages for the two aircraft types, typifying instrument flying capabilities for the two ATC environments are shown in Table 4.3. The six scenarios which result from the combination of these variables characterize the pilot/aircraft/ATC system or operational environment upon which the analyses are focused. Table 4.4 lists the six scenarios.

4.1.4 Structure of the Event Analyses

Each of the six scenarios form the basis for an event analysis. The characteristics, assumptions, and constraints of the event analyses were discussed in Section 4.1.2. A single thread of events from pre-flight planning to engine shutdown at the destination was constructed. The events were

Table 4.2 Event Analyses Variables

Environment	Airport Complexity	Representative Airport	Aircraft Type	Representative Aircraft
1978				
	Congested Hub Satellite of Congested Hub	Atlanta International (ATL) Miami International (MIA) Fulton County (FTY) New Tamiami (TMB)	Twin Engine	Cessna 401
	Remote	Marathon Flight Strip Palm Beach County Glades (PHK)	Single	Cessna 182
Mid 1980				
	Congested Hub Satellite of Congested Hub	Atlanta International (ATL) Miami International (MIA) Fulton County (FTY) New Tamiami (TMB)	Twin Engine	Successor to 401
	Remote	Marathon Flight Strip Palm Beach County Glades (PHK)	Single	Successor to 182

Table 4.3 Avionics Packages

	SINGLE ENGINE	TWIN ENGINE
1978	CALIBRATED GYRO PANEL DUAL VOR NAV/COMS NON-ENCODING ALTIMETER MODE A TRANSPONDER HEADSET PUSH TO TALK SWITCH CLOCK WITH SWEEP SECONDHAND	SLAVED GYRO RADIO MAGNETIC INDICATOR (RMI) AUTOMATIC DIRECTION FINDER (ADF) DISTANCE MEASURING EQUIPMENT (DME) ENCODING ALTIMETER DUAL VOR NAV/COMS GLIDESLOPE MARKER BEACONS TRANSPONDER HEADSET PUSH TO TALK SWITCH CLOCK WITH SWEEP SECONDHAND
MID-1980's	CALIBRATED GYRO PANEL DUAL VOR NAV/COMS NON-ENCODING ALTIMETER DABS TRANSPONDER WITH BLIND ENCODER AUTOMATIC TRAFFIC ADVISORY AND RESOLUTION SERVICE DISPLAY (ATARS) GLIDESLOPE MARKER BEACONS HEADSET PUSH TO TALK SWITCH CLOCK WITH SWEEP SECONDHAND DABS 32 CHARACTER ALPHANUMERIC DISPLAY WITH BUFFER	SLAVED GYRO RADIO MAGNETIC INDICATOR (RMI) AUTOMATIC DIRECTION FINDER (ADF) DISTANCE MEASURING EQUIPMENT (DME) ENCODING ALTIMETER DUAL VOR NAV/COMS GLIDESLOPE MARKER BEACONS DABS TRANSPONDER HEADSET PUSH TO TALK SWITCH CLOCK WITH SWEEP SECONDHAND DABS 32 CHARACTER ALPHANUMERIC DISPLAY WITH BUFFER AUTOMATIC TRAFFIC ADVISORY AND RESOLUTION SERVICE DISPLAY (ATARS) MLS CAT. I CAPABILITY

Table 4.4 Scenarios

EVENT ANALYSIS	*ENVIRONMENT*	*AIRPORT COMPLEXITY*	*AIRCRAFT*
1	1978	Congested Hub	Twin Engine
2	1978	Satellite	Twin Engine
3	1978	Remote	Single Engine
4	Mid 1980's	Congested Hub	Twin Engine
5	Mid 1980's	Satellite with Diversion to Congested Hub	Twin Engine
6	Mid 1980's	Remote with Diversion to Medium Density Hub	Single Engine

grouped into planning, departure, enroute, and approach phases to simplify the time estimation task as well as to provide a relevant structure for isolation of certain event sequences. For every event which is pilot initiated, the information required by the pilot to perform that activity or complete the ongoing action has been analyzed. The primary sources of that information have then been identified. When the event involves two-way communication between the pilot and other components of the system, the person, facility or service the pilot contacts for the required information is noted. The fifth major category of information resulting from the event analyses is alternate events. Activities, decisions, outcomes of actions and other items which could have occurred instead of, or in addition to, the events forming the single thread through the flight, are identified as alternates. A part of Event Analysis 1 is shown as Figure 4.1. The five major categories of information, phase groups and time estimates discussed in this section are contained in this example. All six Event Analyses appear in the Appendix, and a simplified single thread of events for each are shown pictorially in Figures 4.2 thru 4.7.

4.2 OPERATIONAL PROBLEMS DEMONSTRATED BY EVENT ANALYSES

Many of the problems confronting the single pilot during IFR operations have been identified by this study. Four general areas where difficulties exist were isolated through use of the event analyses problem assessment technique. Through examination and comparison of the results of the six analyses, support for the assessment of the problems in these areas is gained. The observation of pilot performance in the context of total system performance allows a determination of all the factors relevant to the system problems and indicates areas of possible solutions. The event analyses identify the following four problem areas:

EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
PHASE: PLANNING TIME: 1600				
Check Airman's Information Manual	Description of Miami International and Hartsfield facilities, radio frequencies, route distances, NOTAMS	Airman's Information Manual		
Check long range weather forecast	Frontal movement, high and low pressure areas, ceiling and visibility forecast for origin and destination airports	National Weather Service, Pilot's Weather Program on T.V.	Flight Service Station telephone call	
CONDITION: Forecast calls for marginal visual meterological conditions at Hartsfield and Miami until 2000, becoming instrument meterological conditions after that hour.				
Study low altitude charts, approach plates, sectionals, terminal area charts, departure and arrival charts	Victor airway routes, possible alternate airports, distances, approach, departure and missed approach procedures, required equipment and frequencies, SIDs, STARs	IFR low altitude enroute charts, approach and departure plates, sectionals, terminal area charts		
Plan IFR flight nonstop from Hartsfield to Miami International on victor airways	Aircraft avionics, true airspeed, fuel capacity and consumption rates, distances between checkpoints, possible alternate airport distances and approaches, weight and balance calculations	Aircraft pilot's manual, IFR charts, plates, sectionals, AIM, computer		
PHASE: DEPARTURE TIME: 1730				
Check weather	Present and forecast ceilings and visibilities for destination and possible alternates, winds aloft, SIGMETS, AIRMETS	National Weather Service	Flight Service Station telephone call	
Select alternate airport: Ft. Lauderdale-Hollywood International	Forecast ceiling and visibility for three (3) hours before and after estimated arrival time, distance from destination, arrival and approach procedures, prescribed alternate minimums	National Weather Service, IFR charts, approach plates, sectional		1) Weather forecast below minimums for destination and all possible alternatives Cancel trip plans
CONDITION: Terminal forecast for Miami predicts ceiling and visibility above ILS minimums; for Ft. Lauderdale predicted at minimums prescribed for filing as alternate. Sequence reports (1710) show Atlanta Hartsfield IFR.				2) Possible alternatives require fuel stop along route in order to arrive at destination with fuel sufficient to reach alternate plus 45 minute reserve
File flight plan	Aircraft equipment, true airspeed in knots, estimated departure time, cruising altitude, route of flight, estimated time enroute, fuel on board, alternate airport, pilot's address, phone number, aircraft home base, number of passengers, remarks, SID request, aircraft color	AIM, IFR Flight Plan form, flight plan	Flight Service Station telephone call	Plan fuel stop
Preflight aircraft	Airworthiness, weight and balance in envelope, fueled as planned	Visual inspection, weight and balance sheet		
Start aircraft				
Contact Automated Terminal Information Service (ATIS)	ATIS frequency	Charts, sectional	ATIS recorded message	
CONDITION: Hartsfield IFR: ILS and CAT II ILS Rwy 8 and 9R in use for simultaneous approaches. Rwy 9L in use instrument departures.				
Contact Atlanta clearance delivery	Clearance delivery (ATL) frequency	ATIS	Clearance delivery (ATL)	
Issued clearance with revised departure time-delay of 50 minutes	Clearance limit, route of flight, altitude data, departure procedure (SID), holding instructions, special information (delays), instructions for contacting departure control	Atlanta center, departure controller		1) Issued clearance as filed with no delay in departure time 2) Issued revised clearance 3) Clearance not issued, notified of delay in clearance

Figure 4.1 Event Analysis of Atlanta to Miami Flight in Present Environment (first page)

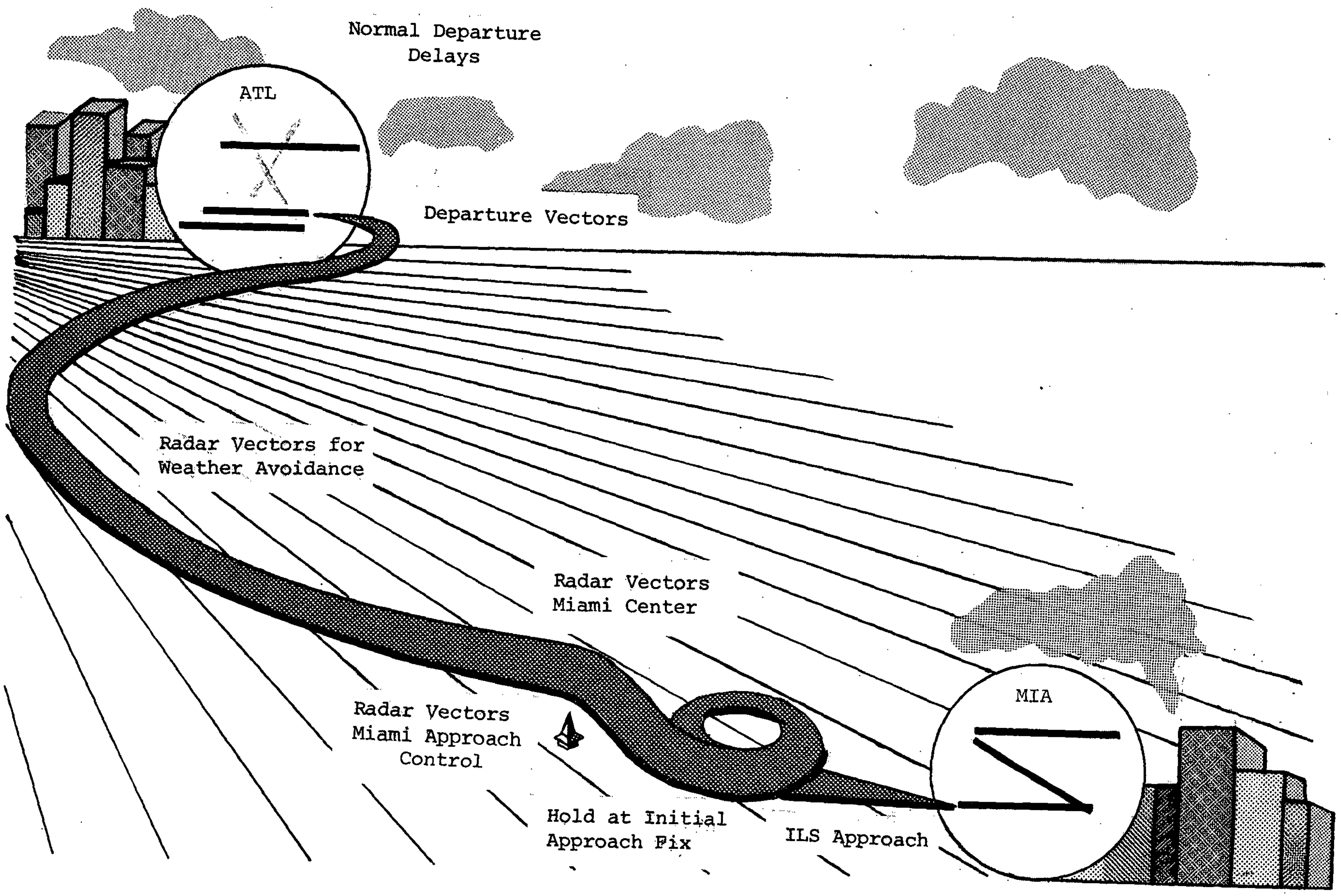


Figure 4.2 Event Analysis 1. Atlanta to Miami Flight in Present Environment

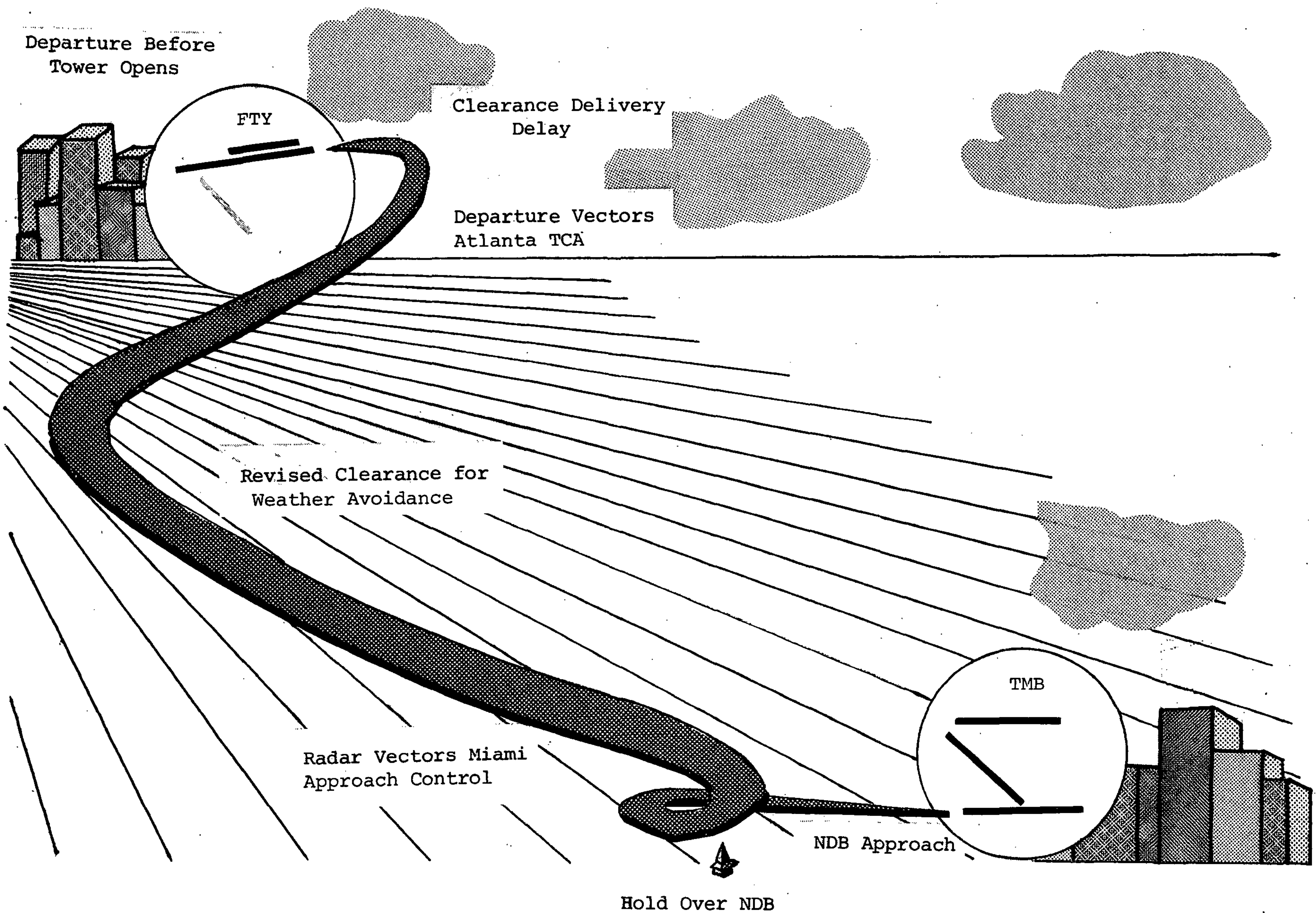


Figure 4.3 Event Analysis 2. Charlie Brown Co. to New Tamiami Flight in Present Environment

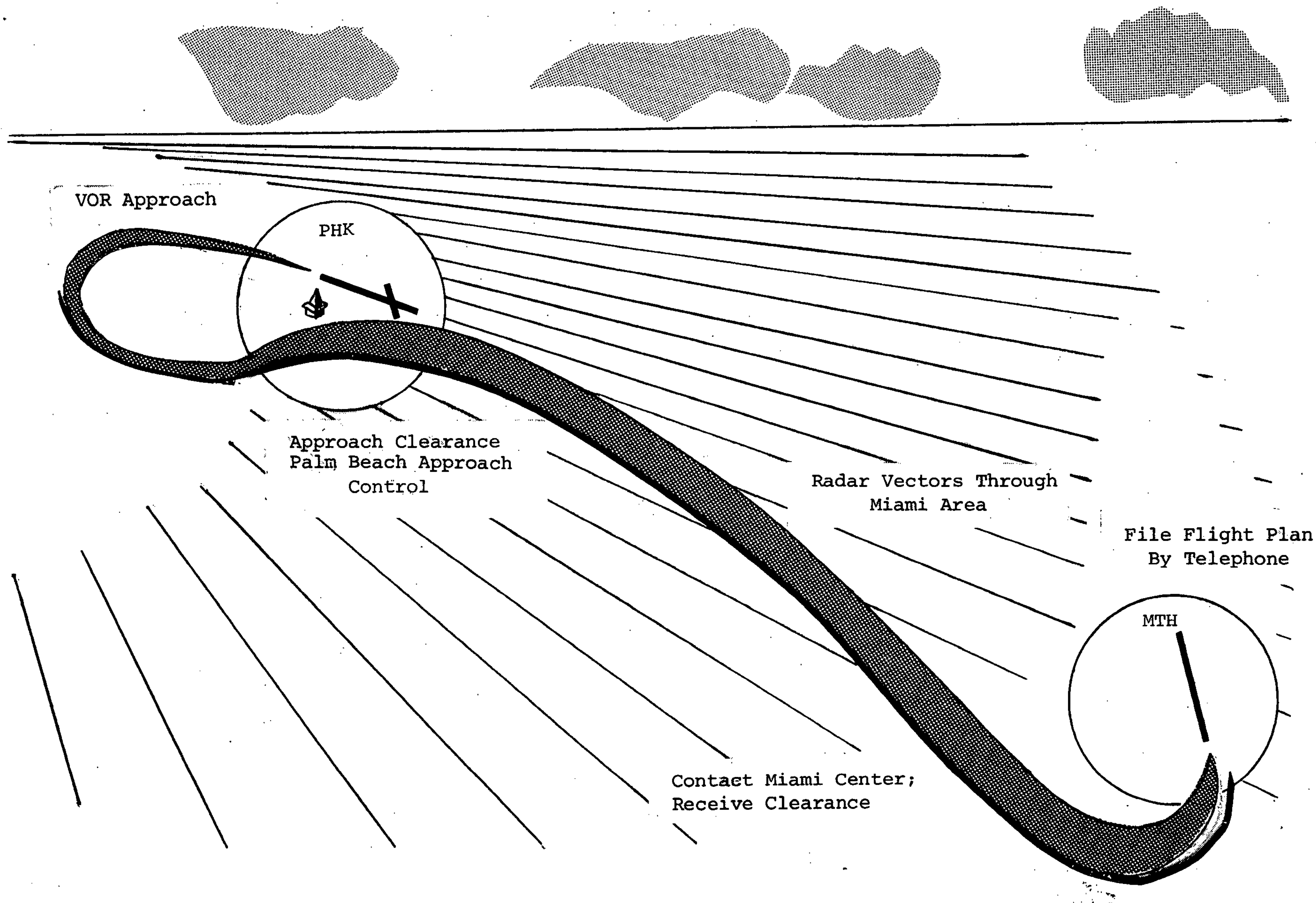


Figure 4.4 Event Analysis 3. Marathon to Pahokee Flight in Present Environment

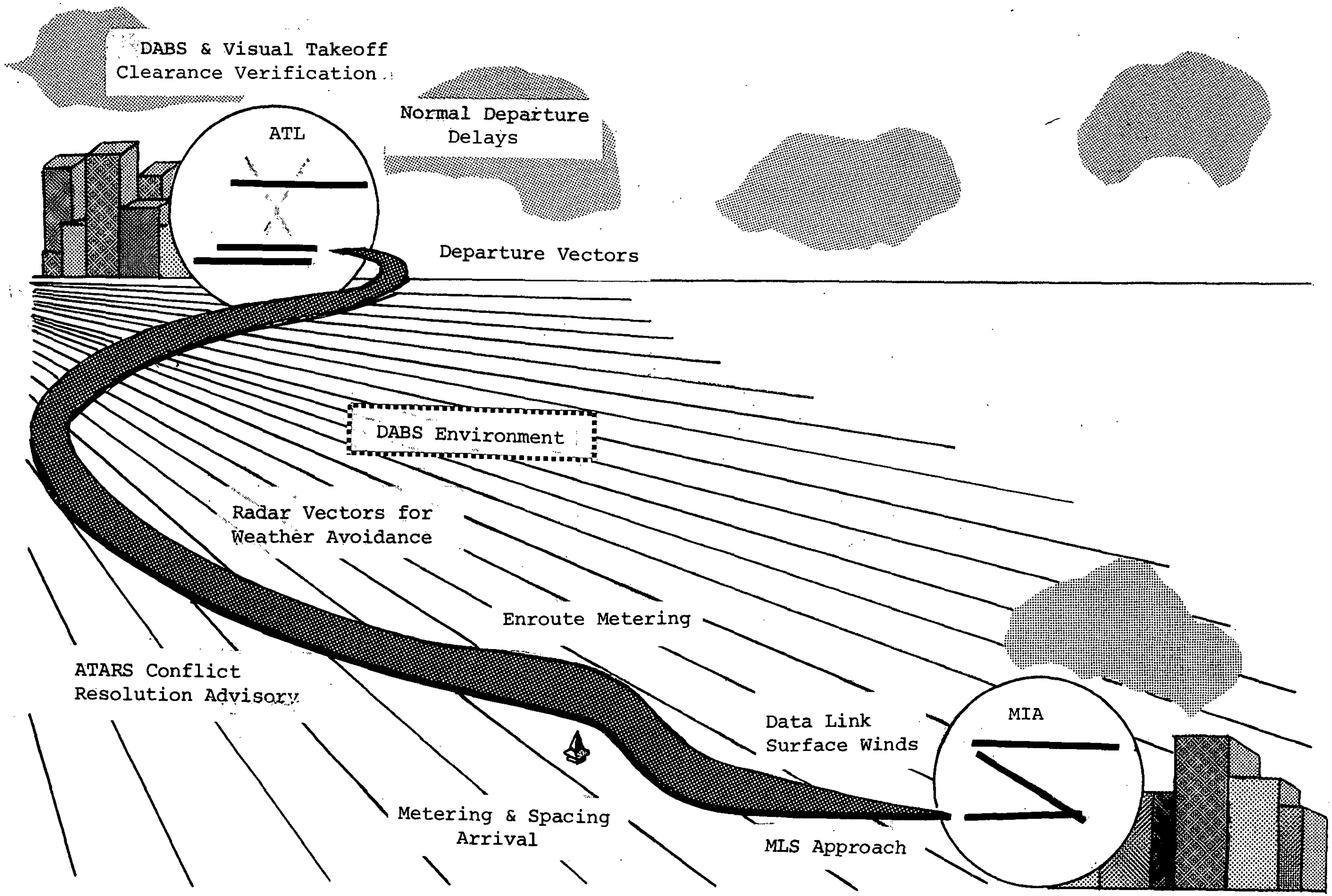


Figure 4.5 Event Analysis 4. Atlanta to Miami in Mid-1980's Environment

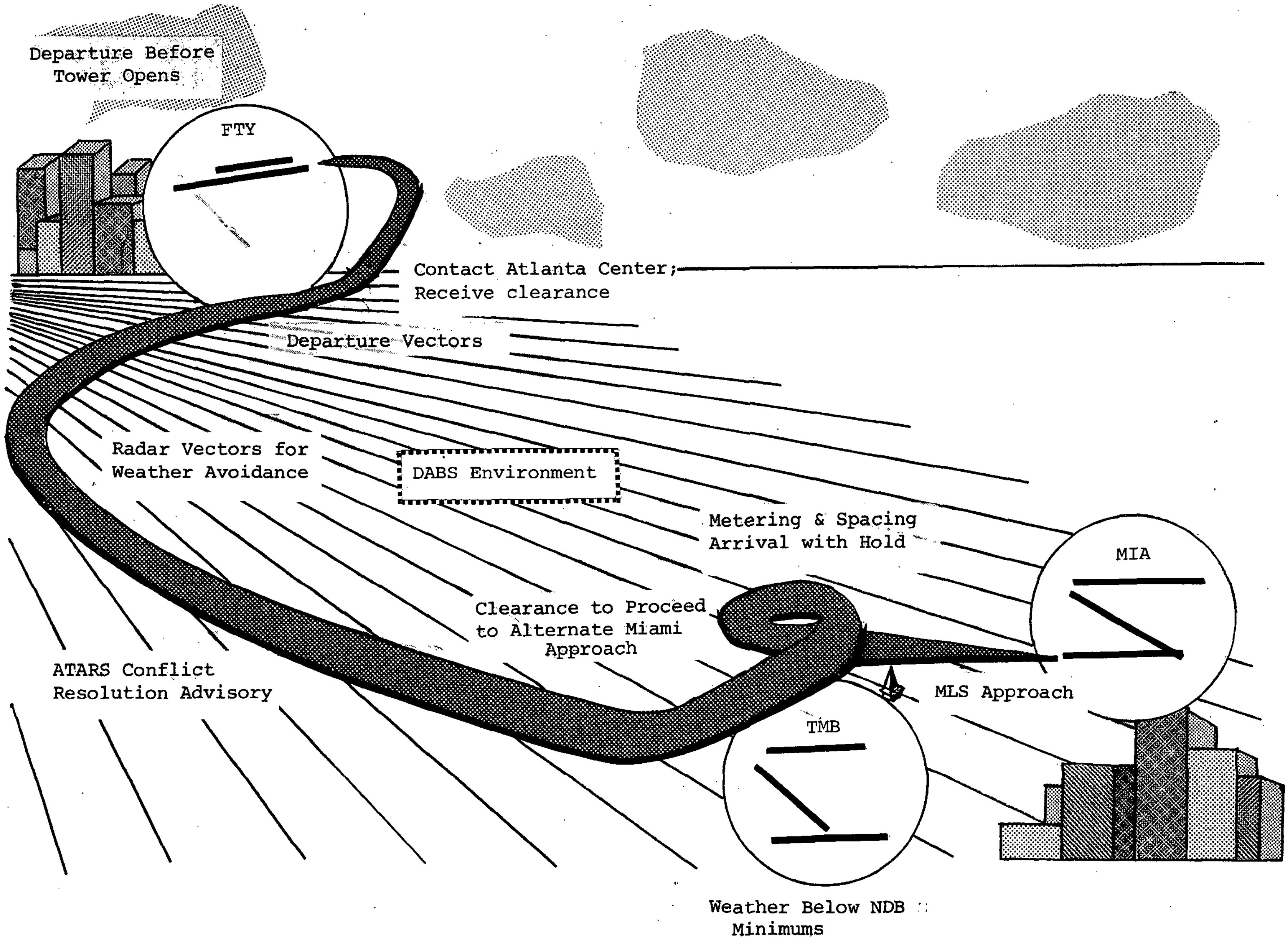


Figure 4.6 Event Analysis 5. Charlie Brown Co. to New Tamiami Flight in Mid-1980's Environment

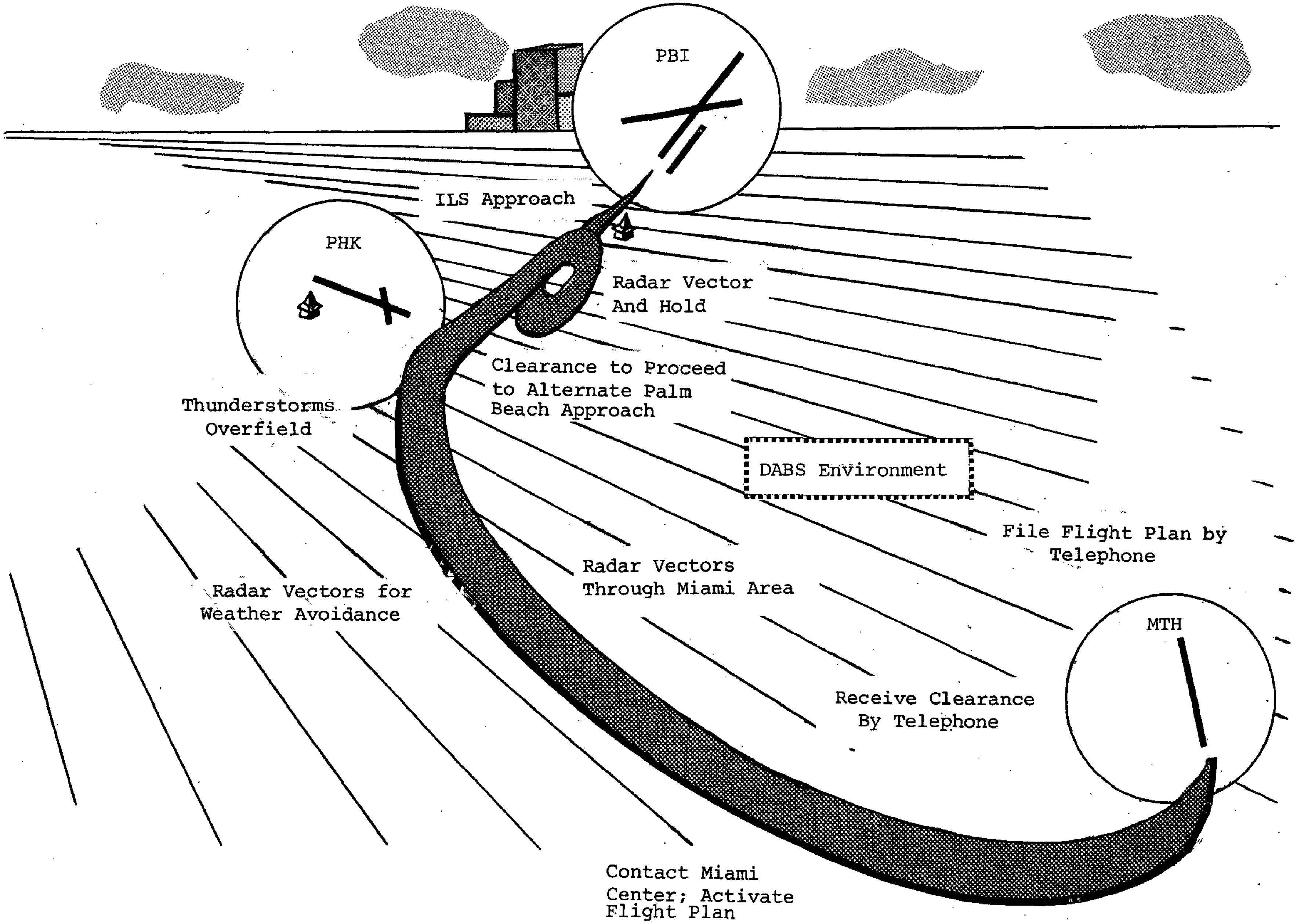


Figure 4.7 Event Analysis 6: Marathon to Pahokee Flight in Mid-1980's Environment

1) Flight Planning

2) Communications

3) Mixed Airspace Operations

4) Pilot Workload

4.2.1 Flight Planning

The first area pointed out by the event analyses as a source of problems is the efficiency and reliability of IFR flight planning. By examining sections of the Planning Phase from Event Analyses 2 and 5, it can be seen that not only is the planning of an IFR flight unnecessarily inefficient and often based on inaccurate data, but few improvements in the performance of this phase will result from the mid-1980's system modifications. One factor contributing to the inefficiency of IFR flight planning is the amount of information necessary and the number and availability of diverse sources of that information. The AIM must be reviewed for information on Weather Reporting Stations, Flight Service Stations, and VOR Receiver Check Points. Preferred routes, Notices to Airmen, and Airport Facility Directory listings must also be checked. Other sources of vital planning information are the Enroute, Area, and Approach and Landing Charts. Facilities and services at the destination and alternate airports, Air Route Traffic Control Center/ Remote Frequencies, Victor Airways, and instrument approach and landing data must be acquired from these charts. Sectional charts provide data on visual characteristics and reference points, general topography, and other highly desirable information. The most important data, weather information, is acquired through yet other sources. The specific flight log prepared depends heavily on current and forecast weather conditions between departure and destination airports. Weather and winds enroute, weather at destination and alternate destinations, local weather and winds, type, location, intensity, direction, and speed of frontal movements, and areas of hazardous and good weather enroute must be gathered to insure a complete weather picture. Pre-flight weather briefings can only be obtained through FAA Flight Service Stations via telephone or in person.

The number of different formats, low availability, and large amount of information required for planning an IFR flight, necessitating the use of many independent sources of information, leads to an unreliable as well as inefficient flight planning system. There are three characteristics of the data acquisition and dissemination system which provides the information discussed above which limit the reliability of flight planning information. First, the information contained in parts of the AIM, and that which appears on IFR and VFR charts and plates, is relatively unstable. Although the FAA and chart manufacturers revise the material periodically, data presented by these publications often are inaccurate, incomplete, or obsolete. Furthermore, the attempts to keep the data on charts and in the AIM current and accurate compound the very problem being addressed-the unreliability of flight planning information. Because of the expense and time involved in maintaining a current AIM and set of the latest revisions of IFR and VFR charts, IFR flight plans are often based on information from sources which are known to be out-of-date and obsolete, but which are easily and inexpensively accessed.

The flight planning data acquisition and dissemination system has two other characteristics which limit flight planning reliability. These both concern weather condition information. The National Weather Service (NWS) maintains a surface and upper air weather observing program and an aviation weather forecasting and pilot briefing service. The usefulness of the aviation weather forecast to the IFR pilot is limited by the accuracy of that forecast and the length of time for which it is valid. The event analyses support the identification of low validity long range forecasting techniques as a problem affecting flight planning reliability. A detailed forecast is accurate for only six hours after filing time. In planning a flight, the current and forecast weather determines whether the flight will be conducted under visual or instrument flight rules, or at all. The planned, as well as actual, route to the destination, alternate destinations, altitude, checkpoints, times, and instrument approach procedures, as well as aircraft weight and balance load limits, are directly related to weather conditions. When flights are planned with weather forecasts of low validity, problems such as adverse weather avoidance deviations and delays, diversions to alternates due to unforecast below minimums conditions, and prolonged operation in weather conditions beyond the capabilities of pilot or aircraft, arise. The last characteristic affecting flight plan reliability cannot be divorced from the issue of weather forecast validity, as it concerns the lack of adequate weather observation and forecasting services necessary for coverage of airports with instrument approach facilities. In 1978, of the 1707 U.S. airports having approved instrument approach procedures, 1050 had no weather observation station [25]. As seen in Event Analyses 3,4, and 5, the unavailability of current or forecast weather conditions for IFR departure, arrival, or alternate airports necessitates the use of the conditions reported by the nearest station for preflight and inflight planning. The serious consequences of flying in marginal conditions with inaccurate weather data, or flying an instrument approach in IMC without the current local barometric pressure expand the problems of low forecast validity and flight planning inefficiency into the area of flight safety.

4.2.2 Communications

The second problem area pointed out by the event analyses is the area of communications. In addition to attending to cockpit duties demanding rapid shifting of attention, quick decisions, concentration, and careful planning, the IFR pilot must be continuously alert to communications from ATC and between other aircraft and ATC, and be able to listen and transmit effectively. The event analyses illustrate the causes of two problems which interfere with effective IFR radio communications. The first problem, errors and inefficiencies in two-way communications, has several causes. One cause is radio equipment design. Only communications equipment of recent design reflects major attempts by the manufacturers to provide for the operational needs of the instrument pilot. Certain aspects of airborne equipment design still contribute to pilot indecision, confusion, and fatigue when under the stresses of IFR flight. For example, some communication systems require an extensive cockpit scan to locate switches, selectors, and displays, and too much time to tune or adjust. Another cause is the lack of adherence to standardized communications terminology and procedures, and the fact that some standarized procedures are inefficient. Transmitting before properly tuning the radio, interrupting other transmissions, repeating unnecessary data, forgetting essential information or entire communications, requesting instructions repeatedly, and use of slang and other nonstandardized words and phrases create misunderstanding and confusion, waste time, and increase the workload on the pilot as well as the rest of the system. Channel congestion is a cause of inefficiencies in communications which is obviously related to equipment design, improper communications techniques, and inefficient procedural concepts and obsolete requirements. However, despite use of standardized words and phrases, proper techniques, and equipment design incorporating human factors considerations, channel congestion exists. Improvements in channel capacities and two-way communication facility capabilities have not kept up with the increases in IFR and VFR traffic and the functions and services required by regulation, or offset the continuance of obsolete procedures.

The second problem is the lack of communications facilities and adequate communications services, which adversely affects the safety and efficiency of IFR operations. Event Analyses 2,3,5, and 6 demonstrate that at remote and even at satellite or reliever airports, the two functions of the Air Traffic Service which are of concern to the instrument pilot, the provision of preflight and inflight services and traffic separation assurance, may be unavailable due to the lack of two-way communications. Two-way communication capabilities are limited by airborne and ground based receiver/transmitter power, reliability and design, as well as ground based system coverage, facility placement, hours of operation, and equipment and operator capacities. Inefficiency in flight planning and filing, lack of clearance delivery, weather reporting, airport advisory, and taxi, takeoff, and landing clearance services, dropouts in radar coverage and lack of ATC or radar surveillance are communications problems, encountered because of the deficiencies of the system, which are illustrated in the event analyses.

4.2.3 Mixed Airspace Operations

The third set of problems facing the SPIFR operator illustrated by the event analyses is not as clearly a defined area as communications. Several difficulties related to mixed airspace and air traffic control have been grouped together in this section. It is felt that they are symptoms of one underlying, fundamental problem. A major cause of difficulties for the pilot flying IFR, and for the VFR pilot as well, is the marginal VFR weather situation. When marginal visual meterological conditions occur, both VFR and IFR traffic exists in all areas of the airspace. This causes problems for operations in both uncontrolled and controlled airspace, in both terminal and enroute airspace.

As shown by the event analyses many problems involve the dependence of pilots on ATC for aircraft separation assurance. During IFR operations from airports in high density areas, navigational guidance is received through radar vectors from ATC. However, a radar-controlled departure or arrival in marginal VFR conditions does not relieve the pilot of the responsibilities of navigating according to the ATC clearance as well as of maintaining adequate separation from VFR aircraft. When departing or arriving at an uncontrolled field in marginal visual conditions, neither radar control, navigation guidance, nor assurance of separation from either IFR or VFR aircraft is available from ATC. However, the flight must depart and proceed in accordance with the IFR clearance, relying on compliance with standard operating procedures to ensure separation.

Enroute separation from other IFR aircraft operating in controlled airspace is provided by ATC in the four ways listed below:

1) Vertically by assignment of different altitudes.
2) Longitudinally by controlling time separation between aircraft.
3) Laterally by assignment of different flight paths.
4) Radar vectors.

All four techniques involve increased workload on the controller. The fourth method, radar vectoring, introduces the problem of lengthly delays, disorientation, stress, and increased workload for the pilot caused by flight rerouting to maintain separation while traversing dense, congested areas. ATC does not provide any radar control services for an IFR aircraft outside controlled airspace, such as for a flight between two remote fields, or at any time in VFR conditions unless requested. The ability of ATC to efficiently provide adequate separation only extends to aircraft under IFR flight plans and is limited by the availability, accuracy and reliability of ATC facilities and personnel and the reports of pilots on IFR flight plans. For operations in VMC or uncontrolled airspace, this problem is intensified for the pilot, who must maintain visual separation without cockpit aids or ground assistance.

4.2.4 Pilot Workload

The last of the four problem areas identified by the event analyses is related to the other problem areas already discussed. Although the event analysis technique was not designed to assess workload, as described in Section 4.1 a qualitative measure of pilot workload did result from the completed event analyses. By examining the single thread of events, the type of information required for the event to be performed, the nature of the information source, and the method, or medium through which the information is acquired, single pilot instrument flight can be demonstrated to be a high workload environment. The problems of SPIFR operations, such as the communications inefficiencies and weather reporting limitations just discussed add to the already high workload involved in instrument navigation and aircraft control and systems management.

There is no generally accepted definition of the term "workload". It has been defined in ways ranging from the number and nature of the displays and controls that must be used by the pilot in performing his/her job, to "the aggregate of the task demands placed on the pilot by the system during some relatively short-duration mission or phase of a mission coupled with the actions required of the pilot to satisfy those task demands" [26]. For every definition of pilot workload, there is a different technique for the measurement of either its physical or mental components. Despite the proliferation of workload definitions and measurement techniques and methodologies, there is agreement that high workload, both mental and physical, exists in single pilot IFR operations and that it can be measured empirically.

The analyses conducted on the single thread of events resulted in the identification of several aspects of the high workload SPIFR environment which are typical of its problems. First, there is an increase in the number and frequency of events, including the physical and cognitive load on the pilot, during flight phases in which the workload caused by aircraft control and configuration management, communications, and traffic separation is already high. In addition, due to the increased load on the pilot during critical flight phases — operating in dense terminal areas or in proximity to the ground, and in transitioning to VFR flight - the stress on the pilot increases. The last aspect which is illustrated is the lack of readily available information in an easily assimilated form. There are many sources of information, both inside and outside of the cockpit, but few present integrated information and none provide the necessary and sufficient information in a format which minimizes the interpretation and translation into actions required of the pilot. The event analyses illustrate that pilots compensate for a high workload condition by:

- Working faster for short periods of time followed by an increase in errors
- Deferring tasks
- Omitting tasks

All of these methods of coping with added workload affects SPIFR operations by reducing the probability of successful mission accomplishment. High workload thus compounds the problems associated with SPIFR operations by increasing pilot fatigue, increasing the probability of error and reducing capacity in adverse circumstances.

4.3 OTHER SIGNIFICANT GA SINGLE PILOT IFR OPERATIONAL PROBLEMS

This section examines other major operational problems of importance to GA IFR operators which are demonstrated or supported by available statistics or analyses. Each subsection below introduces the individual problem area and then presents the supporting documentation which demonstrates the magnitude of the problem. Section 4.4 then presents a summary table of all operational problems determined as being significant by this study and, for each, cross references the subsection of the report which provides supporting documentation of that problem area.

4.3.1 Terminal Arrival Delays Due to Arrival Time Control Limitations

Interarrival spacings between aircraft on final approach are determined by regulations and by the ability of the final approach controller to minimize spacings between aircraft while not violating the minimum spacing requirement. The minimum spacings range from three to six miles depending on the mix of aircraft classes, and will remain that high until solutions to the wake vortex avoidance problem are implemented. High delays have been experienced at the higher density airports for many years, as evidenced by the delay examples in Table 4.5 below, which contains data taken from references 6 and 7. Projections have been made of delay per operation to the year 2000 considering the effects of the proposed ATC system enhancements as they are implemented. Table 4.6 lists projected per operation delays for the same seven airports considering no improvements, near-term improvements (Vortex Avoidance System, basic M&S and TIPS) and all improvements (full WVAS, advanced M&S, TIPS and ETABS, Conflict Alert, Control Message Automation, DABS and ATARS). These values were taken from reference 27, which derived them from original data from reference 28. For purposes of comparison the historic (FY 1974) and projected demand figures for each airport

Table 4.5 Historic Delay per Operation Data at High Delay Airports

AIRPORT	DELAY PER OPERATION	YEAR
ATL	7.13 min.	1973
DEN	4.07	1973
EWR	4.89	1969
JFK	6.74	1969
JFK	6.10	1973
LGA	6.31	1969
LGA	5.46	1973
ORD	7.02	1973
PHL	4.59	1973

Table 4.6 Projected Delays per Operation at Seven Major Airports

AIRPORT	BASE CASE		NEAR-TERM IMPROVEMENTS			ALL IMPROVEMENTS			
	YEAR		YEAR			YEAR			
	1980	1985	1980	1985	1990	1985	1990	1195	2000
ALT	6.68	10.03	5.46	6.56	6.56	3.23	3.82	3.82	3.82
DEN	10.03	10.03	8.12	8.12	8.12	3.88	3.88	3.88	3.88
EWR	3.33	9.33	2.50	8.04	10.02	5.43	6.12	6.12	6.12
JFK	10.00	10.00	8.00	8.00	8.00	6.00	6.00	6.00	6.00
LGA	10.04	10.04	9.33	9.33	9.33	8.69	8.69	8.69	8.69
ORD	9.97	9.97	8.00	8.00	8.00	6.00	6.00	6.00	6.00
PHL	9.94	9.94	9.22	9.22	9.22	9.00	9.00	9.00	9.00

are listed in Table 4.7. These values were limited in the study documented in reference 27 such that an arbitrary maximum delay of ten minutes per operation was not exceeded. This was done to reflect the fact that high delays constrain operations, and is a conservative assumption.

The delay examples cited above in Table 4.5 include delays due to all causes, whereas the projections of Table 4.6 include delays due to ordinary day to day capacity limitations, not temporary services interruptions due to weather below minimums. The effects of the near term improvements and of all improvements on delay are apparent from the reductions in average delay at constant demand shown in Table 4.8 . Reference 27 has shown that the 4D RNAV technique can further reduce delays by improving the ability of ATC to control the spacings between arriving aircraft. As an example, the daily delay projected with and without 4D RNAV for Atlanta is listed by year in Table 4.8 .

The delay savings projected for the ATC enhancements and for 4D RNAV are quite dramatic. However, in actual fact the savings to be experienced will not be that great since a primary result of such improvements will be fewer constraints to the growth of demand. Thus, demand will not level out at some arbitrary level as assumed for academic purposes in that study, but will continue to grow. The result of better service will be more aircraft taking advantage of it, and so delays will continue to be high even with these improvements.

4.3.2 Terminal Arrival Capacity Effects of ATC Controller Limitations

The level of workload imposed on a terminal controller can be a factor limiting the capacity of an airport. The study referenced above [27] also evaluated the level of workload of controllers in the present environment, an environment with the several ATC automation enhancements, and with RNAV and

Table 4.7 Annual Traffic Demand, FY1974 [29], and Projections [27], (Thousands)

AIRPORT	FY1974	1980	1985	1990	1995	2000
ATL	502	619	680*	680*	680*	680*
DEN	379	461*	461*	461*	461*	461*
EWR	220	255	328	341*	341*	341*
JFK	360	393*	393*	393*	393*	393*
LGA	339	363*	363*	363*	363*	363*
ORD	681	707*	707*	707*	707*	707*
PHL	316	385*	385*	385*	385*	385*

*Demand Limited Such That an Average Delay of 10 Min Was Not Exceeded

Table 4.8 Daily Delay Projections at Atlanta (Minutes)

ENHANCEMENT LEVEL	YEAR				
	1980	1985	1990	1995	2000
Base Case +4D RNAV	11300	18700 10800			
Near Term +4D RNAV	9300	12200 6200	12200 6200		
All Imrpovements +4D RNAV		6000 3700	7100 4200	7100 4200	7100 4200

4D RNAV. Figure 4.8 depicts for SFO the capacity, in operations per hour, of each control sector as affected by the number of controllers manning each sector. It is evident from this example that on the average, the Final Approach Control sectors are the most capacity limited in comparison to the Arrival Feeder sectors and Departure sectors.

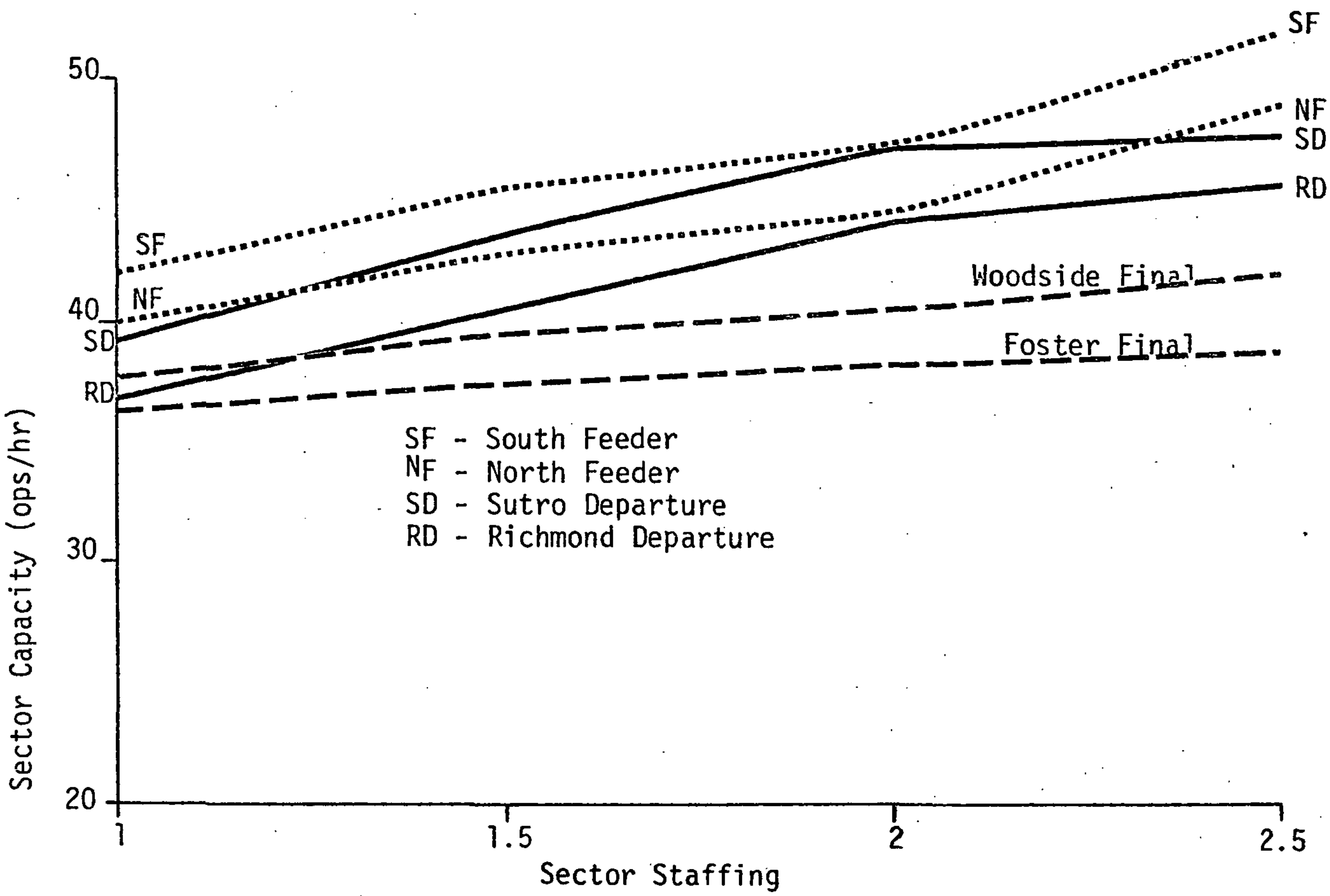


Figure 4.8 Control Sector Capacity at San Francisco

The study evaluated the effect of several levels of automation enhancements and of RNAV on the capacity of each sector type. These improvements are illustrated in Figure 4.9, and in some cases are quite dramatic. In particular, Final Approach sector capacity is improved the most by three enhancements: Metering and Spacing, DABS/Control Message Automation, and the RNAV + 4D capabilities. Without the automation enhancements and RNAV, the capacity limits of the Final sectors are close to IFR runway acceptance rates. As improvements to acceptance rate (such as from the WVAS program) are implemented, enhancements to the controller's capabilities must also be provided in order that capacity is not constrained from the ATC standpoint. Fortunately, two methods of improving runway capacity, Metering and Spacing and 4D RNAV, also improve Final Approach sector capacity.

In typical present day operations, control sector capacity limitations do not cause delays since some method (usually increased staffing) is usually found to increase sector capacity above the runway capacity limit. However, there are definite limits to the capacity increase available through staffing increases. Also, this is a very expensive way of improving sector capacity. Since techniques for improving runway capacity are bound to be implemented, ATC capacity could become the arrival capacity limitation and therefore be the cause of delays.

An unfortunate, but quite significant, side effect of the ATC controller workload/sector capacity problem is that the resulting high workload environment works to the disadvantage of GA IFR operators, particularly those who are under TRACON control but who are not operating to or from the primary airport. Services provided to "over" traffic and operators at secondary airports are molded to serve the convenience of the busy controller; e.g. convenient, rather than efficient, routings are provided and traffic can be

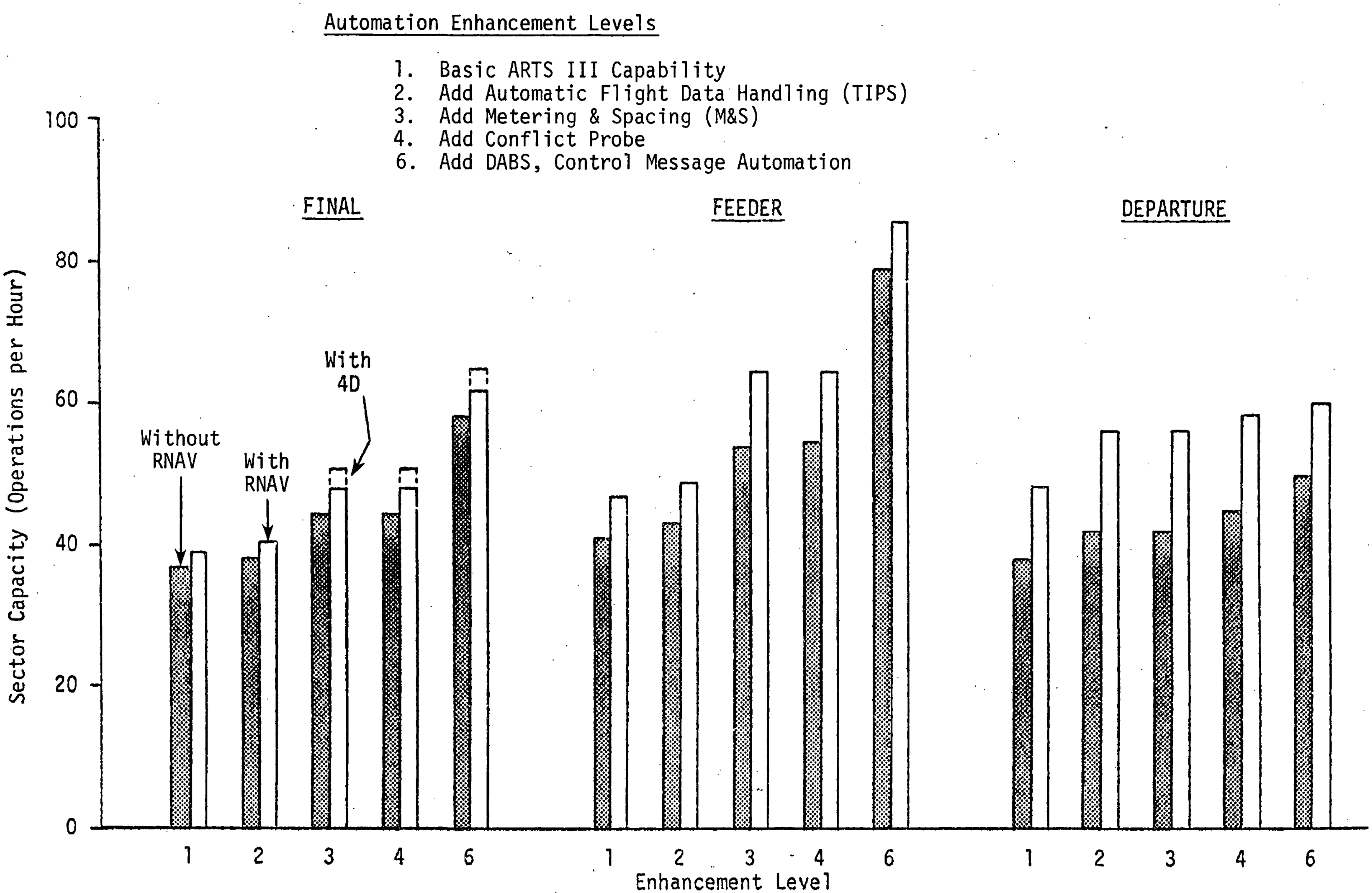


Figure 4.9 Control Sector Capacity of Each Enhancement Level (Cumulative)

held to resolve conflicts or alleviate workload. These factors and their delay implications were discussed in Section 4.2.

4.3.3 Delays and Diversions Due to Severe Weather Conditions

Severe weather conditions, including visibilities below approach minimums, excessive winds or turbulence and factors which render runways unusable, result in long arrival delays. These delays are not limited to the aircraft immediately affected by a temporary service interruption, but propagate to those aircraft arriving after service has been restored due to the long queue which can build up. Therefore, very busy airports will suffer a much higher incidence of weather-induced delays than a low density airport, even if similar weather patterns prevail.

The FAA operates a delay data collection program called the Performance Measurement System which receives daily reports from many air commerce airports. All delays to arriving, departing and enroute aircraft which exceed 30 minutes of delay are reported along with an assigned code indicating cause. Weather causes include categories like heavy rain, thunderstorms, snow, wind, low ceiling, poor runway conditions, etc. Examples of the monthly results of this effort (references 5 and 30) are presented in Table 4.9 for the seven airports mentioned earlier in this section. Three winter months and one summer month are given. Since delays must exceed thirty minutes, most weather-induced delays may not even show up in this data. From that table it is quite apparent that weather-induced delays vary considerably from month to month, airport to airport and season to season. The significance of weather as a causal factor of major delays is shown by the data in Table 4.10 which shows for August 1978 the weather-induced delays exceeding 30 minutes, all delays exceeding 30 minutes, and the weather-induced percentage. Other cause categories include traffic problems and volume, aircraft disruptions, airport disruptions, equipment malfuctions, etc.

4.3.4 Limited Availability of Landing Aids

A major part of many GA IFR operator's problems stem from the fact that many airports at which they operate have no established instrument approach facility. Therefore, if IMC prevails they must either fly to the nearest IFR airport, or postpone their trip. Either choice is very inconvenient and wastes much personal time. Many times corporate plant locational choices are influenced by the availability of a nearby instrument-equipped airport.

Of the 11,627 active airports (1974, reference 31) in the U.S., only 1849 (1976 statistics, reference 32) have some form of instrument approach facility, precision or non-precision. Of these, only 390 CONUS, non-military airports are ILS-equipped (reference 33). Some of these are multiple installations, and counting military and non-CONUS installations there are 559 individual precision ILS runways. The 1459 airports remaining are equipped only with non-precision approaches.

The fact that only 1849 airports are equipped with approach aids is unfortunate in view of the fact that it has been shown [31] that 2884 airports represent only 90.8% of CY1974 nationwide GA activity; therefore there is high activity at perhaps 1000 more airports than are equipped for IFR. If these airports were, in some manner, IFR equipped, it is likely that activity would increase as a result due to the fact that more IFR aircraft would base at these airports. The criteria used for selecting the 2884 airports was a minimum requirement for 5000 annual operations.

4.3.5 Limited Availability of Tower Facilities

In the above paragraph the fact that there are 2884 airports with 5000 or more annual operations was introduced. Of these, only 369 have control towers. However, GA operators operate primarily at non-towered airports, as indicated in Table 4.11. Fully two-thirds of the GA operations are at non-

Table 4.9 Occurrences of Weather-Induced Delays Exceeding 30 Minutes Duration (1978)

AIRPORT	JANUARY		FEBRUARY		MARCH		AUGUST	
	ARR	DEP	ARR	DEP	ARR	DEP	ARR	DEP
ATL	156	22	0	22	147	0	77	194
DEN	275	0	839	0	379	0	534	15
EWR	8	5	0	11	22	29	0	112
JFK	540	175	189	134	338	252	247	412
LGA	274	4	25	0	241	50	109	655
ORD	1764	50	471	63	13	0	0	59
PHL	79	9	11	8	69	5	16	212

Table 4.10 Occurrences of Delays Exceeding 30 Minutes Duration (August 1978)

AIRPORT	ALL CAUSES	WEATHER-INDUCED	
ATL	306	271	89%
DEN	549	549	100%
EWR	158	112	71%
JFK	688	659	96%
LGA	966	764	79%
ORD	59	59	100%
PHL	235	228	97%

Table 4.11 GA Operations at Towered and Non-Towered Airports (1974) [31]

TYPE	#AIRPORTS	ANNUAL OPERATIONS	PERCENT
Towered	369	42,018,000	33.4%
Non-Towered	2515	83,700,000	66.6%

towered airports, which means that the operators have to rely on control services from remote terminal or enroute facilities or have no FAA control services. Also, in most cases there is no radar coverage at the lower altitudes, necessitating the use of non-radar control procedures, which severely limits capacity and affords no protection against VFR traffic.

4.3.6 Route Structure Inefficiencies

Route structure design inefficiencies have crept into the present VOR structure for several reasons:

- Routes pass over VOR stations
- Routes must avoid restricted areas
- Routes must avoid high terrain
- Routes must mesh with terminal airspace allocations

Often a route is considerably lengthened simply because a complex arrival or departure procedure has been included. This is often encountered by low altitude IFR operators at medium and high density terminals. At the lower density terminals and non-towered airports, route wanderings are more likely to be caused by inconvenient station locations or the presence of restricted areas. All low altitude IFR operators often encounter devious routings when operating through areas near medium and high density hubs. This is simply the result of the need to route low altitude traffic away from the busy arrival and departure transition routes serving those airports. Often such operators may have filed a flight plan directly through such an area, and then find themselves vectored away from the dense areas when they actually arrive, as discussed previously in Section 4.2.

The potential savings which may be realized from establishing well designed RNAV route structures has been the subject of serious study for several years. Both high and low altitude route structures have been examined. In one study the intrastate VOR low altitude route structure of California was examined and RNAV routes were created to serve airport pairs with significant IFR traffic demand (reference 14). The resulting structure yielded an improvement of 2.5% on a traffic weighted basis in terms of reduced enroute distance traveled in comparison with the VOR structure. Another even broader evaluation of RNAV in the low altitude environment (reference 34) studied the existing VOR structure for the entire Northeast Corridor (Washington to Boston). This included a very detailed evaluation of existing routes, restricted areas, traffic flows and terminal area airspace requirements, and resulted in a comprehensive RNAV-based low altitude route structure for that area. The traffic-weighted route length improvement determined for that structure was 4.1%. These figures serve to demonstrate the degree of inefficiency present in the existing route structure.

Improved routing efficiency is not the only reason RNAV is attractive to GA operators. A very useful feature is the ability to conduct non-precision RNAV approaches, which offer improved minimums and more straightforward procedures in comparison to circling approach procedures they can replace. Conceivably, RNAV could provide approaches at some airports where no approach presently exists. Another popular usage of RNAV is to ease the night VFR pilotage problem.

4.3.7 Maintaining Required Separation

While midair collisons only account for approximately 4% of all aviation fatalities, they are generally considered to be quite important, probably for the following reasons:

- Midair collisions result not from equipment malfunctions but from human operator error
- A high percentage are fatal

- A high percentage occur near airports, thus endangering urban areas below
- While only a few involve air carrier aircraft, the result of these few is devastating
- Midair collisions often lead to criticism of the ATC system and aircraft operating procedures.

It is therefore useful to review some recent statistics concerning midairs. As reported in reference 35 , in 1976 there were 31 midair collisions, of which 24 resulted in fatalities. Of the 62 aircraft involved:

55 had no flight plan

5 were on VFR flight plans

1 was on IFR flight plan

1 was under military control

No air carrier aircraft were involved in that year. Every accident involved at least one VFR aircraft. Thirty-one percent of the accidents occurred while one or both aircraft were on VFR final approach. The other major operational phase category was the normal inflight cruise phase, which involved 32%.

Of the aircraft involved, 31% were involved in instructional or practice flying, 34% in pleasure flying, and 8% in business or corporate flying.

Historically, midair accidents primarily involve GA aircraft. In the 494 midairs which have occurred from 1957 to 1976, the following types of operators were involved:

Air Carrier/Air Carrier Accidents	2 (0.4%)
Air Carrier/General Aviation Accidents	17 (3.4%)
Air Carrier/Military Accidents	5 (1.0%)
General Aviation/Military Accidents	39 (7.9%)
General Aviation/General Aviation Accidents	431 (87.2%)

As reported in reference 36 , which is a detailed analysis of the 271 midair collisions which occurred from 1964 to 1971, 178 (66%) occurred at an airport (below 2000 ft and within 5 miles of the airport), whereas 93 (34%) were in the enroute or terminal environments. Of the airport accidents, 83% occurred where no tower was present, again pointing out the need for tower facilities. Of the 93 enroute and terminal area accidents, only 18 occurred where one or both were under radar traffic advisory services, as follows:

IFR-IFR	2
IFR-VFR	14
VFR-VFR	2

Of the 178 airport accidents, only 32 involved ATC service, as follows:

IFR-VFR	3
VFR-VFR, with radar	2
VFR-VFR, no radar	27

From all of these statistics, two factors standout: 1) It is extremely advantageous to be on an IFR flight plan, and 2) It is advantageous to be under direct radar control and operate at airports serviced by towers. None of this is surprising, of course, since the objective of ATC is to provide separation services. However, regarding the single pilot IFR operator, while he operates on an IFR flight plan, by the nature of his flying he often operates at uncontrolled fields or fields where no radar services are available at low altitudes. He is therefore often in mixed IFR/VFR traffic, and without benefit of radar. This results in a relatively high risk situation, and so midair collisions continue to constitute an important operational problem for GA operators.

4.3.8 Prevention of Weather-Related Accidents

This section deals with weather-related accidents in flight phases other than approach and landing. The NTSB publishes an annual analysis of weather-related accidents, for example reference 37 relating to 1976. That reference identifies a total of 908 accidents, of which 262 were fatal, where weather was listed as a cause or factor. These accidents occurred in the several flight phases as follows:

Flight Phase	Total	Fatal
Static	1	0
Taxi	39	0
Takeoff	141	27
Inflight	329	192
Landing	398	43

Virtually all of the takeoff fatals occurred during the Initial Climb phase. Most of these are probably the result of equipment failures, misjudgements of takeoff/climb performance capabilities or status, with weather-related factors (low visibility, poor braking action, etc.) being contributing factors.

The fatal inflight accidents group evenly in three sub-categories: Normal Cruise (55), Uncontrolled Descent (53) and other (54) accounting for 85% of the inflight fatal accidents. Nearly all of these accidents (89%) involved VFR operations. The accident briefs regarding all 162 of these fatal accidents were reviewed to isolate actual causes. While weather conditions were factors in each of these accidents, weather is almost never a primary cause of an accident; the causes are usually related to pilot errors in the face of known weather, or poor judgement exercised after unforeseen weather conditions are encountered. Table 4.12 presents the results of this review of the accident briefs.

Table 4.12 lists 144 fatal weather-related accidents for 1976 which occurred while the aircraft were being operated according to Visual Flight Rules. Of these 144 accidents, the majority (84 accidents, 58%) listed "Continued VFR Flight into Adverse Weather Conditions" as a primary cause. Another 18 (13%) were listed under "Initiated Flight in Adverse Weather

Table 4.12 Statistics of Fatal Weather-Related Enroute Accidents in 1976

ACCIDENT PROBABLE CAUSE	NORMAL CRUISE	UNCONTROLLED DESCENT	OTHER
VFR OPERATIONS			
No Certificate	1	0	0
Continued VFR Flight into Adverse Wx	35	28	21
Initiated Flight in Adverse Wx	2	12	4
Poor Flying Judgement	1	1	14
Impaired Vision and Poor Flying Judgement	3	3	2
Flight into Known Turbulence	2	0	1
Powerplant Failure -- Unavoidable	3	0	1
Powerplant Failure -- Ice, etc.	0	0	2
Miscellaneous Failures	2	0	0
Alcohol	0	3	1
Undeterimined	1	0	1
IFR OPERATIONS			
Not Instrument Rated	0	1	2
Disorientation/Loss of Control Due To:			
Turbulence, Thunderstorms	2	0	3
Icing Conditions	0	2	1
Low Visibilities/Ceilings	0	3	0
Improperly Loaded	0	1	0
Instruments Known to be Unreliable	1	0	1
Instrument Failure	0	1	0

Conditions". Both of these categories (71%) involve poor judgement, whereupon the pilot flies into conditions for which he is untrained and unqualified. Another 16 (11%) have been grouped in a broad category labeled "Poor Flying Judgement" which involves such things as failing to maintain clearance from terrain and flying up blind canyons. The remaining 18% deal with a broad number of causes, including equipment failures, poor visibility, flight into known turbulence, alcohol, etc. A common thread of nearly all of these VFR accidents is that the information required to conduct a safe flight (or avoid flying) is nearly always there; it is usually poor judgement which actually precipitates the accident. In some, but not all, cases the IFR accidents contrast.

Eighteen IFR fatal accidents where weather was a cause/factor occurred in 1976. A surprising number, three, involved pilots who were not instrument rated. One resulted from unavoidable instrument failure. Two more categories, "Instruments Known to Be Unreliable", and "Improperly Loaded, Weight and Balance", involved three accidents and are definitely in the "poor judgement" (or worse) category. The remaining eleven (61%) may have involved poor judgement, but also probably involved a <u>lack of necessary information</u> required to conduct a safe flight. These three remaining categories all involved disorientation or loss of control, due to:

- Turbulence and/or Thunderstorms
- Icing Conditions
- Low Visibilities and Ceilings

It is probable in most of these eleven accidents that improved or more up to date information concerning locations of thunderstorms, potential icing conditions and poor visibility could have resulted in pilot avoidance of the territories or altitude strata so affected, thus preventing the accidents.

4.3.9 Prevention of Approach and Landing Accidents

This section deals with Approach and Landing Accidents due to all causes. A recent study (reference 38) has evaluated in detail the data available from NTSB for a twelve year period (1964 to 1975). The study has isolated 335 single-pilot IFR flight plan landing phase accidents where pilot error was cited as a cause or factor. Historically, nearly all landing phase accidents involve pilot error as a cause or factor contributing to the accident. The circumstances of these accidents are quite informative. The accidents are broken down into the phase of the landing procedure in Table 4.13. For each landing phase listed, the two most common types of accidents are indicated. The results are not surprising: The majority of Initial and Final Approach accidents involve collision with stationary objects, indicating that the pilot was off course, too low, or had improperly executed the procedure. In the Final Approach case this includes undershoots. Secondary causes were engine failure for the initial phase, and uncontrolled collision with the ground in the Final Approach phase; these include turbulence-induced and icing accidents. Hard landing and overshoot accidents belong to the leveloff phase. The primary Traffic Pattern phase accident was of the engine failure type. Missed Approach accidents consisted of collisions with stationary objects and engine failures. Landing Roll accidents include roll accidents themselves and hard landings.

The light conditions and weather (visibility) conditions prevailing at the time of these accidents lend considerable insight into underlying causes and potential means of preventing such accidents. While the Initial Approach accidents (wherein the pilot is not typically looking for visual cues) are evenly divided between night and daylight hours, 74% of the final approach accidents occurred at night. Furthermore, conditions were below approach minimums in 32%

Table 4.13 Single Pilot IFR Landing Accident Circumstances

LANDING PHASE	TYPE OF ACCIDENT		CONDITION OF LIGHT			BELOW MIN.	FOG
	Most Common	Second	Night	Day	Dusk/ Dawn		
Initial Approach-59	Collide with Object-34(58%)	Engine Failure-11(19%)	30(51%)	25(42%)	4(7%)	9(15%)	38(64%)
Final, IFR-139	Collide with Object-98(71%)	Uncontr. Coll-15(11%)	103(74%)	31(22%)	5(4%)	45(32%)	115(83%)
Leveloff-59	Hard Landing-40(68%)	Overshoot-11(19%)	14(24%)	39(66%)	6(10%)	----	36(61%)
Traffic Pattern-7	Engine Failure-3(43%)	---------	3(43%)	4(57%)	0(0%)	----	5(71%)
Missed Approach-20	Collide with Object-10(50%)	Engine Failure-7(35%)	5(25%)	12(60%)	3(15%)	----	18(90%)
Landing Roll-27	Roll-16(59%)	Hard Landing-9(33%)	13(48%)	2(7%)	12(45%)	----	11(41%)

of the cases as opposed to 15% in the Initial Approach case, and fog was reported in 83% of the cases as opposed to 64%. This, coupled with the much larger number of Final Approach accidents, demonstrates how critically important the transition from instruments to visual reference is, and how dangerous a lack of suitable visual cues from the ground can be. Capabilities which would improve the ability of the pilot to detect the cues, or which would provide artificial cues, would definitely serve to reduce the incidence of Final Approach accidents.

Curiously, opposite tendencies prevail in the Leveloff landing phase. Daytime and dusk/dawn conditions prevailed in 76% of the cases. Below minimums data was unavailable, but fog was present only 61% of the time. Hard landings and overshoots often occur as a result of arriving over the threshold either too high or too fast, resulting in overreaction or the poor choice of attempting the landing in spite of the situation. It is possible that improvements to landing guidance or visual cues may serve to reduce the accident rate since more aircraft would tend to be stabilized at the proper state at the threshold. In that vein, it is notable that only 13 of the 59 Leveloff accidents occurred while precision approaches were being executed.

Sixty percent of the Missed Approach accidents occurred in daylight conditions, but 90% occurred in fog, indicating the inability to visually acquire obstructions contributes to the accident rate. However, it is generally procedural errors which result in being where the obstructions are.

In the Landing Roll category, only 7% occurred during daytime conditions, but fog entered into only 41% of the occurences. Apparently, the pilot's inability to properly interpret the ground light facilities is a strong contributing factor.

A factor which seems to be contributory in the Initial and Final approach accidents is the fact that in 27% of the cases the ceiling/visibility was below approach minimums, indicating that deficiencies in the weather reporting and forecasting system may be contributing to the incidence of these accidents. It is also possible that the fact that at a majority of airports with instrument approaches, local barometric setting data is not available, which may increase the probability of a hit short or overshoot.

A final factor of great interest regarding these landing accidents is the range of pilot error causes ascribed to them. In Table 4.14 the pilot error categories and the number of times they were cited in these 335 accident reports (more than one cause may be cited per report) are listed. The fact that nearly all landing phase accidents involve pilot error as a cause is a strong argument in favor of reexamining pilot training and proficiency programs in present use.

4.3.10 Communications Channel Congestion

A major problem encountered by all IFR operators is that of communications channel congestion, particularly in the higher density enroute and terminal environments. It is not uncommon to enter an environment where the radio channel is so busy that it is difficult to "get a word in edgewise". Besides inconveniencing all airspace users, this presents serious problems since:

- It indicates that the controller is overburdened, and thus may not be able to function in the optimum manner
- It encourages erroneous communications due to the hurriedness of the situation
- It encourages occurrences of communications dropouts and omissions through the inability to find a vacant slot, or as the result of simultaneous transmissions.

In studies of terminal [39] and enroute [40] controller workload, and of the effects of RNAV on those environments [27], communications

Table 4.14 Pilot Error Cause Categories Cited in 335 Single Pilot IFR Landing Accidents

PILOT ERROR ACCIDENT CAUSE	TIMES CITED
Improper IFR Operation Procedure	170
Failed to Obtain/Maintain Flying Speed	34
Improper In-Flight Decisions	28
Inadequate Preflight Planning	27
Attempted Operation with Known Equipment Deficiencies	27
Failed To Follow Approved Procedure	24
Improper Leveloff	24
Diverted Attention	22
Spatial Disorientation	21
Mismanagement of Fuel	18
Exercised Poor Judgement	14
Failed to Maintain Directional Control	13

workload data are presented (including air/ground as well as ground/air). Table 4.15 presents the results of the enroute analyses, where sectors in the Atlanta Center were studied. From that table it can be seen that communications occupies approximately 20 minutes of each hour (33%) when the control sector is operating at capacity. Since those studies found that a controller reaches capacity when his total workload reaches 48 minutes in an hour, that level of communications occupies approximately 40% of his total available workload. Note that at any instant, communications may occupy much more than 33% of his time, to be compensated for later by gaps in communications.

In the terminal case as shown in Table 4.16 even higher communications times for a sector operating at capacity can occur, particularly in the final approach control sectors where communications can occupy 29 minutes of each hour (48%) or 60% of the total available workload of the sector controller.

Table 4.15 Enroute (Atlanta) Sector Radar Controller Communications Channel Usage at Capacity

Sector Type	Comm Time per A/C (sec)	Sector Capacity	Comm Time per Hour (min)	% of Available Workload
High Enroute	27.93	41.61	19.37	40%
Dep.Transition	28.81	38.39	18.43	38
Departure	22.78	50.63	19.22	40
Arrival	42.71	30.34	21.60	45
Arr.Transition	33.04	36.47	20.08	42
Low Arrival	31.53	35.05	18.42	38
Low Enroute	34.43	33.13	19.01	40

Table 4.16 Terminal (SFO) Sector Radar Controller Communications Channel Usage at Capacity

Sector Type	Comm Time per A/C (sec)	Sector Capacity	Comm Time per Hour (min)	% of Available Workload
Final	46.86	36.80	28.74	60%
Feeder	34.07	41.07	23.32	49
Departure	38.01	37.97	24.05	50

4.3.11 Growing Vehicle Control Complexity

Within the general aircraft performance groups chosen for this study, the character of the task of the pilot in controlling and managing his aircraft has become increasingly demanding, particularly in the case of the single pilot IFR operator. This fact is not caused by any decrease in the basic aerodynamic stability characteristics of the aircraft, but rather it is caused by the mission performance enhancements built into the aircraft by the aircraft manufacturers, who are responding to the competitive demands of the market place. Some of these features specifically impact upon pilot workload during flight phases when the ATC-related workload is already quite high, thus compounding the situation.

Even the fixed gear, single engine aircraft of today presents a systems management challenge in the cockpit, particularly for the moderately trained and marginally proficient general aviation pilot. Independent of the necessity to manage the increasingly complex avionics suite necessary to perform the navigation and communication tasks, many of the additional systems and functions found on today's aircraft are associated with the management and control of the powerplant/fuel system. For instance, with the advent of higher-powered fuel-injected aircraft such as the Cessna Skyhawk XP as an example, the single-engine pilot of today (and even more so in the future) must cope with such controls and displays as fuel selector, fuel shut-off, mixture control, throttle, propellor pitch control, main vs. auxiliary fuel pumps, dual pressure fuel pumps, fuel and oil quantity gauges, fuel flow rate gauges, oil pressure, oil tmperature, cylinder head temperature, and exhaust gas temperature (1 to 6 cylinder sensors), as a partial list. Added to this are other such standard aircraft configuration controls as elevator and rudder trim, wing flaps, cowl flaps and audio panel/electrical system management controls.

Single engine aircraft of the future, and even some of those available today, are increasingly equipped with retractable landing gear, turbocharged engines, air conditioning systems, oxygen systems and in some cases even cabin pressurization systems. While stall and approach speeds are staying reasonably constant, additional aerodynamic and propulsion improvements are resulting in higher cruise speeds, with many single engine aircraft capable of 200 mph, which again compresses the time available to perform the cockpit management tasks.

Twin engine aircraft, of themselves, bring added complexity just due to the doubling of the basic powerplant controls and displays. However, there are additional factors which further aggravate the cockpit workload situation. Fuel system management involving cross-feed, multiple tanks, c.g. control and auxiliary fuel transfer pumps is markedly increasing in complexity as more and more multi-engine aircraft are designed and produced. An increasing percentage of twin-engine aircraft are both turbocharged and pressurized, both features requiring considerable cockpit management activity. Basic multi-engine flight operating procedures, particularly during take-off and climb-out, require considerably more training, skill, and current proficiency in order to ensure safe operation. Recent entries into the low cost light/twin market will increase the number of low-time general aviation pilots operating these complex aircraft into relatively congested airspace. As in the case of the single engine aircraft, approach and landing speeds are not drastically increasing, but cruise speeds in excess of 300 mph are not uncommon even today for the higher end of the general aviation spectum.

As an overall statement it can be said that general aviation aircraft, both single and twin engine, are becoming increasingly complex as regards cockpit management requirements, exclusive of any ATC-related workload. This increased complexity evolves primarily from powerplant/fuel system criteria, plus added consideration for increased speeds (and therefore decreased time available for performing the required actions).

4.4 SUMMARY OF GA SINGLE PILOT IFR OPERATIONAL PROBLEMS

This section presents Table 4.17, which lists all of the major single pilot IFR operational problems determined in this study as being highly significant, particularly in view of anticipated future developments. Beside each problem listed in Table 4.17 is the section or sections of this report which discuss the supporting evidence which demonstrates the significance of each problem. Section 5 then presents recommended solutions to these problems, and the research programs necessary to implement those solutions.

Table 4.17 GA Single Pilot IFR Operational Problems Cross Reference List

OPERATIONAL PROBLEMS	DEMONSTRATION OF PROBLEM
PILOT FACTORS:	
IFR Training Inadequacies	Discussion of Pilot Workload in Section 4.2.4 Discussion of Approach and Landing Accidents in Section 4.3.9
High Workload in Critical Flight Phases	Discussion of Pilot Workload in Section 4.2.4
High Workload in High Density Environments	" "
Future Traffic Growth Rate in High Density Areas	Discussion of Traffic Growth Projections in Section 2.2
Potential Workload Impacts of New ATC Features	Discussion of FAA ATC Development Plans in Sections 3.1 and 3.2
Growing Vehicle Control Complexity	Discussion of Operational Complexity of Varying Aircraft Types in Section 4.3.11
MISSION RELIABILITY AND EFFICIENCY:	
Flight Planning/Information Availability	Discussion of Flight Planning Problems in Section 4.2.1
Fight Delays in Dense Terminal Areas	Discussion of ATC Arrival Time Control as a Limitation to Capacity in Section 4.3.1 Discussion of Controller Workload as a Limitation to Capacity in Section 4.3.2 Discussion of Dense Area Delays to Aircraft Traversing the Areas in Section 4.2.3
Lengthy Delays/Diversions in IMC	Discussion of Severe Weather Delays and Diversions in Section 4.3.3
Limited Availability of Landing Aids	Landing Aid Discussion in Section 4.3.4
Routing Inefficiencies	Discussion of Route Structure Inefficiencies in Section 4.3.6

Table 4.17 GA Single Pilot IFR Operational Problems Cross Reference List (Continued)

OPERATIONAL PROBLEMS	DEMONSTRATION OF PROBLEM
Enroute Weather Avoidance Delays	Discussion of Flight Planning and Resulting Operational Problems in Section 4.2.1
Low Density Area Delays Due to Lack of Tower	Discussion of Operational Inefficiencies Due to Lack of Tower Facilities in Section 4.2.3 and Tower Statistics in Section 4.3.5
SAFETY:	
Maintaining Required Separation	Analysis of Midair Collision Statistics in Section 4.3.7
Weather-Related Accidents	Analysis of Weather-Related Accidents in Section 4.3.8
Growing Airborne Alert Environment Complexity	Discussion of New Cockpit Systems Associated with ATC Enhancements in Sections 3.1 and 3.2
Final Approach Accidents	Analysis of Approach and Landing Accident Statistics in Section 4.3.9
COMMUNICATIONS:	
Communications Channel Congestion	Discussion of Communications Issues in Section 4.2.2 and Channel Congestion in Section 4.3.10
Communications Errors, Omissions and Dropouts	Discussion of Communications Issues in Section 4.2.2
Lack of Tower or Off-Hours Services	Tower-Related Issues Discussions in Sections 4.2.1, 4.2.2 and 4.4.4, and Tower Statistics in Section 4.3.5
Access to Evolving Ground Data Base	DABS and Weather Modernization Program Discussions in Sections 3.1 and 3.2

5.0 GA IFR PROBLEM SOLUTIONS AND RESEARCH REQUIREMENTS

Based on the general aviation single pilot IFR operational problems identified in the previous sections, Section 5.1, below, suggests solutions to those problems, and Section 5.2 presents a set of areas where research is required in order that these solutions may be successfully implemented.

5.1 OPERATIONAL NEEDS AND CANDIDATE SOLUTIONS

A set of twelve GA IFR operational problem solution areas have been identified and are presented on the following pages. The solutions suggested may involve new technology, new approaches to cockpit layout and design, new approaches to airspace design, development of low cost substitutes for existing or planned systems, and development of new displays and guidance techniques, as well as improvements to cockpit and ATC procedures.

Configuration Control and Display Integration

This is a very wide ranging solution area, in that it can encompass any and all aircraft sensors, controls and displays, even including those which have yet to be developed. The major objectives are to integrate and simplify aircraft controls and displays in order to

1) Reduce the overall workload level
2) Reverse the trend towards growing vehicle and avionics control complexity
3) Reverse the trend towards growing airborne alert environment complexity

In addition, an objective is to improve the overall level of safety by providing automated means for monitoring critical engine and operating parameters.

This solution area can take several forms:

1) Integrating engine performance and flight instrument information into common processor/display systems.

2) Redevelopment of the aircraft control system, including autopilot systems and integrated controls such as integrated throttle/mixture/prop pitch controls.

3) Integration of navigation and guidance data with new displays and data presentation techniques.

4) Integration of data link facilities with the navigation system.

5) Control/display integration subjects in general.

The prime objectives of serious study efforts in this area to date (References 41 and 42) have been to simplify IFR flight to the point where the challenge level of a single pilot IFR operation is approximately equivalent to that of a VFR operation, or at least that of a dual pilot IFR operation. Rational approaches to the problem include completely automating the very routine tasks (such as instrument scan, displaying only out of tolerance conditions), or intensively analyzing all cockpit tasks and automating selectively, or concentrating on consolidation of data on a few displays, or simply automating that which is most easily automated.

This solution area addresses all of the pilot workload problems, including:

- High Workload in Critical Flight Phases
- High Workload in High Density Environments
- Future Traffic Growth Rate in High Density Areas
- Potential Workload Impacts of New ATC Features

It also addresses these other Pilot Factor and Safety category issues:

- Growing Vehicle Control Complexity
- Growing Airborne Alert Environment Complexity

Promote CAS/PWI Development

Efforts to develop a workable collision avoidance system, or proximity warning indicator, have been in progress for a long time. There are several technically feasible techniques, all of which utilize one-way or two-way ranging or ground-based radar techniques. These include:

- The McDonnell Douglas Time/Frequency CAS
- RCA and Honeywell two-way ranging techniques
- The ATARS concept under development by FAA
- Active and passive BCAS techniques, which have been recently evaluated by FAA
- Other BCAS techniques, such as Single-Site BCAS

All of these techniques address the objective problem area, Maintaining Required Separation. Each has depended on cooperative type systems, where both aircraft are equipped with suitable avionics, the advantage of BCAS concepts being that the required equipment is the ATC transponder with which most aircraft are already equipped.

General aviation needs collision avoidance service over and above that which ATC provides in separating IFR aircraft from each other and from other aircraft receiving radar advisories. The need stems not so much from the raw collision accident statistics as cited in Section 4.3.7. Only a small percentage of GA fatalities result from midair collisions. The need results from what may happen to GA operators as a result of air transport accidents involving GA aircraft. Many of the operational needs, particularly for IFR operators, cited in this report are available primarily from the larger (therefore air carrier) airports. If access to these airports were denied, controlled or otherwise restricted, the impact on general aviation operational utility would be severe. A primary example of this is the need for instrument runways. The pilot of the GA aircraft involved recently in the fatal midair collision at San Diego was receiving dual instruction on ILS procedures at that airport because it has the only ILS runway within a reasonable range. By the same token, during periods of IFR weather when minimums are low, arriving GA operators at other Southern California airports must go where an ILS runway exists.

A solution to the CAS/PWI problem is essential to assure that GA retains its proper place in the national transportation picture. This solution must be designed in a manner oriented and appropriate to the needs and limitations of GA operators.

Develop Distributed Management/Traffic Situation Display Concepts

This solution area, carried to its logical completion, could revolutionize both ATC and cockpit procedures by transferring part of the responsibility for, and means of executing, air traffic control to the cockpit. The principal problem areas addressed by the distributed management/traffic situation display (TSD) solution area are:

- Arrival Delays Due to Arrival Time Control Limitations
- Arrival Capacity Effects of ATC Controller Limitations
- Delays in Traversing Dense Areas
- Maintaining Required Separation

Ideally a traffic situation display concept could present to each pilot clear, concise, timely and accurate data concerning all aircraft in his immediate surroundings, and also display navigation data and other horizontal situation information. This display would allow the pilot to perform the following functions:

- Route navigation and lateral flight path control
- Separation from other aircraft
- Sequencing and spacing on final approach
- Autonomous off-route navigation through dense traffic areas

The TSD system would also provide a solution to the problem of maintaining cognizance of the local ATC situation when ATC message generation becomes automated and messages are data linked. (Thus data link can be used to provide a solution to its own problem.)

While the system described above represents the desired objective, there are obstacles to its realization, particularly in a general aviation frame of reference:

1) Aircraft data would probably only be available reliably for beacon-equipped aircraft.

2) There are technical problems which may constrain the ability to provide data in the most desireable format, i.e. referenced to each individual aircraft location, with desired update rate, accuracy and reliability.

3) System performance may be wholly dependent on the reliability of the ground ATC equipment (no independently-derived information).

4) Integration of navigation, map and flight instrument data may present technical difficulties.

5) Cost limitations.

Current efforts in TSD systems (primarily the Cockpit Displayed Traffic Information-CDTI-program) are concentrating mainly on the air carrier airspace user. It is necessary for general aviation purposes to pursue the development of low cost avionics providing these functions. It is appropriate to consider all useful aspects of the problem, including:

- Development of improved horizontal situation instrumentation and displays
- Integration of map information.

- Development (or integration) of traffic situation data, either from ground sensors or air-derived.

Such new systems will aid considerably in removing many ATC limitations from constraining system capacity, and will aid in increasing the degree of control the pilot exercises over the safe conduct of his operations.

Develop Remote Weather Display Concepts

This solution area is intended to capitalize on two current FAA programs: the Aviation Weather System (AWES) program, under which many improvements to weather data acquisition and dissemination are under development, and the DABS program, which will include some form of weather information data link capability. The Remote Weather Display (RWD) concept involves providing some form of graphic enroute severe weather information in real-time to the cockpit. It is essentially a ground-based, low user cost substitute for weather radar. The ground-based system would continuously assemble and update weather information from ground radars, PIREPS, possibly from aircraft equipped for weather observation, and from standard meteorological sources, and uplink appropriate information to RWD-equipped aircraft. Data rate, etc. requirements are very low in comparison to those of a TSD system, for example.

The Remote Weather Display concept is intended to approach two of the GA problem areas described above:

1) Enroute Weather Avoidance Delays
2) Prevention of Weather-Related Accidents (particularly in the enroute phase)

The concept would involve developments in ground based, as well as airborne, hardware in order to acquire needed information and package it in a manner usable by the airborne system. If sufficient data could be provided, it would be used by the GA pilot to navigate around enroute and terminal area storm cells, without requiring controller guidance. Thus, the hazardous weather would be safely avoided while at the same time efficiency of both the ground and airborne system would be improved.

Assess Data Link Avionics Requirements

This solution area is intended to foster development of data link avionics systems which are oriented to the needs, capabilities and limitations of general aviation operators. The data link capability offers many potential advantages to GA operators, but not unless the needed avionics can be provided at reasonable costs. Among these potential advantages are:

1) Error-free, uncongested communications, both ground/air and air/ground.
2) Provision of many new ATC features and conveniences for IFR operators (see Section 3.2).
3) Provision of the ATARS function.
4) Access to the ground enroute and terminal weather data bases.
5) Provision of miscellaneous data services, including route definition data.
6) Provision of the Traffic Situation Display function.
7) Provision of the Remote Weather Display function.
8) Inter-aircraft communications to facilitate CAS algorithms.

The major GA single pilot IFR operational problems which this solution area addresses include the following:

- Maintaining Required Separation
- Communications Channel Congestion
- Communications Errors, Omissions and Dropouts
- Access to Evolving Ground Data Bases

The solution area involves accurately projecting the technology which should be available for constructing the processors, displays and data entry facilities as well as determining the optimum configuration for each link function to be provided.

Requirements of Automated and Remote Towers

The objective of this solution area is to determine the specific functional and performance requirements of automated and remote airport control towers such that the actual needs of GA IFR operators can be served at a level of service similar to that available from existing control towers. Successful implementation of such systems would address the following problem areas:

- Low Density Area Delays Due to Lack of Tower
- Lack of Tower or Off-Hours Services

Additionally, such facilities may enhance operating safety, particularly during periods of marginal VFR weather when IFR and VFR traffic coexist.

The solution to the problems stated above is either to provide full manned tower services at many airports where full service is unavailable but needed, which is economically unacceptable, or to provide an automated, or remoted, equivalent. This solution area deals with the first steps required in order to provide successful automated or remote tower services: determining the minimum functional and performance requirements of these systems. It is essential that these minimum requirements be wisely established to avoid development of systems which do not provide the services actually needed, not only to prevent misspending of funds, but to assure safety. Nothing could be worse than a system which does little more than provide a false sense of security.

The present effort in the direction of automated tower services is the experimental Automated Terminal Services [43] which is currently under operational evaluation. While this system does provide certain services to beacon-equipped aircraft, it cannot guarantee IFR separation.

Alternative Precision Landing Aids

The intent of this solution area is to culminate in the deployment on a wide scale of a very low cost precision landing aid for general aviation airports. Economics dictates that such a system would probably utilize some existing (at present or in the future) piece of avionics equipment as the receiver/demodulator, probably with an additional decoder box which would generate the lateral and vertical guidance signals. Existing receivers on typical GA IFR aircraft include ADF, VHF NAV/Localizer, ATCRBS transponder, DABS transponder (future) and the MLS receiver itself (probably in the far future). Some aircraft have glideslope receivers or DME interrogator/receivers. It is almost a certainty that a low cost precision landing aid would be based on pulse techniques in order to minimize multipath effects. This essentially rules out all systems but those operating in the microwave region (the transponders, DME, and the MLS system). Successful implementation of the solution area would address the following problem areas:

- Lengthy Delays/Diversions in IMC
- Limited Availability of Landing Aids

The concept of taking advantage of some microwave receiver already (or assumed in the future to be) in the aircraft for landing system purposes is not new. Earlier this decade an FAA advance planning report [44] considered a GA landing system which utilized the DABS channel as an integral part of an advanced air traffic control system. Furthermore, a landing system based on an ATCRBS transponder modification was designed and tested by FAA in 1974. The test was successful, and the modification did not interfere with normal transponder operation.

If such a low cost precision landing aid could be developed and widely implemented, it would sharply reduce GA delays and diversions in IMC, and would result in improved overall operational reliability.

Area Coverage Systems for Non-Precision Aids

Area coverage navigation systems offer the promise of the ability to establish some form of non-precision approach procedure at any airport where the signals may be received. This could be extremely significant for operators based at the many remote airports and private airports which have no instrument approach aid. This solution area addresses the following problems:

- Lengthy Delays/Diversions in IMC
- Limited Availability of Landing Aids

There are several available or planned area coverage aids which could be suitable for non-precision approaches:

1) VORTAC-based Area Navigation
2) LORAN-C
3) OMEGA/VLF
4) Navstar GPS

At present there are 327 RNAV instrument approaches in active use in the U.S. Each of these area coverage navigation systems have unique problems regarding their usage as non-precision approach aids. For example, RNAV is usable only if there is a VORTAC station located nearby the airport with no signal loss down to minimums. OMEGA provides coverage everywhere, but is very inaccurate relative to the other systems, and so obstacle clearance criteria would be difficult to apply. LORAN-C and GPS are both very accurate. Total U.S. coverage by either system could be readily achieved in the early to mid 1980's. They are the most promising systems, but both involve rather expensive avionics, even for minimal capability systems. A problem common to all such techniques is the need for some form of crosscheck capability to ensure that the approach is being conducted properly.

While each area coverage system identified has some disadvantages, the objective of this solution area is to determine the best system(s) and pursue its development into an efficient, low cost non-precision landing aid.

Advance HUD, VASI and Approach Monitor Concepts

This solution area addresses primarily one problem category:

- Final Approach Accidents

although it is recognized that these concepts can also have positive impacts on pilot workload. This solution area includes Heads Up Displays of both IFR (displaying ILS data) and VFR types, Visual Approach Slope Indicators and ground-based Approach Monitor systems. Systems of each type are under development or in operational use. The most widely used is 3-bar VASI, which is installed at many airports. It is generally regarded as a VFR aid, although it is quite useful as a crosscheck once minimums are reached on an instrument approach. The 3-bar VASI may not be the optimum configuration; T-VASI is under operational test, and others may be even more useful.

HUD systems were originally developed by the military, although there is much interest among airline pilots in HUDs now. The objective of this is solution area is to determine whether a low-cost HUD system can be successfully developed which can be of operational advantage to GA IFR operators. This is particularly difficult in view of the fact that gyros and other flight instruments in GA aircraft do not typically have electrical outputs. Therefore, the HUD would have to provide separate gyro capability.

The approach monitor concept is relatively new. At present a system called FAME (Final Approach Monitor Equipment) is under operational evaluation. It is oriented primarily toward the air carrier operator,and for preventing duck-under accidents specifically. It monitors aircraft position using an elevation-sensing secondary radar antenna, and communicates with the flight crew visually through a series of very high intensity lights. Of course approach monitors in general need not be limited to these techniques, and could be designed to be more appropriate to GA operations and to warn of too-high, as well as too-low approaches.

Enhance IFR Training Programs

This solution area deals with the reevaluation of current training and proficiency requirements and procedures. The intent is not only to assure proficiency in IFR procedures, but also to better prepare GA pilots to deal with the increasingly complex ATC environment. This solution area addresses the following problems:

- IFR Training Inadequacies
- High Workload in Critical Flight Phases
- High Workload in High Density Environments
- Future Traffic Growth Rate in High Density Areas
- Potential Workload Impacts of New ATC Features
- Growing Vehicle Control Complexity
- Weather-Related Accidents
- Final Approach Accidents

While this solution area covers the full range of training issues, there are three outstanding issues to be addressed:

1) Are current IFR proficiency requirements actually sufficient to assure safe IFR operation?

2) For which purposes is simulator training appropriate, and how should simulator time be integrated in training/proficiency programs?

3) How should the basic IFR instruction syllabus be modified to train pilots to be competent operators in dense ATC environment?

Improvements to training procedures should enhance safety directly through better awareness of weather conditions and how to handle the consequences of unexpected weather, and through greater proficiency in executing an instrument approach. These improvements should also enhance safety indirectly as a result of the improved level of perceived workload during critical flight phases which will result from the higher level of competency of pilots.

<u>Innovative Communications Procedures</u>

This solution area consists of a detailed reexamination of the communications procedures is present use in medium and high density ATC environments. The intent is to attempt to organize the flow of information and means of coordinating air and ground activities in such a manner that communications becomes no longer a bottleneck in the operation of the ATC system. This will not only improve the controller workload situation, but will reduce the probability of communications errors and omissions. In all this solution area addresses the following problems:

- High Workload in Critical Flight Phases
- Communications Channel Congestion
- Communications Errors, Omissions and Dropouts

A significant advantage of this solution area is that, if such a reorganization is feasible, it could be implemented in a relatively short time period. Some of the other solution areas promise significant benefits, but will require a long implementation period.

Efficient Route Reorganization and RNAV

This solution area is intended to address the following problems:

- Controller Workload as a Limitation to Capacity
- Routing Inefficiencies

The result would be a redesigned low altitude route structure which could be navigated by the growing fleet of RNAV-equipped GA operators.

Two criteria would be constraining factors in evolving a new structure: (1) provision of convenient and direct routings between points, with city-pair travel demand setting route optimization priorities, and (2) minimization of controller workload. The second criteria is realized by avoiding the tendency to put too many routes through one particular area. Route merging would be done wherever possible.

Two other route design constraining factors which must be considered are navaid coverage and restricted area avoidance. Navaid coverage can be a problematic issue, particularly in areas of uneven terrain. Modifications to the structures may be required in a few locations after flight checking has been performed.

5.2 RECOMMENDED GA RESEARCH AREAS

Sixteen specific research areas are recommended below. Included are listings of tasks to be performed and the tools needed to perform the tasks. Table 5.1 presents a cross reference list of GA operational problems, as determined in Section 4, of candidate solutions, as discussed in Section 5.1, with specific research areas (below). The research areas are identified with a alphabetic codes which are associated with individual research areas.

A) Development of Technology Required for Integrated Configuration Control and Data Display Systems and for Multifunction Graphics Devices

This research area deals with a very broad subject: Control/Display integration. The two general subject categories included here are:

Table 5.1 Recommended Research Areas and Operational Problem/Solution Relationships

OPERATIONAL PROBLEMS \ CANDIDATE SOLUTIONS	Configuration Control and Display Integration	Promote CAS/PWI Development	Develop Distributed Management/TSD Concepts	Develop Remote Weather Display Concepts	Assess Data Link Avionics Requirements	Requirements of Automated and Remote Towers	Alternative Precision Landing Aids	Area Coverage Systems for Non-Precision Aids	Advance HUD, VASI and Approach Monitor Concepts	Enhance IFR Training Programs	Innovative Communications Procedures	Efficient Route Reorganization of RNAV
PILOT FACTORS												
IFR Training Inadequacies										N		
High Workload in Critical Flight Phases	A		E							N	O	
High Workload in High Density Environments	A		E							N		
Future Growth Rate of High Density Areas	A		E							N		
Potential Workload Impacts of New ATC Features	A									N		
Growing Vehicle Control Complexity	A									N		
MISSION RELIABILITY AND EFFICIENCY												
Flight Planning/Information Availability					H	I						
High Delays in Dense Terminal Areas												
- Limits to ATC Arrival Time Control			D									
- Controller Workload Limits to Capacity			F/G									P
- Delays in Traversing Dense Areas			F/G									
Lengthy Delays/Diversions in IMC							J	L				
Limited Availability of Landing Aids							J	L				
Routing Inefficiencies												P
Enroute Weather Avoidance Delays				F/G								
Low Density Area Delays Due to Lack of Tower						I						
SAFETY												
Maintaining Required Separation		C	F/G		H							
Weather Related Accidents				F/G						N		
Airborne Alert Environment Complexity	B											
Final Approach Accidents									K/M	N		
COMMUNICATIONS												
Communications Channel Congestion					H						O	
Communication Errors, Omissions and Dropouts					H						O	
Lack of Tower or Off-Hours Services						I						
Access to Evolving Ground Data Bases					H							

1) Complete reassessment of the methods used to control the vehicle configuration (all control surfaces, engine controls, subsystem controls), with the endpoint objective of centralizing control within an automated system designed to interact with the pilot; complete reassessment of the aircraft parameters sensed and methods of displaying those parameters to the pilot.

2) Assessment of methods of exploiting digital graphics devices which will be installed on many GA IFR aircraft to their fullest potential (e.g. integration of navigation, route structure, data link data, system parameters, etc. with a digital weather radar system).

Studies have been performed (references 41 and 42) which have partially addressed the first general subject category, at least to the point of providing unified aircraft parameter sensor and display systems, and integrated control of avionics. Integrated control of aircraft control surfaces and subsystems was not attempted. Regarding the second general subject category, it is really a subset of the first, but the emphasis is multiple usage of existing (or planned) displays as opposed to the development of wholly new displays. The result could either stand alone or become a part of a more general integration.

There are several research tasks which must be performed in order to properly address this research area:

Task 1. Determine the complete set of pilot information requirements for IFR flight. This will include first a definition of the optimum set of information, followed by the non-optimum substitutions which must be made because of practical limitations or the non-observability of desired parameters.

Task 2. Define the total set of pilot tasks required for IFR flight. Organize those tasks in a prioritized list of candidates for automation. Define an acceptable level of task requirements for performance by the pilot during critical flight phases, and determine the set of tasks to be automated.

Task 3. Determine the technology development requirements of systems which will implement the automation derived above in a highly economical manner. Technology development may be required for sensors, actuators, nav/comm avionics, processors, controls and displays.

These three tasks thus set the stage for the actual development of required technology and design and procurement of a prototype system for test and evaluation.

The performance of each of these tasks will involve detailed analyses of pilot functions and ATC interactions, and of projected technology development. Tasks 1 and 2 may also involve the use of piloted simulators to verify information requirements and pilot tasks, and to aid in the evaluation of task automation priorities. The simulator required would be a moving-base twin engine IFR simulator with all ATC interactions modeled. Simulated visual imagery is not required. The actual scope of the required experiment will be determined as a result of the analytical efforts conducted in Tasks 1 and 2.

B) Evaluation of Sensor Instrumentation and Display Factors Influencing the Design of Integrated Alert Systems or Subsystems

This research area deals with a specific sensor/display integration problem, and so can be considered a part of research area A, above, or could be realized as a stand-alone system. The specific matter under consideration is the large number of warnings at present of which the pilot must be cognizant, and the new warnings which will come about as a result of ATC enhancements. GA aircraft are not typically thought of as having a pilot warning enunciator "problem", as some air carrier aircraft have, because there may be but one actual warning horn (stall warning). However, there are many warnings enunciated, mostly silent, which have to be noticed during the instrument scan. For example:

- Stall warning horn
- Tachometer redline
- Airspeed redline
- Oil Pressure
- Cylinder Head Temperature
- Low fuel
- Electrical problem
- Tripped breakers
- Nav/landing system flags
- Altitude alert (barometric)
- Altitude alert (radio)

There is also a list of warnings which should be enunciated but which are not due to the lack of a needed system: high gross weight or improper C.G. for example.

ATC enhancements and associated avionics extend the list:

- Revised DABS data link clearances
- CAS/PWI enunciations
- ATARS enunciations
- Approach monitor enunciations

There are two major research tasks involved in this area of study:

Task 1. Determination of the sensor instrumentation required to sense each warning parameter in such a manner that it may be included in a centralized, automated system. This task includes specifying technology development requirements to result in economical subsystems.

Task 2. Assess the effects which human factors considerations should have on integrated alert system control/display design.

Both tasks involve analytical investigations. The second task will also require studies with a piloted simulator (moving-base) with sufficient ATC interactions modeled to properly test out the concepts being evaluated. Simulated visual imagery need not be provided. The scope of the simulator study will be determined at the completion of a review of pertinent literature in Task 2.

C) Identification of Operational Procedures or Automated Techniques for Resolving Conflicting Data Sources, Such as ATARS and CAS, in the Future Cockpit Environment

This research area deals broadly with the subject of crosschecks and resolving conflicting indications. This includes navigation and approach crosschecks, where data from more than one sensor is examined to verify proper indications from the primary navigation/approach aid, engine and flight instrument crosschecks and conflicting indications, and conflicting or redundant information from other sources such as conflicts between ATARS indications and an independent CAS or visual observations. The ATARS problem could be particularly disconcerting because of the "pop-up" nature of CAS indications and the lack of a reliably safe escape route in the face of conflicting data (as exists in the form of the missed approach procedure which can be executed at any time during an approach when the guidance information becomes suspect). This research area applies to resolution techniques which would be implemented either through automated techniques or manual procedures.

This research area includes the following three analytical tasks.

Task 1. Identify all sources of redundant information in the cockpit which could seriously affect flight safety (this is a derivative of

Task A.1), and categorize their primary failure modes to identify the seriously misleading cases.

Task 2. Develop operational procedures for either resolving the descrepancies in indications, or for alternative courses of action to resolve the problem in a safe and expeditious manner.

Task 3. Develop techniques suitable for automated implementation to accomplish the objectives of Task 2, including new sensors where appropriate.

D) Development of Methods for Reorganizing Tasks Between the Pilot and the Controller, Particularly Considering an Environment with Traffic Situation Display and Other Enhancements

The objective of this research area are to lay the analytical ground work defining the role of TSD-type systems (and other cockpit enhancements) in the ATC environment. This includes detailed definitions of precisely which ATC functions would be taken over by the cockpit, and how tasks, responsibilities and communications would be reorganized in the process. The emphasis is on the terminal environment, and both standard procedures and Metering and Spacing procedures should be considered. This includes determination of the effect of TSD-type systems on the design of the M&S algorithm.

The tasks required to carry out this research area are as follows:

Task 1. Determine the tasks performed by the air traffic control sector in controlling each individual aircraft. This is an extension to study task A.2 where the pilot tasks were defined.

Task 2. Determine the potential roles the TSD-type systems could play in taking over part of the ATC responsibility through an assessment of the ATC tasks which the pilot could take over and his ability in performing these tasks.

Task 3. Determine the division of responsibilities between controller and pilot, and required communications procedures to implement the TSD roles found to be attractive in Task 2.

Task 4. Evaluate, through piloted simulation, the merits of each potential role, and reject those roles found to be less attractive.

Task 5. Evaluate, through air traffic control sector real-time simulation with simulated pilot stations, the TSD roles remaining after Task 4 to determine their acceptability to ATC, and to isolate the one (or more) optimal role(s).

E) Determination of the Information, Data Rate, Format and Human Factors Requirements for General Aviation TSD-type Systems, and the Resulting Impact of TSD Design Parameters on Pilot Workload

The objective of this research area is to determine the design requirements for a general aviation Traffic Situation Display system, based on the system role and functions as defined in research area D. A critical design constraint which may be particularly difficult to achieve is to try to reduce the system requirements to the absolutely minimal level for purposes of economy. The following set of tasks will be required:

Task 1. Determine the information requirements for displayed data, including update rates, and the on-board processing which will be required in order to reformat the data and drive the display.

Task 2. Determine the necessary requirements of the data link channel, including data formats, overall rate, allowable lags and error rates. Assess the adequacy of the DABS data link channel, considering the other demands on it, for this purpose.

Task 3. Establish the human factors requirements of these TSD displays, and assess the pilot workload implications of variations in design parameters.

The last task will involve the use of a piloted, moving base simulator with ATC interactions modeled in order to complete the evaluation of workload implications.

F) Conduct Operational Evaluations of Remote Weather Display and TSD Concepts

The objective of this research area is to demonstrate the degree of benefit to be derived from successful implementations of Remote Weather Displays and Traffic Situation Displays. Both are intended to improve system capacity, reduce delays and enhance safety, although pilot workload may be somewhat increased as a result. Of course a moderate increase in workload may be an acceptable penalty if the desired benefits can actually be realized.

The primary beneficial impacts of TSD are expected to be in the ability to overcome terminal controller workload limitations to capacity,and arrival spacing control ability limitations to capacity. The benefits expected of RWD in the enroute environment are expected to derive from (1) improvements to route efficiency through the ability to navigate around thunderstorms, and the ability to do so regardless of controller workload limitations. The tasks involved include:

Task 1. Assess the impact of TSD usage on terminal control sector team workload. This will be accomplished through analysis and through the use of an ATC real-time simulation with pilot stations and TSD functions simulated from the controller viewpoint. This may require significant software development for the simulator system. The resulting workload improvements are then to be interpreted in terms of capacity enhancement level.

Task 2. Assess the ability of a TSD-equipped GA pilot to accurately control his interarrival spacing. This will require the use of a piloted, moving base simulator with the TSD function and ATC modeled. The control capabilities measured will then be interpreted in terms of capacity improvements.

Task 3. Assess the ability of a GA pilot to effectively utilize a Remote Weather Display, using a simulator as in the above task. This will involve generating simulated RWD weather characterizations.

Task 4. Determine the impact of the TSD system on overall level of pilot workload in a single pilot IFR operation. This will be determinable from the series of simulator tests conducted under Task 2.

G) Investigation of Data Link Performance, Hardware Requirements and Technology Alternatives such That Remote Weather Display and Traffic Situation Display Systems may Properly Serve Pilot Information Needs.

The objective of this research area is to determine what viable alternatives exist to service the data link requirements of TSD and RWD systems. With respect to TSD systems, this area builds on the work done under Task E.2. The data link requirements of these systems depend on the selected mode of operation of these systems. If the ground system is assigned the task of translating and rotating the information to be displayed for each aircraft such that each aircraft's data is unique, then the DABS technique (or an even higher capacity discrete-addressed link system) may be the only way to support it. If, however, each aircraft is given the capability to process a common set of data, rotating and translating it accordingly, the requirements of the data link change dramatically. In fact, the DABS link would be inappropriate due to the highly inefficient mode it would be operating in. A low data rate VHF link (not discretely addressed) would be far more appropriate. Each aircraft would then receive periodic updates of own position and heading through DABS (or a discretely addressed subset of the VHF link) in order to format and display the information to the pilot.

The following set of tasks will be required under this research area:

Task 1. Define the data link performance requirements and hardware implications for communicating TSD and RWD data to individually-addressed aircraft. Define the impact of such an approach on ground-based computer systems.

Task 2. Define the data link performance requirements and hardware implications for communicating common TSD and RWD data sets to all aircraft in an area. Also define the impact of such an approach on the airborne computer system.

Task 3. Investigate available and projected technology alternatives for reducing the cost or improving the performance of each of the two alternatives above.

H) Reevaluate the Role of Communications Data Links in the ATC Environment in Terms of Services Provided to GA Pilots and Impact on Frequency Congestion, Pilot and ATC Procedures, and Pilot Workload

This research area is intended to determine the potential worth of data linked ATC services to GA pilots. The value of the data link is measurable in terms of the utility of the services over and above the present methods of obtaining equivalent information, provided that pilot procedures and workload are not adversely affected.

The specific ATC services of concern here are those discussed in Section 3.2, the DABS data link discussion, including such things as routine clearances, real time airport data, and enroute and terminal weather data. The following tasks will be performed in this research area:

Task 1. Define in detail the probable and desireable characteristics of each of the data link ATC services. Determine the probable effect of each service in terms of voice channel activity replaced, and interpret those results in terms of reductions to frequency congestion.

Task 2. Determine the impact of each of the services on pilot procedures and workload in the GA cockpit environment. This is an analytical task followed by piloted simulations in a moving-base simulator with ATC interactions modeled in order to resolve those issues which cannot be determined through analysis alone.

Task 3. Determine the impact of each of the services on ATC control procedures and controller workload. If analytical techniques are insufficient to determine these factors and interpret the results in terms of control sector capacity impacts, an ATC simulation study may have to be conducted.

I) Determine Information Content and Communications Format Requirements of Automatic and Remote Towered Airports for Serving GA Operators and Resulting Impact on Procedures

This research area addresses the remote tower and automated tower concepts. In this task the services the towers are to perform will be defined, and the resulting communications channel (voice or data link) information content, air/ground and ground/air, will be determined.

The assessment of the minimum set of services needed by IFR pilots is critically important, for if some needed services are left out, the resulting system may not be safe. In particular consideration must be given to the problem of mixed VFR/IFR traffic in marginal VFR conditions. Since the objective of these systems is low installation/operation costs, it will be important to eliminate non-essential functions. This research area consists of the following tasks:

Task 1: Perform a comprehensive review of low density terminal area IFR operating procedures and problems and determine the minimum set of functional requirements for remote towers and for automated towers. Assess the ground system hardware implications of these requirements.

Task 2. Determine in detail the uplink and downlink message content for all message categories, the message frequencies, etc., and determine the most suitable data transmission format for each (voice/computer generated voice, or data link).

Task 3. Determine the impact of these systems on cockpit procedures, communications procedures, and ATC procedures at the remote site and nearby affected ATC facilities. The evaluation of cockpit procedure and communications procedure impacts may require the use of a piloted, moving-base simulator with the tower ATC interactions modeled.

Task 4. Assess, based on the results of the above tasks, the overall level of utility afforded to GA IFR operators by automated and remote tower systems.

J) Investigation of Candidate Alternative Low Cost Precision Approach Aids For Eventual Widespread Implementation at GA Airports

The primary objective of this research area is to identify those systems, including new or innovative systems, which could provide precision approach capability at GA airports at low cost for both airborne and ground installations. Also, the intent is to select the most promising system(s), procure prototype models and flight test them on an instrumented range.

The characteristics of a good low-cost precision landing aid would include simple null-steering to fixed approach/glide paths, microwave pulse system operation for freedom from multipath effects and high accuracy, and usage of existing avionics receivers/antennas for maximum cost reduction potential. The tasks required to achieve these results include the following:

Task 1. Assess the factors which determine appropriate cost levels for both ground and airborne installations. This would include, first, assessment of those difficult to control ground system costs such as providing power, antenna sites and equipment sheds. Second would be assessments of funds available for ground system installations. The last item is a survey of current avionics costs and installation fees.

Task 2. Identify and evaluate all potential valid concepts for low cost precision landing aids, including the following factors:

- State of development and technical risk
- Potential installation and siting problems
- Accuracy and reliability
- Estimated production unit ground installation cost
- Avionics commonality with existing systems
- Estimated production unit airborne installation cost

This task would conclude with a final system recommendation and specification.

Task 3. Procure prototype system for flight test purposes. This would include making arrangements for a suitable test bed and and airport with precision tracking range.

Task 4. Perform a flight test evaluation of the prototype system including instrumentation, data acquisition, data reduction and statistical analysis.

K) Assess Approach Monitor System Concepts and Determine Human Perception Aspects and Required Characteristics of External Stimulus-Based Approach Monitor Systems

Ground-based approach monitor systems offer the potential for preventing many hit-short and overrun type approach and landing accidents. The objective of this research area is to identify the most promising concepts for monitoring approach progress and for communicating serious deviations from the approach glidepath to the pilot. Methods of communication of deviation data are most attractive if they require no overt action on the part of the pilot for them to be effective. Thus, systems which utilize high intensity light signals, rather than a VHF radio channel, may offer advantages. Other potentially advantageous techniques include the DABS data link channel. A promising approach progress monitor technique is the use of an elevation-sensing secondary radar interrogator.

This research area consists of the following tasks:

Task 1. Perform an assessment of the available system design alternatives available for sensing approach path deviations and for communicating sensed deviation data to the cockpit. The alternatives will be evaluated on the basis of accuracy, reliability, operational utility, ground installation cost and airborne system cost (if any).

Task 2. Determine the human perception aspects and required characteristics of deviation communication techniques which are based on external visual stimuli. This investigation will involve the usage of a moving base piloted simulator with color visual imagery. This system should be capable of accurately modeling low visibility conditions and also the visual stimulus systems themselves. This task will culminate with acquisition of stimulus hardware determined to be most promising in the simulations, and flight test experiments using this hardware.

L) Assessment of Functional Performance Requirements of Area Coverage Navigation Systems for Use as Non-Precision Landing Aids to Significantly Expand the Number of IFR-Capable Airports

This research area is aimed toward determining which of the existing or upcoming area coverage navigation systems (Omega, Loran-C, GPS, VOR/DME RNAV) are best suited for serving as the primary aid for instrument approaches. Suitability consists of many factors including accuracy, reliability, availability, user cost and operational convenience. Another important subject to be studied is the ability to establish non-precision approaches at airports selected at random considering the following constraints: Adverse terrain or obstructions, adequate lighting or the ability to provide lighting, local factors affecting navigation system accuracy, and the ability to crosscheck approach performance with independent information. The last subject is particularly important, since there are many opportunities for the pilot to enter erroneous information into the area coverage navigator which could result in flying the wrong course. Also it is of importance to check the validity of the navigation data itself.

The following tasks would be performed in conjunction with this research area:

Task 1. Acquire data concerning existing systems and project information relating to systems yet to be implemented concerning their accuracy, reliability, availability on a temporal and regional basis, user cost and operational convenience. In assessing these factors it is critical to base them on the projected capabilities of the general aviation class of equipment which would be used.

Task 2. Based upon a review of typical GA airports with no approach aids which would be logical candidates for such service, each candidate area coverage aid will be examined for suitability and probable approach minimums considering availability of navigation signals, accuracy, and the availability of crosscheck information (including sureillance radar). Also considered will be local conditions including terrain, obstacles, runway lighting and visual cues available. The ability of each candidate system to provide the approach capability will be assessed, and the best system will be selected based on cost and operational factors.

Task 3. Projected system performance for the most promising systems will be verified through flight test of the hardware (a delay may be involved for some systems) at the airports for which the procedures were developed. This will require the use of a portable precision aircraft tracking system.

M) <u>Establishment of Design and Performance Characteristics of GA HUD Systems</u>

Head Up Displays could serve to improve the safety of visual and instrument approach procedures to a considerable extent. However, there are many problems that stand in the way of successfully developing these systems, not the least of which are cost and panel/glareshield space. Because of these severe constraints, great care must be exercised in specifying the design requirements for GA HUD systems in order to keep them as simple, small and low cost as possible. Another very significant problem relating to GA HUD design stems from the fact that most GA aircraft use gyros which have no electrical outputs, forcing the HUD to supply their own, or the replacement of existing gyros with compatible equipment. Therefore, the following tasks would be involved in the development and evaluation of GA HUD systems:

<u>Task 1</u>. Define the design requirements for general aviation HUD systems, including:

- Display parameters
- Display format and type
- Size and weight requirements
- Interface requirements
- Target system cost

<u>Task 2.</u> From the design requirements and a survey of existing technology determine the technology development requirements to satisfy the required design parameters. Pursue the development of necessary technological innovations.

<u>Task 3.</u> Procure mockup systems for simulator evaluation. Utilize a moving base piloted simulator with color visual imagery to evaluate

parameter and symbology suitability, pilot workload impact, glideslope capture and track-following error characteristics.

Task 4. Procure a prototype system for flight test evaluation. Conduct flight test evaluations at an airport with an instrumented range to verify the results of the simulator tests.

N) Comprehensive Review of Pilot Training Requirements

This research area is intended to review the suitability of existing training and proficiency requirements in light of the level of safety currently achieved in IFR flight by GA operators, and to specify new training requirements based on the assumption that GA pilots should be better equipped to deal with medium and high density ATC environments. Also included within this research area is the determination of impacts on training which each of the cockpit enhancements identified in this study should have.

The following tasks should be performed to satisfy the requirements of this research area:

Task 1. Perform a comprehensive review of present FAA-required training and proficiency levels for IFR operators. This analysis will include as one of its inputs an analysis of IFR accident statistics oriented towards the training problem. The output will be redefinitions of subjects included, or degree of emphasis provided, in the syllabus of instruction typically administered to instrument flight trainees.

Task 2. Analyze the skills required to conduct IFR operations in medium and high density ATC environments, and determine the additions or changes to the syllabus of training which would be required to develop these skills. Also consider additional skills required as future ATC enhancements are implemented.

Task 3. Determine the proficiency level requirements for these skills through the use of a piloted moving base simulator with ATC interactions modeled. This will probably require a series of pilots who would first be trained and then tested.

Task 4. Determine the training requirements associated with the cockpit procedural and avionics enhancements identified in the present study.

O) Redefinition of Cockpit and ATC Procedures Aimed at Communications Improvements and Pilot Workload Optimization During Critical Flight Phases

The primary objective of this research area is to try to develop revisions to cockpit and communications procedures which will tend to even out the level of workload and reduce the peaks in activity which occur during critical phases of flight, such as terminal arrival and approach. If peak workload levels can be reduced, improvements to communications error/omission potential and flight safety should result. Changes to communications procedures would result in a certain amount of reorganization of ATC procedures and even perhaps airspace allocations.

The following tasks would be required to complete this research area:

Task 1. Analyze the sequence of events currently performed in the cockpit during critical flight phases. Identify those tasks, communications and otherwise, which could be performed earlier than with present procedures, and determine what other factors need to come about (such as modified ATC procedures) in order to permit these procedural changes to be made.

Task 2. Utilizing a piloted, moving base simulator with ATC interactions modeled in detail, perform an evaluation of the degree of workload reduction to be expected from the changes made to procedures. Also measure communications errors and omissions to determine improvements to those measures.

P) Formulation of an Approach to Promote Travel Efficiency Through Route Structure Reorganization and Application of RNAV Techniques

This research area will include a detailed evaluation of the present VOR low altitude route structure and present controller radar vectoring techniques, and will develop and apply a methodology for improving the VOR route structure, developing an optimized low altitude RNAV route structure, and supplanting radar vectors with RNAV routings and RNAV vectoring techniques.

The following set of tasks will be required for this effort:

Task 1. Evaluate the existing VOR structure and formulate guidelines for laying in RNAV routes which would significantly shorten travel distance involved, or which service city-pairs with no direct connecting routes but which should generate significant IFR traffic. The guidelines should resolve problems where the structure is unduly complicated by combining closely spaced route segments. Restricted areas should be avoided appropriately.

Task 2. Identify in detail the types of impromptu procedures which typical GA RNAV systems can readily execute in order to respond to RNAV vectoring instructions. Develop appropriate phraseology to minimize communications requirements and reduce the chances for errors in communications.

Tasks 3. Complete the design of a low altitude RNAV route structure for a significant portion of the U.S. Analyze the design and compare route mileages flown with the present VOR route case on a traffic-weighted basis in order to get a realistic estimate of overall projected benefits in terms of fuel and time savings.

In summary, Table 5.2 below lists each recommended research area and the tools recommended for research in each area. These include, of course, analytical studies, piloted simulations, ATC simulations with controller subjects, and flight tests.

Table 5.2 Summary of Research Tools

RESEARCH TASK	RESEARCH TOOL			
	ANALYSIS	SIMULATION COCKPIT	SIMULATION ATC	FLIGHT TEST
A) INTEGRATED CONFIGURATION CONTROL/ DISPLAYS				
COCKPIT INFORMATION REQUIREMENTS AND HUMAN FACTORS	X	X		
PERFORMANCE REQUIREMENTS AND TECHNOLOGY ALTERNATIVES	X			
B) ALERT SYSTEM INSTRUMENTATION/DISPLAY FACTORS	X	X		
C) RESOLVING CONFLICTING DATA SOURCES	X			
D) TSD PILOT/CONTROLLER TASKS	X		X	
E) TSD INFORMATION REQUIREMENTS/PILOT WORKLOAD	X	X		
F) REMOTE WEATHER/TSD EVALUATION				
ENROUTE/TERMINAL CAPACITY IMPACT	X		X	
PILOT WORKLOAD IMPACT	X	X		
G) WEATHER DISPLAY/TSD DATA LINK REQUIREMENTS	X	X	X	
H) COMM. DATA LINK IMPACT	X	X	X	
I) REMOTE TOWERED AIRPORT COMM. REQUIREMENTS	X	X		
J) LOW COST PRECISION APPROACH AIDS	X			X
K) EXTERNAL STIMULUS APPROACH MONITOR		X		X
L) AREA COVERAGE NON-PRECISION APPROACH REQUIREMENTS	X			X
M) HEAD-UP DISPLAYS				
DESIGN AND TECHNOLOGY REQUIREMENTS	X			
PILOT PERFORMANCE/WORKLOAD		X		X
N) PILOT TRAINING REQUIREMENTS				
SYLLABUS/PROFICIENCY FOR HIGH DENSITY/ATC	X	X		
TRAINING REQUIREMENTS OF NEW PROCEDURES/AVIONICS		X		
O) REDEFINITION OF COCKPIT/ATC PROCEDURES	X	X	X	
P) ROUTE STRUCTURE EFFICIENCY	X			

6.0 CONCLUSIONS

The detailed conclusions of this study consist of the findings discussed in Section 5: the GA IFR operational problem solution areas and the corresponding research task recommendations. The general conclusions stated in this section are presented in an effort emphasize the magnitude and pervasiveness of the GA IFR operator's problems.

- At present GA IFR operations constitute a major segment of the U.S. air transportation system. Projections show that in the future, GA IFR operations will grow to the point where they will dominate air carrier operations in terms of sheer numbers. This is true in high density urban areas as well as outlying areas. The major finding of this study is that the GA IFR operator's problems are very serious, and will get much worse.
- The primary role of the FAA is to be the provider of ATC services. Thus it is in character that the thrust of the FAA's own modernization program is to improve the efficiency with which such services are provided, without necessarily concentrating on the efficiency of the services themselves or the particular needs of the various classes of operators. The resulting ATC facilities modernization plans for the most part will result in continued, or increased, operating costs for GA IFR operators while not significantly improving the efficiency of their operations. Potential exceptions include the program for improved weather data collection and distribution, the ATARS concept, factors improving airport capacities, and area navigation (which will be implemented very slowly).

- ATC plans for expansions to positive controlled airspace through reductions in the altitude "floor" and through expansions to the number of TCA's tends to drive general aviation out of that airspace, and in particular, drives lower capability IFR operators away while, possibly, attracting the higher capability IFR operators [45]. Unfortunately for the lower capability GA IFR operator he is therefore being driven away from the <u>very services he needs</u> so desperately.
- In light of the above factors, the cost to a GA IFR operator to improve his mission reliability on his own is very high and the payoff which results is often insufficient to cover that cost. Likewise, the cost to an airport operator to provide the ground segments of these ATC services is very high utilizing present technology, and so is typically justified only at airports with significant air carrier traffic, or very large GA airports.
- The tendency of the ATC system to control more and more airspace as time passes provides improved safety <u>to controlled aircraft</u> but at a general price of reduced operating efficiency for those aircraft. Also such trends tend to drive many operators out of that airspace, actually degrading their safety of operation by compressing them in a smaller amount of airspace. A potential solution to this problem is to improve the means by which aircraft operators can manage their own separation and ATC procedures, either

through air-derived collision avoidance sensors, or through the display of ground-derived traffic data.

- A comprehensive, well planned attack on the operational problems of GA IFR operators is needed to provide viable and economical solutions in order that such a valuable transportation resource can develop to the benefit of all. This program will include research which not only addresses the technology development issues, but the operational procedures issues as well.

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APPENDIX

DETAILED OPERATIONAL EVENT ANALYSES

This appendix presents the detailed analyses of the events of six flights used as the basis for identifying and evaluating GA IFR operational problems, as described in Section 4.2 of this report. Each analysis is presented in three parts:

1) A discussion of the baseline assumptions describing each flight (1 page).
2) A graphic depiction of the circumstances and events of each flight (1 page).
3) A detailed list of the events of each flight (4-6 pages).

For convenience, Table 4.4 is repeated below. It lists the basic parameters of each of the flights.

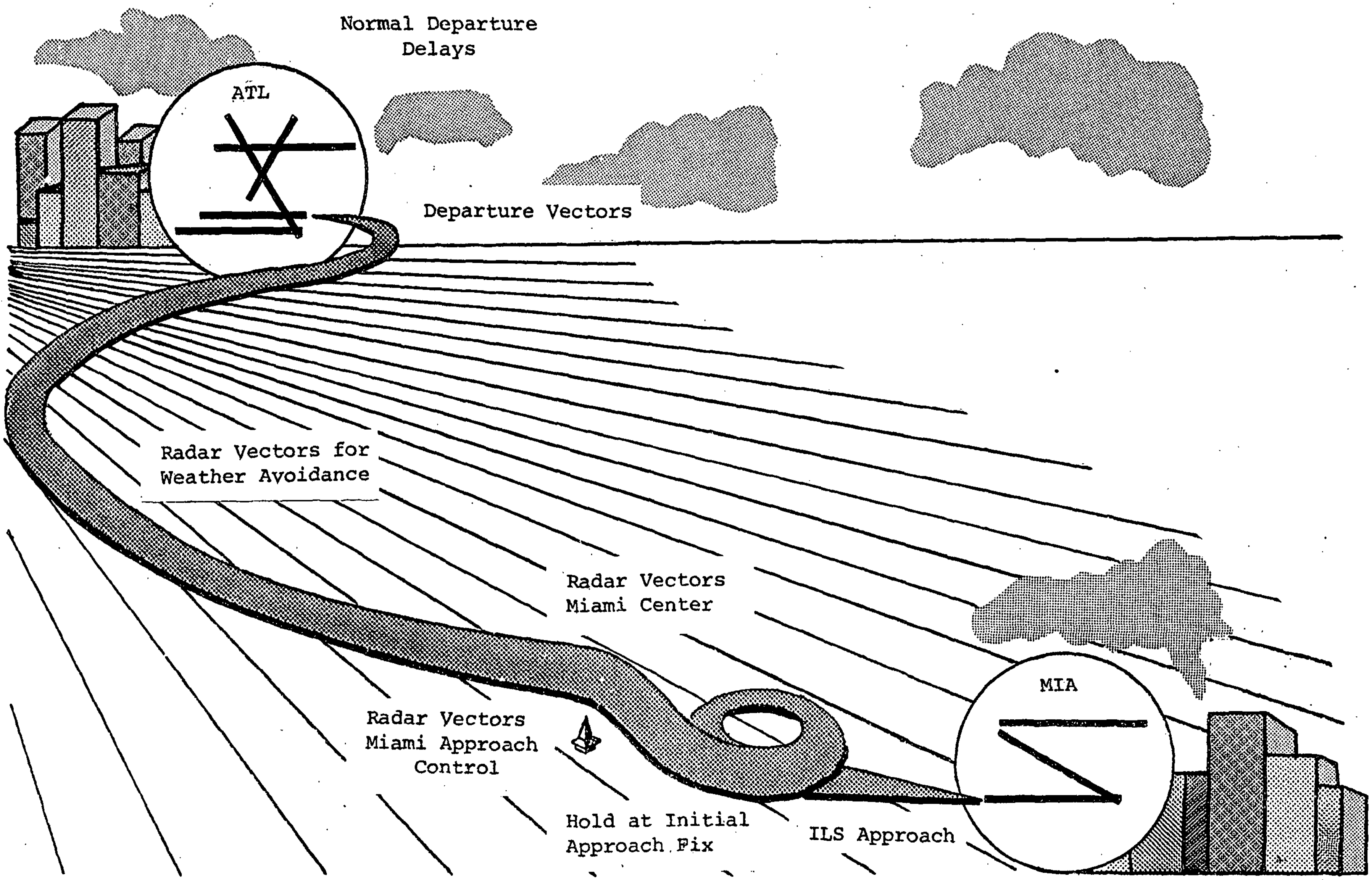
Scenarios

EVENT ANALYSIS	ENVIRONMENT	AIRPORT COMPLEXITY	AIRCRAFT
1	1978	Congested Hub	Twin Engine
2	1978	Satellite	Twin Engine
3	1978	Remote	Single Engine
4	Mid 1980's	Congested Hub	Twin Engine
5	Mid 1980's	Satellite with Diversion to Congested Hub	Twin Engine
6	Mid 1980's	Remote with Diversion to Medium Density Hub	Single Engine

1. Event Analysis of Atlanta International to Miami International Flight in Present Environment

Operation:	General aviation, single pilot, instrument flight rules
Environment:	1978 Air Traffic Control System
Airport Complexity:	Departure and arrival at congested hub air carrier airports
Aircraft:	Light twin engine, retractable gear, constant speed propeller: e.g. Cessna 401
Avionics:	Slaved gyro, Radio Magnetic Indicator (RMI), Automatic Direction Finder (ADF), Distance Measuring Equipment (DME), Encoding altimeter, Dual VOR Nav/Coms, Glideslope indicator, Marker beacons, Transponder, Headset, Push to talk switch, Clock with sweep secondhand

This scenario portrays a flight from Atlanta International to Miami International in a twin engine aircraft piloted by a single pilot in instrument meteorological conditions at night, with three passengers aboard. Takeoff is planned for early evening, with an estimated enroute time of two hours and thirty minutes. Instrument meteorological conditions exist at departure time, and this, along with the usual early evening congestion at hub airports, leads to lengthy but normal departure delays. Departing aircraft are issued radar vectored departures. Weather enroute is forecast marginal visual meteorological conditions, with pilot reports (PIREPS) of moderate turbulence below 15,000 feet and scattered thunderstorms south of Jacksonville, Florida. Actual weather enroute is instrument meteorological conditions. Radar vectors around thunderstorms are received. Arrival delays are experienced at Miami due to the weather and the normal traffic congestion. Arriving aircraft receive radar vectoring and are assigned a hold over the approach fix. Actual enroute time is approximately three hours.



Event Analysis 1. Atlanta to Miami Flight in Present Environment

EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
PHASE: PLANNING TIME: 1600				
Check Airman's Information Manual	Description of Miami International and Hartsfield facilities, radio frequencies, route distances, NOTAMS	Airman's Information Manual		
Check long range weather forecast	Frontal movement, high and low pressure areas, ceiling and visibility forecast for origin and destination airports	National Weather Service, Pilot's Weather Program on T.V.	Flight Service Station telephone call	
CONDITION: Forecast calls for marginal visual meterological conditions at Hartsfield and Miami until 2000, becoming instrument meterological conditions after that hour.				
Study low altitude charts, approach plates, sectionals, terminal area charts, departure and arrival charts	Victor airway routes, possible alternate airports, distances, approach, departure and missed approach procedures, required equipment and frequencies, SIDs, STARs	IFR low altitude enroute charts, approach and departure plates, sectionals, terminal area charts		
Plan IFR flight nonstop from Hartsfield to Miami International on victor airways	Aircraft avionics, true airspeed, fuel capacity and consumption rates, distances between check-points, possible alternate airport distances and approaches, weight and balance calculations	Aircraft pilot's manual, IFR charts, plates, sectionals, AIM, computer		
PHASE: DEPARTURE TIME: 1730				
Check weather	Present and forecast ceilings and visibilities for destination and possible alternates, winds aloft, SIGMETS, AIRMETS	National Weather Service	Flight Service Station telephone call	
Select alternate airport: Ft. Lauderdale-Hollywood International	Forecast ceiling and visibility for three (3) hours before and after estimated arrival time, distance from destination, arrival and approach procedures, prescribed alternate minimums	National Weather Service, IFR charts, approach plates, sectional		1) Weather forecast below minimums for destination and all possible alternatives Cancel trip plans 2) Possible alternatives require fuel stop along route in order to arrive at destination with fuel sufficient to reach alternate plus 45 minute reserve
CONDITION: Terminal forecast for Miami predicts ceiling and visibility above ILS minimums; for Ft. Lauderdale predicted at minimums prescribed for filing as alternate. Sequence reports (1710) show Atlanta Hartsfield IFR.				
File flight plan	Aircraft equipment, true airspeed in knots, estimated departure time, cruising altitude, route of flight, estimated time enroute, fuel on board, alternate airport, pilot's address, phone number, aircraft home base, number of passengers, remarks, SID request, aircraft color	AIM, IFR Flight Plan form, flight plan	Flight Service Station telephone call	Plan fuel stop
Preflight aircraft	Airworthiness, weight and balance in envelope, fueled as planned	Visual inspection, weight and balance sheet		
Start aircraft				
Contact Automated Terminal Information Service (ATIS)	ATIS frequency	Charts, sectional	ATIS recorded message	
CONDITION: Hartsfield IFR: ILS and CAT II ILS Rwy 8 and 9R in use for simultaneous approaches. Rwy 9L in use instrument departures.				
Contact Atlanta clearance delivery	Clearance delivery (ATL) frequency	ATIS	Clearance delivery (ATL)	
Issued clearance with revised departure time-delay of 50 minutes	Clearance limit, route of flight, altitude data, departure procedure (SID), holding instructions, special information (delays), instructions for contacting departure control	Atlanta center, departure controller		1) Issued clearance as filed with no delay in departure time 2) Issued revised clearance 3) Clearance not issued, notified of delay in clearance

Event Analysis 1. Atlanta to Miami Flight in Present Environment

EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
PHASE: ENROUTE TIME: 2005				
Contact Atlanta center	Atlanta center frequency, altitude clearance limit, altitude through which climbing	Atlanta departure control, navigation instruments, clearance	Atlanta center	
Issued identification instructions				
Perform identification procedure	Transponder code	Atlanta center		
Receive vector to position on route as filed	Position to which vectored, reporting fix, altitude clearance			1) Issued radar vectors until handed off to Jacksonville center
Proceed as vectored	Heading, altitude, orientation with respect to cleared route, time, reporting points	Atlanta center, navigation instruments, clock, charts, clearance		2) Cleared enroute as filed
CONDITION: COM: Atlanta center COM: Atlanta departure control NAV: Atlanta VOR NAV: Macon VOR				Radar service terminated, requested to report when reaching designated fixes Proceed as filed, making mandatory position reports as well as reporting at fixes
Position report requested				
Report position relative to route filed for	Position, time, altitude, type flight plan, estimated time arrival at next reporting point, name of next reporting point, remarks	DME, flight plan, victor airway, IFR chart, clearance	Atlanta center	
Receive clearance to proceed as filed				
Check weather enroute	Ceilings, visibilities, PIREPS, winds aloft	National Weather Service	Flight Service Station	1) Receive weather reports from center
Record position, time over checkpoints	Time, position relative to flight route filed, checkpoint position, next checkpoint location	Navigation instruments, clock, charts, flight plan		2) Receive automatic weather reports from VOR at 15 minutes past each hour
Receive handoff to Jacksonville center				3) Receive weather reports from Flight Watch 122.0
Contact Jacksonville center	Jacksonville center frequency	Atlanta center	Jacksonville center	No identification instructions issued if positive contact made by center assuming control
Issued identification instructions				
Perform identification procedure Receive confirmation of radar contact	Transponder code	Jacksonville center		
Check weather	Ceilings, visibilities, PIREPS, winds aloft	National Weather Service	Flight Service Station	
CONDITION: PIREPS and radar reports of thunderstorms along route, with moderate turbulence and rain.				
Request radar vectors around thunderstorm and higher altitude			Jacksonville center	
Receive vectors and new altitude clearances	Headings, fixes, altitudes, reporting points, location of heavy storm activity	Jacksonville center		Center unable to issue vectors around thunderstorm
Proceed as vectored	Heading, altitude, orientation with respect to cleared route, time	Jacksonville center, navigation instruments, clock, charts, clearance		Proceed as filed
CONDITION: COM: Jacksonville center COM: Atlanta center NAV: Waycross VOR NAV: Jacksonville VOR				
Report changing altitudes as requested, and when reaching designated fixes	Altitude, position, vectors, reporting points	Navigation instruments, charts, clock, vector instructions		
Encounter mild turbulence and hail				Turbulence and hail undetected on center radar Vectors take route through areas of turbulence and rain

Event Analysis 1. Atlanta to Miami Flight in Present Environment - Continued

EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
Receive position with respect to route as filed, clearance to proceed as filed	Position in relation to filed route, victor airways	Charts, navigation instruments, Jacksonville center, clearance	Jacksonville center	
Record time over checkpoints, keep track of position along route filed	Time, position, checkpoints, route filed, estimated distance to next checkpoint	Clock, charts, navigation instruments, clearance		
Receive handoff to Miami center				
Contact Miami center	Miami center frequency, position	Jacksonville center		
Receive identification instructions	Transponder codes	Miami center	Miami center	
CONDITION: COM: Miami center COM: Jacksonville center NAV: Miami VOR NAV: Pahokee VOR				
Receive notification of reported traffic				
Look for reported traffic but don't locate it	Other aircraft heading, relative position, altitude if known, type	Miami center, look and see procedure		See reported traffic
Receive vectors to avoid traffic			Miami center	Take avoidance procedures if necessary
Proceed as vectored	Heading, altitude, position relative to route as cleared	Miami center, navigation instruments, flight plan, charts		
Receive clearance to proceed as filed				
Proceed as filed	Position relative to route as filed, reporting fixes, VOR locations	Navigation instruments, charts, clearance		
Check weather	Ceiling, visibilities, PIREPS, winds aloft	National Weather Service	Flight Service Station	Check weather with center or VOR
CONDITION: Terminal forecast for Miami International predicts ceiling and visibility at ILS minimums; Ft. Lauderdale forecast at minimums prescribed for filing as alternate. PIREPS of scattered thunderstorm activity.				
Receive notification of revised clearance, beginning of radar vectoring into Miami				Cleared as filed to clearance limit Proceed with route as filed on victor airways
Receive radar vectors			Miami center	
Proceed as vectored	Heading, fixes, altitudes, reporting points, location of traffic, position to which vectored, heading, altitude, orientation with respect to victor airways of filed route, time, reporting points, traffic	Miami center, navigation instruments, clock, charts, flight plan, look and see traffic procedure		
PHASE: ARRIVAL TIME: 2225				
Receive handoff to Miami approach control				
Contact Miami approach control	Miami approach control frequency, altitude	Miami center, navigation instruments, charts, sectional	Miami approach control	
Contact ATIS	ATIS frequency	ATIS	ATIS recorded message	
Select plates for instrument approaches in use	Runways in use, special procedures, reporting point			
Give position reports over checkpoints	Aircraft identification, position, time, altitude, IFR plan, estimated time of arrival at next fix, remarks	Navigation instruments, flight plan, clock, computer, winds aloft forecast	Miami approach control	

Event Analysis 1. Atlanta to Miami Flight in Present Environment - Continued

EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
CONDITION: ILS Rwy 9L and R simultaneously in use. Delays in arrivals due to weather conditions and traffic density.				
Receive notification of expected delay and issued general holding instructions and type of approach to anticipate			Miami approach control	
Report arrival at clearance limit (Miami VOR)	Position, heading, altitude, time, remarks, location of Miami VOR	Navigation instruments, charts, plates, clearance, clock		
CONDITION: COM: Miami approach control COM: Miami center NAV: ILS frequency NAV: Miami VOR				
Receive clearance to proceed to initial approach fix for standard holding pattern			Miami approach	Holding pattern at initial approach fix has aircraft at every assignable altitude Assigned hold at VOR Hold at VOR according to instructions
Proceed to fix	Direction of fix from clearance limit, name of fix, altitude, vectors	Miami approach control, plate for assigned approach		
Report arrival at approach fix			Miami approach	
Enter holding pattern, and hold according to instructions	Aircraft heading at fix, holding pattern, direction of hold from fix, altitude assigned, outbound leg length, wind direction and speed, expect approach clearance and expect further clearance times	Miami approach, ILS Rwy 9R plate, clock, navigation instruments		
TIME: 2300				
Receive further clearance to begin approach at EAC time			Miami approach	
Report leaving holding fix to begin approach	Time leaving holding fix, fix position, aircraft position, approach profile, procedure, altimeter setting, wind direction and velocity, runway information	Plate, clock, navigation instruments		
CONDITION: COM: Miami approach COM: Miami tower NAV: ILS frequency NAV: Biscayne Bay VOR				
Fly ILS approach to Rwy 9R	Heading, outer and middle marker passage, minimum authorized transition altitude, descent rate, position relative to localizer, position on glideslope, marker beacon signal, procedure turn, time, minimums, approach course, glidepath interception profile, reporting points, altitude, airspeed, decision height, wind direction and speed, altimeter setting	Navigation instruments, clearance, marker beacons, lites and auditory signals, approach plate, altimeter, clock, localizer and glideslope indicators, warning flags, Miami approach control, volume settings of receivers		
CONDITION: Ceiling and visibility at Miami International above minimums for ILS Rwy 9R. Ceiling and visibility at Ft. Lauderdale below minimums prescribed for alternate.				
Runway environment sighted before decision height, visibility above minimums	Decision height, visibility minimums, altitude, distance to threshold, visibility	Approach plate, navigation instruments, visual contact outside cockpit		Runway environment not sighted at decision height and missed approach point
Contact Miami tower	Miami tower frequency	Charts, plates	Miami tower	Execute missed approach procedure State intentions to Miami approach control
Issued clearance to land				

Event Analysis 1. Atlanta to Miami Flight in Present Environment - Continued

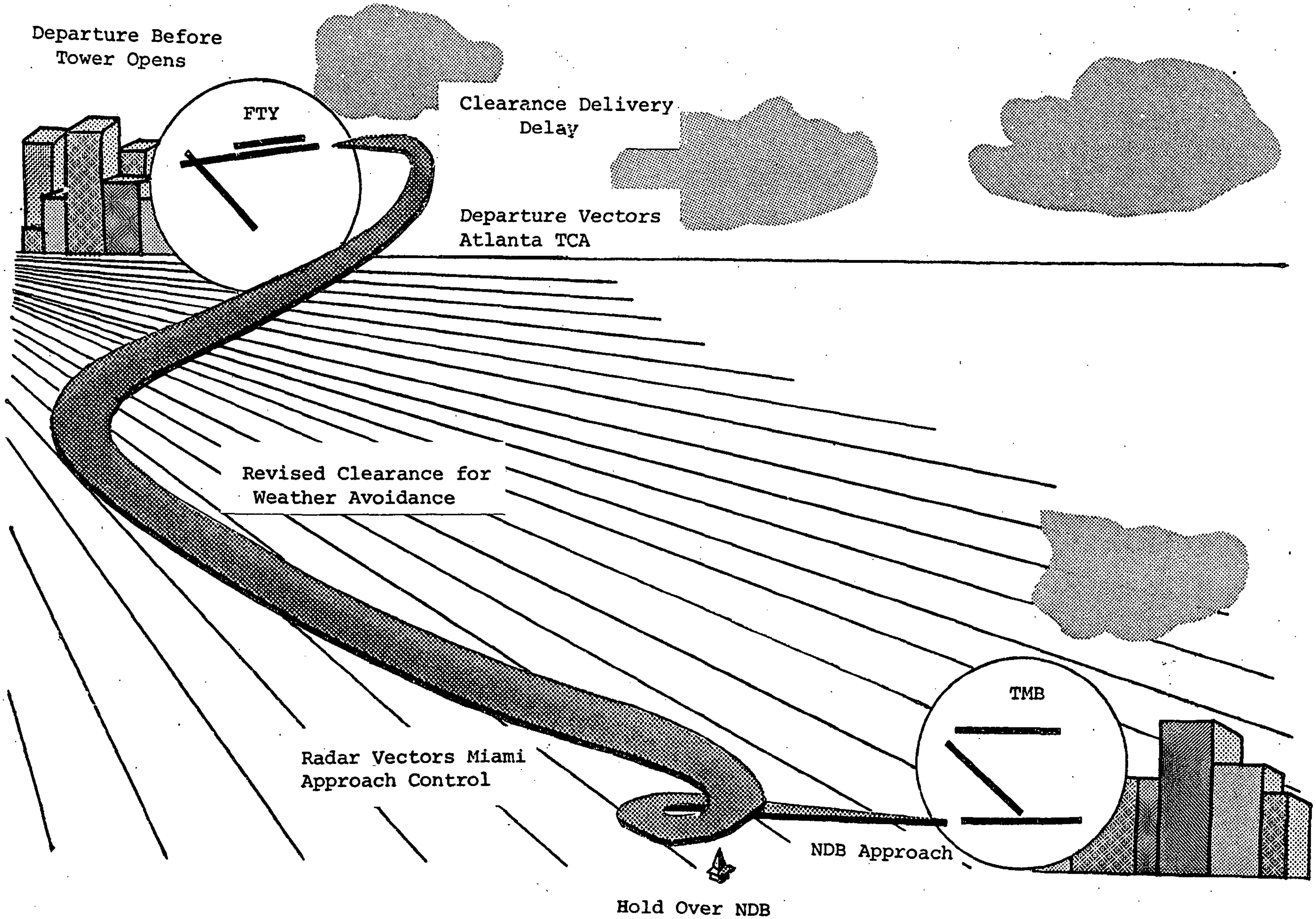
EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
Proceed with approach and landing visually	Runway alignment, rate of descent, glideslope, airspeed, distance from landing zone, wind direction and speed	Navigation instruments, visual cues from runway environment, Miami approach control		
Contact ground control for Rwy 9R	Miami ground control frequency	Charts, plates	Miami ground control	
Receive instructions for taxiing				
Taxi	Destination on airport, taxiway pattern, route assigned	Taxiway charts, Miami ground control		
Shut down aircraft TIME: 2325				
TOTAL TIME				
Start engine to shutdown:				
1915 to 2325: 4 hours 10 minutes				

Event Analysis 1. Atlanta to Miami Flight in Present Environment - Continued

2. Event Analysis of Atlanta's Charlie Brown County to Miami's New Tamiami Flight in Present Environment

Operation:	General aviation, single pilot, instrument flight rules
Environment:	1978 Air Traffic Control System
Airport Complexity:	Departure and arrival at general aviation satellites in congested hubs
Aircraft:	Light twin engine, retractable gear, constant speed propeller: e.g. Cessna 401
Avionics:	Slaved gyro, Radio Magnetic Indicator (RMI), Automatic Direction Finder (ADF), Distance Measuring Equipment (DME), Encoding altimeter, Dual VOR Nav/Coms, Glideslope indicator, Marker beacons, Transponder, Headset, Push to talk switch, Clock with sweep secondhand

This scenario portrays a flight from Charlie Brown County Airport, near Atlanta, to New Tamiami Airport near Miami, in a twin engine aircraft piloted by a single pilot in instrument metorological conditions. Takeoff is scheduled for early morning, and a non-stop flight is planned in order for the four passengers to arrive by eleven o'clock. Enroute time is estimated to be two hours and thirty minutes. Marginal visual meteorological conditions exist at departure time, and this combined with the tower not being in operation, leads to slight delays in IFR clearance delivery, departure, and arrival times. Weather enroute is forecast marginal visual meteorological conditions with scattered thunderstorms reported south of Orlando, Florida. Actual weather enroute is instrument meterological conditions, necessitating issuance of a revised clearance for weather avoidance. Radar vectoring is received by arriving aircraft due to normal traffic congestion, and the increased percentage of IFR traffic requires that the flight hold before being cleared for the NDB approach. Actual time enroute is approximately two hours and fifty minutes.



Event Analysis 2. Charlie Brown Co. to New Tamiami Flight in Present Environment

EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
PHASE: PLANNING TIME: 1730				
Check Airman's Information Manual	Description of New Tamiami and Charlie Brown facilities, radio frequencies, route distances, NOTAMS	Airman's Information Manual		
Check long range weather forecast	Frontal movement, high and low pressure areas, ceiling and visibility forecast for origin and destination airports	National Weather Service, Pilot's Weather Program on T.V.	Flight Service Station telephone call	
CONDITION: Forecast calls for marginal visual meterological conditions at Charlie Brown County and New Tamiami until 0700, becoming instrument meterological conditions after.				
Study low altitude charts, approach plates, sectionals, terminal area charts, departure and arrival charts	Victor airway routes, possible alternate airports, distances, approach, departure, and missed approach procedures, required equipment and frequencies, SIDs, STARs	IFR low altitude enroute charts, approach and departure plates, sectionals, terminal area charts		
Plan IFR flight non-stop from Charlie Brown County to New Tamiami on victor airways	Aircraft avionics, true airspeed, fuel capacity, consumption rates, distances between checkpoints, possible alternate airports, distances, approaches, weight and balance calculations, hours of tower operation	Aircraft pilot's manual, IFR charts, plates, sectionals, terminal area charts, AIM, computer		
CONDITION: NDB runway 9R approach is only approach available at New Tamiami.				
PHASE: DEPARTURE TIME: 0600				
Check weather	Present and forecast ceiling and visibilities for destination and possible alternates, winds aloft, SIGMETS, AIRMETS	National Weather Service	Flight Service Station, in person	1) Weather forecast below minimums for destination and all possible alternates Cancel trip plans
Select alternate airport: Miami International	Forecast ceiling and visibility for three hours before and after estimated arrival time, distance from destination, arrival and approach procedures, prescribed alternate minimums	National Weather Service, IFR charts, approach plates, sectionals		2) Possible alternates require fuel stop along route in order to arrive at destination with fuel sufficient to reach alternate plus 45 minute reserve Plan fuel stop
CONDITION: Terminal forecast for New Tamiami not available, terminal forecast for Miami predicts marginal visual meterological conditions until 0800 becoming instrument meterological conditions at that time. Sequence report for Charlie Brown indicates marginal visual meterological conditions. Tower not operative until 0700.				Tower at New Tamiami in operation 0700-2300 Sequence reports and ATIS available
File flight plan	Aircraft equipment, true airspeed in knots, estimated departure time, cruising altitude, route of flight, estimated time enroute, fuel on board, alternate airport, pilot's address, phone number, aircraft home base, number of passengers, remarks, aircraft color	Airman's Information Manual, IFR Flight Plan Form, flight plan	Flight Service Station, in person	Flight Service Station not on field Telephone FSS
Preflight aircraft	Airworthiness, weight and balance in limits, fueled as planned	Visual inspection, weight and balance sheet		
Start aircraft TIME: 0630				
Contact Automatic Terminal Information Service	ATIS frequency	Charts, sectional	ATIS not available until tower begins operation	Tower at Charlie Brown in operation 0700-2300 ATIS available
Contact Flight Service Station	Flight Service Station Frequency			
Receive airport advisory	Wind direction and velocity, favored runway, IFR departure runway, altimeter setting, known traffic, NOTAMS, taxi routes, traffic patterns, instrument procedures	Flight Service Station, AIM, airport plan	Flight Service Station (Atlanta Radio)	

Event Analysis 2. Charlie Brown Co. to New Tamiami Flight in Present Environment

EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
Receive notification of delay in clearance delivery	Estimated time of clearance delivery	Atlanta departure control, Atlanta center	Atlanta Radio	Issued clearance with no delay
<u>CONDITION</u>: VFR and IFR arrivals and departures at Charlie Brown County.				
Taxi to runway maintaining separation from VFR and IFR traffic	Wind direction and speed, location of other traffic on ground, active runways, taxiway location	Atlanta Radio, visual contact with environment, airport charts		
Contact Flight Service Station	Frequency for Flight Service Station (Atlanta Radio)	IFR charts, plates, sectional	Atlanta Radio	
Receive revised clearance, with delayed departure time of ten minutes and radar controlled departure procedure	Clearance limit, route of flight, altitude clearance, departure procedure, special information, instructions for contacting departure control, initial heading	Atlanta center, Atlanta departure control		
Copy and repeat clearance with revised departure time				Issued clearance with no delay in departure time
Perform runup and checklists	Aircraft functioning properly, radio equipment and navigation instruments set up, doors locked, seat belts fastened	Checklists		Proceed with takeoff
Contact Atlanta Radio	Atlanta Radio frequency			
State beginning of takeoff roll	Runway, airport name, aircraft identification, direction of flight	IFR charts, plate, clearance	Atlanta Radio	
<u>CONDITION</u>: COM: Atlanta Radio COM: Atlanta Departure Control NAV: Atlanta VOR NAV: Albany VOR				
Takeoff and climb out <u>TIME</u>: 0700	Takeoff, departure procedure, time, VFR traffic	Clearance, IFR charts, plates, clock		
Contact Atlanta departure control	Atlanta departure control frequency, aircraft altitude, position, time of departure	Atlanta Radio, navigation instruments, clock		
Receive contact verification, radar controlled departure instructions	Purpose of vector, route to which vectored, heading, altitude and climb instructions	Atlanta departure control		Radar controlled departure not given
Proceed with departure as vectored	Heading, altitudes, checkpoints, time, orientation with respect to cleared route	Atlanta departure control, clock, clearance, charts, plates navigation instruments	Atlanta departure control	Proceed as filed
Receive clearance to climb to filed altitude				
Proceed with climb	Cleared altitude, reporting points, position with respect to route cleared for, time	Atlanta departure control, clock, clearance, charts, plates		
Receive handoff to Atlanta center				
Contact Atlanta center	Atlanta center frequency, altitude, altitude clearance limit	Atlanta departure control, navigation instruments, clearance		
Issued identification instructions				
Perform identification procedure	Transponder code		Atlanta center	
Cleared to continue climb to filed altitude, receive radar vectors				Position reports requested
Proceed as vectored, climb to enroute altitude	Altitude clearance limit, checkpoints, position with respect to route filed, time	Atlanta center, clock, clearance, charts		Report position as required

Event Analysis 2. Charlie Brown Co. to New Tamiami Flight in Present Environment - Continued

EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
PHASE: ENROUTE TIME: 0740				
Position report requested				
Report position	Distance from next checkpoint VOR, altitude	DME, navigation instruments, vector instructions	Atlanta center	
Receive vector to position on route filed, clearance to proceed as filed	Purpose of vector, victor airway to which vectored, heading, altitude, and climb instructions			
Receive notification of termination of radar services				
Proceed normal navigation on route as filed	Position, victor airways, VOR location, route filed, checkpoints, time, other traffic	IFR charts, clearance, navigation instruments, clock, visual search, DME		
Report position at compulsory reporting point	Aircraft identification, position, time over checkpoint, altitude, estimated time of arrival over next reporting point, name of next reporting point, remarks	Navigation instruments, clearance, clock, computer, DME, charts	Atlanta center	
Receive confirmation of position report				
Proceed as filed	Position, victor airways, VOR location, route filed, checkpoints, time, other traffic, compulsory reporting points	IFR charts, clearance, navigation instruments, clock, visual search, DME		
Receive handoff to Jacksonville center				
Contact Jacksonville center	Jacksonville center frequency, altitude, position, time	Atlanta center, navigation instruments, DME, clock, charts		
Informed no radar coverage available, position reporting required				Radar coverage available
Receive traffic advisory	Traffic position relative to own, heading		Jacksonville center	Position reporting not required
Look for reported traffic	Altitude, heading, position of reported aircraft, type of reported aircraft	Visual search, Jacksonville center		
Report position at compulsory reporting point	Aircraft identification, position, time over checkpoint, altitude, estimated time over next reporting point, name of next reporting point	Navigation instruments, clearance, clock, computer, DME, charts		
CONDITION: COM: Jacksonville center COM: Atlanta center NAV: Gainesville VOR NAV: Orlando VOR				
See traffic at "ten o'clock" at same altitude				
Proceed with conflict avoidance procedures	Traffic heading, airspeed, altitude, position relative to own route of flight, collision avoidance procedure	Visual contact and judgement		Traffic at ten o'clock not seen Collision Near miss
Proceed as filed	Position relative to route filed, victor airway, VOR location, checkpoints, compulsory reporting points, time, other traffic	IFR charts, clearance, navigation instruments, DME, clock, charts		
Check weather	Ceilings, visibilities, PIREPS, winds aloft, storm activity	National Weather Service	Flight Service Station	
CONDITION: PIREPS of heavy thunderstorm activity south of Orlando, radar heaviest north of Lake Okeechobee, tops to 30,000'.				
Request radar vectors around storm			Jacksonville center	

Event Analysis 2. Charlie Brown Co. to New Tamiami Flight in Present Environment - Continued

EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
Radar vectoring unavailable				Radar vectors available
Receive revised clearance to proceed on alternative victor airways	Victor airway, altitude, climb instructions, reporting points		Jacksonville center	Alternate victor route does not route aircraft clear of storm
Proceed with new route cleared	Victor airways, VOR locations, position relative to original clearance, time, checkpoints	IFR charts, flight plan, clock, navigation instruments, clock, DME		Encounter rain, hail, etc.
Receive handoff to Miami center				
CONDITION: COM volume not properly turned up.				
Contact Miami center	Miami center frequency, position, altitude, time	Jacksonville center, navigation instruments, revised clearance, DME, clock		Volume properly adjusted Contact Miami [illegible] problem
Receive no reply				
Contact Miami center				
Receive request for message repeat				
Turn volume up				
Contact Miami center	Miami center frequency, position, altitude, time	Jacksonville center, navigation instruments, revised clearance, DME, clock		
Receive contact confirmation and identification instructions			Miami center	
Perform identification procedure	Transponder code, position report, altitude	Miami center, navigation instruments		
Receive identification confirmation and radar vectors	Purpose of vector, heading, altitude, and descent instructions			
Proceed as vectored	Altitude, orientation with respect to original clearance, time, reporting points	Miami center, navigation instruments, clearance, clock, IFR charts		
Check weather	Ceilings, visibilities, PIREPS for New Tamiami and Miami International	National Weather Service	Flight Service Station	
PHASE: ARRIVAL TIME: 0920				
Receive handoff to Miami approach control				
Contact Miami approach control	Miami approach control frequency, aircraft position, altitude, time	Miami center, navigation instruments, clock, charts	Miami approach control	
Receive contact verification and radar vectors to Miami VOR	Purpose of vectors, heading, altitude, and descent instructions			Density of traffic in Miami area causes communications congestion
Proceed as vectored to Miami VOR	Altitude, orientation with respect to route as filed, time	Navigation instruments, Miami center		Unable to contact Miami approach Delay in contacting Miami approach
CONDITION: COM: Miami approach control COM: Miami center NAV: Miami VOR NAV: Biscayne Bay VOR ADF: New Tamiami NDB				
Contact Automatic Terminal Information Service	ATIS frequency	Charts, plates, sectional	ATIS recorded message	
CONDITION: New Tamiami NDB Rwy 9R approach in use, ceiling and visibility above minimums, Miami International ceiling and visibility at the minimums required for filing as alternate.				

Event Analysis 2. Charlie Brown Co. to New Tamiami Flight in Present Environment - Continued

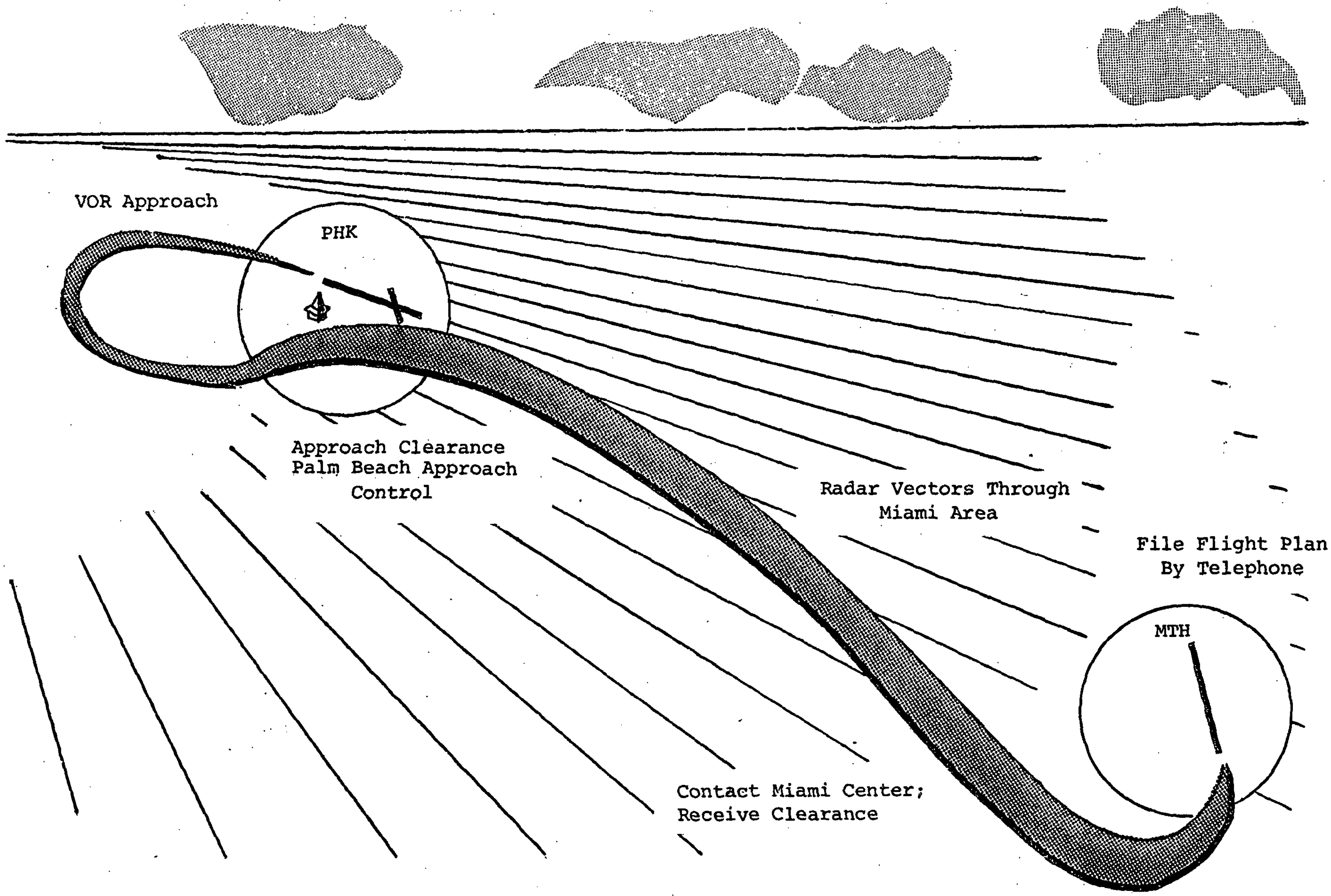
EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
Select approach plate for NDB approach				
Set up ADF to NDB frequency				
Report arrival at clearance limit (Miami VOR)	Position, time, altitude, location of VOR	Navigation instruments, clock, DME, IFR charts, ADF	Miami approach control	No hold issued, EFC time issued
Receive clearance to proceed to Perrine NDB and hold				Proceed to Perrine NDB for further clearance
Proceed to NDB	NDB frequency, location, VOR fix radials	Navigation instruments, ADF, RMI, charts		
Proceed with normal holding pattern entry at NDB arrival	Time, holding pattern entry procedure, wind direction and speed, relative bearing of inbound, outbound legs	IFR plate, navigation instruments, clearance, clock, ATIS, ADF		
Receive clearance for ADF approach TIME: 0950			Atlanta approach control	Clearance for approach not issued
Begin descent to procedure turn altitude	Procedure turn altitude, holding pattern, time, wind speed and direction, relative bearings	ADF, RMI, NDB approach plate, ATIS		Continue hold
Proceed with NDB approach	Inbound course, minimum authorized altitude, NDB location, station passage, minimum descent altitude, time	Approach plate, ADF, RMI, clock		
Contact Atlanta approach control	Time of station passage, position		Atlanta approach control	
Proceed toward station at MDA	Time, groundspeed, distance to field, minimum descent altitude	IFR plates, clock, computer, ATIS		
Establish visual contact with runway environment	Time, distance to field, inbound course, visual contact	Clock, plate, computer, visual search outside cockpit		Visual contact with runway environment not made
Proceed with approach and landing visually	Runway alignment, rate of descent, glideslope, airspeed, distance from landing zone, wind direction and speed	Navigation instruments, visual cues from runway environment, Miami approach control		Execute missed approach procedure State intentions to Miami approach control
Contact New Tamiami tower control	New Tamiami tower frequency, visual contact with runway	Chart, plates	New Tamiami tower	
Receive clearance to land				
Land				
Contact New Tamiami ground control	New Tamiami ground control frequency	Approach plates		
Receive instructions for taxiing				
Taxi	Destination on airport, taxiway pattern, route assigned	Taxiway charts, New Tamiami ground control	New Tamiami ground control	
Shut down aircraft TIME: 1010				
TOTAL TIME:				
Start engine to shutdown:				
0630 to 1010: 3 hours 40 minutes				

Event Analysis 2. Charlie Brown Co. to New Tamiami Flight in Present Environment - Continued

3. Event Analysis of Marathon Flight Strip to Palm Beach County Glades Flight in Present Environment

Operation:	General aviation, single pilot, instrument flight rules
Environment:	1978 Air Traffic Control System
Airport Complexity:	Departure and arrival at general aviation airports in remote location
Aircraft:	Single engine, fixed gear, constant speed propeller: e.g. Cessna 182
Avionics:	Calibrated gyro panel, Dual VOR Nav/Coms, Non-encoding altimeter, Mode A Transponder, Headset, Push to talk switch, Clock with sweep secondhand

This scenario portrays a flight returning from Marathon Flight Strip in the Florida Keys, to Pahokee, Florida in a single engine aircraft piloted by a single pilot in instrument meteorological conditions. Takeoff is scheduled for mid-afternoon, and a non-stop flight is planned, as the pilot and the three members of his family aboard desire to land before dark. Enroute time is estimated to be one hour and ten minutes. Instrument meteorological conditions exist at departure time, but since this is a remote, uncontrolled field, there is very little traffic and no delay is experienced. IFR clearance is received after departure. Weather enroute is forecast marginal visual meteorological conditions, however, the actual weather is instrument conditions. Radar vectors are received through Miami's TCA. No delays are encountered upon arrival at the approach fix, and a VOR approach to minimums is flown. Actual enroute time is approximately one hour and twenty minutes.



Event Analysis 3. Marathon to Pahokee Flight in Present Environment

EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
PHASE: PLANNING TIME: 2000				
Check Airman's Information Manual	Description of Pahokee and Marathon facilities, radio frequencies, route distance, NOTAMS	Airman's Information Manual		
Check long range weather forecast	Frontal Movement, high and low pressure areas, ceiling and visibility forecast for origin and destination airports, Flight Service Station telephone number	National Weather Service, Pilot's Weather Program on T.V.	Flight Service Station telephone call	
CONDITION: Forecast calls for marginal visual meterological conditions at Marathon and Palm Beach County Glades until 0800. Forecast unavailable after that time.				
Study IFR charts, plates, sectionals, terminal area chart for Miami, recheck AIM	Victor airway routes, possible alternate airports, distances, approach, departure, and missed approach procedures, required equipment and frequencies, procedures for radar control	IFR low altitude enroute charts, approach and departure plates, Miami TCA chart, sectionals		
Plan IFR flight non-stop from Marathon Flight Strip to Palm Beach County Glades on victor airways	Aircraft avionics, true airspeed, fuel capacity and consumption rates, distances, checkpoints, possible alternate distances and approaches, weight and balance calculations	Aircraft pilot's manual, IFR charts, plates, sectionals, AIM, computer		Range of aircraft not sufficient to reach destination non-stop with sufficient reserve for alternate Plan fuel stop
TIME: 0800				
Check long range forecast	Flight Service Station telephone number, frontal movement, high and low pressure areas, ceiling and visibility forecast for origin and destination airports	National Weather Service, Pilot's Program on T.V.	Flight Service Station telephone call	
PHASE: DEPARTURE TIME: 1600				
Check weather	Flight Service Station telephone number, present and forecast ceilings and visibilities for destination and possible alternatives, winds aloft, SIGMETS, AIRMETS	National Weather Service	Flight Service Station telephone call	
Select alternate airport: Palm Beach International Airport	Forecast ceiling and visibility for three hours before and after estimated arrival time, distance from destination, arrival and approach procedures, prescribed alternate minimums	National Weather Service, IFR charts, approach plates, sectionals		
CONDITION: Terminal forecast for Pahokee unavailable. Terminal forecast for West Palm Beach predicts 1000' ceiling and 2 miles visibility. Sequence report for Marathon unavailable. Marginal visual meterological conditions measured at Marathon UNICOM station.				Terminal forecast for Palm Beach below Pahokee approach minimums, forecast below prescribed minimums for all possible alternates Cancel return flight for that day
File flight plan 30 minutes prior to estimated departure time	Aircraft equipment, true airspeed in knots, estimated departure time, point of departure, cruising altitude, route of flight, estimated time enroute, fuel on board, alternate airport, pilot's address and phone number, aircraft home base, number of passengers, remarks, color of aircraft	AIM, IFR Flight Plan form, flight plan, IFR charts, pilot's manual	Flight Service Station telephone call	
Receive initial contact frequency	Frequency on which to contact Miami center, checkpoint for making contact		Flight Service Station telephone call	Weather conditions make it undesirable to attempt to maintain VFR departure
Preflight aircraft	Airworthiness, fuel on board as planned, weight and balance in limitations	Visual inspection, weight and balance sheet		Contact FSS by telephone and request clearance
TIME: 1640				
Start aircraft				

Event Analysis 3. Marathon to Pahokee Flight in Present Environment

EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
Contact UNICOM	UNICOM frequency, position and intentions	Charts, sectional	Marathon UNICOM	Field does not have UNICOM
Receive airport advisory	Wind direction and velocity, favored runway, altimeter setting, known traffic, applicable NOTAMS, taxi routes, traffic pattern	Airport weather station, UNICOM operator		Select runway favored by winds and/or traffic
CONDITION: PIREP to UNICOM reported ceiling of 1500' and visibility of 1 mile.				
Taxi to active runway	Taxiway patterns, active runway, known traffic	IFR charts, UNICOM operator		
Perform runup and checklists				
CONDITION: COM: UNICOM COM: Miami center NAV: Miami VOR NAV: Key West VOR				
Notify UNICOM of takeoff	UNICOM frequency, takeoff runway	IFR charts	UNICOM	Unable to contact UNICOM Continue with takeoff
Takeoff TIME: 1655	Time of takeoff, existing traffic, departure procedure	Clock, UNICOM		
Proceed as filed to designated checkpoint	Flight plan, victor airway intersections, altitudes, climb profile, radials for checkpoint	Flight plan, charts, sectionals, Flight Service Station, navigation instruments		1) Unable to maintain VFR to designated fix Contact Miami center for IFR clearance
Contact Miami center and request IFR clearance	Initial contact frequency for Miami center, aircraft identification, position, time of departure, altitude, plan, remarks, next fix	Flight Service Station, navigation instruments, flight plan, charts	Miami center	2) Able to maintain VFR Cancel IFR flight plan
Receive clearance to proceed as filed	Clearance for filed flight plan, reporting points			Receive revised clearance
Copy and repeat clearance				Proceed according to revised clearance
PHASE: ENROUTE TIME: 1710				
CONDITION: COM: Miami center COM: Flight Service Station NAV: Miami VOR NAV: Key West VOR				
Proceed on flight as cleared	Position, victor airway intersections, winds aloft, altitude, VOR positions and frequencies	Flight plan, clearance, navigation instruments		
Report position over checkpoints	Checkpoints, position relative to route filed, time, aircraft identification, altitude	Clock, flight plan, clearance, instruments	Miami center	Under radar control of Miami center Position reports not required
Check weather TIME: 1715	Ceilings, visibilities, PIREPS, storm activity	National Weather Service	Flight Service Station	Weather briefing can be received from: a) VOR automatic broadcast at 15 past hour b) Flight Service Station at other times c) 122.0 Flight Watch anytime d) Miami center has limited weather information available
CONDITION: Pilot attempting to contact FSS at 15 minutes past the hour, is interrupting the scheduled weather broadcast, interferring with broadcast as well as causing his own transmission to be garbled.				
Contact Flight Watch on 122.0	Aircraft position with respect to nearest VOR		En Route Flight Advisory Service	
Receive weather information				
Report position over checkpoint	Checkpoints, position relative to route filed, time, altitude, aircraft identification, winds aloft, next reporting point, time over next reporting point	Clock, flight plan, clearance, navigation instruments, computer, FSS	Miami center	

Event Analysis 3. Marathon to Pahokee Flight to Present Environment - Continued

EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
Receive notification of revised clearance, radar control thru Miami area			Miami center	No radar vectoring received
Receive identification instructions				Proceed with flight as filed
Perform identification procedure	Heading, turn directions, transponder codes			
State altitude				
Receive radar vectors	Purpose of vector, route to which vectored			
Proceed as vectored	Headings, altitudes, position with respect to cleared route, time, checkpoints, fixes	Navigation instruments, flight plan, charts, vector instructions, clock		
Receive vector to position on route as filed	Purpose of vector, route to which vectored			
Proceed as vectored	Heading, altitudes, position with respect to cleared route, time, checkpoints, fixes			
Receive notification of end of radar control, cleared to proceed as filed				Radar vectoring continues to destination fix
Proceed as filed	Victor airways, position with respect to filed plan, winds aloft, intersections, VOR position and frequency	Flight plan as filed, clearance, navigation instruments, clock, charts		Proceed as vectored
TIME: 1755				
Check weather	Ceiling, visibilities, PIREPS, winds aloft, Palm Beach altimeter setting	National Weather Service	Flight Service Station	
Report position	Checkpoints, position relative to route filed, time, altitude, aircraft identification, winds aloft, next reporting point, time at next reporting point	Clock, flight plan, clearance, navigation instruments, computer, FSS	Miami Center	
CONDITION: Terminal forecast for Palm Beach International predicts ceiling and visibility at 800' and 2 miles.				
PHASE: ARRIVAL TIME: 1800				
Contact Palm Beach approach prior to destination fix	Position, time, next checkpoint, altitude, heading	IFR plate, navigation instruments, clock, flight plan	Palm Beach approach control	
Receive clearance to Pahokee VOR	Altitude, reporting points, estimated approach time, altimeter	Miami center, Palm Beach approach control		Issued revised clearance to hold northwest of Pahokee VOR with delayed estimated approach time
CONDITION: COM: Palm Beach approach control; COM: Miami center; NAV: Pahokee VOR; NAV: Palm Beach VOR				
Contact Pahokee airport advisory			Pahokee UNICOM	
Receive airport advisory	Wind direction, velocity, runway information, known traffic	UNICOM weather station, UNICOM operator		
Report position over VOR	Time, position, altitude, aircraft identification	Navigation instruments, clock, charts, plates	Palm Beach approach control	
Receive clearance for VOR approach to Runway 17				Hold given in initial clearance to VOR
Proceed with VOR approach	Procedure turn altitude, descent profile, outbound radial, distance not to exceed outbound, procedure turn, inbound radial, minimum descent altitude	IFR approach plates, clock, navigation instruments		Proceed with VOR holding pattern until cleared for the approach

Event Analysis 3. Marathon to Pahokee Flight in Present Environment - Continued

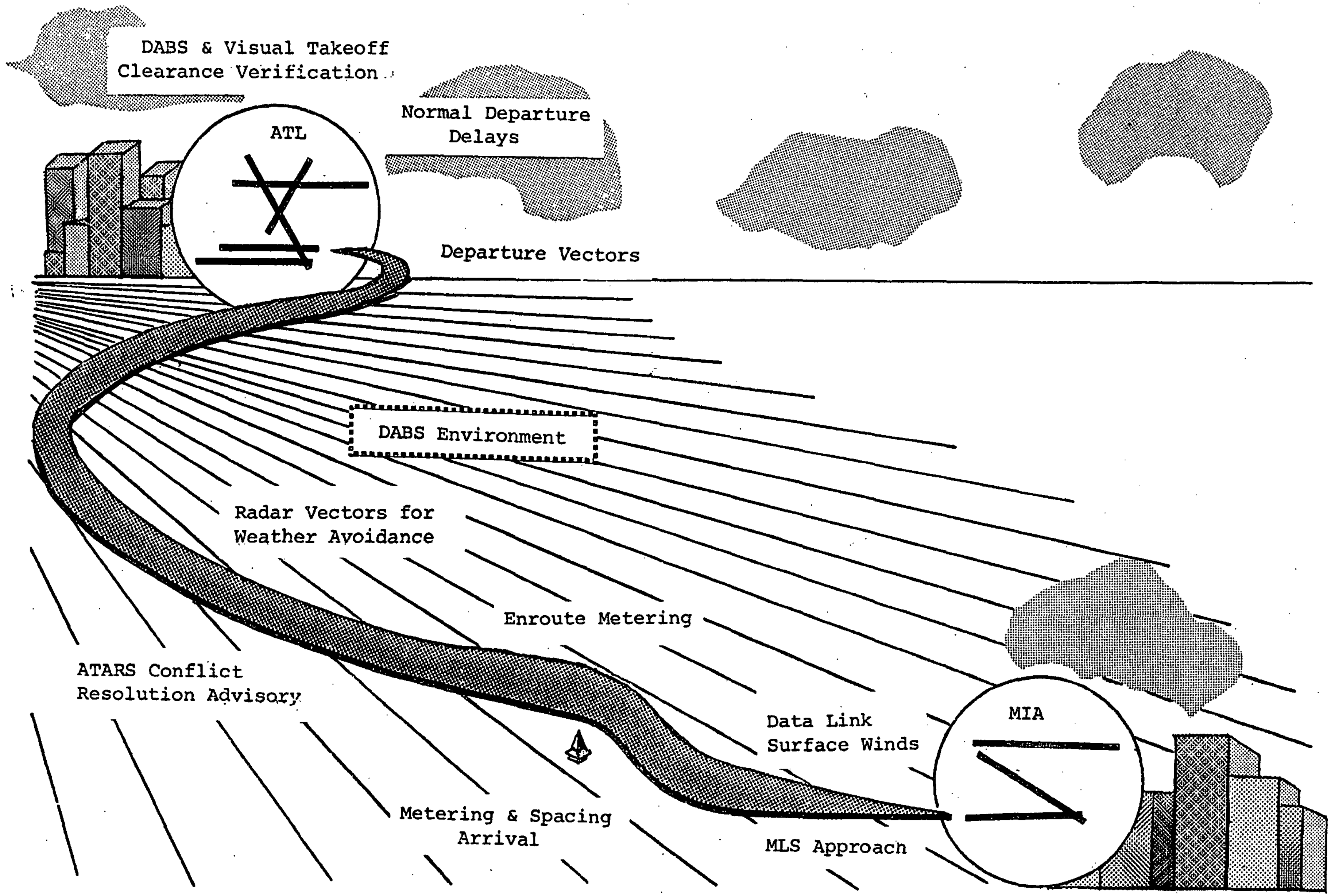
EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
CONDITION: Ceiling and visibility at Palm Beach County Glades at VOR approach minimums. Ceiling and visibility at Palm Beach International at minimums for filing as alternate.				
Establish visual contact with runway environment at MDA and before missed approach point	Minimum descent altitude, runway information, location of VOR, missed approach point, minimum visibility	IFR plates, airport chart, visual contact with runway		Visual contact not established at minimums
Continue visual approach	Runway alignment, glideslope, descent rate, airspeed, distance from landing zone, wind direction and speed	Visual cues from runway environment, navigation instruments		Execute missed approach procedure, then notify Palm Beach approach of intentions
Land TIME: 1830				
Contact UNICOM	UNICOM frequency, aircraft position and taxi requirements	Charts, sectional	Pahokee UNICOM	1) Familiar with airport, destination
Receive taxi instructions				Taxi, maintaining visual search for other traffic
Taxi	Taxiway pattern, traffic, destination on airport	UNICOM operator, IFR chart, visual search outside cockpit		2) Airport does not have UNICOM Taxi, maintaining visual search for other traffic
Shut down aircraft TIME: 1835				
Close IFR flight plan	Flight Service Station telephone number, aircraft identification, time	Phone book, clock	Flight Service Station telephone call	
TOTAL TIME				
Start engine to shutdown:				
1640 to 1835: 1 hour 55 minutes				

Event Analysis 3. Marathon to Pahokee Flight in Present Environment - Continued

4. Event Analysis of Atlanta International to Miami International Flight in Mid-1980's Environment

Operation:	General aviation, single pilot, instrument flight rules
Environment:	Mid 1980's Air Traffic Control System
Airport Complexity:	Departure and arrival at congested hub air carrier airports
Aircraft:	Light twin engine, retractable gear, constant speed propeller: e.g. Cessna 401 successor
Avionics:	Slaved gyro, Radio Magnetic Indicator (RMI), Automatic Direction Finder (ADF), Distance Measuring Equipment (DME), Encoding altimeter, Dual VOR Nav/Coms, Glideslope indicator, Marker beacons, Discrete Address Beacon System (DABS) transponder, DABS data link with 32 character alphanumeric display with buffer, Automatic Traffic Advisory and Resolution Service Display (ATARS), MLS Category I capability, Headset, Push to talk switch, Clock with sweep secondhand

This scenario portrays a flight from Atlanta International to Miami International in a twin engine aircraft piloted by a single pilot in instrument meteorological conditions at night. Takeoff is planned for early evening, with an estimated enroute time of two hours and ten minutes. Three passengers are aboard. Instrument meteorological conditions exist at departure time, and this, along with the usual early evening congestion at hub airports, leads to typical departure delays. Both DABS data link and visual takeoff clearance verification is received prior to takeoff. Departing aircraft are issued radar vectored departures. Weather enroute is forecast marginal visual meteorological conditions, with pilot reports of moderate turbulence below 15,000 feet and scattered thunderstorms south of Jacksonville, Florida. Actual weather for most of the enroute phase of the flight is marginal visual conditions, with instrument meteorological conditions around Atlanta, Jacksonville, and Miami. Radar vectors around thunderstorms are received enroute, as are ATARS conflict resolution advisories. Due to the weather conditions and the high density of IFR traffic, a flight slowdown necessitated by Enroute Metering is required. Normal arrival delays are experienced upon arrival while under Metering and Spacing control. A MLS approach is flown. Actual enroute time is approximately two hours and thirty minutes.



Event Analysis 4. Atlanta to Miami in Mid-1980's Environment

EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
PHASE: PLANNING TIME: 1600				
Check Airman's Information Manual	Description Miami International and Hartsfield facilities, radio frequencies, route distances, NOTAMS	Airman's Information Manual		
Check long range weather forecast	Frontal movement, high and low pressure areas, ceiling and visibility forecast for origin and destination airports	National Weather Service, Pilot's Weather Program on T.V.	Flight Service Station pilot self-briefing terminal	1) Telephone call to Flight Service Station - briefing by: a) automated briefing generation system b) specialist with computer terminal 2) Personal visit to Flight Service Station - briefed by specialist with computer terminal
CONDITION: Forecast calls for marginal visual meterological conditions at Hartsfield and Miami until 2000, becoming instrument meterological conditions after that hour.				
Study low altitude routes, approaches, sectionals, terminal areas, departure and arrivals	Victor airway routes, possible alternate airports, distances, approach, departure and missed approach procedures, required equipment and frequencies, SIDs, STARs	IFR low altitude enroute charts, approach and departure plates, sectionals, terminal area charts		
Plan IFR flight nonstop from Hartsfield to Miami International on victor airways	Aircraft avionics, true airspeed, fuel capacity, consumption rates, distances between checkpoints, possible alternate airports, distances and approaches, weight and balance calculations	Aircraft pilot's manual, IFR charts, plates, sectionals, AIM computer, Miami and Atlanta TCA charts		
PHASE: DEPARTURE TIME: 1725				
Check weather	Present and forecast ceilings and visibilities for destination and possible alternates, winds aloft, SIGMETS, AIRMETS	National Weather Service	Flight Service Station pilot self-briefing terminal	1) Briefing indicates runways unservicable at Miami International due to weather Cancel flight plans
Select alternate airport: Ft. Lauderdale	Forecast ceiling and visibility for three hours before and after estimated arrival time, distance from destination, arrival and approach procedures, prescribed alternate minimums	National Weather Service, IFR charts, approach plates, sectionals		2) Weather forecast below minimums for destination and all possible alternates Cancel flight plans
CONDITION: Terminal forecast for Miami predicts ceiling and visibility above MLS CAT I minimums prescribed for filing as alternate. Sequence reports (1710) show Atlanta Hartsfield IFR.				
File flight plan	Aircraft equipment, true airspeed in knots, estimated departure time, cruising altitude, route of flight, estimated time enroute, fuel on board, alternate airport, pilot's address, phone number, aircraft home base, number of passengers, remarks, SID request, aircraft color	AIM, IFR Flight Plan Form, flight plan	Flight Service Station pilot self-briefing terminal	1) Telephone call to Flight Service Station - file flight plan with specialist with computer terminal 2) File flight plan in person at Flight Service Station
Preflight aircraft	Airworthiness, weight and balance, fueled as planned	Visual inspection, weight and balance sheet		
Start aircraft TIME: 1745				
Receive verification of DABS contact		Altitude Echo on DABS transponder		
Contact Discrete Address Beacon System Terminal Information Service for Atlanta Hartsfield	DABS code for TIS, code for Atlanta Hartsfield	IFR approach and departure plates, sectionals		

Event Analysis 4. Atlanta to Miami in Mid-1980's Environment

EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
CONDITION: Hartsfield IFR: Rwy 8 and 9R in use for simultaneous MLS approaches. Rwy 9L in use for instrument departures.				
Contact clearance delivery	Clearance delivery frequency	Terminal Information Service		1) Issued clearance as filed, no departure time delay
Issued clearance with revised departure time of 40 minute delay	Clearance limit, route of flight, altitude data, departure procedure (SID), holding instructions, special information (delays), instructions for contacting departure control			2) Issued revised clearance 3) Clearance not issued, delay in clearance delivery
Copy and repeat clearance TIME: 1750				
Shut down aircraft				
Wait 30 minutes	Time	Clock		Wait in aircraft
Start aircraft TIME: 1825				
Contact clearance delivery	Clearance delivery frequency	Terminal Information Service		
Receive confirmation of clearance and departure time			Atlanta clearance delivery	1) Issued revised clearance
Copy and repeat confirmation of clearance and departure time	Clearance, time of departure	Atlanta center, departure controller		Copy and repeat revised clearance 2) Issued revised departure time
Contact Atlanta ground control	Atlanta ground control frequency, location of aircraft on airport	Approach plates		Wait
Issued taxi instructions to Runway 9L	Taxiway layout, traffic on airport, departure runway		Atlanta ground control	
Taxi as instructed, maintaining assigned sequence position	Taxi route and procedure	Taxi instructions, taxiway plate		
Perform runup and checklists	Aircraft functioning properly, radio equipment and navigation instruments set up, doors closed and locked, seat belts fastened, DABS functioning properly	Checklists, visual monitoring of instruments, equipment		
CONDITION: COM: Atlanta tower COM: Atlanta departure control NAV: Atlanta VOR NAV: Macon VOR				
Contact Atlanta tower	Atlanta tower frequency	Approach plates		Contact Atlanta tower without problem of NAV/COM adjustment
Unable to get response				
Contact Atlanta tower again	COM volume adjustment, frequency tuning, interference with other transmissions	Auditory monitoring of COM equipment		
Issued hold for takeoff				Cleared for immediate takeoff
CONDITION: Takeoff clearance delayed for instrument arrivals and departures of aircraft ahead in sequence.			Atlanta tower	Take off
Monitor real-time surface winds	DABS code for surface wind monitor and display	Approach and departure plates, ground sensors, DABS display		
Receive takeoff clearance	Clearance, initial heading, SID fix, advised to expect radar vectors, departure control frequency	Atlanta clearance delivery; SID chart, Atlanta tower, departure control		1) Not informed to expect radar vectors Perform departure as filed
Receive clearance verification		DABS data link,		2) Do not receive takeoff clearance verification by DABS display and light system Misunderstood clearance, continue hold for clearance

Event Analysis 4. Atlanta to Miami in Mid-1980's Environment - Continued

EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
Takeoff	Takeoff procedure, IFR departure procedure, time	Atlanta tower, takeoff clearance, plates, clock		
Receive handoff to Atlanta departure control			Atlanta tower	
Contact Atlanta departure control	Atlanta departure control frequency	Atlanta clearance delivery, Atlanta tower		
DABS Altitude Echo verifies radar contact		Altitude Echo on DABS transponder	Atlanta departure control	
Receive radar controlled departure instructions	Purpose of vectors, route to which vectored, heading, altitude, climb instructions	Atlanta departure control		
Proceed with departure as vectored	Heading, altitude, checkpoints, time, orientation with respect to cleared route	Radar vectors, clock, flight plan		
Receive clearance to filed altitude			Atlanta departure control	1) Do not receive altitude clearance verification
Receive altitude clearance verification	Altitude to which cleared	DABS Altitude Clearance verification		Do not climb Contact Atlanta departure control
PHASE: ENROUTE TIME: 1920				2) Altitude verified not same as understood from verbal transmission
Receive handoff to Atlanta center				
Contact Atlanta center	Atlanta center frequency		Atlanta center	Contact Atlanta departure control
Receive radar contact verification		Altitude Echo on DABS transponder		Altitude Echo on DABS transponder does not show aircraft altitude
Receive altitude assignment confirmation	Altitude clearance limit	DABS Altitude Clearance verification		Radar contact not made Contact Atlanta center
Receive vectors through high density airspace	Position to which vectored, heading, altitude climb instructions			Altitude Assignment confirmation does not agree with that which was understood
Proceed as vectored	Heading, altitude, orientation with respect to cleared route, time	Radar vectors, navigation instruments, clock, charts, flight plan, clearance, DABS display		Contact Atlanta center
CONDITION: COM: Atlanta center COM: Atlanta departure control NAV: Dublin VOR NAV: Alma VOR				
Check weather enroute	Ceilings, visibilities, PIREPS, winds aloft, Flight Service Station frequency	National Weather Service	Flight Service Station	
Record position, time over checkpoints	Time, position relative to route filed, checkpoint position	Navigation instruments, DME, clock, charts, radar vectors, flight plan, clearance		
Receive handoff to Jacksonville center			Atlanta center	
Contact Jacksonville center TIME: 2010	Jacksonville center frequency	Atlanta center	Jacksonville center	
Receive radar contact verification		Altitude Echo on DABS transponder		
Receive altitude assignment confirmation	Altitude clearance limit	DABS Altitude Clearance verification		
Receive vector back to route filed	Position on airway to which vectored, heading, altitude, and climb instructions		Jacksonville center	
Proceed to route as filed, proceed on victor airways	Heading, altitude, airway, location of VORs, position, checkpoints, distances, time, route filed, clearance	Navigation instruments, radar vectors, IFR charts, DME, flight plan, clock, clearance, DABS display		

Event Analysis 4. Atlanta to Miami in Mid-1980's Environment - Continued

EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
Check weather enroute	Ceiling, visibility, PIREPS, winds aloft, storm activity, Flight Service Station frequency	National Weather Service, IFR charts, sectionals	Flight Service Station	1) 122.0 Flight Watch weather briefing 2) 15 minutes past hour, VOR recorded weather briefing
CONDITION: PIREPS and radar reports of thunderstorms along route for next fifty miles, with moderate turbulence and rain.				
Request radar vectors around thunderstorm, and higher altitude clearance				
Receive vectors and higher altitude clearance	Position to which vectored, heading, altitude and climb instructions.			
Receive altitude clearance verification	Altitude clearance limits	DABS Altitude Clearance verification	Jacksonville Center	Turbulence and rain undetected on weather radar mode, vectored thru edge of storm
Proceed as vectored	Altitude, position with respect to route filed, clearance, time, heading	Navigation instruments, radar vectors, clock, charts, flight plan, clearance, DABS display		Proceed as vectored through storm
Receive position with respect to route, clearance to proceed as filed	Position on airway to which vectored, heading altitude, climb instructions			Request additional vectors
Receive altitude clearance verification	Altitude clearance limits	DABS Altitude Clearance verification		
Proceed to victor airway, continue on route as filed	Heading, altitude, airway location, VOR, position, checkpoints, distances, time, route filed, clearance	Navigation instruments, radar vectors, IFR charts, DME, flight plan, clock clearance, DABS display		
CONDITION: COM: Jacksonville center COM: Altanta center NAV: Orlando VOR NAV: Pahokee VOR				
Receive handoff to Miami center			Jacksonville center	
Contact Miami Center	Miami center frequency	Jacksonville center	Miami center	
Receive radar contact verification		Altitude Echo on DABS transponder		
Receive altitude assignment confirmation	Altitude clearance limit	DABS Altitude Clearance verification		
Receive traffic advisory	Location of other aircraft relative to own route of flight, potential threat	ATARS display, DABS data link		
Attempt to acquire traffic visually				
Receive ATARS resolution advisory	Manuever to avoid collision	ATARS display, DABS data link		Receive resolution advisory from Jacksonville center controller
Proceed with resolution advisory	Turn, heading, climb or descent instructions			
Receive speed reduction instructions			Miami Center	Speed reduction not commanded
Reduce speed	Current airspeed, commanded airspeed	Airspeed indicator, slowdown instructions		Proceed at enroute airspeed
Check weather	Ceiling, visibilities, PIREPS, winds aloft, Flight Service Station frequency	National Weather Service	Flight Service Station	Delays for takeoff, departure vectoring through Atlanta terminal area and around thunderstorms created an inadequate fuel condition
CONDITON: Terminal forecast for Miami International predicts ceiling and visibility at MLS CAT I minimums; Ft. Lauderdale forecast at minimums prescribed for filing as alternate, sequence report for Miami shows ceiling 400' and visibility of ½ mi.				Divert to nearest airport with proper fuel, land and refuel
Contact Terminal Information Service	DABS code for TIS and Miami International	Approach plates, IFR charts, DABS Terminal Information Service Alphanumeric display		
Receive enroute delay vector	Heading, altitude instructions		Miami Center	Delay vector not given
Proceed on delay vector	Heading, time	Clock, navigation instruments		Proceed as filed

Event Analysis 4. Altanta to Miami in Mid-1980's Environment - Continued

EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
PHASE: ARRIVAL TIME: 2100				
Receive handoff to Miami approach control				
Contact Miami approach control	Miami approach control frequency	Miami center	Miami approach control	Receive new altitude assignment from Miami approach control
Receive radar contact verification	Radar contact with Miami center established	Altitude Echo on DABS transponder		
Receive altitude assignment confirmation	Altitude clearance limit	DABS Altitude Clearance verification		Proceed to new altitude
Select plates for MLS Rwy 9R	Runways in use, special procedures, time	Clock, IFR approach plates, arrival charts, TIS		
Select glideslope angle	Outer marker location, rate of descent, minimum glideslope angle	Approach plates		
Receive radar vectors to feeder fix	Position to which vectored, heading, altitude, and descent instructions		Miami approach control	Delay vectors given to feeder fix
Proceed to feeder fix	Time, heading, altitude, airspeed	Radar vectors, navigation instruments. Enroute Metering and Spacing system		
Receive vector to inner fix	Position to which vectored, heading, altitude and descent instructions		Miami approach control	Delay vectors given to inner fix
Proceed to inner fix	Heading, altitude, vector end point	Radar vectors, navigation instruments, clock Enroute Metering and Spacing system		Receive delay vectors to inner fix Proceed as vectored
Perform landing checklist				
Receive vectors to gate fix				
Proceed as vectored to gate fix	Heading, altitude, position of gate fix	Radar vectors, navigation instruments, approach plates		
Monitor real-time surface winds, RVR	DABS code for surface winds	Ground sensors, IFR approach plates, DABS display	Miami approach control	
Receive clearance for MLS approach TIME: 2125				
Receive clearance verification		DABS display		
CONDITION: COM: Miami approach COM: Miami center NAV: Miami VOR NAV: Biscayne Bay VOR MLS: MLS channel for Rwy 9R				
Proceed with MLS approach	Heading, glideslope, outer and middle marker passage, minimum authorized transition altitude, descent rate, position relative to localizer, glideslope, time, minimums, approach course, altitude, airspeed, decision height, wind speed and direction, altimeter setting, RVR, time	Navigation instruments, MLS receiver, IFR plates, DABS display, DABS transponder, clock		
CONDITION: Ceiling and visibility at Miami International above MLS CAT 1 Rwy 9R minimums. Ceiling and visibility at Ft. Lauderdale below minimums prescribed for alternate.				
Runway environment sighted before decision height, visibility above minimums	Decision height, RVR, altitude, distance to threshold, visibility minimums, visual contact	Approach plate, navigation instruments DABS display, visual contact search outside cockpit		Runway environment not sighted at decision height and minimums Execute missed approach procedure Contact Miami approach control and state intentions

Event Analysis 4. Atlanta to Miami in Mid-1980's Environment - Continued

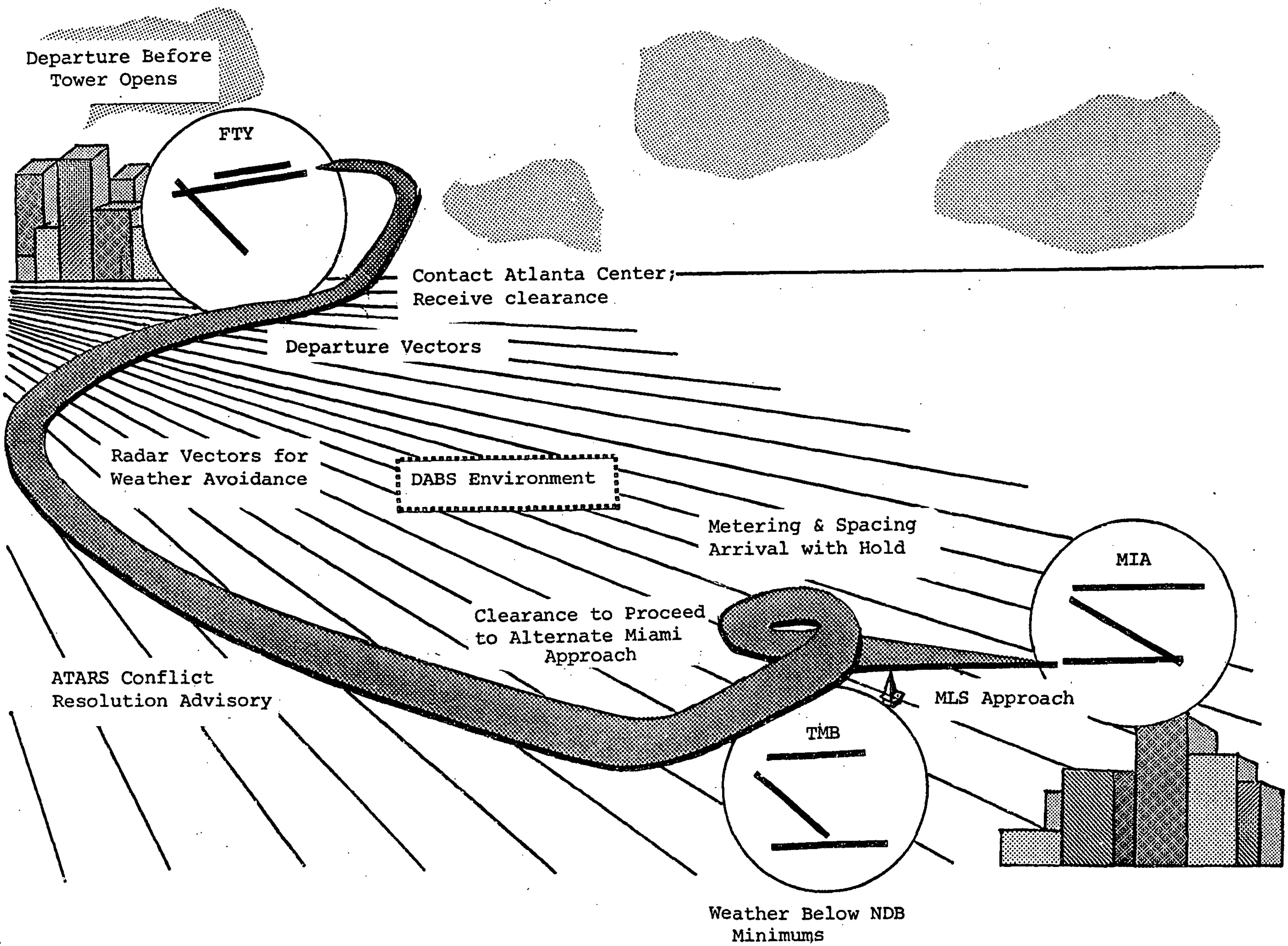
EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
Contact Miami tower	Miami tower frequency	Charts, plates		
Issued clearance to land			*Miami tower*	
Receive landing clearance verification		DABS display		
Proceed with approach and landing visually	Runway alignment, rate of descent, glideslope, airspeed, distance *from* landing zone, wind direction and speed	Navigation instruments, visual cues *from runway environment, DME*, DABS display		
Land <u>TIME</u>: 2145				
Contact ground control	Miami ground control frequency, aircraft *position, destination on airport*	IFR taxiway chart, plates	Miami ground control	
Receive instruction for taxiing				
Taxi	Destination of airport taxiway pattern, route assigned	IFR charts, ground control, visual contact outside cockpit		
Shut down aircraft <u>TIME</u>: 2155				
<u>Total Time</u>:				
Start aircraft to shutdown:				
1745 to 2155: 4 hours 10 minutes				

Event Analysis 4. Atlanta to Miami in Mid-1980's Environment - Continued

5. Event Analysis of Atlanta's Charlie Brown County to Miami's New Tamiami Flight in Mid-1980's Environment

Operation:	General aviation, single pilot, instrument flight rules
Environment:	1980's Air Traffic Control System
Airport Complexity:	Departure and arrival at general aviation satellites in congested hubs
Aircraft:	Light twin engine, retractable gear, constant speed propeller: e.g. Cessna 401 successor
Avionics:	Slaved gyro, Radio Magnetic Indicator (RMI), Automatic Direction Finder (ADF), Distance Measuring Equipment (DME), Encoding altimeter, Dual VOR Nav/Coms, Glideslope indicator, Marker beacons, Discrete Address Beacon System (DABS) transponder, DABS data link with 32 character alphanumeric display with buffer, Automatic Traffic Advisory and Resolution Service Display (ATARS), MLS Category I capability, Headset, Push to talk switch, Clock with sweep secondhand

This scenario portrays a flight from Charlie Brown County Airport near Atlanta, to New Tamiami Airport near Miami, in a twin engine aircraft piloted by a single pilot in instrument meteorological conditions. Takeoff is scheduled for early morning and a non-stop flight is planned in order for the four passengers to arrive by eleven o'clock. Enroute time is estimated to be two hours and fifteen minutes. Marginal visual meteorological conditions exist at departure time, and this, combined with the tower not being in operation, leads to delays in IFR clearance delivery, departure, and arrival times. DABS data link is not accessible prior to takeoff. Departing aircraft are issued radar vectored departures. Weather enroute is forecast marginal visual meteorological conditions with pilot reports of moderate turbulence below 15,000 feet associated with scattered thunderstorms south of Jacksonville, Florida. Actual weather enroute is instrument meteorological conditions Radar vectors around thunderstorms are received enroute, as are ATARS conflict resolution advisories. Due to the below NDB approach minimums weather conditions existing at the airport, the pilot diverts to his alternate, Miami International. Typical arrival delay of a hold is experienced upon arrival while under Metering and Spacing control. A MLS approach is flown. Actual enroute time is approximately two hours and fifty minutes.



Event Analysis 5. Charlie Brown Co. to New Tamiami Flight in Mid-1980's Environment

EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
PHASE: PLANNING TIME: 2000				
Check Airman's Information Manual	Description of New Tamiami and Charlie Brown facilities, radio frequencies, route distances, NOTAMS.	Airman's Information Manual		
Check long range weather forecast	Frontal movement, high and low pressure areas, ceiling and visibility forecasts for origin and destination airports	National Weather Service, Pilot's Weather Program on T.V.	Flight Service Station telephone call	1) Personal visit to Flight Service Station - briefed by specialist with computer terminal 2) Personal visit to facility with Flight Service Station pilot self-briefing terminal
CONDITION: Forecast calls for marginal visual meterological conditions at Charlie Brown County and New Tamiami until 0700, becoming instrument meterological conditions after that hour.				
Study low altitude routes, approaches, sectionals, terminal area charts, departure and arrival charts	Victor airway routes, possible alternate airports, distances, approach, departure, and missed approach procedures, required equipment and frequencies, SIDs, STARs	IFR low altitude enroute charts, approach and departure plates, sectionals, terminal area charts		
Plan IFR flight non-stop from Charlie Brown County to New Tamiami on victor airways	Aircraft avionics, true airspeed, fuel capacity, fuel consumption rates, distances between check-points, possible alternate airports, distances, approaches, weight and balance calculations	Aircraft pilot's manual, IFR charts, plates, sectionals, AIM, computer, terminal area charts		
CONDITION: NDB Runway 9R approach is only instrument approach available at New Tamiami.				
PHASE: DEPARTURE TIME: 0600				
Check weather	Present and forecast ceilings and visibilities for destination and possible alternates, winds aloft, SIGMETS, AIRMETS	National Weather Service	Flight Service Station telephone call	Weather forecast below minimums for destination and all possible alternates Cancel trip plans
Select alternate airport: Miami International	Forecast ceiling and visibility for three hours before and after estimated arrival time, distance from destination, arrival and approach procedures, prescribed alternate minimums	National Weather Service, IFR charts, approach plates, sectionals		Possible alternates require fuel stop along route in order to arrive at destination with fuel sufficient to reach alternate plus 45 minutes reserve Plan fuel stop
CONDITION: Terminal forecast for New Tamiami not available. Terminal forecast for Miami predicts marginal visual meterological conditions until 0800 becoming instrument meterological conditions at that time. Sequence report for Charlie Brown indicates marginal visual meterological conditions. Charlie Brown and New Tamiami towers not operative until 0700.				
File flight plan thirty minutes prior to estimated departure time	Aircraft equipment, true airspeed in knots, estimated departure time, cruising altitude, route of flight, estimated time enroute, fuel on board, alternate airport, pilot's address and phone number, aircraft home base, number of passengers, remarks	AIM, IFR Flight Plan form, flight plan	Flight Service Station telephone call	1) Flight Service Station on field File in person 2) Pilot self-briefing terminal available File through terminal
Receive initial contact frequency	Instructions for making contact with Atlanta center			
Preflight aircraft	Airworthiness, weight and balance in limits, fueled as planned	Visual inspection, weight and balance sheet		
Start aircraft TIME: 0630				

Event Analysis 5. Charlie Brown Co. to New Tamiami Flight in Mid-1980's Environment

EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
Contact Discrete Address Beacon System Terminal Information Service for Charlie Brown	DABS code for TIS, DABS code for Charlie Brown	IFR approach and departure plates, sectionals		
Unable to receive DABS				Able to receive DABS TIS
Contact Automatic Terminal Information Service	ATIS frequency	IFR charts, sectionals		
Unable to receive ATIS				1) Tower at Charlie Brown in operation 0700-2300
Taxi to runway favored by traffic and winds, maintain separation from other traffic	Wind direction and speed, location of other traffic on ground, active runways, taxiway location	Visual contact with environment, airport charts		Able to contact ATIS
Perform runup and checklists	Aircraft functioning properly, radio equipment, navigation instruments set, doors locked, seat belts fastened	Checklists, aircraft pilot's manual		2) Contact AV-AWOS automatic weather service for airport winds, ceiling and visibility
CONDITION: COM: Atlanta center COM: Multicom NAV: Atlanta VOR NAV: Albany VOR				
State beginning of takeoff roll	Runway, airport name, aircraft identification, direction of flight, Multicom frequency		Multicom	Tower in operation
Takeoff and climb out TIME: 0655				Receive clearance for takeoff and Visual Takeoff Clearance verification
Contact Atlanta center	Initial contact frequency for Atlanta center, aircraft identification, position, time of departure, altitude, IFR plan, remarks	Flight Service Station, navigation instruments		
Receive verification of DABS contact		Altitude Echo on DABS transponder		
Receive flight plan clearance	Clearance limit, route of flight, altitude clearance, special instructions	Atlanta center	Atlanta center	
Copy and repeat clearance				
Receive radar vectored departure through Atlanta Terminal Control Area	Purpose of vectors, route to which vectored, heading, altitude, climb instructions	Atlanta center		
Proceed with departure as vectored	Heading, altitude, checkpoints, time, orientation with respect to cleared route	Radar vectors, clock, flight plan, charts, navigation instruments		
Receive clearance to filed cruising altitude			Atlanta center	
Receive altitude clearance verification	Altitude clearance limit	DABS Altitude Clearance verification		
Proceed as vectored, climb to enroute altitude	Altitude clearance limit, checkpoints, position with respect to route filed, time	Radar vectors, DABS display, navigation instruments, IFR charts, clock, clearance		
PHASE: ENROUTE TIME: 0730				
Check weather enroute	Ceiling, visibilities, PIREPs, winds aloft, storm activity, Flight Service Station frequency	National Weather Service	Flight Service Station	
Record position, time over checkpoints	Time, position relative to route filed, next checkpoint position	Navigation instruments, DME, clock, charts, flight plan, clearance, radar vectors		
Receive vector to position on airway, clearance to proceed as filed	Purpose of vector, airway to which vectored, heading, altitude, climb instructions		Atlanta center	

Event Analysis 5. Charlie Brown Co. to New Tamiami Flight in Mid-1980's Environment - Continued

EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
Proceed on victor airway route as filed				
Receive notification of termination of radar services			Atlanta center	
Report position	Aircraft identification, position, time over checkpoint, altitude, estimated time over next reporting point, name of next reporting point	Navigation instruments, clearance, clock, computer, DME, charts		
Receive handoff to Jacksonville center				
Contact Jacksonville center	Jacksonville center frequency	Atlanta center	Jacksonville center	
Receive contact verification	Radar contact with Jacksonville center established	Altitude Echo on DABS transponder		Jacksonville radar services unavailable
				Proceed with flight as filed
Receive altitude assignment confirmation	Altitude clearance limit	DABS Altitude Clearance verification		
Check weather enroute	Ceiling, visibility, PIREPS, winds aloft, storm activity, Flight Service Station frequency	National Weather Service, IFR charts, sectionals	Flight Service Station	No contact verification or altitude assignment verification received
				Report position over checkpoints
<u>CONDITION</u>: PIREPS and radar reports of thunderstorms along route for next sixty miles, with moderate turbulence and hail reported.				
Request radar vectors around thunderstorm, and higher altitude clearance				
Receive vectors and new altitude clearance limit	Position to which vectored, heading, altitude, and climb instructions		Jacksonville center	
Receive altitude clearance verification	Altitude clearance limit	DABS Altitude Clearance verification		
Proceed as vectored	Altitude, position with respect to route filed, storm location, clearance, time, heading	Navigation instruments, radar vectors, clock, charts, Jacksonville center, flight plan, clearance limit, DABS display		
Receive position with respect to route, clearance to proceed as filed			Jacksonville center	
Receive altitude clearance verification	Altitude clearance limit	DABS Altitude Clearance verification		
Proceed to victor airway, continue on route as filed	Heading, altitude, airway location, VOR position, checkpoints, distances, time, route filed, clearance	Navigation instruments, radar vectors, IFR charts, DME, flight plan, clock, clearance, DABS display		
<u>CONDITION</u>: COM: Jacksonville center COM: Altanta center NAV: Orlando VOR NAV: Pahokee VOR				
Receive traffic advisory	Location of other aircraft relative to own route of flight, potential threat	ATARS display, DABS data link		
Attempt to acquire traffic visually				
Receive ATARS conflict resolution advisory	Maneuver necessary to avoid collision	ATARS display, DABS data link		
Proceed with resolution advisory	Turn, heading, climb, or descent instructions			
Receive handoff to Miami center			Jacksonville center	
Contact Miami center	Miami center frequency	Jacksonville center	Miami Center	

Event Analysis 5. Charlie Brown Co. to New Tamiami Flight in Mid-1980's Environment - Continued

EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
Receive radar contact verification		Altitude Echo on DABS transponder		
Receive altitude assignment confirmation	Altitude clearance limit	DABS Altitude Clearance verification		
Check weather	Ceiling, visibilities, PIREPS, winds aloft, Flight Service Station frequency, storm activity	National Weather Service, charts	Flight Service Station	
CONDITION: Terminal forecast for New Tamiami predicts ceiling and visibility slightly above NDB approach minimums. Miami forecast at minimums prescribed for filing as alternate. Sequence report for New Tamiami shows ceiling 570' and visibility of 2 miles.				
Continue on route as filed	Position on airway, heading, altitude, check-points, distances, time, route filed, clearance	Navigation instruments, radar vectors IFR charts, DME, flight plan, clock, clearance, DABS display		Flight through Miami terminal area controlled by Enroute Metering Receive slowdown and/or delay vector instructions
PHASE: ARRIVAL TIME: 0905				
Receive handoff to Miami approach control			Miami center	
Contact Miami approach control	Miami approach control frequency	Miami center	Miami approach control	
Receive radar contact verification	Radar contact with Miami approach established	Altitude Echo on DABS transponder		
Receive altitude assignment confirmation	Altitude clearance limit	DABS Altitude Clearance verification		
Receive radar vectors to Perrine NDB	Purpose of vectors, heading, altitude, and descent instructions	Miami Approach Control	Miami approach control	
Select approach plate for NDB approach				
Proceed as vectored to initial approach fix	Altitude, orientation with respect to route as filed, time, position of NDB	Navigation instruments, Miami center clock, charts		
Contact New Tamiami Terminal Information Service	DABS code for TIS and New Tamiami	Approach plates, IFR charts, DABS Terminal Information Service alphanumeric display		TIS for New Tamiami not available Contact ATIS Contact UNICOM
Receive New Tamiami airport advisory				
CONDITION: New Tamimi ceiling and visibility below NDB minimums.				
Contract Miami approach control	Miami approach control frequency	Miami center	Miami approach control	Weather conditions at New Tamiami above or at NDB minimums Fly NDB approach
Request clearance to proceed to alternate				
Receive clearance to proceed to alternate, metering instructions and vectors				
Proceed with metering instructions and vectors	Current airspeed, command airspeed, heading, altitude instructions, clearance, time, vector directions	Airspeed indicator, slowdown instructions, clock, navigation instruments, Miami approach control		
Contact Terminal Information Service for Miami International	DABS code for TIS and Miami International	Approach plates, IFR charts, DABS alphanumeric display		
Receive Miami airport advisory	Runways and approaches in use, special procedures, time	IFR approach plates, arrival charts		

Event Analysis 5. Charlie Brown Co. to New Tamiami Flight in Mid-1980's Environment - Continued

EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
Select plates for MLS Runway 9R approach				MLS approach not in use
Select glideslope angle				Select plate for approach in use
Receive radar vectors to feeder fix, and instructions to hold at fix	Position to which vectored, heading, altitude, and descent instructions, holding pattern instructions		Miami approach control	Receive instructions to increase airspeed airspeed for sequencing into Miami approach traffic
Proceed to feeder fix	Time, heading, altitude, airspeed, location of fix, position	Radar vectors, navigation instruments, clock, Miami approach control		
Proceed with holding pattern	Time, holding pattern entry procedures, wind direction and speed, relative bearing of inbound, outbound legs	IFR plates, navigation instruments, clearance, clock, TIS, Miami approach control		Hold at feeder fix not required
				Proceed as vectored to inner fix
Receive vector to inner fix	Position to which vectored, heading, altitude and descent instructions		Miami approach control	
Proceed to inner fix	Heading, altitude, vector end point	Radar vectors, navigation instruments, clock		
Perform landing checklist		Aircraft pilot's manual, placards		
Receive vectors to gate fix			Miami approach control	
Proceed as vectored to gate fix	Heading, altitude, location of gate fix	Radar vectors, navigation instruments, approach plates		
Monitor real-time surface winds and RVR	DABS code for surface winds, RVR, wind speed and direction	DABS display, ground sensors, IFR approach plates		
Receive clearance for MLS approach		Miami approach control	Miami approach control	
TIME: 0945				
Receive approach clearance verification		DABS display		
CONDITION: COM: Miami approach COM: Miami center NAV: Miami VOR NAV: Biscayne Bay VOR MLS: MLS channel for Rwy 9R				
Proceed with MLS approach	Heading, glideslope, outer and middle marker passage, minimum authorized transition altitude, descent rate, position relative to localizer, glideslope, time, minimums, approach course, altitude, airspeed, decision height, wind speed and direction, altimeter setting, RVR, time	Navigation instruments, MLS receiver, IFR plates, DABS display, DABS transponder, clock		
CONDITION: Ceiling and visibility at Miami International above MLS CAT 1 Rwy 9R minimums.				
Runway environment sighted before decision height	Decision height, RVR, altitude, distance to threshold, visibility minimums	Approach plate, navigation instruments, DABS display, visual contact		
Contact Miami tower	Miami tower frequency	Charts, plates		
Issued clearance to land			Miami tower	
Receive landing clearance verification		DABS display		

Event Analysis 5. Charlie Brown Co. to New Tamiami Flight in Mid-1980's Environment - Continued

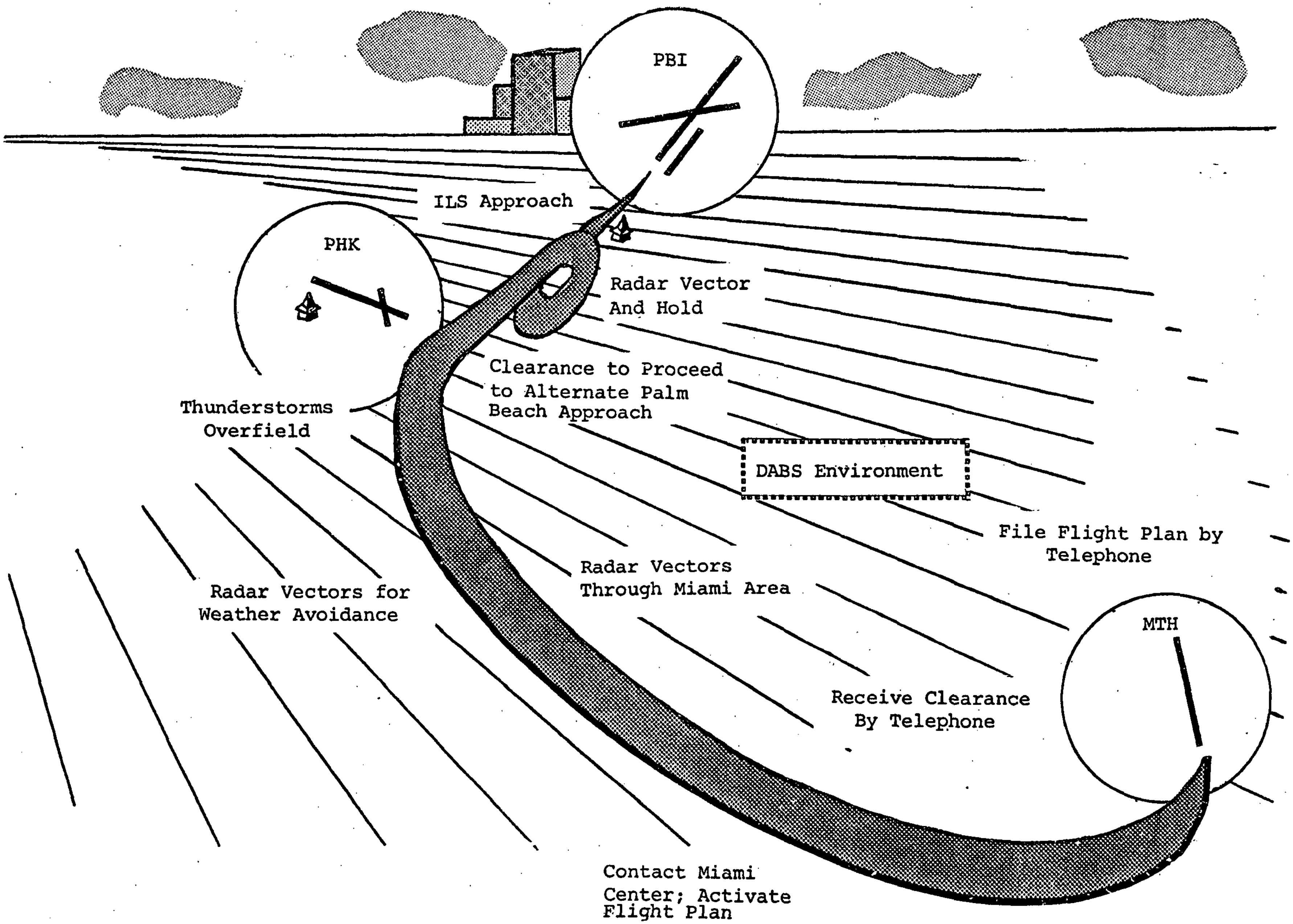
EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
Proceed with approach and landing visually	Runway alignment, rate of descent, glideslope, airspeed, distance from landing zone, wind direction and speed	Navigation instruments, visual cues from runway environment, DME, DABS display		
Land				
Contact ground control	Miami ground control frequency, aircraft position, destination on airport	IFR taxiway chart, plates	Miami ground control	
Receive instructions for taxiing				
Taxi	Destination on airport, taxiway pattern, taxi instructions	Taxiway chart, plates, Miami ground control		
Shut down aircraft TIME: 1005				
TOTAL TIME				
Start aircraft to shutdown:				
0630 to 1005: 3 hours 35 minutes				

Event Analysis 5. Charlie Brown Co. to New Tamiami Flight in Mid-1980's Environment - Continued

6. Event Analysis of Marathon Flight Strip to Palm Beach County Glades Flight in Mid-1980's Environment

Operation:	General aviation, single pilot, instrument flight rules
Environment:	Mid-1980's Air Traffic Control System
Airport Complexity:	Departure and arrival at general aviation airports in remote location
Aircraft:	Single engine, fixed gear, constant speed propeller: e.g. Cessna 182 successor
Avionics:	Calibrated gyro panel, dual VOR Nav/Coms, Non-encoding altimeter, Glideslope indicator, Marker beacons, Discrete Address Beacon System (DABS) transporder with blind encoder, DABS data link with 32 character alphanumeric display with buffer, Automatic Traffic Advisory and Resolution Service Display (ATARS), Headset, Push to talk switch, Clock with sweep secondhand

This scenario portrays a flight returning from Marathon Flight Strip in the Florida Keys, to Pahokee, Florida, in a single engine aircraft piloted by a single pilot in instrument meteorological conditions. Takeoff is scheduled for mid-afternoon, and a non-stop flight is planned, as the pilot and the three members of his family aboard desire to land before dark. Enroute time is estimated to be one hour and ten minutes. Instrument meteorological conditions exist at departure time, but with very little traffic operating at this uncontrolled field, no takeoff delays are experienced. IFR clearance is received via phone call to the Flight Service Station. Weather enroute is forecast marginal visual meteorological conditions, however, the actual weather conditions are instrument. Radar vectors are received through Miami's TCA, as well as for thunderstorm avoidance enroute. A traffic advisory is received through ATARS while under control of Miami center. Unreported traffic is seen and avoided by the pilot after radar service is terminated. Due to thunderstorm activity over the destination airport, the pilot diverts to his alternate and an ILS approach is flown to Palm Beach International. Actual enroute time is approximately one hour and forty minutes.



Event Analysis 6. Marathon to Pahokee Flight in Mid-1980's Environment

EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
PHASE: PLANNING TIME: 0800				
Check Airman's Information Manual	Description of Palm Beach County Glades and Marathon facilities, radio frequencies, route distances, NOTAMS	Airman's Information Manual		
Check long range weather forecast	Frontal movement, high and low pressure areas, ceiling and visibility forecast for origin and destination airports	National Weather Service, Pilot's Weather Program on T.V.	Flight Service Station telephone call	1) Pilot self-briefing terminal, if available at airport 2) In person visit to Flight Service Station, briefed by specialist with computer terminal
CONDITION: Forecast calls for marginal visual meterological conditions at Marathon and Palm Beach County Glades until 2000. Forecast for after 2000 unavailable.				
Study IFR charts, plates, sectionals, terminal area chart for Miami	Victor airway routes, possible alternate airports, distances, approach, departure, and missed approach procedures, required equipment and frequencies, procedures for radar control	IFR low altitude enroute charts, approach and departure plates, Miami TCA chart, sectionals, AIM		
Plan IFR flight non-stop from Marathon Flight Strip to Palm Beach County Glades on victor airways	Aircraft avionics, true airspeed, fuel capacity and consumption rates, distances, checkpoints, possible alternate distances and approaches, weight and balance calculations	Aircraft pilot's manual, IFR charts, plates, sectionals, AIM, computer		1) No instrument approach facilities at Pahokee a) Plan VFR flight b) Cancel trip plans 2) Range of aircraft not sufficient to reach destination non-stop with sufficient reserve for alternate Plan fuel stop
PHASE: DEPARTURE TIME: 1600				
Check weather	Present and forecast ceilings and visibilities for destination and alternates, winds aloft, SIGMETS, AIRMETS	National Weather Service	Flight Service Station telephone call	
Select alternate airport: Palm Beach International Airport	Forecast ceiling and visibility for three hours before and after estimated arrival time, distance from destination, arrival and approach procedures, prescribed alternate minimums	National Weather Service, IFR charts, approach plates, sectionals		Terminal forecast for Palm Beach below Pahokee approach minimums and minimums for filing Palm Beach as alternate Cancel trip plans
CONDITION: Terminal forecast for Pahokee unavailable. Terminal forecast for West Palm Beach predicts 1000' ceiling and 2 miles visibility. Sequence report for Marathon unavailable. UNICOM reports of ceiling and visibility at Marathon indicate instrument meterological conditions.				
File flight plan thirty minutes prior to estimated departure time	Aircraft equipment, true airspeed in knots, estimated departure time, point of departure, cruising altitude, route of flight, estimated time enroute, fuel on board, alternate airport, pilot's address and phone number, aircraft home base, number of passengers, color of aircraft, remarks	AIM, IFR charts, IFR flight plan form, flight plan, pilot's manual	Flight Service Station telephone call	
Preflight aircraft	Airworthiness, fuel on board as planned, weight and balance in limitations	Visual inspection, weight and balance sheet		
Wait 15 minutes				
Contact Flight Service Station			Flight Service Station telephone call	Contact FSS by aircraft radio
Receive IFR clearance and initial contact frequency	Clearance, frequency on which to contact Miami center			
Copy and repeat clearance				
Start aircraft TIME: 1645				
Turn DABS, NAV/COMS on				

Event Analysis 6. Marathon to Pahokee Flight in Mid-1980's Environment

EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
Contact UNICOM	UNICOM frequency, position on airport and intentions	IFR charts, sectional	Marathon UNICOM	Field does not have UNICOM
Receive airport advisory	Wind direction and velocity, favored runway, altimeter setting, known traffic, applicable NOTAMS, taxi routes, traffic pattern			Select runway favored by winds and/or traffic
Taxi to active runway	Taxiway patterns, active runway, surface winds	IFR charts, UNICOM operator, visual observation		
Perform runup and checklists				
CONDITION: COM: UNICOM COM: Miami Center NAV: Miami VOR NAV: Key West VOR				
Notify UNICOM of takeoff	UNICOM frequency, active runway	IFR charts	Marathon UNICOM	Unable to contact UNICOM
Takeoff TIME: 1700				Continue with takeoff
Proceed as cleared to checkpoint	Flight clearance, victor airways, climb profile, radials for checkpoint, traffic separation	Flight plan, charts, sectional Miami center, navigation instruments		
Contact Miami center	Miami center frequency, position and altitude	Flight Service Station	Miami center	Unable to contact Miami center to receive DABS coverage until ~ 50 miles from antenna
Receive radar contact verification		DABS transponder Altitude Echo		
Receive altitude clearance verification	Altitude to which cleared	DABS Altitude Clearance verification		a) Proceed as cleared until able to contact Miami center
Proceed with flight plan as cleared	Position, victor airway, intersections, winds aloft, altitude, VOR positions and frequencies	Flight plan, clearance, navigation instruments		b) Make mandatory position reports to FSS
PHASE: ENROUTE TIME: 1720				
Record time over checkpoints	Checkpoint, position relative to route filed, time	Flight plan, clearance, navigation instruments		
Check weather	Ceilings, visibility, PIREPS, winds aloft, storm activity, Flight Service Station frequency	National Weather Service, IFR charts, sectionals	Flight Service Station	1) 122.0 Flight Watch weather briefing 2) 15 minutes past hour listen over the VOR to local weather recording
Receive notification of revised clearance and beginning of radar vectoring through Miami area	Position to which vectored, heading, altitude, climb instructions		Miami center	
Receive altitude clearance verification	Altitude clearance limit	DABS Altitude Clearance verification		
Proceed as vectored	Altitude, position with respect to route filed, clearance, time, heading	Navigation instruments, radar vectors, clock, charts, flight plan, clearance, DABS display		
Request additional radar vector around thunderstorm in line of vectoring	Aircraft position, altitude, location of thunderstorm			1) Storm appears on Miami center scope, original clearance revision provides vectors around storm
Receive vectors and additional altitude clearance	Position to which vectored, heading, altitude and climb instructions			Proceed as vectored around storm
Receive altitude clearance verification	Altitude clearance limit	DABS Altitude Clearance verification	Miami center	2) Center unable to issue vectors around storm
Proceed as vectored around thunderstorm	Altitude, position with respect to route filed, storm location, clearance, time, heading	Navigation instruments, radar vectors, clock, charts, flight plan, clearance, DABS display		a) Proceed as originally vectored b) Detour around storm
Receive traffic advisory	Location of other aircraft relative to own route of flight, degree of threat	ATARS display, DABS data link		

Event Analysis 6. Marathon to Pahokee Flight in Mid-1980's Environment - Continued

EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
Attempt to acquire traffic visually	Location of other aircraft, altitude, type of aircraft			
Receive resolution advisory	Maneuver procedures	ATARS display, DABS data link		
Proceed with resolution procedure	Heading, altitude change, position relative to route filed	Navigation instruments		
Receive vector to route filed, notification of end of radar control, clearance to proceed as filed	Purpose of vector, route to which vectored		Miami center	
Proceed as vectored to route	Heading, altitude, position with respect to flight plan, time, checkpoints	Navigation instruments, vector, clock, charts, flight plan, clearance, DABS display		
Proceed as filed	Victor airways, position with respect to filed route, winds aloft, intersections, VOR position and frequencies	Flight plan as filed, clearance, navigation instruments, clock, charts		Radar vectoring continues to destination fix Proceed as vectored
Check weather	Ceiling, visibilities, PIREPS, winds aloft, Palm Beach altimeter setting	National Weather Service	Flight Watch 122.0	Flight Service Station briefing
Report position	Checkpoints, position relative to route filed, time, altitude, aircraft identification, winds aloft, next reporting point, time over next reporting point	Clock, flight plan, clearance, navigation instruments, computer, FSS		
<u>CONDITION</u>: Terminal forecast for Palm Beach International predicts ceiling and visibility at non-precision approach minimums for filing as alternate. Sequence report (1710) shows PBI at 1000' and 2 miles.				
<u>PHASE</u>: ARRIVAL <u>TIME</u>: 1750				
Contact Palm Beach approach	Position, time, next checkpoint	IFR approach plate, navigation instruments, clock, flight plan	Palm Beach approach control	
Receive radar contact verification	*Radar contact at Palm Beach approach control established*	*Altitude Echo on DABS transponder*		*No verification of radar contact* a) Proceed as filed, maintaining two-way communications with center
Receive altitude clearance verification	Altitude clearance limit	DABS Altitude Clearance verification		
Receive clearance to Pahokee VOR	Altitude, reporting point, estimated approach time	Miami center, Palm Beach approach control	Palm Beach approach control	b) Make mandatory position reports
<u>CONDITION</u>: COM: Palm Beach approach control COM: Miami center NAV: Pahokee VOR NAV: Palm Beach VOR				
Observe traffic at 11 o'clock	"Look and see" procedure	Visual surveillance		Traffic in potential conflict not observed
Determine proximity and assess threat of aircraft	Traffic distance, rate of closure, heading, altitude, flight path relative to own flight path	Visual surveillance		a) Traffic performs avoidance maneuver
Perform avoidance maneuver				b) Near miss or mid-air collision
Proceed as filed and cleared				
Contact Pahokee airport advisory	UNICOM frequency			
Receive airport advisory	Wind direction, velocity, runway information, NOTAMS, known traffic	UNICOM weather instruments on airport, UNICOM operator	Pahokee UNICOM	

Event Analysis 6. Marathon to Pahokee Flight in Mid-1980's Environment - Continued

EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
Observe reported severe thunderstorm along approach route to Rwy 17	Location, tops of thunderstorm, movement, turbulence, hail activity	PIREPS, UNICOM airport advisory visual observation		
Contact Palm Beach approach control TIME: 1815				
No radar contact verification or two-way communications	Radar contact and two-way communications with *Palm Beach approach*	Altitude Echo on DABS transponder, COM equipment		Radar contact and two-way communications established
Proceed toward Palm Beach International on victor airways after climb to appropriate altitude	Victor airways, altitude, minimum safe altitude	IFR charts, navigation instruments		State position and intentions
Contact Palm Beach approach control				
State intentions to proceed to alternate				
Receive Palm Beach International airport advisory	Altimeter setting, ceiling and visibility, surface winds, active instrument approach runway	Palm Beach approach control	Palm Beach approach control	
Receive revised clearance to proceed to alternate				
Receive radar vectors to Palm Beach International	Heading, altitude, climb instructions	Palm Beach approach control		
Proceed as vectored	Heading, altitude, time, airspeed			
Contact Terminal Information Service	DABS codes for Palm Beach International and TIS	IFR charts, approach plates, sectionals, DABS Terminal Information Service alphanumeric display		
Receive holding instructions	Heading, altitude, holding fix instructions		Palm Beach approach control	
Proceed to intersection and hold	Heading, altitude, airspeed, time	Clock, navigation instruments		
Select plates for ILS Rwy 9L	Instrument approach in use, special procedures	TIS, Palm Beach approach control, IFR approach plates, charts		
Receive clearance to initial approach fix	Position to which vectored, heading, altitude, and descent instructions, time	Navigation instruments, vector instructions, clock	Palm Beach approach control	
Proceed to initial approach fix	Time, heading, altitude, airspeed, location of outer marker, clearance limits	Radar vectors, navigation instruments, clock, IFR plates, charts, clearance		
Perform landing checklist		Aircraft pilot's manual, checklist placards		
CONDITION: COM: Palm Beach approach COM: Palm Beach tower NAV: ILS frequency NAV: Palm Beach VOR				
Report arrival at initial approach fix	Time, position, initial approach fix location	Navigation instruments, clock, IFR plates		Runway surface winds and Runway Visual Range available
Receive clearance for ILS approach			Palm Beach approach control	Monitor on DABS display
Receive clearance verification				Issued revised clearance to hold at VOR
Fly ILS approach to Rwy 9L TIME: 1845	Heading, outer and middle marker passage, minimum authorized transition altitude, descent rate, position relative to localizer, position on glideslope, marker beacon signal codes, procedure turn, time, minimums, approach course, glidepath, interception profile, reporting points, altitude, airspeed, decision height, wind direction and speed, altimeter setting	Navigation instruments, clearance, marker beacon lights and auditory signal, approach plate, altimeter, clock, localizer and glideslope indicators, warning flags, Palm Beach approach control, volume settings		Proceed with holding pattern as directed

Event Analysis 6. Marathon to Pahokee Flight in Mid-1980's Environment - Continued

EVENT	INFORMATION REQUIRED	INFORMATION SOURCES	COMMUNICATIONS	ALTERNATE EVENTS
CONDITION: Ceiling and visibility at Palm Beach International (sequence report) reported at 500' and one mile.				
Runway environment sighted before decision height, visibility above minimums	Decision height, visibility minimums, altitude, distance to threshold, visibility	Approach plate, navigation instruments, visual contact outside cockpit		Visual contact not established at minimums
Contact Palm Beach tower	Palm Beach tower frequency	charts, plates		Execute missed approach procedure, then notify approach control of intentions
Issued clearance to land			Palm Beach tower	
Receive landing clearance verification		DABS display		
Proceed with approach and landing visually	Runway alignment, rate of descent, glideslope, airspeed, distance from landing zone, wind direction and speed	Navigation instruments, visual cues from runway environment		
Land TIME: 1855				
Contact ground control	Palm Beach ground control frequency, aircraft position, destination on airport	IFR taxiway chart, plates, ground control	Palm Beach ground control	
Receive taxi instructions				
Taxi	Destination on airport, taxiway pattern, traffic	IFR charts, ground control, visual contact outside cockpit		
Shut down aircraft TIME: 1905				
Total Time:				
Start engine to shutdown: 1645 to 1905: 2 hours 20 minutes				

Event Analysis 6. Marathon to Pahokee Flight in Mid-1980's Environment - Continued