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FORECAST OF THE GENERAL AVIATION AIR TRAFFIC CONTROL ENVIRONMENT FOR THE 1980'S

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FORECAST OF THE GENERAL AVIATION AIR TRAFFIC CONTROL ENVIRONMENT FOR THE 1980'S

FINAL REPORT

by

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Prepared under
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for

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FOREWORD

This report was prepared by Aerospace Systems, Inc. (ASI), Burlington, Massachusetts, for the National Aeronautics and Space Administration (NASA) under Contract No. NAS2-9067. The report documents the results of research performed during the period November 1975 to June 1976. The study was sponsored by the Aircraft Guidance and Navigation Branch, NASA Ames Research Center (ARC), Moffett Field, California. Ms. Betty Berkstresser served as Technical Monitor on the contract.

The effort was directed by Mr. William C. Hoffman as the ASI Project Engineer. Dr. Walter M. Hollister, of the MIT Department of Aeronautics and Astronautics, served as principal technical consultant and coinvestigator. Mr. Jack D. Howell, a member of the ASI engineering staff and an Eastern Airlines pilot, also contributed to the study.

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NOMENCLATURE

ACAS	Airborne Collision Avoidance System
ADF	Automatic Direction Finder
A/G	Air to Ground
ARTCC	Air Route Traffic Control Center
ARTS	Automated Radar Terminal System
ASA	Aircraft Separation Assurance
ASDE	Airport Surface Detection Equipment
ASI	Aerospace Systems, Incorporated
ASTC	Airport Surface Traffic Control
ATC	Air Traffic Control
ATCAC	Air Traffic Control Advisory Committee
ATCRBS	Air Traffic Control Radar Beacon System
ATSD	Airborne Traffic Situation Display
AWANS	Aviation Weather and Notam System
BCAS	Beacon Collision Avoidance System
CA	Conflict Alert
CAT	Category (for precision instrument approaches)
CRT	Cathode Ray Tube
DABS	Discrete Address Beacon System
DABSEF	Experimental DABS Facility
DDBS	Digital Data Broadcast System
DME	Distance Measuring Equipment
EADI	Electronic Attitude Direction Indicator
EHSI	Electronic Horizontal Situation Indicator

NOMENCLATURE (Continued)

ELT	Emergency Locator Transmitter
ESA	European Space Agency
ETS	Electronic Test Set
FAA	Federal Aviation Administration
FSS	Flight Service Station
FY	Fiscal Year
GA	General Aviation
GCA	Ground Controlled Approach
GPS	Global Positioning System (Navstar)
GPWS	Ground Proximity Warning System
GS	Glide Slope
HF	High Frequency
IAS	Indicated Airspeed
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMLS	Interim Microwave Landing System
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
I/O	Input/Output
IPC	Intermittant Positive Control
LED	Light Emitting Diode
LOC	Localizer
MIT	Massachusetts Institute of Technology

MLS	Microwave Landing System
N/A	Not Applicable
NAFEC	FAA National Aviation Facilities Experimental Center (Atlantic City, NJ)
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NDB	Non-Directional Beacon
NOTAM	Notice to Airmen
PALM	Precision Altitude Landing Monitor
PCA	Positive Control Airspace
PWI	Proximity Warning Indication
RCVR	Receiver
RNAV	Area Navigation
RTCA	Radio Technical Committee for Avionics
SAS	Separation Assurance System
SE	Single Engine
SID	Standard Instrument Departure Route
STAR	Standard Terminal Arrival Route
STOL	Short Take Off and Landing
TACAN	Tactical Air Navigation
TAGS	Tower Automated Ground Surveillance
TCA	Terminal Control Area
TRACON	Terminal Radar Approach Control
TSO	Technical Standard Order
TX	Transmitter

NOMENCLATURE (Continued)

UG3RD	Upgraded Third Generation ATC System
UHF	Ultra High Frequency (300-3000 MHz)
VFR	Visual Flight Rules
VHF	Very High Frequency (30-300 MHz)
VLF	Very Low Frequency (3-30 MHz)
VNAV	3D Area Navigation (includes vertical navigation)
VOR	VHF Omnidirectional Range
VORTAC	Co-located VOR and TACAN Stations
VTOL	Vertical Take Off and Landing
WVAS	Wake Vortex Avoidance System
WX	Weather
2D, 3D, 4D	Two-, Three-, and Four-Dimensional RNAV

SECTION 1

INTRODUCTION

1.1 GENERAL AVIATION BACKGROUND

The term General Aviation (GA) includes all aircraft, pilots and operations other than the military, and the scheduled and supplemental air carriers. This includes such varied services as air taxi, air cargo, industry, agriculture, business, personal, instructional, research, patrol, and sport flying. Consequently, the spectrum of vehicle types ranges from four engine turbo jets to simple sport gliders and balloons. Table 1 illustrates the broad range of vehicle characteristics associated with the above flying categories.

Table 1. Performance Characteristics for Typical General Aviation Aircraft.

Category	Typical Aircraft	Gross Weight (lb)	Thrust or Horsepower at Takeoff	Max. Cruise Speed (mph)	Range (stat.mi.)
Air Taxi	Twin Otter	12,500	2 x 650	210	780
Air Cargo	Electra	155,000	4 x 4000	350	3000
Industry	S-64 Sky Crane (Helicopter)	42,000	2 x 4800	125	250
Agriculture	Pawnee	2,900	260	130	300
Business	Learjet	15,000	2 x 5900	530	2500
Personal	Bonanza	3,400	285	200	950
Instructional	Cessna 150	1,600	100	120	650
Research	DC-3	25,000	2 x 1425	215	3000
Patrol	Bell Jet Ranger (Helicopter)	3,200	317	140	345
Sport	Citabria	1,650	150	130	525

The GA fleet numbers over 162,000 aircraft, compared to the air carrier fleet of approximately 2,300. Thus, GA makes up 98.5 percent of all the civil aircraft in the U.S. At the end of 1974 the turbine-powered GA fleet alone numbered about 3,500 as opposed to 2,200 for the airlines. By 1984 the GA fleet is projected to grow to 8,200 while the airlines will number 3,500. Single-engine piston aircraft, numbering over 100,000, dominate the general aviation fleet, and in the 1980's these are expected to aggregate more than 200,000 planes. Figures 1 to 3 illustrate several FAA projections of the growth of general aviation during the next decade (References 27 and 28).

General aviation carries one in every three intercity air passengers and is the only air link to more than 19,000 incorporated American communities; 379 of these cities have populations of 25,000 to 100,000 but no other kind of air service. By 1980 general aviation aircraft will be making two-thirds as many IFR (Instrument Flight Rules) flights as the scheduled airlines. With continued improvements in pilot training, basic aircraft safety, and low-cost Air Traffic Control (ATC) and navigational avionics, the general aviation aircraft will be used ever more effectively in airspace where they will "mix" with airlines and military aircraft. These heavily trafficked areas of mixed populations of airspace users generate the knottiest problems.

1.2 NASA GENERAL AVIATION ADVANCED AVIONICS SYSTEM PROGRAM

The overall objective of this program is to provide the critical information required for the design of a reliable, low-cost, advanced avionics system which would enhance the safety and utility of this mode of transportation. Sufficient data will be accumulated upon which industry can base the design of a reasonably priced system having the capability required by general aviation in and beyond the 1980's. It is presumed that the architecture of this advanced system would be quite different from

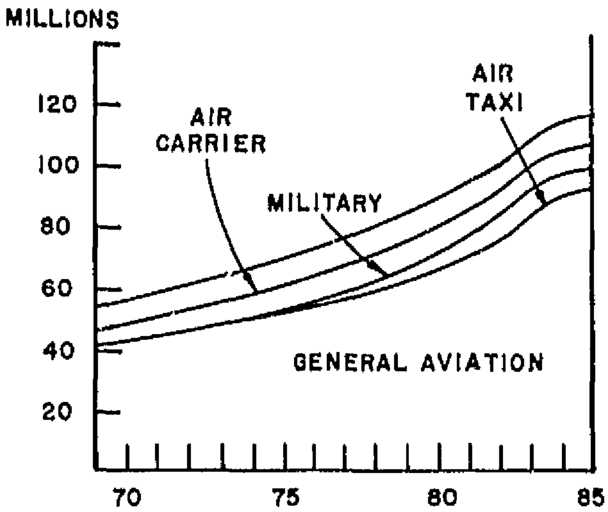

Figure 1. U.S. Aircraft Operations (Reference 27).

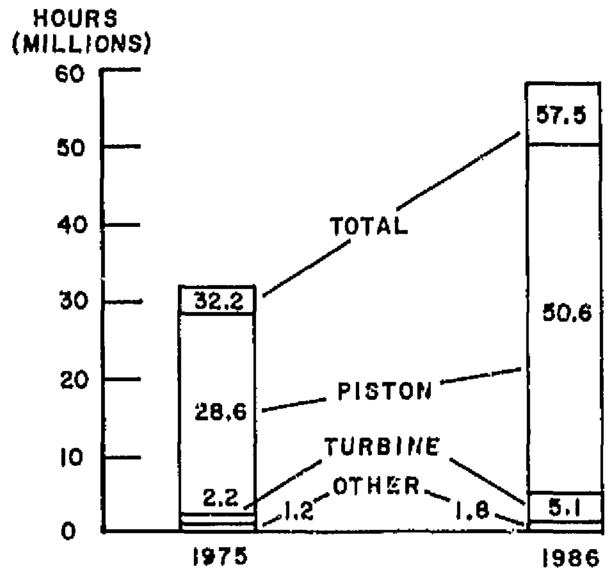

Figure 2. G.A. Hours Flown by Aircraft Type (Reference 27).

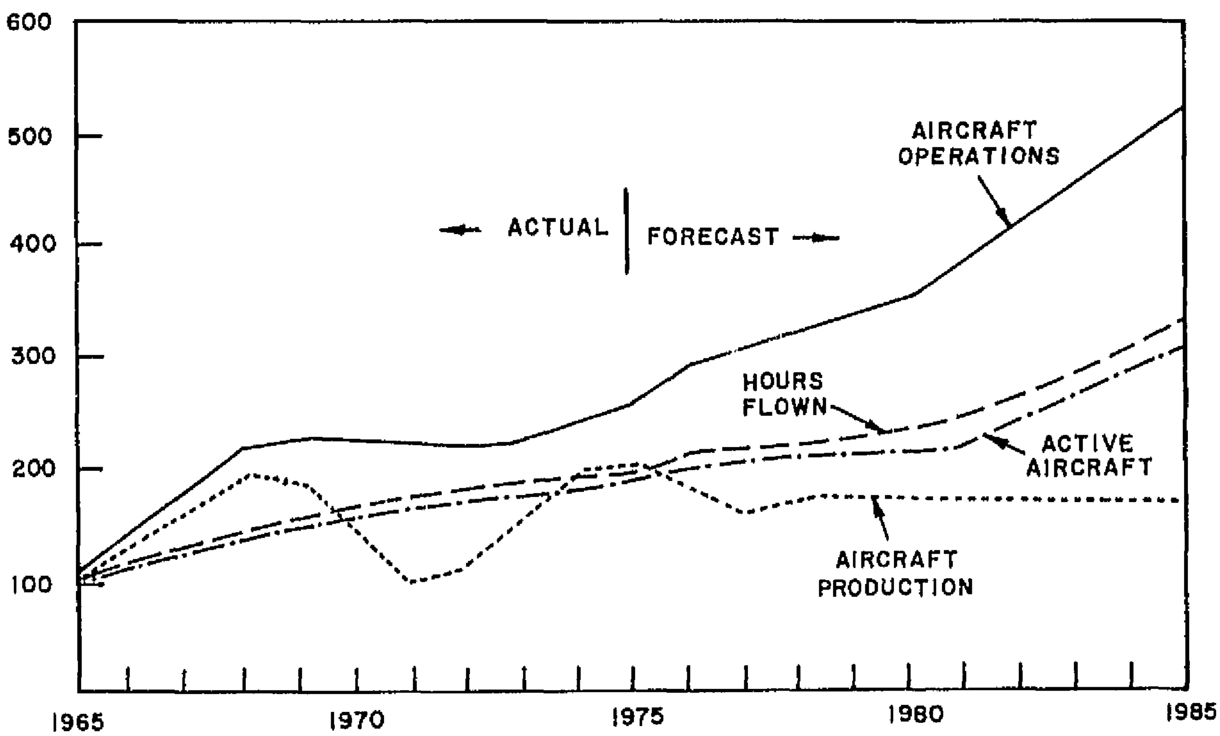

Figure 3. General Aviation Growth (Reference 28).

current general aviation avionics. The program will attempt to establish the technology for a total avionics system design (i.e., navigation, guidance, control, powerplant management, displays, etc.) rather than singling out a particular subsystem, or function upon which to concentrate the research effort.

Since general aviation accounts for the vast majority of civil aircraft operations, as well as a substantial fraction of the passenger miles flown, it has a significant impact on the nation's economy and on the international balance of payments. Considering the future, this segment of civil aviation can and should play an even more important role in transportation and in the nation's economy. However, a number of formidable obstacles exist. Operating procedures are complicated. Regulations are comprehensive and restrictive. There are the ever-increasing demands of the National Air Traffic Control system. These requirements cause an increase in the complexity of the onboard avionics with an associated increase in avionics systems cost. A related result is greater demands on the pilot in terms of training and proficiency in order to avoid any degradation in operational safety.

To help overcome these obstacles, NASA has undertaken a general aviation avionics research and technology program. This program will utilize recent advances in microelectronics to make significant advances in general aviation systems and operational capability. Its completion is keyed to providing the information required for the design of low-cost integrated avionic systems needed to enable general aviation to fulfill its role in the 1980's.

Specific objectives of the program are as follows:

a. In FY75, initiate the formulation of an advanced airborne avionics system concept. This design would emphaisze efficient integration of all elements of the onboard avionics system, with the aircraft, with the ATC, and with the ground navigation systems.

b. In FY76, define preliminary specifications and performance requirements for the experimental avionics system.

c. By FY77, identify optimal subsystems resulting from a tradeoff of candidate systems design as a function of:

   1. Cost
   2. Reliability
   3. Expandability
   4. Flexibility
   5. Maintainability
   6. Simplicity of Operation
   7. Performance

   These cost-benefits-analysis studies will make visible the many trade-offs between system requirements and system architecture. These studies will also evaluate the technical risks associated with the particular systems design-approach and the associated electronics technology used in the design of the system elements, i.e., sensors, displays, actuators, etc.

d. In FY78, provide specifications and performance requirements for a final systems design.

e. In FY79, complete final systems design. System fabric 'ion and flight investigations are to be conducted to examine acceptability and performance.

Five years will be required to complete the program activities. The first four years will be primarily concerned with the development and validation of design information, upon which the final system specifications will be based. The last year of the program will emphasize the final systems design and an examination of its performance and suitability using the NASA Cessna 402B aircraft.

1.3 OBJECTIVES OF ATC ENVIRONMENT FORECAST

The objective of this particular study is to forecast the ATC environment for general aviation in the 1980's and beyond. It is recognized that the FAA is proceeding with the development of the "Upgraded Third Generation ATC System"

(UG3RD) which is scheduled for use in that time frame. General aviation aircraft, of course, will be operating in that system. To support the Advanced Avionics Program, NASA desires to know what requirements will be placed on general aviation aircraft operating in the UG3RD system. Any changes in the methods used to accomplish the four primary functions of ATC (control, navigation, surveillance, and communication) could have an impact on the onboard avionics system design.

In the course of this study, ASI performed the following tasks:

- Task I. Since general aviation covers a broad spectrum of users, such as air taxi service, business travel, personal travel, recreational flying, agricultural applications, and police surveillance, to name only a few, the avionics requirements to operate in the future ATC system will undoubtedly differ. We have therefore attempted to categorize the different users of general aviation based on avionics requirements.

- Task II. The UG3RD ATC system being developed by the FAA has nine key features as listed below:

  Discrete Address Beacon System (DABS)

  Separation Assurance System (SAS)

  Area Navigation (RNAV)

  Microwave Landing System (MLS)

  Upgraded ATC Automation

  Airport Surface Traffic Control (ASTC)

  Wake Vortex Avoidance System (WVAS)

  Flight Service Stations (FSS)

  Aeronautical Satellites (AEROSAT)

  ASI has assessed the avionics requirements placed on each of the use categories identified in Task I by each of the nine features of the UG3RD system, particularly those features of the UG3RD ATC which will make new or modified avionics equipment either required or desirable. Avionics that will be required have been identified separately from those that will be desirable, but not required.

- Task III. For each use category, the critical parameters that are necessary for component design have been identified. Examples include the following: the frequency range and spacing of communications channels; the range and accuracy required of the various navigation and communication systems; the type and format of information that will be available through data-link systems.

- Task IV. Although the FAA is proceeding with the UG3RD as defined in Task I, it is also recognized that certain deviations from this plan are being investigated. An example of these deviations is the use of the Airborne Traffic Situation Display (ATSD) for collision avoidance. Consequently, we have surveyed all possible deviations from the UG3RD plan and assessed the impact of these deviations on the avionics requirements for general aviation aircraft.

- Task V. The UG3RD system appears to be headed toward more mixing of commercial and general aviation aircraft in the ATC system, but the possibility remains that ATC for commercial and at least certain segments of general aviation aircraft could be more separated in the future. The possibility or feasibility of this situation has been assessed.

- Task VI. Finally, features of the UG3RD that could be changed to minimize the avionics requirements for the different use categories of general aviation, without changing the objectives of the UG3RD system, have been identified.

1.4 OUTLINE OF THE REPORT

Section 2 of the report discusses the air traffic control environment in the 1980's, including the upgraded third generation ATC system and several potential additions to it. A series of general aviation user groups based on increasing avionics requirements is defined, and specific ATC scenarios are hypothesized in Section 3; the associated avionics requirements are then presented for each group. Section 4 summarizes critical system design parameters for the various airborne equipments. The possibility of some general aviation alternatives to the presently envisioned UG3RD are discussed in Section 5. Conclusions and recommendations are presented in Section 6. Finally, the Bibliography contains a variety of pertinent documents which were consulted during this study. Individual references in the text of the report are citations from the Bibliography.

SECTION 2

AIR TRAFFIC CONTROL FOR THE 1980's

2.1 HISTORICAL PERSPECTIVE

The air traffic control (ATC) system currently operated by the FAA in the United States' National Airspace System (NAS) is the result of an evolutionary process. Improved capabilities, based on technology advances, have been introduced into the system to support the increasing utilization of the ATC services.

Significant levels of evolutionary progress in the ATC system have been loosely identified as successive generations, as shown in Table 2 (Reference 111). The earliest air traffic control system, or first generation, relied solely on manual operating procedures, with aircraft separation based on pilot position reporting. Radar and other advanced technological concepts developed during World War II were adapted for the post-war air traffic control system, resulting in the second generation ATC system.

Table 2. ATC Generations (Reference 111).

Generation	Time Period	Key Features
First	1936-1960	- Procedural Control - Flight Strips - Limited Control - Mostly by A/G Radio
Second	1960-1970	- Radar Control Introduction of ATCRBS - Limited Flight Strip Printing
Third	1970-1975+	- NAS Enroute and ARTS Automation - Increased Use of ATCRBS - Centralized Flow Control
Upgraded Third	1975-1995	- Upgraded ATC Automation - DABS, ASA, RNAV, MLS etc.
Fourth	1995-?	- New System Organization - More Automation - New Surveillance, Communications, and Navigation Systems

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Additional technical progress, particularly in automation and other forms of electronics innovations, resulted in what is recognized as the existing third generation ATC system. Based on the results of Project Beacon (Reference 23), the third generation system constitutes the first stage of automation for ATC operations and utilizes secondary radar to augment the surveillance function. This initial step of automation consists of two subsystems: NAS Stage A, which is operational at all 20 Air Route Traffic Control Centers providing enroute control over the entire conterminous United States; and ARTS III, which is used at 61 of the busiest terminals. In addition, a slightly scaled-down version of ARTS III is scheduled for implementation at a number of terminal areas of lower density traffic activity by 1980.

In 1969, the Department of Transportation's Air Traffic Control Advisory Committee's (ATCAC) report was issued (Reference 22). Its primary conclusion was that continued upgrading of the ATC system would be necessary even after the Project Beacon recommendations were implemented, in order to meet the projected demands for ATC service in the late 1970s and beyond. Specific recommendations were made for an evolutionary upgrading of the system. Accordingly, the term "upgraded third generation system" was applied to the resulting configuration. This is the system intended for operational use through the 1980s and into the 1990s.

2.2 THE UPGRADED THIRD GENERATION ATC SYSTEM

Upgrading of the present ATC system will continue through the late 1970s and well into the 1980s. The upgraded third generation (UG3RD) system has nine major features which are under development to satisfy four important system needs: improved safety, increased capacity, lower user costs, and lower operating cost. The nine principal elements of the UG3RD are described briefly in this subsection. It must be recognized, however, that although development activities have started on all nine, implementation decisions have not been made on most and will not be made until comprehensive cost/benefit analyses are completed. The development and implementation schedules presented are based on FAA program plans (Reference 7), and the latest reported milestones (Reference 111).

2.2.1 DISCRETE ADDRESS BEACON SYSTEM (DABS)

The DABS was a major aspect of the ATCAC recommendations (Reference 22) to provide intermittent positive control (IPC) for aircraft separation assurance. The ground-based IPC service was expected to be completely automatic, based on computer processing of surveillance data, detection of impending conflicts, and the generation of the necessary data link messages. The transmission of information to/from the aircraft required that the discrete address beacon system have the capability for a data link. The objectives of the DABS development, therefore, are to provide the basis for the IPC function through improved surveillance and accuracy, plus an integral data link between the ground and the aircraft.

An additional objective of the DABS system is to interrogate aircraft individually to avoid a situation known as synchronous garble. The present air traffic control radar beacon system (ATCRBS) generates about forty replies from an aircraft during the time that the beam is illuminating the target. Synchronous garble occurs when two aircraft are at the same range and the same bearing, but not at the same altitude. This causes their replies to overlap, making it difficult to identify the individual replies. The discrete address beacon system would use a single coded interrogation for each aircraft; since only that aircraft would reply to the interrogation, the problem of synchronous garble would be eliminated. Another major advantage of DABS is its ability to limit interrogations to only those targets for which it has surveillance responsibility, rather than continuously interrogate all targets within line-of-sight. This prevents surveillance system saturation caused by all transponders responding to all interrogators within line-of-sight.

An important consideration in the design of DABS is the ability to implement it on a time scale and at a cost acceptable to the aviation community. By the time deployment of DABS could begin, there will be on the order of 200,000 aircraft equipped with ATCRBS transponders and approximately 500 ground interrogators. DABS must be designed to operate in this environment and in a way which permits a gradual, economic transition to an all-DABS operation over a 10- to 15-year period.

This has been achieved by providing a high degree of compatibility between DABS and ATCRBS. DABS uses the same interrogation and reply frequencies as ATCRBS, and the signal formats have been chosen to permit substantial commonality in hardware. This degree of compatibility permits economic realization of two essential elements of a smooth transition:

a. DABS interrogators provide surveillance of ATCRBS-equipped aircraft;

b. DABS transponders reply to ATCRBS interrogators.

Thus DABS equipment, both on the ground and in aircraft, can be introduced gradually and continue to operate with existing systems during an extended transition phase. Table 3 presents a comparison of DABS and ATCRBS characteristics and accuracies.

The development of DABS was assigned to MIT's Lincoln Laboratory as the system design contractor. The basic design and breadboard verification of DABS is essentially complete, and an experimental DABS facility (DABSEF) is currently in operation at Lincoln. The DABS design is now being tested together with the IPC concept by Lincoln Lab, and the FAA is currently testing sensors and transponders at NAFEC. A contract for three prototype ground sensors and 30 airborne transponders was recently awarded by the FAA, with the first ground installation scheduled for late 1977. The

Table 3. Comparison of DABS vs ATCRBS Characteristics.

PARAMETERS	DABS	ATCRBS
Frequency Up	1030 MHz	1030 MHz
Frequency Down	1090 MHz	1090 MHz
Range Accuracy (3σ)	100 ft.	1000 ft.
Azimuth Accuracy (3σ)	0.1°	0.75°
Altitude Accuracy (3σ)	125 ft.	125 ft.
Addresses	16 Million (224)	4096
Uplink Message Length	32.5 μsec 112 bits	8 to 21 μsec 3 bits
Downlink Message Length	120 μsec 112 bits	20.3 μsec 15 bits
Data Link Messages	Unlimited Ground-Air-Ground	Limited to Aircraft I.D. and Altitude-Downlink Only
Surveillance Capacity	2000 A/C Per Sensor	Garble Limited
Coverage	ATC Facility can draw on any sensor in its airspace	ATC Facilities use only their own sensors

implementation decision will follow nearly two years of operational testing, with 1981 being the earliest possible implementation date. Table 4 presents a summary of the latest development/implementation schedule for DABS.

Although the development of DABS is well underway, its eventual implementation remains uncertain. This decision still depends strongly upon the future of intermittent positive control, which at the present time is an unproven concept. Moreover, the IPC function could potentially be achieved with the existing ATCRBS, providing the accuracy were enhanced and a separate data link were utilized. Equivalent accuracy to that provided by DABS might possibly be obtained by upgrading the

Table 4. Projected Implementation Schedule for DABS.

Date	Milestones
Through 1975	Basic design and signal format. Experimental facility operational at MIT Lincoln Laboratory.
March 1976	Contract to Texas Instruments for three prototype ground sensors. Subcontract to Collins Radio for 30 prototype airborne transponders.
Summer 1976	National standard for airborne transponder.
October 1977	First prototype ground sensor installation at NAFEC.
December 1977	Begin year of multi-site testing, followed by year of tests at field facilities.
January 1978	Second ground sensor installation at Philadelphia.
April 1978	Third ground sensor installation at Elwood, NJ.
1979	Implementation decision.
1981	Earliest date for system implementation.

existing ATCRBS transmitters to use monopulse techniques instead of beam-splitting. However, the synchronous garble problem could not be avoided without discrete addressing. The magnitude of this problem is difficult to evaluate because it is so strongly linked to the density of aircraft, which has not increased as rapidly as predicted. The establishment of terminal control areas (TCAs) has discouraged large numbers of VFR aircraft from utilizing the terminal air space. In addition, commercial traffic growth has diminished partially due to the increased use of wide-body jets and a general decrease in the demand for air carrier services.

If the discrete address beacon system is implemented, it will require a new transponder which is targeted to cost slightly more than the present ATCRBS transponder and encoding altimeter. In addition, an IPC display probably would be required. Those sophisticated users who desired to use the data link from air to ground would require an optional on-board console. Although such consoles for DABS have not been developed yet, they could be expected to cost in the neighborhood of $20,000 or more. The critical system cost element will be the ground sensor and associated software.

Although DABS' primary function is to provide surveillance and air-ground communication service to air traffic control facilities (including IPC), an air-to-air mode, termed Synchro-DABS (Reference 88), could operate as backup to the ground-based IPC function. By proper timing of the interrogations to all DABS-equipped aircraft, suitably equipped aircraft could utilize the DABS replies from other nearby aircraft to perform onboard proximity warning indication (PWI) and conflict detection.

2.2.2 AIRCRAFT SEPARATION ASSURANCE

The aircraft separation assurance program consists of five separate but related activities:

1. Conflict Alert (CA)
2. Extended Flight Plan Requirements
3. Expanded Altitude-Reporting Transponder Requirements
4. Beacon Collision Avoidance System (BCAS)
5. Intermittent Positive Control (IPC)

These span a period of time from those which are being implemented immediately to those which may be implemented over a number of years. Included also is a mixture of software and hardware techniques.

2.2.2.1 CONFLICT ALERT (CA)

A near-term activity involves the upgrading of the enroute and terminal automation software to alert the controller of impending conflicts. This automatic backup alarm for conflicting traffic is a software program using existing computers to project the flightpaths of transponder-equipped aircraft for the next two minutes. It will alert controllers of a potential conflict so that they can take the necessary action via radio to warn the pilots. This activity is now completed in 20 domestic air route traffic control centers for airspace above 12,500 feet. A similar capability is being developed for automated terminal systems with a planned installation at the 60-plus airports during 1977.

2.2.2.2 EXTENDED FLIGHT PLAN REQUIREMENTS

New flight-plan requirements will be established for passenger-carrying aircraft. These aircraft will include air taxis, commuter airlines, and the executive corporate fleet. The new scheme requires these types of aircraft to file a flight plan and operate under IFR to ensure continuous monitoring by ATC.

2.2.2.3 EXPANDED ALTITUDE REPORTING TRANSPONDER REQUIREMENTS

Automatic identity and altitude reporting transponder equipment will be required for all aircraft flying in certain controlled airspace. The altitude/identity information is displayed directly on controllers' radarscopes, giving them a more complete picture of the traffic under their control. The altitude-reporting transponder will be the key to the enhancement of both CA and the upcoming BCAS.

2.2.2.4 BEACON COLLISION AVOIDANCE SYSTEM (BCAS)

The beacon collision avoidance system was recently selected by the FAA as the preferred airborne system to detect and resolve conflicts independent of the present ATC system. BCAS was chosen over the cooperative airborne collision avoidance system (ACAS) as the quickest and least expensive way to provide an independent backup capability for the ground-based ATC system. By its nature, BCAS will make the ATC transponder with altitude reporting an essential equipment need for aircraft operating in certain airspace, particularly that used by the air carriers.

The two forms of BCAS, active and semiactive, are still in competition for the final selection. The active BCAS concept was originally conceived several years ago for use over oceans, but was not pursued because of the potential interference by the airborne interrogator/transponders with the ground surveillance system. An active BCAS emits a conventional mode C interrogation once each second. Antennas are necessary both on the top and on the bottom of the fuselage to avoid masking by the airplane; presumably, the interrogation would be alternated between antennas. The active BCAS signal elicits a reply from all transponder-equipped aircraft within range. From each reply the airborne system measures the separation distance using the round-trip transit time, and also receives the identity and the barometric altitude of each responding aircraft. By differencing the measured slant ranges the active BCAS determines the range rate. The system can determine from this information whether a threat exists, and whether a climb, descend or level-off evasive maneuver is appropriate.

The semiactive BCAS (Reference 85) uses an active mode only when there are inadequate ground interrogators in the vicinity. The passive measurement involves listening to the responses of other airborne transponders to the ground interrogations. When two ground interrogators are within range, sufficient information is available to determine range and bearing to a transponder. This system does revert to an active mode when there are insufficient ground interrogators in the aircraft's vicinity. Since the semiactive system provides the pilot an indication of the direction as well as the range and altitude of a threat aircraft, it provides the option of a horizontal, vertical or combined maneuver to avoid a collision. In contrast, the active BCAS is restricted to only vertical maneuvers.

At the present time, the semiactive BCAS appears to offer more advantages than the active system. But since both techniques rely upon signals received from aircraft transponders, they are not mutually incompatible. Conceivably, a combination of the two techniques might emerge as the optimum design. The active BCAS has been demonstrated in flight by the FAA and is considered feasible. The semiactive system is about to undergo a similar flight evaluation program at NAFEC. A final BCAS system design should be available early in 1978.

Preliminary FAA planning is to seek mandatory installation of BCAS on all aircraft capable of transporting ten passengers or more, which would exclude most of the GA fleet as well as much of the military fleet. Current estimates are that an active BCAS would sell for about $20,000, in production quantities, with the semiactive version costing slightly more.

2.2.2.5 INTERMITTENT POSITIVE CONTROL (IPC)

Intermittent positive control is still the FAA's preferred, long-range solution to the separation assurance problem. IPC was first conceived as a cornerstone of the UG3RD by the ATCAC report, and has only recently been augmented by BCAS. This technique protects both VFR and IFR aircraft, provides more flexibility for conflict resolution through use of horizontal maneuvers, and assures maximum coordination with air traffic control in resolving conflicts. Advisories and collision avoidance commands will be ground-determined and transmitted via a data link to the aircraft. This data link can be provided by the discrete address beacon system.

The present experimental version of IPC involves a cockpit display of proximity warning lights and ground derived commands (Figure 4) which indicate avoidance maneuvers or restraining advisories (negative commands). An extremely complicated logic determines when the various commands are issued, depending on such things as:

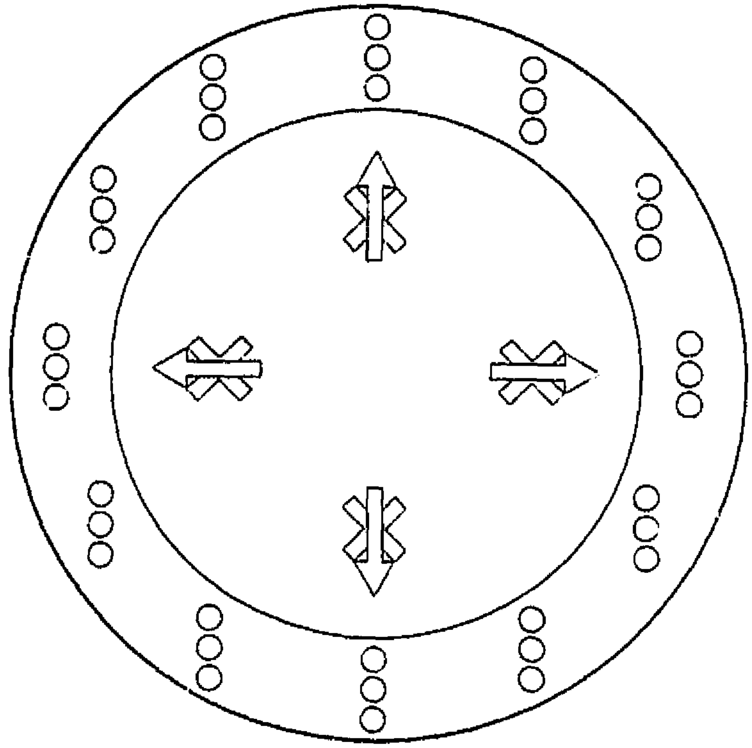


Figure 4. IPC Display

- whether the aircraft are DABS or ATCRBS equipped
- whether the aircraft are under IFR or VFR flight plans
- the groundspeed of the aircraft
- the predicted time to point of closest approach
- the relative geometries of the conflict situation
- whether the aircraft responds to initial commands.

The experimental proximity warning indicator in Figure 4 provides the relative bearing to the nearest 30 degrees (clock code), and the relative altitude (high, level or low) which is quantized to about 500 feet. Because the warning lights come on at different times under different situations, the unit provides effectively no range information. Several pilots have expressed a desire to have the range information displayed since it is available from the computer.

If IPC is implemented, a DABS transponder and a display will be required to receive protection from all altitude-encoded, transponder-equipped aircraft. An input/output device would be required to use the data link for other messages. Compared to the present cost of a GA ATCRBS transponder of about $750, a future DABS transponder with IPC cockpit display is estimated to sell for about $2,000, excluding the cost of the altitude encoder.

The IPC concept is currently under test using the Lincoln Laboratory DABSEF facility and a fleet of general aviation aircraft equipped with the DABS transponders. Evaluation flights with general aviation subject pilots have been conducted regularly for several months to evaluate their response to commands, and their reaction to the system. Preliminary conclusions show that the proximity warning is universally received with enthusiasm. However, the positive and negative commands are generally less favorably accepted, partially because the commands are frequently inconsistent with normal evasive practices when the intruding aircraft can be seen visually.

As previously discussed, a prerequisite for the IPC service is the implementation of the Discrete Address Beacon System. A prototype test of IPC is scheduled for late 1977 at NAFEC, using the first DABS ground sensor. The first operational IPC service is scheduled to begin in Philadelphia in 1979.

If BCAS and DABS are both implemented, a question arises as to which would be the primary means of assuring separation. Some think that the DABS IPC should be the principal separation assurance system in areas where coverage is available, and that BCAS would protect in areas where there was no DABS coverage. This would probably require that the active BCAS be deactivated in areas where DABS coverage was available to prevent possible conflicts in evasive maneuvers prescribed by the two systems. Also, with the implementation of DABS it will be necessary for active airborne transmitters to interrogate other aircraft in both a DABS and an ATCRBS mode. Once communication between aircraft using the DABS equipment is established, many interesting possibilities exist, such as having one aircraft advise the other of an escape maneuver. Conceivably, the aircraft could effectively have "turn signals" that would be flashed to equipped aircraft whenever the pilot intended to change direction or altitude.

2.2.3 AREA NAVIGATION (RNAV)

The existing structure of enroute airways and routes within terminal areas consists of flight segments defined by radials of the existing VORTAC network. This limitation to radial segments has imposed extra mileage between certain terminals and has limited the number and capacity of air routes. Area navigation systems give aircraft the capability to follow predetermined altitude and time schedules in proceeding from one navigational waypoint to the next, unconstrained by the location of the navigation station. These RNAV routes permit possible traffic segregation by speed classes and separation of traffic bound for metropolitan areas according to the airport of destination. Vectoring by the ground controller will be reduced, and aircraft operating costs will be lowered by more direct routes and optimum climb profiles. Table 5 presents a detailed outline of the potential benefits of RNAV (Reference 7).

The problems associated with RNAV are primarily due to the integration of the new routings into the present air traffic control system. The existing NAS enroute system does not readily accept flight plans with direct routings, because it is difficult for the human controller to handle RNAV direct traffic when the majority of the traffic is following the established airways. However, the 1980's undoubtedly will see

Table 5. Area Navigation Features and Potential Benefits.

I. RNAV (2D)

A. Designated Routes

1. Efficient Restructuring of Terminal Airspace for Departures
2. Efficient Restructuring of Terminal Airspace for Arrivals
3. Shorter Standard Instrument Arrival and Departure Routes
4. Pilot-Navigated Noise Abatement Arrival and Departure Routes
5. Segregation of Traffic by Speed/Climb/Descent Capabilities
6. Replace Some Metering and Spacing Vectoring
7. Shorter Low Altitude Routes
8. High Altitude Great Circle Routes
9. Optimized High Altitude Weather Routes
10. More Favorable High Altitude Flight Level Assignments
11. More Optimum Routes through Restricted Areas When Not in Use
12. Fewer VOR/DME's to Support Expanded Route Structure
13. Fewer VOR's to Provide Instrument Approaches
14. Fewer Dual VOR/DME's Required
15. Increased Continuity of Service
16. Many Non-RNAV Users Will Not Require 50 kHz Frequency Spacing
17. Change Route Structure Without Moving VOR/DME's
18. VFR Guidance Airport to Airport

B. Parallel Routes

1. Convenience of Parallel Offset
2. Simplified Passing Procedures
3. Simple Spacing Procedure

C. Impromptu Routes

1. Severe Weather Avoidance with Pilot Navigation
2. Direct to Next or Other Waypoint Navigation
3. Metering and Spacing Applications

D. Pre-Planned Routes

E. Instrument Operations to Non-ILS or VOR Instrumented Runways

1. Separate Approach Paths for STOL and General Aviation
2. "Straight-In" Approaches
3. RNAV/VNAV Instrument Operations When ILS Inoperative

Table 5. Area Navigation Features and Potential Benefits (Continued).

F. Pilot Navigation Instead of Vectoring

1. Pilot Awareness
2. Back-up Following Radar or ARTS Failures

G. Improved Navigation Performance

1. Linear, Smoothed Course Indications
2. Reduced Airborne VOR Error
3. Improved Lateral Navigation Accuracy

II. VNAV (3D)

A. Designated Routes

1. Inclined Tunneling
2. More Economic Descent Profiles
3. Inclined Plane Floor/Ceiling Boundaries
4. Parallel, Precise Climb/Descent Paths

B. Vertical Guidance for Instrument Approaches

1. Lower Minimums Than with RNAV
2. Two-Segment Approaches

III. TNAV (4D)

A. En Route and Transition Application

B. Terminal Area Application

additional use of RNAV, first at the higher altitudes, then in the more densely-populated terminals, and finally over most of the airspace. Equipment for area navigation already exists, and is in operation in many general aviation aircraft. In the future, certain airspace such as the present terminal control areas may only be available to RNAV-equipped aircraft.

Navigation equipments most likely to be used in an RNAV structure include: VOR/DME, Omega/VLF, Loran-C, and inertial navigation systems. NAVSTAR, the military satellite Global Positioning System, is also a candidate, although it is not scheduled to become operationally available until after 1984, and initially may find only limited civil use. VOR/DME area navigation has several disadvantages despite the fact that it is presently the primary navigation system. One major disadvantage is that the bearing accuracy of the VOR is relatively poor, of the order of 3-4 degrees, which leads to large position errors at significant distances from the VOR facility. DME is more accurate, having a random bias error of 500 feet (1σ). Consequently, for more accurate RNAV, multiple DME holds much more promise than VOR/DME, and it is reasonable to expect a multiple DME RNAV to provide position accuracies of 0.1 nm (1σ).

Another problem associated with VOR/DME area navigation is coverage. Because VHF and UHF signals propagate along a straight line, a large number of stations is needed to provide uninterrupted coverage, especially at low altitudes. Because individual ground stations cost several hundred thousand dollars each, VOR/DME coverage over the entire United States at all altitudes is a very expensive way of providing area navigation capability.

mega, on the other hand, is a much lower cost RNAV system, in that only eight stations are required to provide complete world-wide coverage. The eight stations are already funded and most are operational. The accuracy of Omega is normally considered to be one mile in the daytime and two miles at night. Improved accuracy of the order of 2,000 feet could be obtained using differential Omega, but this would require differential ground stations located every few hundred miles. However, the cost of these stations would still be extremely inexpensive relative to the cost of providing a complete VOR/DME RNAV network.

Loran-C has an intermediate cost between Omega and VOR/DME. Loran-C stations cost about five million dollars each, but the usable range extends out to approximately 1,000 miles, which is about an order of magnitude greater than for VOR/DME. Like Omega, Loran-C is a low frequency system and provides coverage all the way to the ground. Over the total area of coverage it would be reasonable to expect accuracies of a tenth of a nautical mile. However, under the best geometry Loran-C has the potential of significantly enhanced accuracy, with a repeatability of the order of 100 feet. At the present time, the FAA is studying the possibility of using Loran-C as the standard navigational aid to replace the present VOR/DME system. In addition to its potential cost savings, the Department of Transportation has specified Loran-C in the National Plan for Navigation in the coastal confluence area. Loran-C chains are presently operating on the East Coast and in the Great Lakes, and a West Coast chain will seen be commissioned. Relatively few additional stations would be needed to provide complete Loran-C coverage over the conterminous United States.

Inertial navigation systems (INS) will probably be limited to the more sophisticated users because of their high cost, on the order of $100,000. However, low cost versions for GA are forecast to eventually cost around $30,000 or less. The accuracy of an inertial navigation system is typically one nautical mile per hour. A significant advantage of inertial navigation systems is their complete independence from ground stations. Recently, general aviation aircraft have been certificated for use of inertial navigation under IFR.

It is difficult to speculate on which of the navigation systems will become the primary system for general aviation use inasmuch as the outcome depends largely on political decisions to be made by the FAA, by the Congress, and by ICAO. All of the navigation systems discussed above are presently in operation and none can be completely eliminated in the time span under consideration, since a large number of aircraft are and will be equipped with the respective avionics and dependent upon the ground stations. Modifications to the ATC system can only be undertaken if they will be compatible with existing equipment. As a consequence, additional new systems will be slow in implementation, and those which are in existence will remain in operation long after their shortcomings are recognized. The most probable situation for the 1980s is that all of the systems will have found some use and that the ATC system will accept any of the various RNAV equipments that can achieve sufficient accuracy, which is presently specified in the FAA Advisory Circular 90-45.

One important factor in the design of RNAV equipment is the pilot workload created by its use in the terminal area. Since manually changing from waypoint to waypoint can produce significant workloads, stored waypoints that have been preset prior to flight will probably be necessary, at least for high density terminals. In addition, the system has to be designed to minimize the possibility of operator errors in setting the waypoints. For example, it is relatively easy to inadvertently transpose digits in specifying a latitude and longitude or a bearing and distance: hence, some kind of cross-check is desirable.

The implementation of RNAV has proceeded at a very low level during the past few years. However, the implementation rate is expected to accelerate during the remainder of this decade and into the early 1980's. Considerable effort has been spent in configuration studies and avionics standards, and a decision on major implementation is expected within a year. It is possible that the high altitude enroute airway structures and certain dense terminal areas will require RNAV capability by 1980-82. By 1985, RNAV will likely be used exclusively at all medium and high density terminals (at least during peak traffic periods), as well as in the high altitude enroute structure.

2.2.4 MICROWAVE LANDING SYSTEM (MLS)

The universal microwave landing system now under consideration by ICAO is intended to provide more flexible yet more precise approach and departure paths than the existing VHF/UHF instrument landing system. The basic system is being developed to satisfy both civil and military requirements, with variations in several versions adapted to the particular needs of each. The civil version will be designed for both commercial air carrier and general aviation requirements. The high cost of site preparation frequently required for the ILS will be significantly lessened, and installations will be possible at sites where the conventional ILS is not now practical. Improved flexibility will be provided in the form of multiple glide slope selection and curved approach capability, which could have a marked impact on reducing noise in areas immediately surrounding the airport.

The development program for MLS has been underway for a number of years. Many MLS systems are already in operation, and the problem is to select one universal system for the international community. The United States has chosen the time reference scanning beam MLS technique as its proposal to ICAO, after a close competition with the Doppler scanning technique which the United Kingdom is promoting. The Federal Republic of Germany is proposing a system involving interferometer measurements with L-Band DME. Therefore, it is not clear which MLS concept will eventually be selected by the international community.

In the interim, several MLS systems are already in operation: the Canadians are operating a C-Scan system; MADGE (microwave aircraft digital guidance equipment) has been recommended for adoption by NATO, and is being supplied to the UK Ministry of Defense; and each of the U.S. military services has a different MLS system in current operation. The FAA has designated Tull Aviation's system as the official interim standard MLS, and a few installations have been commissioned. Individual organizations, such as Rocky Mountain Airways, are operating with the TALAR system and others. Consequently, there is still some doubt as to the form that MLS will take, since there is no international agreement yet, and by practice there is a proliferation of interim MLS systems.

It is conceivable that MLS will not be implemented in its complete form, since it is only needed at airports with siting problems or where steep and curved approaches are required. Implementation of just the glide slope portion of MLS could meet these requirements. It would be relatively easy to add or substitute just the MLS glide slope to existing ILS facilities, since the conventional UHF glide slope is entirely independent of the VHF localizer. The conventional ILS glide slope is often difficult to form since it normally requires reflection of the radiated energy off the ground plane, and it is limited to approximately 3 degrees which does not permit steep approaches. However, pilots have shown reluctance to make steep approaches that do not level off to the conventional 3 degree approach prior to the final flare. Also, they have expressed reluctance to fly curved approaches beyond the same point where the glide slope shallows to 3 degrees. The steep and curved portions of these approaches can probably be flown with area navigation equipment with interception of a conventional 3 degree glide slope at the point 400 to 600 feet above the runway.

Furthermore, a number of technical improvements could be made to the existing ILS to make it a strong competitor for remaining as the primary landing system. The majority of VOR navigation receivers process the ILS localizer signals as a standard feature. Conventional ILS has been accepted by ICAO and is used at airports around the world. Airport operators will tend to install a conventional ILS before a new MLS because very few users are equipped to use the MLS, and the form of the universal MLS is still in doubt. Since a new MLS would generally be located where an ILS is also installed, there is little advantage to providing two localizers if the VHF one is satisfactory. Similarly, there is little reason to initiate a new C-band DME, which is planned as a part of the scanning beam MLS, when we already have L-band DME.

MLS probably will be most important for Category III landings where higher accuracy for flare is required. Again, the MLS glide slope will probably be aligned with the conventional ILS and be used primarily by those aircraft which need Category III capability. It should be pointed out that the conventional UHF glide slope is inadequate for flare guidance because it does not intersect the runway. Instead it has a hyperbolic share near the ground, typically rounding off some 10 to 20 feet in the air depending on the distance of the antenna mast from the center of the runway. The main reason for not placing the UHF glide slope antenna closer to the runway center line is that it becomes an obstacle for landing aircraft. However, flexible antennas have been developed to reduce the hazard to landing traffic.

Despite considerable controversy, the U.S. MLS development program has proceeded nearly as scheduled (Figure 5). The U.S. choice of a scanning beam system has been flight demonstrated in the NASA TCV aircraft and submitted for ICAO consideration. The ICAO is scheduled to specify one of the competing systems as the universal MLS by the fall of 1977. Commencement of international operations with the universal MLS is expected by the beginning of the 1980's.

2.2.5 UPGRADED ATC AUTOMATION

The specific objectives of the UG3RD automation development program apply to all major portions of the ATC system, i.e., enroute, terminal, and central

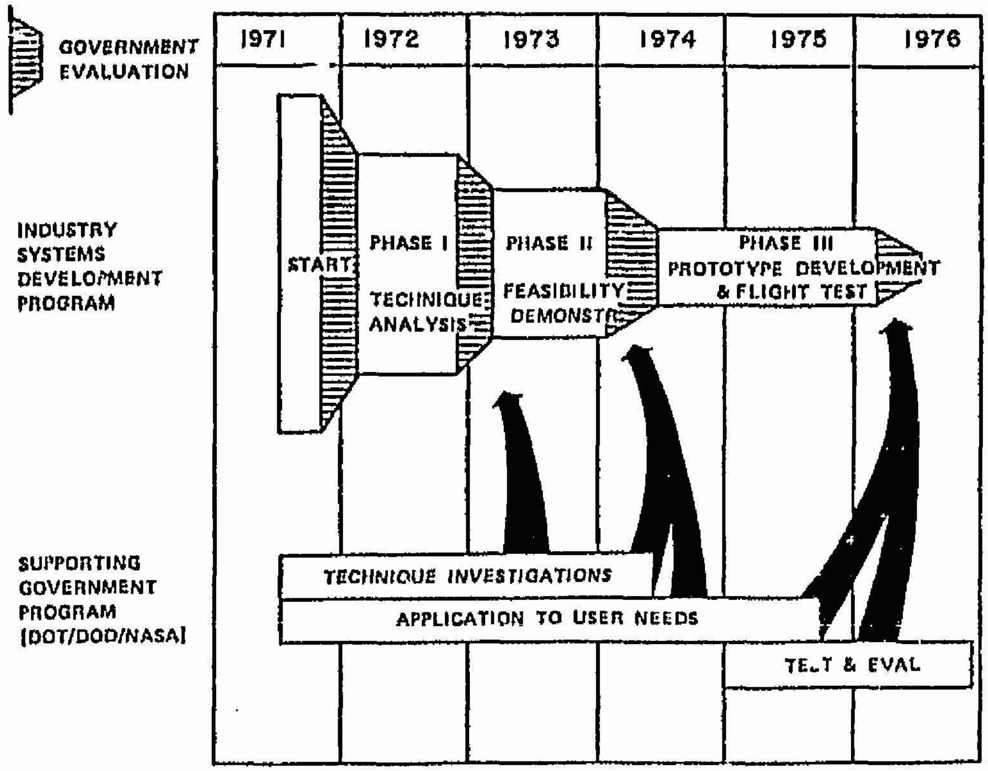


Figure 5. National Plan for Developing the Microwave Landing System.

flow control. These objectives are: improve management of air traffic flow through the ATC system to reduce costs of airborne delays; increase productivity of ATC controllers to stabilize or reduce the numbers of required personnel; maintain or improve the current level of safety for controlled aircraft; increase airport capacity; provide the automation hardware, software, and control procedures needed to operate with other features of the UG3RD; and improve automation system reliability.

Many improvements will be provided by additions or modifications to the existing NAS and ARTS computer programs. A few of the basic additions which will assist in the transition to automatic air traffic management are: flight profile generation; sector clearance planning; flight progress monitoring; automatic clearance delivery timing; improved aircraft tracking (radar and beacon); metering and spacing; and conflict prediction and solution. Some longer term automation functions will rely heavily on the availability of an automatic data link for the exchange of ATC messages with airborne aircraft. The system is planned to move from a labor-intensive to a machine-intensive base, with the air traffic controller ultimately becoming a system manager.

Implementation of several elements of the increased automation is already well underway, while other aspects are inseparably linked to other features of the UG3RD. The conflict alert system, discussed in Subsection 2.2.2.1, has been operational above 12,500 feet for several months, but has a problem with numerous false alarms. A minimum safe altitude warning feature is being implemented at the ARTS facilities. Despite significant research, all metering and spacing systems tested to date have been unacceptable. In general, increased ATC automation will not involve additional avionics beyond those required by the other UG3RD features (DABS, RNAV, IPC, etc.).

2.2.6 AIRPORT SURFACE TRAFFIC CONTROL (ASTC)

Growing traffic loads, increased all-weather operations, and new airport construction which blocks the visibility of airport facilities from many control towers result in new requirements for handling traffic on the airport surfaces. Three needs have been identified:

- Improved surveillance of the airport surface
- Guidance information for aircraft, and
- Improved control of the airport situation.

To improve surveillance, the current airport surface detection equipment (ASDE) is being modified, and new ground surveillance radars are being developed with the goal of achieving automatic tracking of aircraft and surface vehicles from enhanced radar presentations. The use of discrete sensors such as magnetic loops placed in runway and taxiway surfaces has been analyzed, and completely automated and integrated control systems using hundreds of intersections have been considered.

A major research effort is being devoted to a beacon trilateration system, using ATCRBS at first and eventually DABS, for surveillance of the airport surface (Reference 94). This TAGS (Tower Automated Ground Surveillance) technique will involve additions and modifications to the ground-based beacon system, but fortunately will not require additional avionics aboard the aircraft. Experimental equipment using two phased array antennas has been built by Bendix and recently demonstrated the feasibility of the concept at NAFEC (Reference 82). An implementation decision on this system is not expected for at least two years.

2.2.7 WAKE VORTEX AVOIDANCE SYSTEM (WVAS)

Trailing wake vortices, especially from large aircraft on approach and landing, present hazards to aircraft following too closely behind. This is particularly true for general aviation aircraft. Increased longitudinal separations (up to four and five miles behind "heavy" aircraft) provide safety, but significantly reduce airport capacity and introduce delays.

Beyond efforts to minimize the size and effects of these vortices by aerodynamic means, the FAA is working on ground-based systems to detect and avoid these vortices. It has now been demonstrated that pulsed and Doppler radar-like devices operating at acoustical frequencies can detect and track these wake vortices, and development and test of these devices continues on an expedited basis. Given improved knowledge of the movement and effect of vortices on aircraft, such a sensor might be the central factor in a system which would detect the presence of vortices, predict their behavior and intensity, and present this information in a suitable fashion to ground controllers who can appropriately adjust aircraft spacings. On a longer term basis, it is planned to couple this system directly into automatic metering and spacing programs. It is possible that the DABS data link could be used to issue wake vortex warning advisories on final approach.

Wake vortex data collection efforts have been conducted at Heathrow, Stapleton, and Kennedy airports, and an experimental Meteorological Vortex Advisory System has been installed at O'Hare for testing. However, no advanced implementation plans for WVAS have been released.

Because severe wind shear was a contributing factor in some recent accidents, a program to develop a detection method is receiving priority attention from the FAA. Wind shear pressure sensors to predict the approach of thunderstorms are being evaluated at O'Hare, and wind shear equipment is to be installed at Dulles this summer. Research efforts at Stanford Research Institute and elsewhere are aimed at developing airborne equipment to detect severe wind shears.

2.2.8 FLIGHT SERVICE STATIONS (FSS)

The FAA currently operates a network of some 400 Flight Service Stations (FSS) at which general aviation pilots (the primary users) may obtain face-to-face or telephone weather briefings from FSS personnel and file their flight plans. This network of stations is technologically and functionally the same as it was in the 1940's; most facilities and equipment are deteriorating and obsolete, and the system is labor-intensive and unable to meet the present demands for flight services.

A new automated Flight Service Station concept, developed by a joint study team of FAA and the Department of Transportation, proposed three basic elements (Figure 6):

- A central processing facility
- 30 to 50 full-time, manned hub stations
- A nationwide total of some 3,500 unmanned, pilot-self-service terminals at approximately 2,500 locations.

When this network is completed, virtually all pilot requests for preflight service (i.e., weather briefings and flight-plan-filing) should be fulfilled through unattended, automated terminals (Reference 34). A touchtone telephone system data link or the DABS data link might be used to access automated services. However, there will probably still be voice response to airborne requests far into the foreseeable future

A demonstration AWANS (Aviation Weather and Notam System) is in operation at Atlanta and will be installed at Leesburg, Virginia. This system uses a computer, keyboard and display scopes to improve the efficiency of the FSS weather briefer. The next stage is the development of the Baseline system which will permit the user to bypass the briefer for weather information or to file a flight plan. Specifications are expected to be issued before the end of 1976; the first system will be installed at NAFEC in mid-1979; and the first operational system is scheduled for implementation by mid-1980.

2.2.9 AERONAUTICAL SATELLITE (AEROSAT)

Oceanic air traffic control and air carrier communications are presently conducted over high-frequency radio circuits which are of relatively low reliability and approaching saturation in the North Atlantic and eastern Pacific. Surveillance of the oceanic airspace is non-existent; separation and control are based on pilots' reports

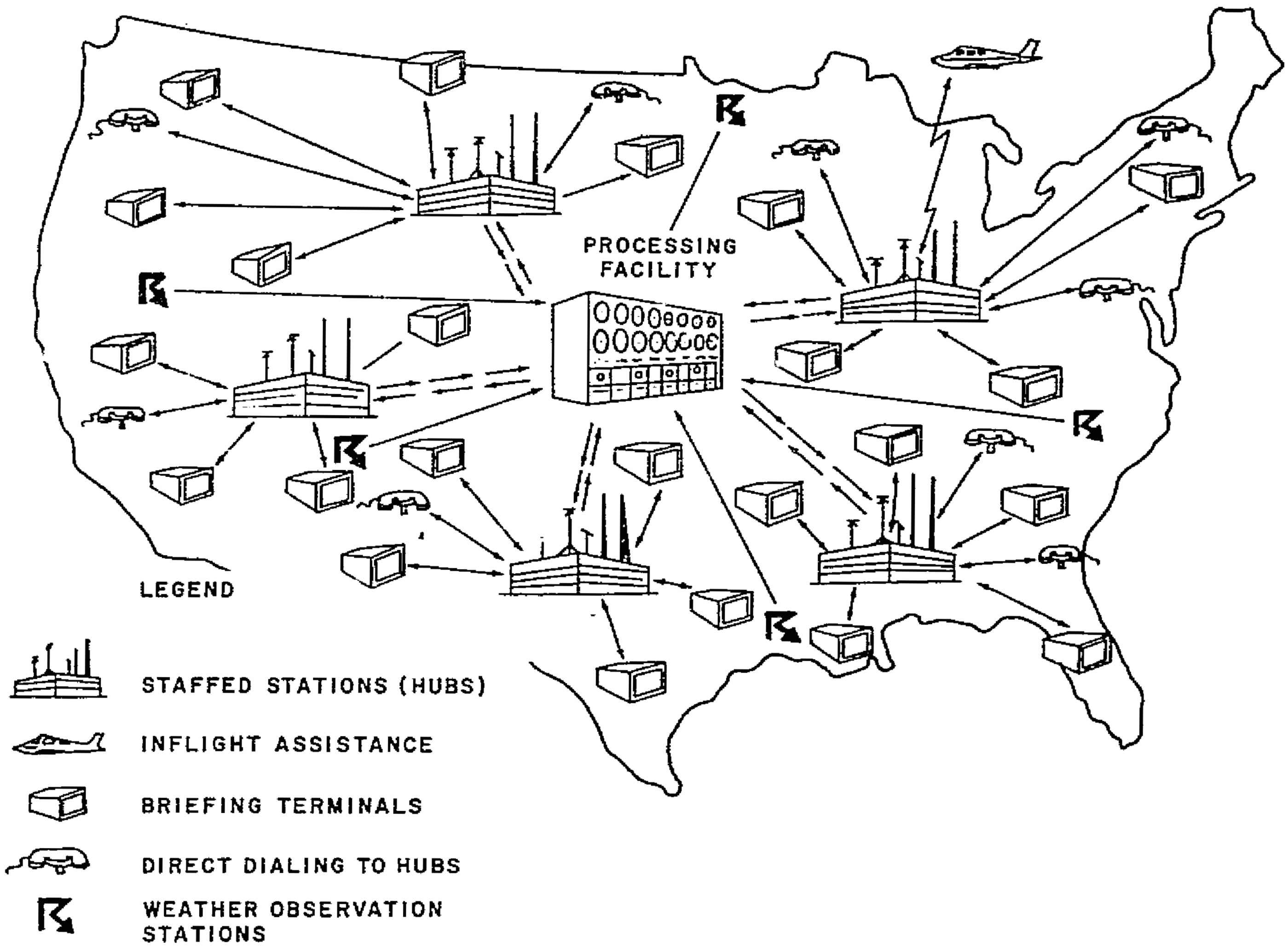


Figure 6. Schematic Conception of Future FSS Network.

of their aircraft positions as determined from on-board navigation equipment. Improved communications and surveillance will be required to handle the reduced aircraft separations necessary with traffic loads forecast for the 1980's; the alternative will be lengthy ground delays or the use by some aircraft of less advantageous flight tracks. Since these over-ocean flights tend to originate at the major hub airports, such ground delays would also contribute to surface congestion to some degree.

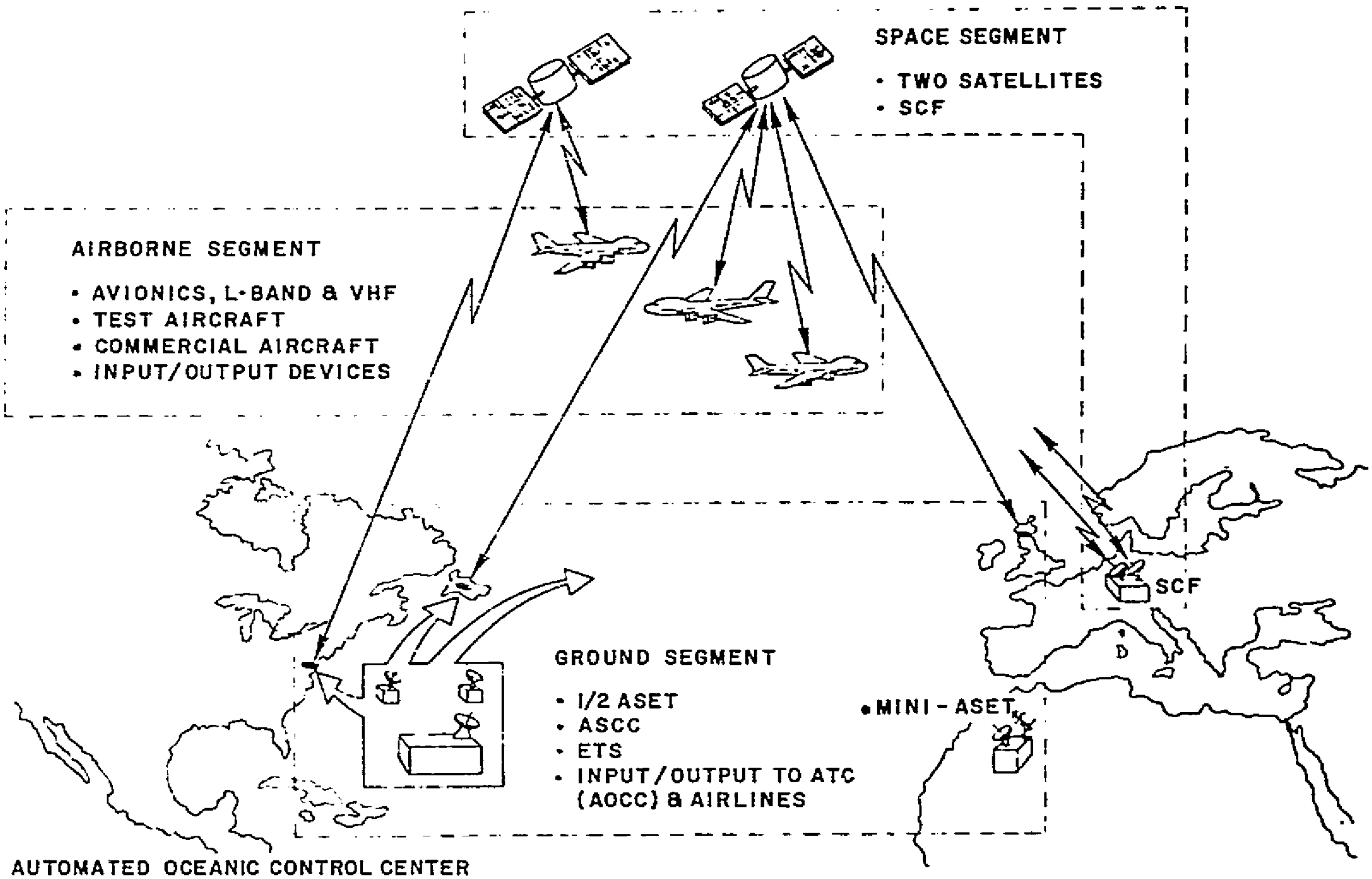
The Aerosat program is exploring the utility of satellites for expanding the availability of or improving oceanic communications, and providing complete surveillance to reduce oceanic separation standards. The program is jointly sponsored in a formal agreement with Canada, the European Space Agency (ESA), and the United States. The objective is to establish the design of a future operational system and international agreement on standard operating procedures to be followed in its use. The present configuration is illustrated in Figure 7.

The Aerosat Council (U.S., Canada, ESA) has agreed to launch two satellites for test and evaluation of satellite communications for oceanic ATC. The first launch is expected in late 1979, with a second to follow a few months later. Equipment decisions for any operational system are still uncertain and a long time away. Aerosat will probably not have a major impact on general aviation because it applies primarily to over-ocean flights.

2.3 ADDITIONAL POTENTIAL FEATURES BEYOND THE UG3RD

2.3.1 GROUND PROXIMITY WARNING SYSTEM (GPWS)

Federal air regulations require a GPWS on all turbine powered air carrier aircraft after September 1976. The system is required to operate in four different modes: 1) excessive rates of descent; 2) excessive closure rate close to the terrain; 3) negative climb rate after takeoff or missed approach; and 4) flight into terrain when the aircraft



LEGEND

AOCC	AUTOMATED OCEANIC CONTROL CENTER
ASCC	AERONAUTICAL SATELLITE COMMUNICATIONS CENTER
1/2 ASET	ONE HALF OF AN AERONAUTICAL SERVICES EARTH TERMINAL
ATC	AIR TRAFFIC CONTROL
ETS	ELECTRONIC TEST SET
MINI-ASET	SMALL, REMOTE EARTH TERMINAL FOR L-BAND & VHF ACCESSING
SCF	SATELLITE CONTROL FACILITY

Figure 7. Aerosat Configuration.

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is not in the landing configuration. A fifth mode, expected to be required in the future, warns if the aircraft is below safe limits during an ILS approach. In this mode an advisory alert is sounded when the aircraft is slightly below the center of the glide-path beam, and a pull up warning is announced if the aircraft descends significantly below the glidepath, especially if the aircraft should near terrain clearance of approximately 150 feet. The GPWS provides the pilot with both aural and visual warnings in all modes.

The FAA requirement for GPWS will probably be expanded to include larger general aviation aircraft and eventually might become a general requirement for all aircraft operated under IFR. Other governments are making the ground proximity warning system mandatory in foreign transport aircraft. Although there are few objections to the concept of a ground proximity warning system, the early implementation of these systems has resulted in a number of false alarms which, unfortunately, have reduced pilot confidence in the equipment. Clearly, some warning of ground proximity is desirable for all instrument-qualified aircraft. The main constraint against implementation of such equipment in all IFR general aviation aircraft is the cost. A radar altimeter would be desirable in aircraft which conduct low approaches in instrument weather. Ground proximity warning would also be valuable for any night operations conducted at low altitude.

Related to the GPWS is the FAA's terrain warning program in which the current NAS and ARTS computers are being modified to alert controllers whenever an IFR aircraft descends below a minimum safe altitude. However, the warning is only available to those aircraft operating in radar contact under IFR control. Moreover, radar surveillance provides altitude of equipped aircraft only to the nearest 100-foot increment, and the reporting function could be in error even more than this value. Although this technique will provide some assurance to the general aviation pilot making an instrument approach at a major terminal, it cannot help VFR pilots at night nor pilots making instrument approaches to remote airports beyond surveillance or communication limits.

2.3.2 AIRBORNE TRAFFIC SITUATION DISPLAY

A somewhat controversial issue not currently part of the UG3RD program involves the airborne traffic situation display (ATSD), which enables the air crew to participate actively in traffic management. Proponents of the concept maintain that VFR capacity levels are achievable under IFR conditions by introducing the ATSD. Opponents argue that an aircraft cannot safely and efficiently determine what it should do without reference to the intentions and locations of many other aircraft, and to distribute such information is technically difficult and expensive.

For several years MIT has experimented with a cockpit simulation of the ATSD, and the results of that research have been universally favorable. The display itself is a cathode-ray tube which shows the navigation routes, the surrounding traffic, obstructions, terrain, weather features, and ATC directives. It permits the pilot to maintain his own separation on other aircraft and allows him to verify the reasonableness of ATC directives. In the present system, the traffic information available to the pilot is obtained visually, or relayed via the air traffic controller on the ground. The MIT research shows that the traffic situation display is an extremely effective way of transferring complete traffic and other information to the pilot. In high density terminal areas, the information could be used to provide spacing; some metering would probably be pilot assisted. The ATSD would certainly be used for separation assurance or collision avoidance, and might also be used to display air traffic control clearances, weather conditions, NOTAMs, runway conditions, etc.

The impact of ATSD on general aviation is that many users will want the equipment if it can be provided at a reasonable cost. Early estimates of the cost of a general aviation airborne traffic situation display are on the order of $1,000 to $2,000. A major consideration for general aviation is whether or not to present heading information. The MIT simulation results have shown the pilots prefer to have the display indicate heading up, but this requires that aircraft headings be made available to the display. Unfortunately, general aviation aircraft at the lower end of the spectrum usually do not have heading information available in a useful form. A gyro heading reference with an electrical readout, slaved to the magnetic sensor would cost around $1,000.

Another somewhat radical possibility afforded by ATSD is for uncontrolled IFR operations. By giving an aircraft the ability to see other traffic independent of the ground controller (such as with BCAS and ATSD), it would be reasonable to permit an equipped aircraft to fly in instrument conditions without being under the control of the ATC system. This would give general aviation considerable freedom to fly in poor weather essentially in the same mode that they currently operate under VFR flight rules. Although this concept is probably not feasible within high density areas, it would be a major improvement for general aviation in vicinities where flights now are often increased by 50 percent because of segregated airspace like the New York City area. For example, on an IFR flight from Boston to Atlantic City, the approved route is either via Scranton, Pennsylvania, to avoid the New York Metroplex, or alternatively over water, which is an uncomfortable operation for single engine aircraft. Although it would not be feasible for an aircraft with its own traffic viewing capability to proceed directly through the New York Metroplex, it would be very reasonable to proceed a few miles to the west of New York, for example. This is particularly true if a low altitude were maintained, which at the present time would be below the coverage area of the ATC surveillance system.

2.3.3 NAVSTAR GLOBAL POSITIONING SYSTEM (GPS)

GPS is the Department of Defense's anticipated replacement for Navy's TRANSIT navigation satellite system (References 40, 91, 106). Phase 1 of the NAVSTAR program will provide for the launch of six satellites into 12 hour, circular, high inclination orbits by August 1977. The satellites will be so spaced that they will provide up to 5-1/2 hours of test time periodically each day for receivers located in the Continental United States and the coastal ocean areas. Control stations located in the U.S. will update the atomic clocks and provide ephemeris data to the satellites.

During this first phase of the program, several types of user equipments will be developed to meet the spectrum of future needs by the military services. A decision to proceed with the full scale development of the system worldwide will be based on the demonstrated achievement of two goals: high positioning accuracy and moderate cost of the system. The user must be able to position himself quickly to an accuracy of approximately 10 meters (2σ) in three dimensions, and the user's equipment should be comparably priced or less expensive than the other less accurate military navigation systems available today. Present unit cost projections for user sets range from under $10,000 to $40,000 for the most elaborate NAVSTAR equipment. The decision date to determine if the system will proceed beyond Phase 1 of the program has been scheduled for the spring of 1978.

The first satellite, NTS-1 containing the prototype rubidium clocks and a transmitter with the NAVSTAR frequency and type of signal code, was launched in 1974 and had limited experimental success before developing a stabilization problem. A second satellite, NTS-2, is under development and is scheduled for launch in late 1976. It will contain two cesium clocks and will be the first satellite launched as part of the six satellite demonstration constellation. In early 1977, the first of five commercially built satellites will be launched. The fifth commercial satellite should be in orbit by August 1977 and will bring the constellation to the required total of six.

If the decision is made to deploy NAVSTAR as a worldwide system, then a second generation of satellites will be developed. The clocks on the second generation satellites will be based on the demonstrated performance of the NTS-2 cesium clock standards developed by the Navy and tested in Phase 1, which should reduce the frequency of updating required by ground stations to once per day per satellite for a worldwide system. The second generation will have an ability to secure telemetry and data channels and may be powered by radioisotope thermal electric power sources. Another difference will be in the satellite life expectancy. While the Phase 1 satellites are being built with a design life expectancy of four years, the Phase 2 satellites should have nearly double that longevity.

Once the decision is made to proceed with the system development in Phase 2, the satellites will be built and launched to expedite a two dimensional, worldwide capability (assuming program approval in early 1978) in 1981. As more satellites are added, the two dimensional system will have increasing periods where three dimensional capability is available. These periods will gradually be extended until a continuous, 3-D availability is achieved by 1984.

The user sets consist of an antenna, receiver, data processor and control/display. There are three basic receiver configurations for the NAVSTAR development and concept validation phase. The first configuration (model X) receives signals from four satellites simultaneously, which requires four channels in the receiver and the largest data processing capability. It would be used in a highly dynamic platform or where minimum fix time is essential. The second configuration (model Y) would have one or two channels, time sharing them among the four satellite signals required. The

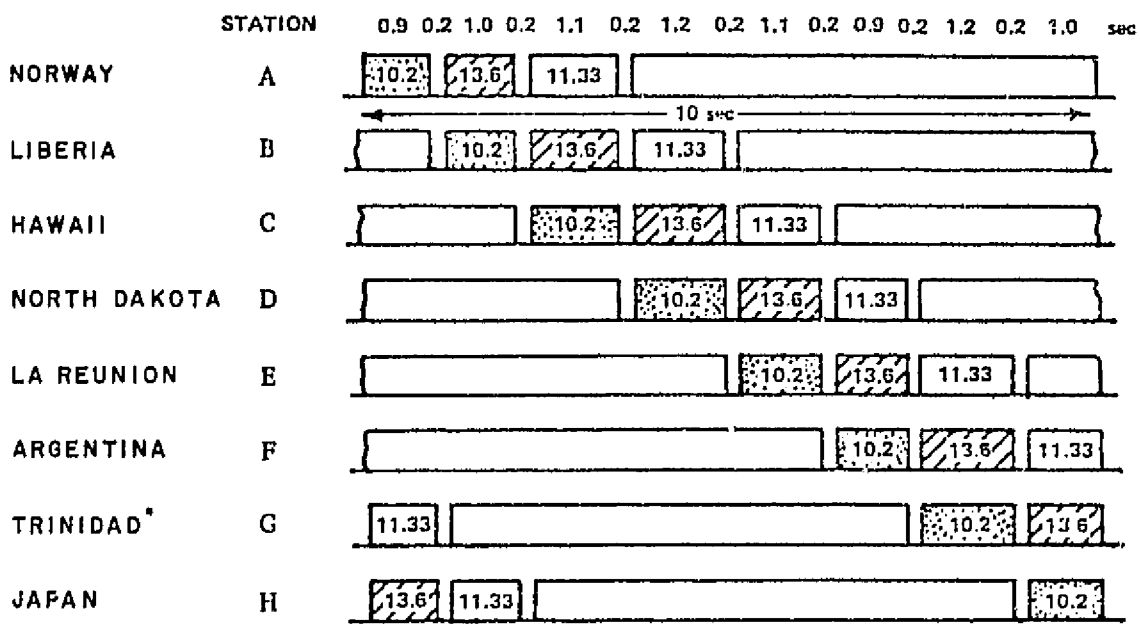
Y class should be less complex and expensive with a corresponding reduction in dynamic capabilities, but not in precise position determination. The third configuration (model Z) will be further reduced in complexity, cost, capability and accuracy from the Y class. Though the simplest, it may be the first in production if the program is approved. If it meets specs, its accuracy will be better than provided today by an existing externally referenced system. From these three development configurations, the production classes of user sets will be derived. Currently, seven classes of equipment are seen as variants of the three development models.

2.3.4 DIGITAL DATA BROADCAST SYSTEM (DDBS)

The Digital Data Broadcast System (Reference 25) is a concept to provide the airborne RNAV system with the information required to satisfactorily navigate both preplanned direct RNAV routes and whatever charted routes will be retained as an integral part of the ultimate area navigation environment. This data would be broadcast in repeating data streams for specified station or route coverage. The acquisition process would be initiated by simply tuning the desired VORTAC station frequency. The predesignated waypoints would then be selected out or the data stream, verified and stored in an airborne digital decoder or interface unit. In the case of the terminal area, the waypoints will be automatically sequenced for the pre-selected SID or STAR. Enroute, the waypoint spacing would require frequency switching to another enroute facility prior to acquisition of the next route waypoint. Of course, even with the availability of broadcast data, the RNAV functions of preflight route selection and planning, waypoint location and definition, and ground station selection would still be required. The main advantage of having the data broadcast would be the decrease in pilot workload required to identify a waypoint and successfully input this data into a computer during the times of intense cockpit activity. The system as planned would establish a standard system of RNAV waypoints, based on bearing and distance from each VORTAC. Unfortunately, this concept would marry the RNAV route structure to the existing VORTAC ground system, rather than providing for a flixible waypoint definition based on general latitude and longitude coordinates.

2.3.5 OMEGA/VLF NAVIGATION

Omega is a very low frequency (VLF) hyperbolic navigation system designed for worldwide navigation coverage with eight ground stations, transmitting on frequencies of 10.2, 11.33, and 13.6 kHz alternately. At the present time the continental United States has complete Omega coverage. Signals are being transmitted on all eight transmission segments (Figure 8). Seven of these are from the permanent full power (10 kw) stations. The G segment is being used by Trinidad at 1 kw awaiting commissioning of the Australian station. Omega is extremely significant to general aviation because it has the potential for providing remote area and worldwide area navigation coverate at extremely low cost.



* Trinidad will ultimately be replaced by Australia.

Figure 8. Omega Navigation Signal Format.

The transmitted signals are sinusoidal with tight phase tolerances maintained by quadruple cesium standards. The only modulation is the turn on and turn off of the transmitter. The signals travel in the waveguide formed by the earth's surface and the ionosphere. As the height of the ionosphere varies diurnally, the effective speed of propagation varies, and so does the phase of the signal at the receiver. Propagation variations are a function of specific path, time of day, and time of year. Sky-wave correction models which can reduce the positioning error to less than one nm can be applied automatically using a small computer at the receiver.

Distances are derived from differential phase measurements, which have an ambiguity of one cycle. Thus, when obtaining a position fix with the 10.2 kHz signals, the position estimate will be accurate to one or two miles, but with an ambiguity of approximately 8, 16, 24,... nautical miles. For most applications, many measurements will be taken before the vehicle has traveled eight miles, and the receiver will not lose track of the number of eight mile lanes it has crossed. Receivers utilizing all three frequencies observe ambiguities spaced approximately 72 miles apart.

Differential Omega is a proposed technique for further reducing the magnitude of Omega propagation errors. Ground stations at known geographic locations would measure the Omega propagation error and broadcast a current correction to local aircraft, in the same manner as local barometric pressure is provided for altimeter corrections. The error due to propagation variation would be reduced to the difference in the error at the aircraft and at the reporting station, which is on the order of a half mile at a distance of 200 miles. This correction could improve the absolute Omega accuracy from about 10,000 feet to approximately 1,000 feet.

In addition to the Omega navigation transmitters, several U.S. Navy communications stations broadcast VLF signals with phase stability suitable for navigation.

These signals are ten to 100 times as powerful as the Omega transmissions and have a 100 percent duty cycle. Global and Ontrack VLF receivers are now operational using both Omega and communication station signals simultaneously. Equipment cost is about $25K.

2.3.6 LORAN-C

Loran-C is a hyperbolic navigation system which operates in the 90-110 kHz frequency band. It can achieve position accuracy better than 100 feet by using phase information in addition to timing pulses, and is therefore very attractive for area navigation. Each pulse is designed to build up and decay slowly to keep 99 percent of the radiated energy within the assigned frequency band. Skywave contamination becomes significant about 30 μsec after the beginning of the pulse so only the first three cycles are generally used for navigation. The receiver must have a very high effective selectivity because the first three cycles may be contaminated by atmospheric noise and other interference. Selectivity is obtained by tracking the received signal with a servo loop that has a long characteristic response time. For use in aircraft the receiver must have velocity information to keep the servo loop locked onto the signal.

Modern Loran-C receivers using integrated circuits feature automatic search, weigh about 25 pounds, and use about 200 watts of power. Readout from the receiver itself is in time differences, requiring the navigator to transfer these to the corresponding hyperbolic lines on a chart. Digital computers are available which (at the price of doubling the size, weight, and cost) provide readout in latitude and longitude, together with left-right steering information and distance along track. Existing airborne Loran-C receivers are mostly military designs and are to expensive for general aviation. Although several low cost Loran-C receivers have been developed for marine use, they do not allow for the introduction of way[illegible] [illegible] transformation of hyperbolic position information into cruise and deviation [illegible] to go.

Atmospheric noise at the receiver is the major source of error in the Loran-C system. The accuracy depends on the signal-to-noise ratio which varies widely with range, and on the response time of the servo tracking loop. For averaging times of 100 seconds at medium range, an error of 300 feet (1σ) is typical. The instantaneous accuracy could change by a factor of three in either direction depending upon actual range. Loran-C is not limited by line of sight, and the high accuracy makes it particularly attractive for the 1980 period.

About 20 Loran-C stations are required to provide full U.S. coverage. Relative to VOR DME, the system cost per square mile of coverage is an order of magnitude less and the average accuracy is an order of magnitude better. On the other hand, the system cost of Omega is about one tenth that of Loran-C, but the accuracy is ten times lower. However, a modified form of Differential Omega could be obtained by development of a hybrid Loran-C/Omega receiver. The cost of the hybrid receiver would probably not exceed the cost of a single receiver by more than 25 percent since both systems use common components except for the receiver front end. The advantages would be improved accuracy and improved reliability over that available by either component system alone. Loran-C would provide the differential update for Omega, while Omega would guarantee coverage over oceans or wherever there were coverage gaps or outages of the Loran-C.

2.3.7 INTEGRATED COCKPIT

The integrated cockpit is a concept to reduce the proliferation of individual instruments, radios, and other subsystems that have grown in the general aviation cockpit. Each of the individual instruments has a common need for data processing and display, which can be provided with current technology in an integrated manner such that the user receives more benefits for an equivalent cost. Once the cockpit contains a CRT-type display and some computing capability, separate systems can be economically combined. The integrated cockpit should be modular because the typical general aviation user starts at the lower end of the avionics spectrum and progresses up as he can afford it. At the lower end of the spectrum, the integrated cockpit would have the capability of providing the information associated with the basic flight instruments, engine instruments, and navigational equipment. At the high end of the spectrum it might also include the information associated with RNAV, precision approach, weather radar, ground proximity warning, traffic situation, collision avoidance data link, and engine analyses. The particular information displayed would be selected at the pilot's option. Dual CRT's would provide operational reliability through redundancy.

Current GA avionic systems consist primarily of independent electro-mechanical boxes for various functions. Each function is handled by the combination of a sensor, pilot control, data processing and a display and/or actuator. Integration of these functions using advanced avionics can be accomplished with a common data processor, common pilot control and common display. Individual sensors and actuators would still be required. However, they can be redesigned to give a better interface with the digital data processors, probably with advantages in cost and reliability.

In most current avionics installations, individual wires connect each of the sensors, actuators and pilot controls with their associated data processors and display. To minimize the wiring many of the electro-mechanical devices are housed behind the instrument panel close to the pilot control and display area. This location is crowded, and access is difficult for maintenance. A common display and control unit could free much of the space on the front of the instrument panel, while a common data bus could eliminate much of the conventional wiring behind the panel. Further, the data processing functions could be shared and located in areas which are more easily accessible for maintenance. An all digital, integrated cockpit would create a complete departure from the "separate box for each function" approach. During the 1980's, hardware for computing functions will become relatively inexpensive. With sensors, actuators, displays and controls already integrated, the incremental cost of providing new functions will be minimal. The major risk is the danger of common mode failures. The design must make provisions for such effects as loss of the prime electrical power source, failure of the common indicator, shorting of the data bus, or malfunction of the common pilot control. An emergency dropout generator on a separate power bus can provide backup protection against the loss of primary electrical power. Dual indicators and pilot control panels, one for the pilot and one for the co-pilot with cross-feed capability provides protection against a single failure of either. The data bus can be triplicated for redundancy with electrical isolation between buses.

To simplify pilot input/output, a substantial portion of the congested array of unipurpose indicators, switches, and knobs on the present instrument panel could be replaced with a single multipurpose alphanumeric keyboard-display unit. With a simple, but powerful, keyboard language, the pilot could set frequencies, store RNAV waypoint coordinates, select operating modes for individual subsystems, and perform many other control and information management functions which today require separate I/O devices.

Another improvement could be to integrate several conventional flight instruments whose functions overlap into two multipurpose electronic displays, i.e., an EADI and an EHSI/ATSD combination. Many panel indicators, whose sole purpose is to indicate the status of some aircraft system (engine, electrical, hydraulic, etc.) could be eliminated. Today's pilot must monitor these indicators constantly to detect abnormal conditions, whereas in the advanced system, the central processor will assume this function, and only advise the pilot when an abnormal condition exists. To further reduce pilot workload the more sophisticated avionics system would provide bulk data storage easily accessed via the keyboard-display unit for enroute navigation, navaid frequencies, STARs, SIDs, etc.

2.4 GA AVIONICS GROWTH PROJECTIONS

The future demand for various avionic equipment has been projected in Figure 9. These plots show the expected total number of equipments installed in general aviation aircraft as a function of time. The projections are based on forecast growth in the GA fleet and anticipated changes in percentage of the fleet that will install each equipment. The growth in VHF #1 and #2 communications transceivers, ELT, ADF, #1 and #2 VOR/ILS LOC receivers and marker beacon is basically due to the growth in the size of the fleet. The ILS glide slope receiver percentage will reduce only slightly late in the period as MLS is introduced. DME is expected to show a percentage increase in the near 80's but will decrease later in the 1980's as use of Loran-C becomes more common. VHF RNAV will show only modest growth. By the time that the majority of general aviation moves toward RNAV, more common use of Loran-C and VLF is anticipated. This is reflected in their growth in the late 1980's. MLS will make only modest inroads on the ILS market until the late 1980's. Autopilot installations are expected to increase in both percentage and total numbers. The number of ATCRBS transponders will grow until the mid-1980's and then level off as DABS becomes operational early in the 1980's. The altitude encoder will continue to grow in use since it is used with either transponder and will be a requirement for flight in almost all the airspace. Weather radar, radar altimeter and GPWS will increase considerably in percentage, but the fraction of the total fleet will remain relatively small.

Figure 9. Projected Growth of Various Avionics Equipments.

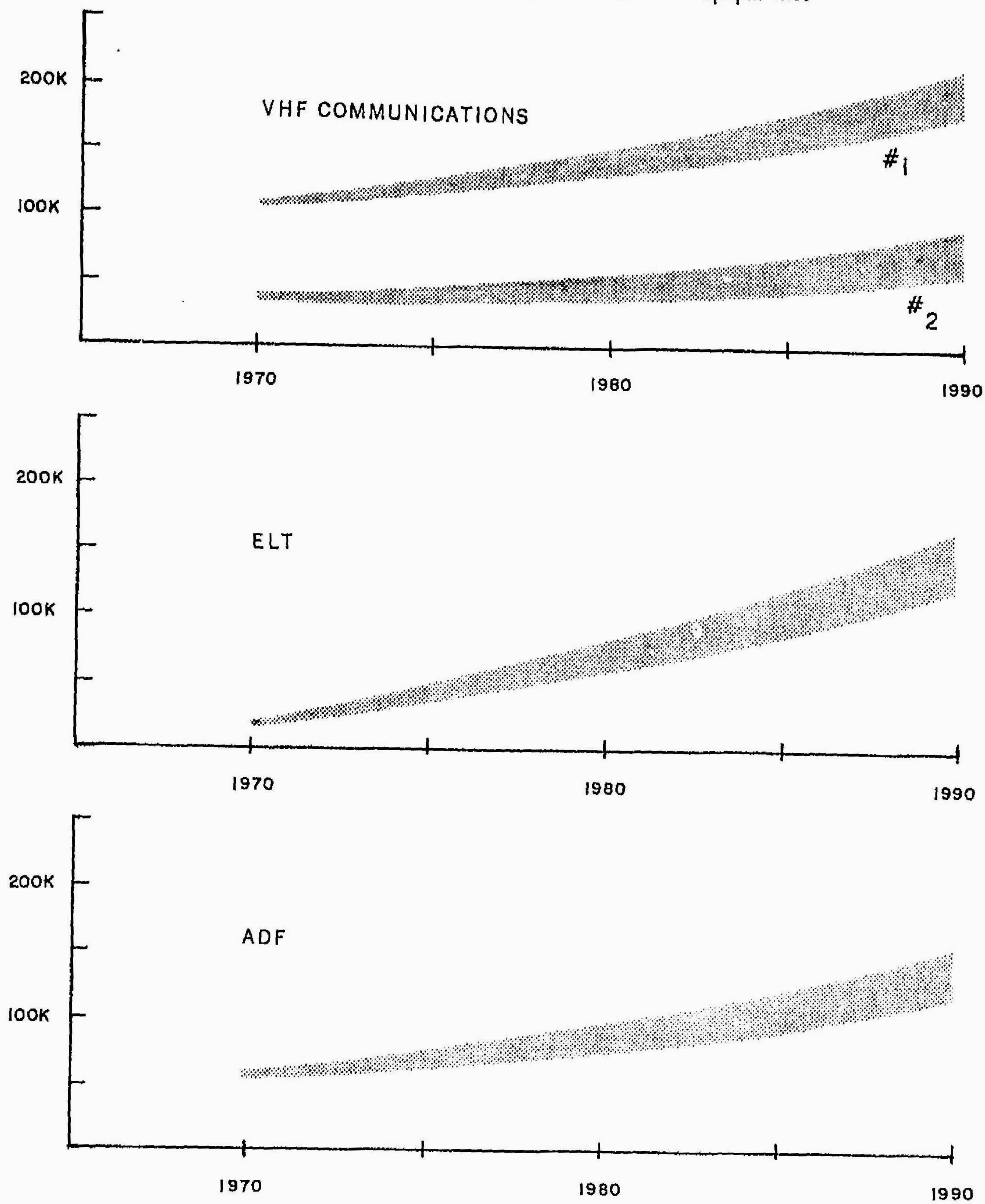


Figure 9. Projected Growth of Various Avionics Equipments (Continued).

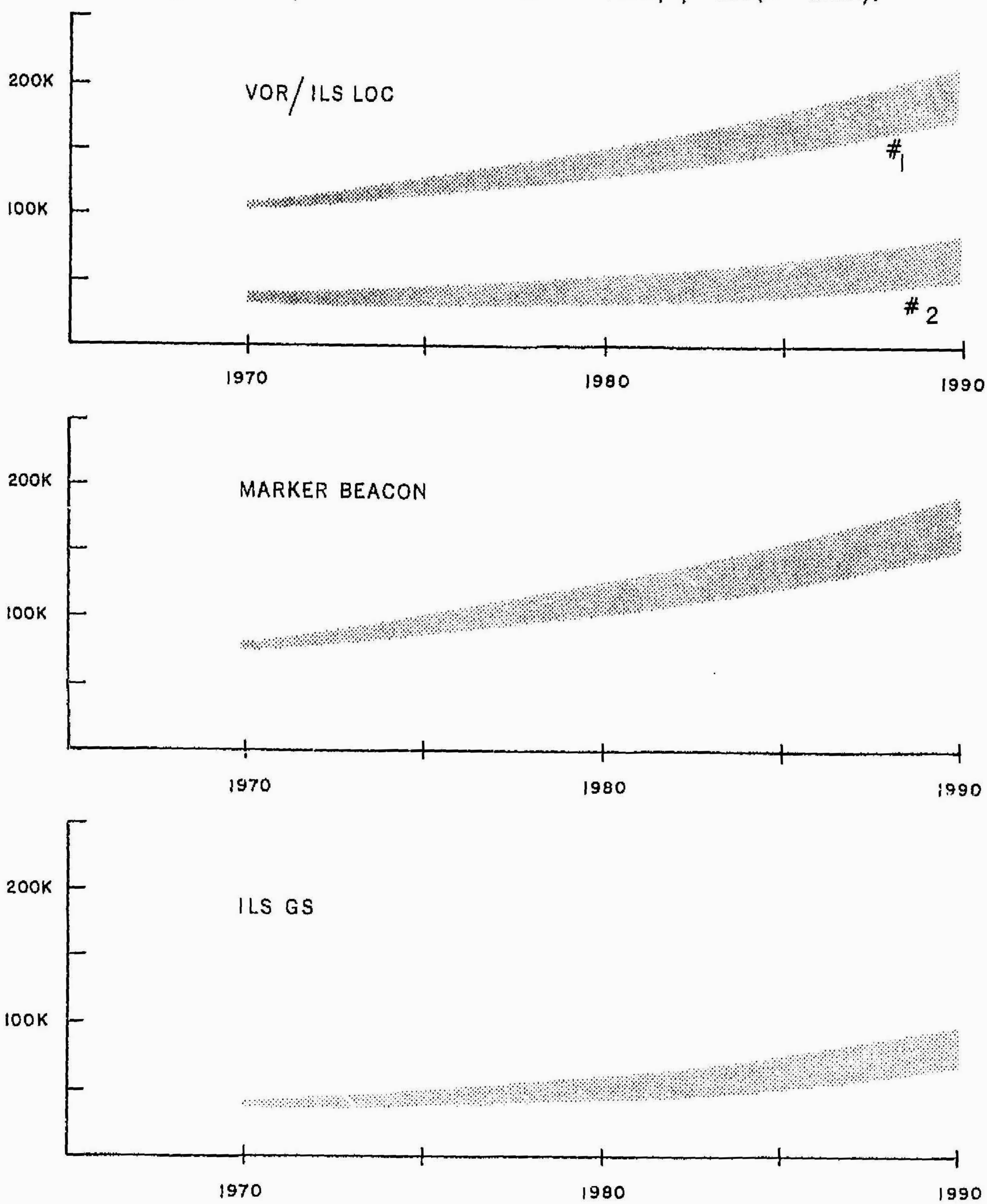


Figure 9. Projected Growth of Various Avionics Equipments (Continued).

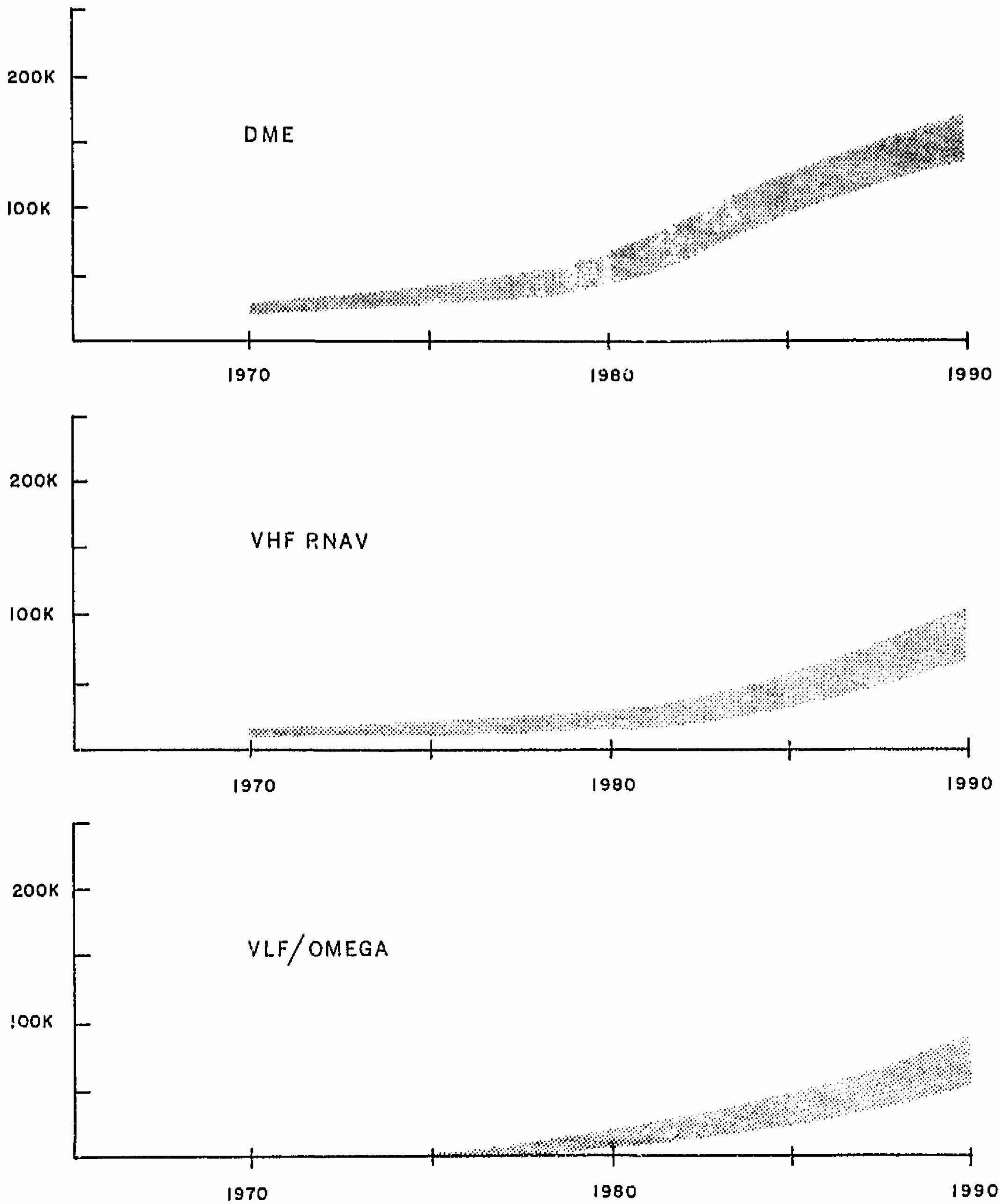


Figure 9. Projected Growth of Various Avionics Equipments (Continued).

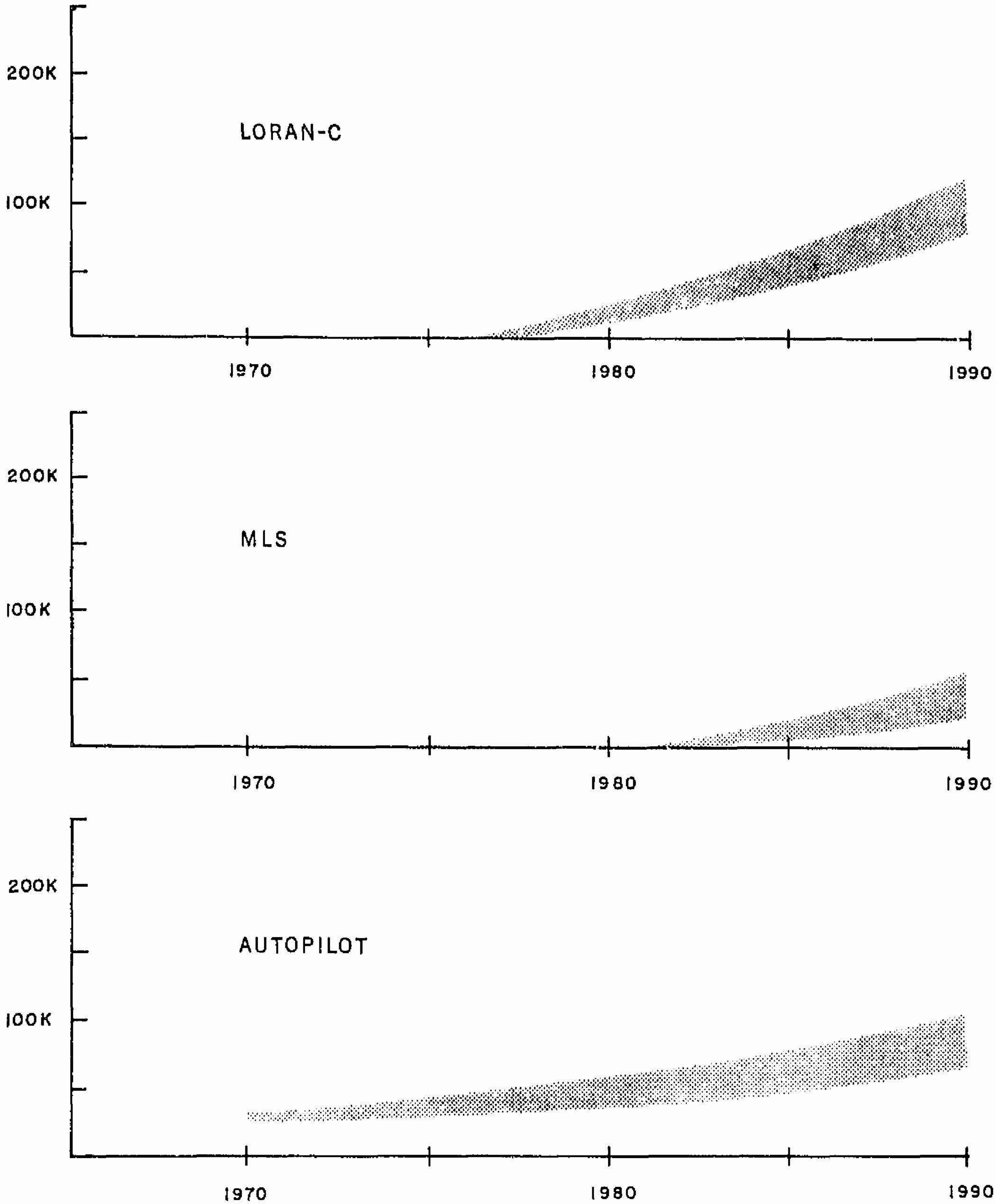


Figure 9. Projected Growth of Various Avionics Equipments (Continued).

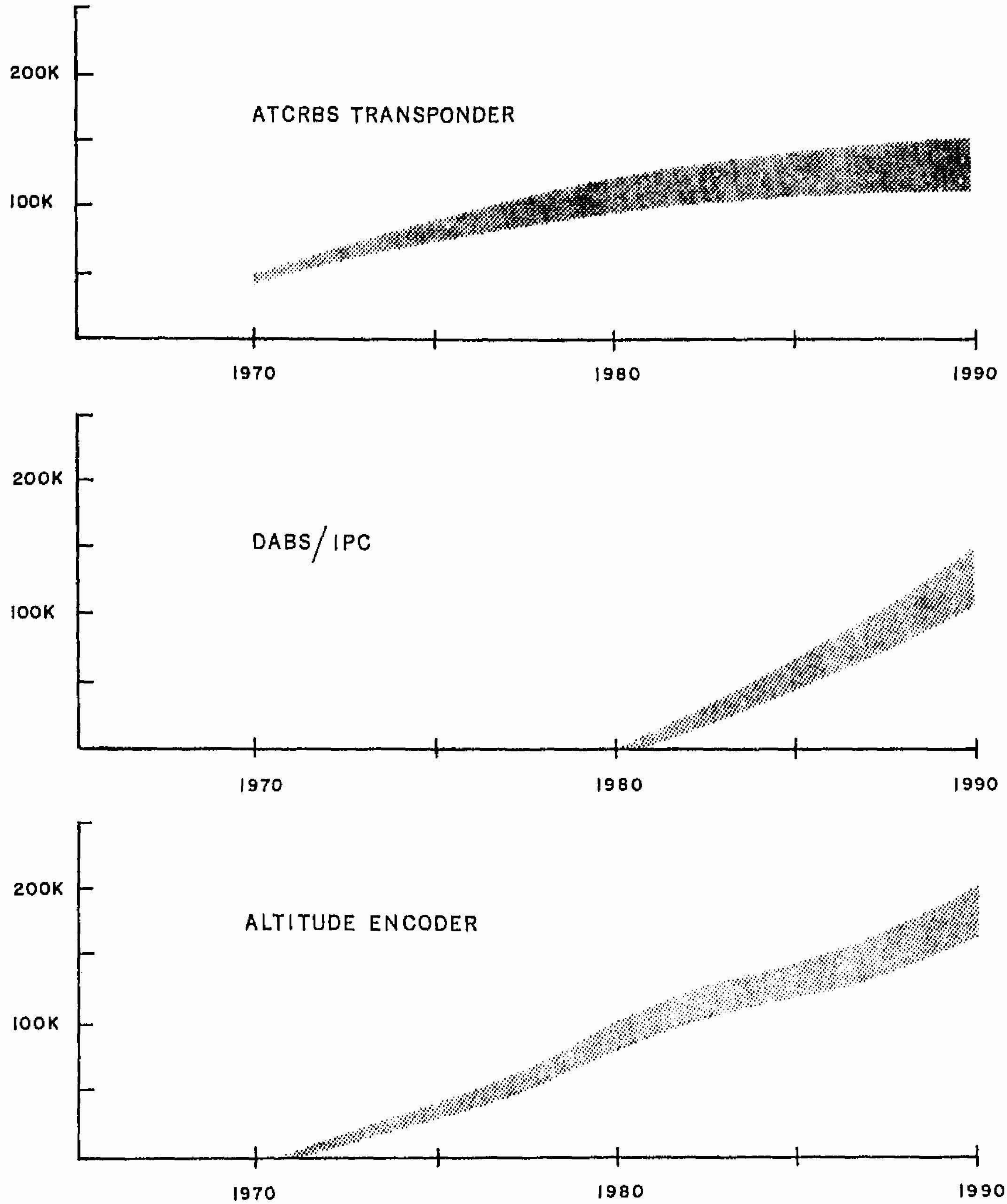
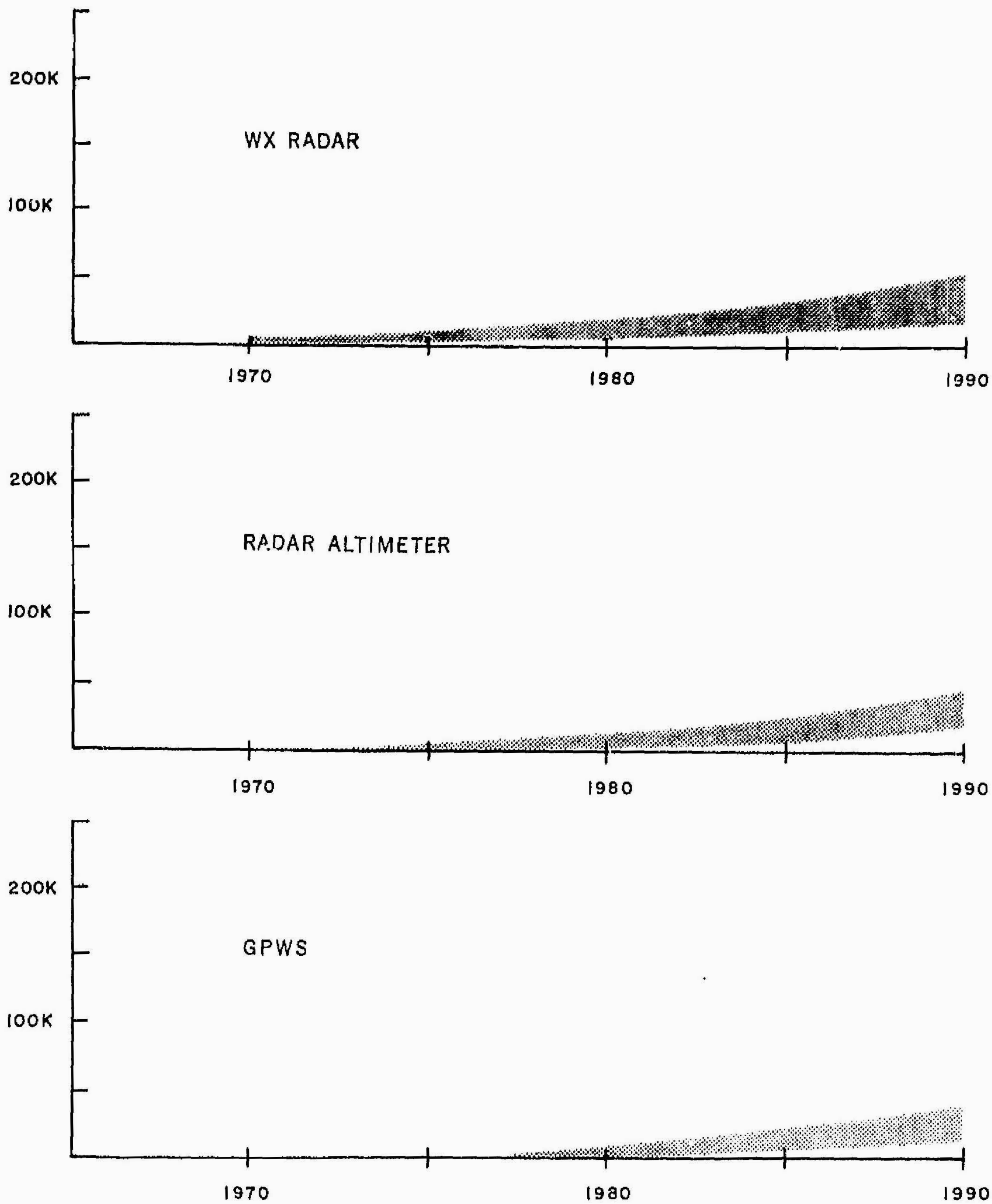


Figure 9. Projected Growth of Various Avionics Equipments (Continued).



SECTION 3

GENERAL AVIATION AVIONICS REQUIREMENTS IN THE 1980's

3.1 AVIONICS USER GROUPS

General aviation users comprise a broad spectrum with widely varying avionics requirements. At one end of the spectrum is the sport pilot who operates his glider in the airspace with no avionics at all. At the other end are the corporate flight operations which take well-equipped four-engine executive jets in and out of international airports. Some of these general aviation aircraft contain more avionics capability than air carriers because of their strong motivation for reliability and versatility. Cost is the prime motivation at the lower end of the spectrum while safety and reliability are the prime motivations at the higher end. The cost is relatively unimportant when providing safe, reliable transportation for the chief executive of a multimillion dollar corporation.

There are many possible dimensions for categorizing the users. One approach is based on the standard FAA user categories which are related to the aviation applications:

- Business Transportation--

  Individual - Any use of an aircraft not for compensation or hire by an individual for the purposes of transportation required by a business in which he is engaged.

  Corporate - Any use of an aircraft by a corporation, company, or other organization for the purposes of transporting its employees and/or property not for compensation or hire and employing professional pilots for the operation of the aircraft.

- Personal Flying-- Any use of an aircraft for personal purposes not associated with a business or profession, and not for hire. This includes travel, recreation and maintenance of pilot proficiency.

- Aerial Application-- Aerial application in agriculture consists of those activities that involve the discharge of materials from aircraft in flight and a miscellaneous collection of minor activities that do not require the distribution of any materials.

- Instructional Flying-- Any use of an aircraft for the purposes of formal instruction with the maneuvers on the particular flight(s) specified by the flight instructor.

- Commercial Operations--

  Air Taxi - Any use of an aircraft by the holder of an Air Taxi Operating Certificate which is authorized by that certificate (includes operations by scheduled commuter airlines and non-scheduled air taxi operators).

  Air Cargo - Non-passenger-carrying commercial transportation of goods, materials, etc.

- Industrial/Special-- Any use of an aircraft for specialized work allied with industrial activity, excluding transportation and aerial application (examples: pipeline patrol, survey, advertising, search/rescue, photography, helicopter hoist).

- Other-- Any use of an aircraft not accounted for by the previous user categories.

In terms of avionics, the most appropriate user categories are based on the types of operations conducted within the air traffic control environment.

- VFR Operations
- IFR Operations
- All-Weather Operations

The VFR operations category includes all those users whose avionics requirements are based on the fact that they only want to fly in good weather. They have no need to fly under instrument conditions but require basic navigation capability.

The IFR operations category includes all those users whose avionics requirements are based on the desire for an additional capability to fly on instruments in marginal weather conditions. They are not, however, motivated to pay for the reliability associated with complete all-weather capability. There is a general requirement beyond the VFR category for basic surveillance; i.e., something which provides the ATC system with position, altitude and identity. There is also a requirement for approach capability. At the low end this means non-precision approach capability to typical minimums of 500 foot ceiling and one mile visibility. At the high end it means precision approach capability to CAT I minimums of 200 foot ceiling and one-half mile visibility.

The All-Weather operations category includes those users who are primarily motivated by high reliability, requiring redundancy through dual and backup systems, weather protection through de-icing equipment and onboard radar, and lower minimums using flight directors and autopilots. The lower end of this category requires CAT II approach capability and the higher end needs CAT III approach capability.

The avionics required for these varied operations form a continuous spectrum. However, it is desirable to identify discrete categories within this spectrum just as we identify specific colors within the spectrum of visible light. To that end we have separated the users into six groups, which are identified according to their avionics requirements in Table 6.

At the low end of the avionics spectrum (i.e., for the VFR Only and Limited IFR Groups), the avionics requirements are dominated by cost; the user wants to accomplish the necessary functions at minimum cost. In the middle portion of the spectrum (i.e., for the Standard and High Performance IFR Groups), the avionics requirements are dominated by performance; the user wants to achieve the maximum

Table 6. General Aviation Avionics User Groups.

	Avionics Requirements Category					
	Group F	Group E	Group D	Group C	Group B	Group A
Objective	VFR Only	Limited IFR	Standard IFR	High Performance IFR	All Weather	Highest Reliability
Typical Aircraft	SE, 2-Place	SE, 2-Place	SE, Complex	Twin	Turbo-prop/jet	Jet
Typical Approach Capability	VFR	Non-Precision	CAT I	CAT I	CAT II	CAT III
Typical Avionics Investment	$2K	$8K	$20K	$40K	$80K	$150K

capability in terms of landing conditions, routing, and availabl orts. At the highest end of the spectrum (i.e., for the All Weather and High Reliability Groups), the avionics requirements are dominated by reliability; the user seeks maximum confidence that he can reach his destination and land safely despite the weather conditions. The typical avionics complement for each of these groups at the present time are summarized in Table 7.

Table 8 shows the estimated current distribution of general aviation users by the avionics categories. The user categories in Table 8 follow the FAA application categories, and the percentage breakdowns are based on ASI estimates. Note that the percentages for a given user category (e.g., business travel) total to 100 percent. However, completely accurate statistics are not possible because, in practice, there is significant overlap between the various groups selected for this study. For comparison,

Table 7. Typical User Group Avionics Requirements.

User Group	Avionics Requirements	User Group	Avionics Requirements
Group F	VHF Comm ELT VOR These equipments may not meet TSO or FAA IFR certification requirements.	Group E	2 VHF Comm ELT 2 VOR ADF Marker Beacon Transponder Wing Leveler
Group D	2 VHF Comm ELT 2 VOR ADF Marker Beacon Glide Slope DME Transponder Encoding Altimeter 2-Axis Autopilot	Group C	2 VHF Comm ELT 2 VOR ADF Marker Beacon Glide Slope DME RNAV Horizontal Situation Display Transponder Encoding Altimeter 3-Axis Autopilot Weather Radar
Group B	2 VHF Comm ELT 2 VOR ADF Marker Beacon 2 Glide Slope DME RNAV Horizontal Situation Display Transponder Encoding Altimeter Flight Director 3-Axis Autopilot Radar Altimeter Weather Radar	Group A	2 VHF Comm ELT 2 VOR 2 ADF 2 Marker Beacon 2 Glide Slope 2 DME 2 RNAV 2 Transponder 2 Encoding Altimeter 2 Horizontal Situation Display 2 Flight Director 2 3-Axis Autopilot Auto Throttle 2 Radar Altimeter Weather Radar

Table 8. Current Distribution of G.A. Users by Avionics Category, Percent of Fleet.

	Avionics Requirements Category					
	F	E	D	C	B	A
	VFR Only	Limited IFR	Standard IFR	High Perf. IFR	All Weather	Highest Reliability
Business Transportation						
Individual	5	10	55	30	*	0
Corporate	*	*	30	60	5	*
Personal						
Travel	10	30	40	20	*	0
Recreation	40	30	20	10	0	0
Aerial Application	90	10	*	0	0	0
Instructional						
VFR	30	60	10	0	0	0
IFR	0	0	60	35	5	*
Commercial Operations						
Air Taxi	*	30	35	30	5	0
Air Cargo	10	40	30	20	*	0
Industrial/Special						
Survey	25	60	10	5	0	0
Patrol	30	50	10	10	0	0
Search/Rescue	20	20	30	25	5	0
Construction	40	60	*	0	0	0

* Less than 5 percent.

Table 9 shows the estimated 1980's distribution of general aviation users based on avionics category. The percentages still total to 100 percent for each user category; however, the distribution has generally shifted toward the higher end of the spectrum, indicating a greater demand for more sophisticated avionics capability.

3.2 AIR TRAFFIC CONTROL SCENARIOS FOR THE 1980's

This section outlines three scenarios for the air traffic control environment in the 1980 to 1990 time span, to provide a basis for the anticipated avionics requirements. For perspective, Table 10 presents a few projected numbers on fleet size and general aviation operations to show the extent of growth anticipated during the 1980's.

Table 11 presents the scenarios for three times in the 1980 period -- 1980 which is only four years from the present date; 1985 which is nine years in the future; and 1990 which is fourteen years hence. The bases for these scenarios are the FAA forecasts in References 9 and 28. In the near term, the major navigation change will be the widespread introduction of area navigation. VOR/DME area navigation is already in limited use and will probably be expanded in the very near future by extended use of 50 kHz spacing VOR stations which are paired with the channel Y DME.* Most of the newer VOR/DME receivers are designed to accommodate this channel splitting. The expansion of RNAV in the near future will be in the high altitude enroute structure and in the dense terminals to alleviate controller vectoring. Some three-dimensional RNAV approach and departure routes will be introduced.

In the mid 1980's, the high altitude sector routes will be exclusively RNAV as will be those in the high density terminals. A standard grid of waypoints will be established for area navigation to provide routing flexibility and to permit automatic

* Channel Y DME operates on the same carrier frequencies as channel X, but uses different pulse spacing for discrimination.

Table 9. 1980's Distribution of G.A. Users by Avionics Category, Percent of Fleet.

	Avionics Requirements Category					
	F	E	D	C	B	A
	VFR Only	Limited IFR	Standard IFR	High Perf. IFR	All Weather	Highest Relia-bility
Business Transportation						
Individual	*	5	60	35	*	0
Corporate	*	*	20	75	5	*
Personal						
Travel	10	20	40	30	*	0
Recreation	25	5	25	15	0	0
Aerial Application	80	15	5	*	0	0
Instructional						
VFR	20	70	10	0	0	0
IFR	0	0	50	45	5	*
Commercial Operations						
Air Taxi	*	10	30	50	10	0
Air Cargo	5	15	30	45	5	0
Industrial/Special						
Survey	15	45	30	10	0	0
Patrol	20	40	20	20	*	0
Search/Rescue	10	20	40	25	5	0
Construction	20	70	10	0	0	0

* Less than 5 percent.

Table 10. General Aviation Projections for the 1980 Period.

	1980	1985	1990
Total GA Fleet	190K	230K	275K
Peak Airborne Count	20K	25K	32K
GA Operations	60M	85M	110M
GA Hours Flown	45M	60M	80M
Total Active Pilots	900K	1100K	1400K

Table 11. ATC Scenarios for 1980's.

ATC Feature	1980	198[illegible]	1990
RNAV	Initial use for high altitude enroute and dense terminals to alleviate vectoring. 3-D RNAV Routes for approach introduced. VLF/Omega operational.	Exclusive use of RNAV in high altitude sector and high density terminals. Established grid of RNAV waypoints. Automation of waypoint insertion. 3-D RNAV approaches standard.	RNAV the standard navigation mode for ATC. 4-D RNAV approaches in use at dense terminals.
	Extended use of 50 kHz VOR and channel Y DME.	GPS operational in military. Loran-C in civil use. Multiple DME RNAV in civil use.	GPS in civil use.
MLS	Limited use of IMLS and MLS glide slope at difficult sites and for CAT I & II	DME colocated with ILS & MLS. ILS & MLS colocated at major terminals. MLS at difficult sites.	Gradual replacement of ILS with MLS.

Table 11. ATC Scenarios for 1980's (Continued).

ATC Feature	1980	1985	1990
Surveillance	ATCRBS transponder and encoding altimeter required in all positive control airspace. Floor of enroute positive control lowered to 12,500 ft. TCA's expanded to include military airfields and ceilings raised to intersect enroute positive control airspace.	ATCRBS or DABS transponder with encoding altimeter required to fly in controlled airspace.	DABS transponder and IPC or BCAS required to fly in controlled airspace.
	First DABS ground facilities implemented. Introduction of IPC service in limited areas. DABS transponders available.	Mixed use of DABS and ATCRBS transponders. IPC service expanded.	DABS transponder and data link required in positive control airspace.
	ARTS II installed at medium density terminals. Radar service available at all tower controlled fields.	DABS surveillance available at medium density terminals.	
	BCAS introduced in air carriers and high performance aircraft.	BCAS in common use as cost comes down.	
Communications	Introduction of 25 kHz VHF channel spacing.	Introduction of data link (DABS or VHF).	Common use of data link for ATC communications.
	Test of Aerosat for oceanic communications.	Possible implementation of Aerosat although introduction BCAS reduces requirement for Aerosat.	Use of CRT in cockpit for display of data link information.
			Increased general aviation use of radio telephone.
FSS	Implementation of automated stations.	3400 unmanned FSS. 30 manned FSS.	Communication with FSS by touchtone data link.

insertion of waypoints. Ideally this grid will be based on latitude and longitude, although other techniques have been studied (the DDBS concept using bearing and distance from VORTAC stations). By this time frame three-dimensional area navigation approaches will probably be standard.

At the end of the 1980's, 4-D RNAV approaches will be in use at the denser terminals in order to provide spacing of aircraft into the airports. Routing by area navigation will be standard at low and high altitudes.

Although initial RNAV use will be mostly with VOR/DME, VLF and Omega are also expected to be utilized. VLF/Omega has already been certificated for enroute use and is available in general aviation aircraft. By the middle of the 1980's it is anticipated that Loran-C will be in civil use for air navigation, that multiple DME RNAV also will be in use, and that the global positioning system will be operational in military aircraft. 1985 is the expiration year of the existing ICAO regulations which specify VOR/DME as the standard navigation system, and some studies have examined Loran-C as a replacement for VOR/DME at that time. However, it is more likely that the RNAV system will be predicated on accuracy without specification of what system is used or provided. By the end of the 1980's the global positioning system is expected to be available for civil use.

Turning to the microwave landing system, limited use of the standard interim microwave landing system (IMLS) and the universal microwave landing system glide slope is expected at sites requiring microwave glide slope and for Categories II and III in the early part of the 1980's. In the mid 1980's, ILS and MLS will probably be colocated at the major terminals with MLS being used at difficult sites. DME will probably be colocated with ILS and MLS by 1985, but the DME is more likely to be the existing DME than it is to be the new C-band DME. By the end of the 1980's one should look for gradual replacement of ILS with MLS if the universal MLS is accepted by ICAO in the near future.

For surveillance in the near 1980's, the ATCRBS transponder and an encoding altimeter will be required in all positive control airspace, and the floor of the enroute positive control airspace will be lowered to 12,500 feet in most regions. The terminal control areas probably will be expanded to include military airfields, and the TCA ceilings will be raised to the floor of the overlying enroute positive control airspace. Implementation of DABS will begin in the early 1980's, and IPC will probably be introduced in limited areas. The ARTS II will be installed at medium density terminals and some form of radar will be available at essentially all tower controlled fields. BCAS will be introduced by 1980, but its high cost will probably limit its use to air carriers and high performance aircraft.

In the middle of the 1980's, the transponder with encoding altimeter will probably be required to fly in any controlled airspace, and implementation of DABS will have produced a mixed use of DABS and ATCRBS transponders. The IPC service will be expanded to more areas and BCAS will find greater use as the equipment costs fall. By the end of the 1980's, some form of collision avoidance system, either IPC or BCAS, might be required in order to fly in controlled airspace. The DABS transponder with a data link readout might be required in positive controlled airspace.

In communications, channel splitting in the VHF band will be utilized throughout the 1980's. Most of the new VHF communications radios already have 25 kHz spacing. A data link utilizing either DABS or a dedicated VHF frequency will probably be introduced by the middle of the 1980's, and by the end of the 1980's data link will be in common use for air traffic control communications. There will probably be considerably more general aviation use of the radio telephone as the cost declines and the GA users discover its convenience. Aerosat is to be tested in the early 1980's with possible implementation; however, the introduction of BCAS will greatly reduce the requirement for an aeronautical satellite.

Flight service stations should begin automation in the early 1980's. By the mid 1980's the FAA forecasts that there will be only 30 manned flight service stations remaining, with 3,400 unmanned self-briefing stations. By the end of the 1980's, it should be possible to communicate directly with the flight service station data links using touch-tone dialing and computerized voice synthesis.

3.3 GA AVIONICS REQUIREMENTS FOR THE 1980's

Table 12 indicates the impact of the preceding scenarios on the incremental avionics requirements beyond those shown in Table 7. In general, the equipment finds implementation at the highest level of sophistication and tends to filter down to the lower levels as the cost reduces, as the advantage to the user is demonstrated, and as regulations and common usage tend to force it upon the less sophisticated user. In the case of the area navigation system, groups A, B, and C are already generally using area navigation in varying degrees. Groups D, E, and F are expected to see major introduction of RNAV by the years 1980, 1985, and 1990, respectively. The particular type of area navigation which the various user groups will utilize will probably be split among VOR/DME, DME/DME, VLF/Omega, Loran-C and the Global Positioning System. Inertial navigation will probably not be used extensively outside of the more sophisticated general aviation users because of its high cost relative to the other options.

The rest of this section discusses in more detail the avionics requirements which are dictated by the UG3RD, which are desired for the UG3RD or beyond the

Table 12. Changes to GA User Group Avionics Requirements.

(By approximate year of introduction.)

Avionics Change	GA User Group A	B	C	D	E	F
VHF Comm. to 25 kHz Spacing	80	80	80	85	85	90
Encoding Altimeter	x	x	x	x	80	-
DABS Transponder	80	85	85	85	90	-
IPC	80	85	85	85	90	-
Data Link Readout	85	85	90	90	-	-
BCAS	80	85	85	-	-	-
MLS	80	80	85	85	-	-
VOR to 50 kHz Spacing	80	80	80	85	85	90
DME to Y Channels	80	80	80	85	-	-
RNAV	x	x	x	80	85	90
VNAV	80	80	85	85	90	-
VLF/OMEGA	80	80	85	85	85	90
LORAN C	85	85	85	90	90	90
DME/DME	85	85	85	90	90	-
GPS	90	90	-	-	-	-

x indicates change already exists.

UG3RD. These discussions contain some repetition from previous sections since they are intended to be self-contained explanations.

3.3.1 REQUIREMENTS FOR THE UG3RD

Table 13 indicates how the ATC functions under the upgraded third generation system would affect the various avionics user groups. For navigation equipment, the major impact is expected to be a requirement for area navigation for all of the user groups that operate IFR. As previously mentioned, it is anticipated that area navigation structures will be introduced into the air traffic control system in the relatively near future, and by the 1980 time period that portions of the air space may be restricted to users with RNAV capability.

Table 13. New Avionics Requirements for UG3RD.

<table>
<tr><th rowspan="2">ATC Function</th><th colspan="6">Avionics Requirements Category</th></tr>
<tr><th>Group F</th><th>Group E</th><th>Group D</th><th>Group C</th><th>Group B</th><th>Group A</th></tr>
<tr><td><u>Navigation</u></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>RNAV</td><td></td><td colspan="5">VOR/DME or VLF/OMEGA or LORAN-C or INS</td></tr>
<tr><td>MLS</td><td></td><td></td><td></td><td></td><td colspan="2">Glide Slope</td></tr>
<tr><td><u>Communications</u></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Data Link</td><td></td><td></td><td colspan="4">DABS Data Link</td></tr>
<tr><td><u>Surveillance</u></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Altitude Reporting</td><td colspan="6">Altitude Encoder</td></tr>
<tr><td>DABS</td><td></td><td></td><td colspan="4">DABS Transponder</td></tr>
<tr><td>IPC/BCAS</td><td></td><td></td><td colspan="4">IPC Display</td></tr>
</table>

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The type of RNAV equipment will probably not be specified, except that it must be certificated for operation in the system. The criteria for certification are expected to remain similar to FAA Advisory Circular 90-45. The possible types of RNAV are: VOR/DME, which is already available to the general aviation community; VLF/Omega, which is also available but has received only limited IFR certification; Loran-C, which meets the accuracy requirements but has not received IFR certification; or INS, where some equipments have been certified for IFR operation.

Area navigation equipments using multiple DME or DME in a fast-hopping mode may be preferable to VOR/DME RNAV since the accuracy of the DME is better than VOR. The multiple DME equipments, however, are not yet generally available although there are a number of sets in a development stage. Certain problems arise with the proliferation of fast-hopping DMEs in that a DME ground station can be saturated by over interrogation. The DME ground equipment is designed to reduce the sensitivity of the receiver whenever the interrogation rate is too high to keep the number of using aircraft at the level that the ground station can handle. Consequently, aircraft transmitters having the strongest received power at the ground station will be the ones granted service. Since the received power depends on both the transmitted power and the aircraft range, there is some user advantage to transmitting at high power. Presently, a DME ground station can handle about 100 aircraft simultaneously. Potential improvements in the DME system could increase the number of interrogators by a factor of about 8. Some of these changes involve slower interrogation rates on the part of the using aircraft and improved capability of the ground systems to handle the interrogations.

The requirement for the MLS glide slope is placed on the user groups who seek very high reliability, Groups A and B. It is anticipated that some airports will provide only an MLS glide slope, and the user would be unable to make a precision instrument approach to that field without the MLS glide slope receiver. MLS is not considered as a requirement for any of the lower user classes since the majority of the airports will provide precision approach capability through existing instrument landing systems. The possibility exists that the glide slope portion of the MLS will be implemented independent of the localizer portion, and be used essentially as a replacement for the UHF glide slope component in the standard ILS configuration. Consequently, an MLS localizer is not seen as a requirement.

The major new requirement for communications is a data link which will most likely be the DABS data link. The data link would be required for all aircraft participating in the IPC system, shown to include the four highest user groups.

Under surveillance, an altitude reporting capability will be required of all user groups. There is a strong probability of a requirement for every user of the airspace system to announce his identity and altitude with his radar position reply. The FAA is already initiating rule-making proposals to require beacon transponders and reporting altimeters for all aircraft operating in controlled airspace. This requirement is presently in existence for TCA's and Positive Controlled Airspace, but can be waived at the controller's discretion. The altitude encoder for the two lowest categories would be used in conjunction with the existing ATCRBS transponder. For those aircraft equipped with DABS, it would be used in conjunction with the DABS transponder.

In summary, the major impact on requirements from the UG3RD is anticipated to be some form of RNAV capability for all of the users flying IFR, an MLS glide slope for the high reliability and all-weather users, an altitude encoder for all aircraft in the system, and the DABS transponder data link and display for the four highest groups.

3.3.2 ADDITIONAL DESIRED EQUIPMENT FOR THE UG3RD

Table 14 shows equipment which would be desirable as a result of the UG3RD. These are equipments in addition to those discussed above which would be considered essential.

Table 14. New Equipment Desired for UG3RD.

Avionics	Avionics Requirements Category					
	Group F	Group E	Group D	Group C	Group B	Group A
DABS	← DABS Transponder* with Encoding Altimeter	→	←	DABS Transponder with Encoding Altimeter		→
IPC	← IPC Display* or ECAS	→	←	IPC Display		→
RNAV	Low-Cost RNAV*	←	VLF/OMEGA or VOR/DME LORAN-C or INS			→
MLS		←	MLS GS*	→	← MLS GS & Loc*	→
Automation		←		Data Link*		→
ASTC				←	Data Link*	→
WVAS			←	Data Link*		→
FSS	←		Touchtone	Data Link*		→
Aero Sat						TX/RCVR* Antenna

* Indicates over and beyond required equipment.

The DABS transponder with encoding altimeter would be desirable for all aircraft in the system, whereas it was considered required only for the four highest categories. The advantage of having all aircraft DABS equipped is that the IPC service would include all aircraft in the system. The IPC display will also be required; consequently, the IPC display is extended to cover all user groups.

Low cost area navigation equipment would be desirable, even for Group F (VFR-only) users, inasmuch as it allows the user to fly direct routes and to locate airports not served by other navaids. The RNAV equipment would not need to meet the requirements for IFR certification as outlined in Advisory Circular 90-45, but should have an accuracy of the order of 2 miles. There is a good deal of promise for this low cost capability from VLF/Omega. The RNAV using VOR/DME is probably not satisfactory for this purpose because it does not provide coverage at low altitudes throughout the continental United States, whereas many of the Group F users typically operate in remote areas or at low altitudes. Loran-C could serve this need except that at the present time Omega sets cost less than Loran-C equipment because of the simpler signal processing required. In the future, with advanced electronic components, Omega and Loran-C should approach the same cost to the user.

Under MLS, it would be desirable for all of the IFR users to be equipped with the MLS glide slope receiver to permit precision approaches to runways not served with the conventional ILS glide slope. For the highest reliability users, the availability of the MLS localizer would provide a back up to the conventional ILS localizer and provide additional accuracy and reliability for automatic approaches.

The UG3RD function of automation leads to the requirement for some form of data link in order that increased voice communications do not cancel the gains in traffic handling capability made possible through automation. Consequently, a data link capability for the aircraft flying IFR is desirable to achieve the full benefits of increased ATC automation.

Data link would also be desirable for airport surface traffic control. It is included for the three highest user categories since they are more likely to operate at the high density terminals which require this surface control.

Data link is also desirable for providing advisories to aircraft as part of the wake vortex avoidance system. The desirability of data link is extended into the standard IFR group since the wake vortex avoidance system could be utilized to advantage at many airports with insufficient traffic to justify surface control.

A much lower cost form of data link could utilize the touch-tone system developed by the telephone company for transmitting digital information over a voice channel. It would be suitable for use in connection with flight service stations which will be using automated weather information transmission over voice communications lines. Since all groups utilize the flight service stations, the touch-tone data link would be a desirable feature for all users.

Aerosat only applies to the few GA users who would be flying oceanic routes. If the system develops using carrier frequencies already available on the aircraft, the new requirement would be for an antenna with directional capability pointing generally upwards towards the satellite. If the carrier frequencies are different than those existing on current aircraft, then a dedicated transmitter and receiver would also be desirable.

3.3.3 ADDITIONAL DESIRED FEATURES BEYOND THE UG3RD

Table 15 suggests several additional desired avionics features for each user group beyond those called out in the upgraded third generation system.

The Ground Proximity Warning System (GPWS) is considered desirable for the four highest categories of IFR users. The GPWS will be required by turbine-powered airliners after December 1976. The potential capability is useful for all aircraft operating in instrument weather or at night. GPWS would require a radar altimeter plus a warning system with pilot display and associated logic to drive the warning system. The requirements as set out for the airliners might be relaxed for general aviation aircraft, but certainly the presence of a radar altimeter for low approaches in IFR weather is an extremely desirable feature.

The airborne traffic situation display would be extremely desirable for many of the users, since it would place the traffic information in the cockpit.

Table 15. Additional Desired Features Beyond UG3RD.

Avionics	Avionics Requirements Category					
	Group F	Group E	Group D	Group C	Group B	Group A
GPWS			← Radar	Altimeter	+ Logic +	Warning →
ATSD		←	Data Link	+ Logic +	Display	→
OMEGA/VLF	←	Low Cost	Receiver,	Computation	& Display	→
LORAN C	←	Receiver,	Computation	& Display		→
INS				← IMU,	Computer,	Display →
Touchtone Datalink	←	Simple	Modulation	on VHF	Comm	→
Fuel Optimization				← Flight	Management	Feature →
GPS					← RCVR	TX →

Three of the previously mentioned RNAV systems are associated with user groups in Table 14. A VLF/Omega system would require a low-cost receiver, computation and display. The same is true for Loran-C, and all user groups would potentially be interested in this form of RNAV. The INS system, because of its high cost, would probably only be desirable for the more sophisticated user.

The touch-tone data link, which was mentioned earlier, would amount to a simple modulation on the VHF communications channel. It would be desirable for all users since it could be a major communications channel to flight service and small fields not served by a tower.

Fuel optimization is considered to be a flight management system feature which would conserve fuel by flying a fuel optimum trajectory during letdown and landing with a programmed speed reduction and delayed flap extension. It would only be reasonable to use this equipment on the higher performance aircraft and is only listed, therefore, for the three highest categories.

The Global Positioning System, if implemented, will provide an extremely accurate worldwide navigation capability. However, due to the limited need for this capability and the cost of obtaining it, only the two most sophisticated groups are shown as potential users during the 1980's.

SECTION 4

PARAMETERS FOR AVIONICS COMPONENTS

A matrix of critical parameters versus avionics user group has been prepared for each major element of the avionics complement. The parameters are listed in approximate order of relative importance. Tables 16 - 34 present these parameters for each of the following existing or future equipment.

1. VHF Communications Transceiver
2. ELT
3. VOR/ILS Localizer Receiver
4. ADF
5. Marker Beacon Receiver
6. ILS UHF Glide Slope Receiver
7. DME
8. RNAV
9. ATCRBS Transponder
10. Encoding Altimeter
11. Horizontal Situation Display
12. Autopilot
13. Radar Altimeter
14. Weather Radar
15. DABS Transponder
16. IPC Display
17. GPWS
18. MLS Receiver
19. HF Communications Transceiver

Each of these avionics components has been reviewed in an attempt to establish which design features will have the major effect on equipment cost. These "cost drivers" and some suggested research and development areas are summarized in Table 35.

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Table 16. Critical Parameters for VHF Communications Transceiver.

Parameter	VFR Only	Limited IFR	Standard IFR	High Performance IFR	All Weather	Highest Reliability
Approximate Cost	\$500	\$700	\$1,000	\$2,000	\$3,000	\$5,000
Power Output	5w	7w	10w	15w	20w	25w
Spectrum	← 118.000 to 135.975 MHz →					
Channels						
Number	360	360	720	720	720	720
Spacing	50 kHz	50 kHz	25 kHz	25 kHz	25 kHz	25 kHz
Modulation	AM	AM	AM	AM	AM	AM
Transmitting Range	100 n.m.	125 n.m.	150 n.m.	175 n.m.	200 n.m.	225 n.m.

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Table 17. Critical Parameters for ELT.

Parameter	VFR Only	Limited IFR	Standard IFR	High Performance IFR	All Weather	Highest Reliability
Approximate Cost	\$150	\$200	\$250	\$300	\$350	\$400
TSO	← C91 (Ref RTCA DO-145 5 Nov 1970) →					
Frequency	← 121.5 and 243.0 MHz →					
Power Output (after 48 hours operation at $-20^{o}C$)	75 mw	125 mw	200 mw	300 mw	500 mw	750 mw
Modulation	Downward sweeping audio tone over at least 700 Hz between 1600 and 300 Hz at a repetition rate of 2-4 times per second.					
Activation	When longitudinal acceleration exceeds 5 (+2, -0) g for longer than 11 (+5, -0) millisec					

Table 18a. Critical Parameters for VOR Navigation Receiver.

Parameter	VFR Only	Limited IFR	Standard IFR	High Performance IFR	All Weather	Highest Reliability
Approximate Cost	$500	$700	$1,000	$2,000	$3,000	$5,000
Spectrum	108.00 to 117.95 MHz					
Channels						
(50 kHz Spacing)	200	200	200	200	200	200
Accuracy (2 σ)	3.0°	2.5°	2°	1.5°	1°	0.5°

Table 18b. Critical Parameters for ILS Localizer Receiver.

Parameter	VFR Only	Limited IFR	Standard IFR	High Performance IFR	All Weather	Highest Reliability
Approximate Cost	N/A	(Part of VOR Receiver)				
TSO		C36c (Ref RTCA DO-131 15 December 1965)				
Frequency Range		108-112 MHz				
Channels		40 (50 kHz spacing)				

Table 19. Critical Parameters for ADF.

Parameter	VFR Only	Limited IFR	Standard IFR	High Performance IFR	All Weather	Highest Reliability
Approximate Cost	N/A ↓	$1000	$1500	$3000	$5000	$8000
TSO		C41c	C41c	C41c	C41c	C41c
			(Ref RTCA DO-142 dated 8 January 1970)			
Frequency Range		← 200-1800 kHz →				
Quantization		1 kHz	1 kHz	.5 kHz	.5 kHz	.5 kHz
Tuning		← Digital →				
Relative Bearing Accuracy (2σ)		3°	2.5°	2.5°	2°	2°
Mounting		Panel	Panel	Remote	Remote	Remote

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Table 20. Critical Parameters for Marker Beacon Receiver.

Parameter	VFR Only	Limited IFR	Standard IFR	High Performance IFR	All Weather	Highest Reliability
Approximate Cost	N/A	$150	$200	$200	$500	$700
TSO		C35c Ref RTCA DO-143 dated 8 January 1970				
Frequency		75 MHz				
Display		Lights and Audio Tone				
Receiver Threshold Selection		No	Yes	Yes	Yes	Yes

Table 21. Critical Parameters for ILS Glide Slope Receiver.

Parameter	VFR Only	Limited IFR	Standard IFR	High Performance IFR	All Weather	Highest Reliability
Approximate Cost	N/A	N/A	$500	$1000	$2000	$2500
TSO			C34c (Ref. RTCA DO-138 June 27, 1968) and RTCA DO-132 March 15, 1966)			
Frequency Range			329-335 MHz			
Channels			40 at 0.15 MHz spacing (Paired with ILS localizer frequency)			
Remote Mounting			No	Yes	Yes	Yes

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Table 22. Critical Parameters for DME.

Parameter	VFR Only	Limited IFR	Standard IFR	High Performance IFR	All Weather	Highest Reliability
Approximate Cost	$2,000	$3,000	$4,500	$7,000	$10,000	$14,000
Range	100 n.m.	150 n.m.	200 n.m.	300 n.m.	350 n.m.	400 n.m.
Power Output	70w	150w	300w	500w	700w	1,000w
Spectrum	← 960 to 1215 MHz →					
Number of Channels*	100 X only	100 X only	200 (X & Y)	200 (X & Y)	252 (X & Y)	252 (X & Y)
TSO	66a	66a	66a	66a	66a	66a
Accuracy (2σ)	0.5 n.m. or 3%	.4 n.m. or 2%	.3 n.m. or 1.5%	0.2 n.m. or 1%	0.1 n.m.	0.1 n.m.
Features			← [RNAV Compatible] →			
			← [Fast Hopping Capability] →			

* X Channels are paired with VOR stations at 100 kHz spacing; Y Channels are paired with VOR stations at 50 kHz spacing.

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Table 23. Critical Parameters for RNAV.*

Parameter	VFR Only	Limited IFR	Standard IFR	High Performance IFR	All Weather	Highest Reliability
Approximate Cost	\$2000	\$4000	\$7000	\$15,000	\$30,000	\$40,000
Accuracy	± 2 n. mi. (σ)	← As specified in FAA AC-90-45 →				
Waypoints	1	2	10	10	20	20
VNAV Capability	No	No	Yes	Yes	Yes	Yes
Track Offset	No	No	Yes	Yes	Yes	Yes
Display	L/R & miles to go	L/R & miles to go	L/R & miles to go	Map & alpha-numerics	Map & alpha-numerics	Map & alpha-numerics
Wind Estimation	No	No	No	Yes	Yes	Yes
D/R Capability	No	No	No	Yes	Yes	Yes

*Includes UHF/VHF, Omega/VLF, Loran-C, GPS.

Figure 24. Critical Parameters for ATCRBS Transponder.

Parameter	VFR Only	Limited IFR	Standard IFR	High Performance IFR	All Weather	Highest Reliability
Approximate Cost	$600	$1000	$1500	$2000	$4000	$6000
TSO C74c Class	2B	2B	2A	1B	1A	1A
	A = above 15,000' B = below 15,000'			1 = higher standard 2 = lower standard		
Power Output (Watts)	75	125	250	250	500	500
Modes	A,C	A,C	A,C	A,C	A,B,C, D	A,B,C,D
Environmental Standards	RTCA DO-138 Paragraphs 4.0 - 7.0 & 9.0 only (Temp-altitude-humidity shock, vibration, power input)			RTCA DO-138		
Frequency						
TX	1090	1090	1090	1090	1090	1090
RCV	1030	1030	1030	1030	1030	1030
Codes	4096	4096	4096	4096	4096	4096

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Table 25. Critical Parameters for Encoding Altimeter.

Parameter	VFR Only	Limited IFR	Standard IFR	High Performance IFR	All Weather	Highest Reliability
Approximate Cost	$600	$1,000	$1,500	$2,000	$4,000	$6,000
TSO	C88	C88	C88	C88	C88	C88
Altitude Range	-1,000' to 17,000'	-1,000' to 17,000'	-1,000' to 25,000'	-1,000' to 35,000'	-1,000' to 50,000'	-1,000' to 50,000'
Quantization	[100 ft Standard ICAO Altitude Code]					
Accuracy	[±125' 2σ]					
Features - Compatible with both ATCRBS & DABS Transponders Optional outputs for autopilot, altitude alerter, & RNAV						

Table 26. Critical Parameters for Horizontal Situation Display.

Parameter	VFR Only	Limited IFR	Standard IFR	High Performance IFR	All Weather	Highest Reliability
Approximate Cost	N/A	N/A	N/A	$2000	$4000	$6000

Table 27. Critical Parameters for Autopilots.

Parameter	VFR Only	Limited IFR	Standard IFR	High Performance IFR	All Weather	Highest Reliability
Approximate Cost	N/A	$800	$1500	$3000	$7000	$15000
Stabilized Axes		Roll	Roll/Yaw	Roll/Yaw/Pitch	Roll/Yaw/Pitch	Roll/Yaw/Pitch Auto Throttle
Command Capability		Bias	Turn/Heading	Turn/Heading/ Pitch Rate/ Altitude	Turn/Heading/ Pitch Rate/ Altitude	Turn/Heading/ Pitch Rate/ Airspeed
Tracking Capability		None	VOR/LOC	VOR/RNAV/LOC VNAV/GS	VOR/RNAV/LOC VNAV/GS	VOR/RNAV/LOC VNAV/GS
TSO		C3b	C3b	C9c	C9c	C9c
				(Ref. SAE AS-402A dated 1 February 1959)		
Flight Director Interface		No	No	No	Yes	Yes
Missed Approach Capability		No	No	No	Yes	Yes

Table 28. Critical Parameters for Radar Altimeters.

Parameter	VFR Only	Limited IFR	Standard IFR	High Performance IFR	All Weather	Highest Reliability
Approximate Cost	N/A	N/A	$2,000	$4,000	$7,000	$10,000
TSO			C87	C87	C87	C87
Altitude Range			0-2,000'	0-2,000'	0-3,000'	0-3,000'
Accuracy (2σ)						
Below 100'			5'	4'	3'	2'
100-500'			5%	4%	3%	2%
Above 500'			7%	6%	5%	4%
Power Output			35 mw	70 mw	150 mw	500 mw
Response Time			.1 sec	.1 sec	.1 sec	.1 sec
Autopilot Output			No	Yes	Yes	Yes
Noise Output Below 100' (to Autopilot)			--	.25'	.25'	.25'
Features			[Adaptable to GPWS]			

Table 29. Critical Parameters for Weather Radar.

Parameter	VFR Only	Limited IFR	Standard IFR	High Performance IFR	All Weather	Highest Reliability
Approximate Cost	N/A	N/A	N/A	$5000	$10000	$20000
TSO				C63b (Ref. RTCA DO-134 dated 16 February 1967)		
Frequency				X-Band		
Power Output (peak)				8 kw	15 kw	
Display				5 " CRT		
Range				100 n.m.	200 n.m.	300 n.m.
Bearing Accuracy (2σ)				5°	4°	3°
Range Accuracy (2σ)				6%	5%	4%
Scan				90°	120°	180°
Stabilization				None	1 axis	2 axis

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Table 30. Critical Parameters for DABS Transponder.

Parameter	VFR Only	Limited IFR	Standard IFR	High Performance IFR	All Weather	Highest Reliability
Approximate Cost	$800	$1100	$1800	$3000	$6000	$9000
TSO Class	2B	2B	2A	1B	1A	1A
Power Output (Watts)	100	200	300	500	500	700
Frequency (MHz)						
Tx	1030	1030	1030	1030	1030	1030
Rcv	1090	1090	1090	1090	1090	1090
Address Codes	2^{24}	2^{24}	2^{24}	2^{24}	2^{24}	2^{24}
Message Length						
Uplink	← 32.5 μsec →					
Downlink	← 120 μsec →					
Environment	← Same as ATCRBS →					

Table 31. Critical Parameters for IPC Display.

Parameter	VFR Only	Limited IFR	Standard IFR	High Performance IFR	All Weather	Highest Reliability
Approximate Cost	$500	$700	$1200	$2000	$3000	$4000
Displayed Information	← 36 Proximity Warning Indication Lights plus four Positive and Negative Commands →					
Audio	← Warning Tone →					
Data Refresh Rate	← 4 sec →					

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Table 32. Critical Parameters for GPWS.

Parameter	VFR Only	Limited IFR	Standard IFR	High Performance IFR	All Weather	Highest Reliability
Approximate Cost	N/A	N/A	$500	$1200	$2000	$3000
TSO			ARINC Characteristic 594			
Mode 1 – Excessive Sink Rate for Altitude			Yes	Yes	Yes	Yes
Mode 2 – Excessive Terrain Closure Rate			Yes	Yes	Yes	Yes
Mode 3 – Negative Climb After Takeoff or Missed Approach			No	Yes	Yes	Yes
Mode 4 – Flight Info Terrain when not in Landing Configuration			No	No	Yes	Yes
Mode 5 – Below ILS Glide Path			No	No	Yes	Yes
Visual Display			Red Warning Light			
Audio Display			400-800 Hz Modulated Tone			

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Table 33. Critical Parameters for MLS Receiver.*

Parameter	VFR Only	Limited IFR	Standard IFR	High Performance IFR	All Weather	Highest Reliability
Approximate Cost	N/A	N/A	$1500	$2000	$2500	$3000
Frequency Range				5 - 5.25 GHz		
Channels				200		

Table 34. Critical Parameters for HF Communications Transceiver.

Parameter	VFR Only	Limited IFR	Standard IFR	High Performance IFR	All Weather	Highest Reliability
Approximate Cost	N/A	N/A	$1,000	$2,000	$3,000	$4,000
Power Output			50w	100w	150w	200 w
Spectrum				1.5 to 30 MHz		
Channels			5	10	15	20
Modulation			AM	AM + SSB	AM + SSB	AM + SSB
TSO			C31	C31	C31	C31
			C32	C32	C32	C32

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Table 35. Avionics Cost Drivers and Possible Research Areas.

Avionics	Cost Drivers	Possible R&D Areas
RNAV	. Loran-C: extensive data processing . VLF/Omega: phase locked loop tracking at low signal/noise . DME/DME: transmitter . INS: gyros	. Low cost Loran-C/Omega hybrid receiver . Logic chips for standard navigation functions . Input-output displays for 3D and 4D RNAV . Atomic clocks for GA
Encoding Altimeter	. Optical encoder	. Packaged encoder for altitude, heading airspeed
Horizontal Situation Display	. Gyro-stabilized heading reference . Contrast at all ambient light levels	. Low cost heading reference . Low cost CRT, LED or liquid crystal display
Autopilot	. Gyro components . Servo drive installation	. Low-cost inertial package . Low-cost digital servo drives
Weather Radar	. Display . Antenna	. Multipurpose display . Low-cost phased-array antenna
DABS	. Data link output	. Low-cost input-output unit for data link
HF Communications Transceiver	. Antenna installation	

Table 35. Avionics Cost Drivers and Possible Research Areas (Continued).

Avionics	Cost Drivers	Possible R&D Areas
VHF Communications Transceiver	. Reliability under high ambient temperature . Frequency tolerance . Manual frequency selection	. Avionics heat protection . Microprocessor r.f. generator development . Electronic switching . Improved fidelity/noise attenuation
ELT	. Battery life . Inadvertent activation . Voice modulation	. Alternate power source . Improved deceleration detectors . Additional features (identity, theft protection, etc.)
VOR/ILS Localizer Receiver	. Reliability under high ambient temperature . Reliability under vibration	. Avionics heat protection . Improved reliability under temperature and vibration
ADF	. Accurate heading reference	. Low-cost, gyro-stabilized compass . Sense and loop antenna consolidation with integral phase compensation
ILS Glide-Slope Receiver	. UHF circuitry more expensive than VHF	
DME	. High power output	. Low-cost, high power, solid state transmitter

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Table 35. Component Cost Drivers and Possible Research Areas (Continued).

Avionics	Cost Drivers	Possible R&D Areas
IPC	. Special purpose display	. Low cost multipurpose display
MLS*	. Additional C-band DME	. Glide slope converter to drive ILS receiver.

* No ICAO agreement yet on final configuration.

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SECTION 5

GA ALTERNATIVES FOR THE UG3RD

This section discusses possible variations in the UG3RD ATC system insofar as general aviation is concerned. Specifically it investigates the possibility of separated ATC for general aviation and changes in the UG3RD to minimize the GA avionics requirements, or to maximinze their utility.

5.1 SEPARATED ATC FOR GA

A natural segregation of air traffic has developed over the years, but this separation has been based on capability and cost factors and is not a segregation of general aviation as a whole. Aircraft performance capabilities (e.g., high altitude versus low altitude or single engine versus multi-engine), equipment expenses (transponder, altitude encoder, IFR versus VFR, etc.), and user costs (e.g., landing fees) are generic features which tend to discriminate part of the GA fleet from the air carriers. While the air traffic control system either creates some of these differences or tends to reflect and emphasize them, airport operators are responsible for some discrimination.

In the terminal area, a natural segregation based on airspeed capability is almost unavoidable in order to make maximum use of available runway capacity. It is desirable to have all aircraft in the landing queue flying the same airspeed so that separation can be maintained without leaving gaps. However, the approach speeds for the larger turbojet aircraft are greater than the maximum cruise speeds of many smaller general aviation aircraft. Furthermore, the length of the landing roll and consequently the length of runway required is a direct function of the landing speed. Therefore, it is desirable not only to segregate the traffic by speed capability, during the approach, but also to direct them to different runways of appropriate length.

Another consideration is that more than one speed is needed for each class of aircraft in order to permit metering and spacing by speed control. Also, the deceleration process takes place in stages from cruise speed to approach speed to landing speed. Therefore, a range of airspeed capability is necessary for all aircraft in a particular class. The typical airspeed capability for each avionics user group is shown in Figure 10. Typical air carrier and helicopter capabilities are also shown for comparison. The upper bound of 250 kts indicated airspeed (IAS) is the FAA established speed limit at altitudes below 10,000 feet. The figure shows clearly that two segregated classes are necessary, with possibly a third class for VTOL.

This segregation of aircraft will continue during the 1980's as more of the airspace becomes restricted in terms of equipment required and user flexibility (expanding TCAs, PCA, IPC, etc.). Unfortunately, segregation will probably continue to expand as much to satisfy the ATC complex as out of operational necessity. Although feasible alternatives exist to expedite mixed traffic flow, the evolution of responsibility toward the ground system practically precludes pilot participation and resolution of mixed conflicts.

The air carriers are primarily motivated by schedule reliability into the country's major airports to maximize their market profitability. However, GA Groups A and B are just as interested in operational (schedule) reliability, with Group A being perhaps more interested even than the airlines. General aviation corporate aircraft take up where the airlines fail to provide reliable and timely service for executive transportation. The general aviation fleet as a whole is becoming more sophisticated in terms of performance and equipment. This will continue during the 1980's, partially as a result of new technology, but also due to availability of better equipment at moderate costs. Moreover, the limits of the spectrum are expanding through implementation of advanced vehicle designs in many areas, such as VTOL.

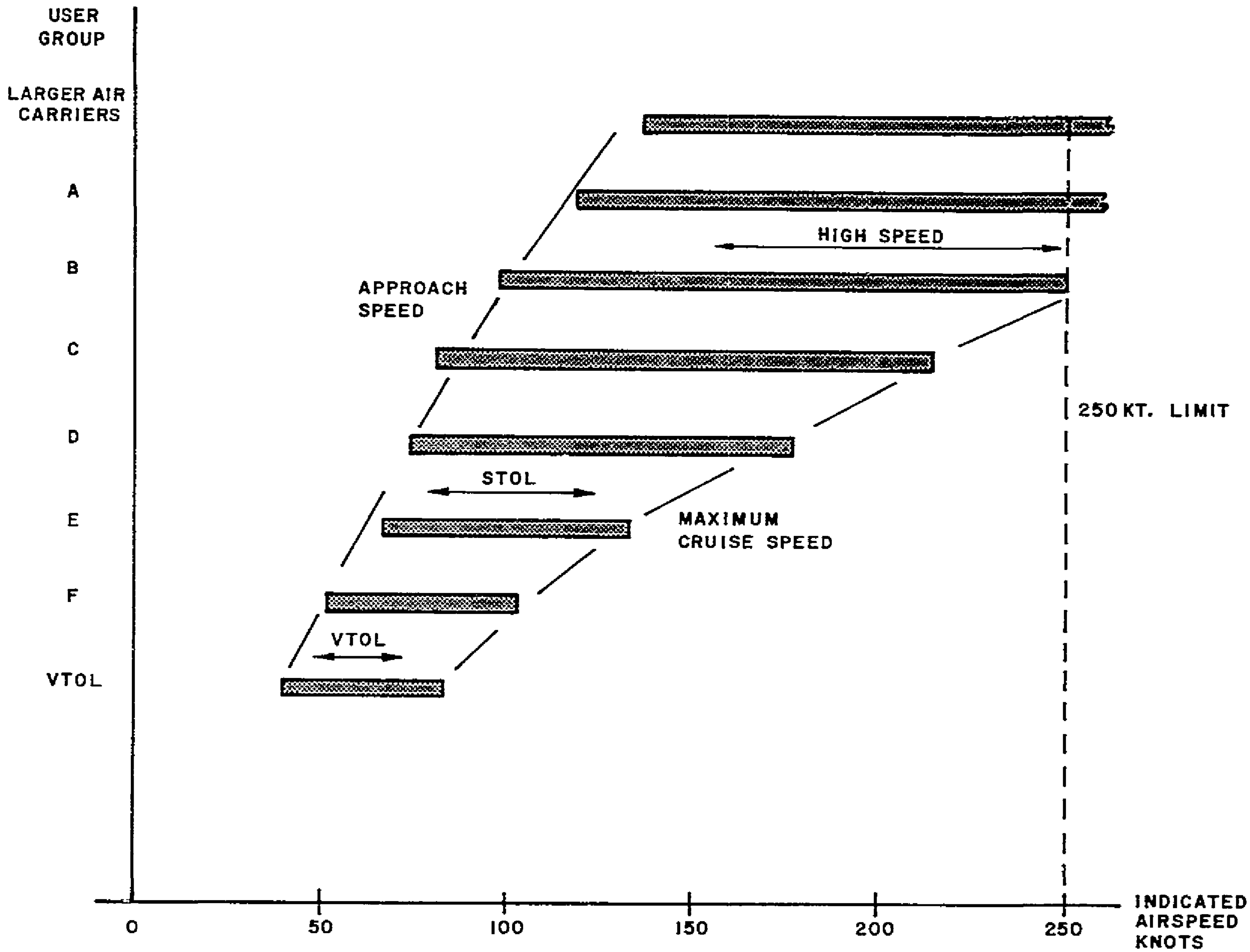

Figure 10. Typical Airspeed Capabilities.

An enforced segregation of general aviation traffic would be unfair to the conti 'ly expanding GA industry and would have significant economic repercussions. Many general aviation flights (including air taxis, corporate, and commuters) are connections to the air carriers for passengers or cargo. Also, a large number of general aviation operations are supplemental to the air carrier service at principal airports, serving the same market for passengers and cargo as well as the smaller airports not served by the air carriers. Some major pros and cons regarding segregated airspace are compared in Table 36.

In summary, there is a very strong possibility that segregation will continue due to concentration of ground based authority in the air traffic control system. However, in terms of feasibility, continued segregation other than as described is undesirable. The utility of general aircraft can only be fully realized by providing adequate flexibility in operational capability. The future air traffic control environment should provide means to minimize or limit segregation through proper instrumentation and pilot participation in traffic management.

5.2 CHANGES TO THE UG3RD TO MAXIMIZE GA BENEFIT

The following comments pertain to changes in the UG3RD which would minimize avionics requirements for GA, or which could offer additional services as a result of avionics that will be introduced in the UG3RD. They include modifications or additional potential capabilities of IPC, RNAV, DABS and BCAS.

The IPC proximity warning display consists of 36 lights which indicate threatening traffic, using a clock code for azimuth and either high, level, or low for altitude; no range information is provided. The collision avoidance commands will consist of one of four positive commands, (climb, dive, turn left, turn right) or four negative commands (do not turn left, right, climb, or dive). The foremost

Table 36. Pros and Cons of Segregated Airspace.

Positive	Negative
1. Reduced collision risk between dissimilar aircraft.	1. Defeats flexibility designed into vehicles. 2. Requires stratification (horizontal boundaries) or vertical boundaries requiring a certain degree of navigational sophistication; horizontal boundaries restrict flexibility. 3. Requires constant monitoring of boundaries. 4. Requires evasion techniques after intrusion detection and the high performance aircraft must adjust. 5. Limits origin/destination (e.g., intercity VTOL).

problem with IPC is that the system will attempt to accept responsibility for aircraft separation with as little as 30 seconds to go before a potential collision. Moreover, this is to be done with relatively limited information, with no interaction between the pilots or the controllers, and with logic which has proven to be detrimental to the solution of the conflict in some cases. A more attractive alternative to the IPC display is to uplink the information about conflicting aircraft using the DABS data link in a format such that range, altitude and bearing information are available for the user to display in whatever manner he prefers. This might involve purchase of the prototype IPC display or an alternative, such as an alphanumeric printout of the information, a map display of the conflict, or as input to an airborne traffic situation display. In any case, the user could decide for himself how to utilize the information and display it meaningfully and economically for his avionics complement.

Secondly, IPC commands should be considered as advisories. If the pilot were unable to see the other aircraft and resolve the conflict on his own, he could then respond to the advisory command with confidence that it would tend to improve the situation. The logic for avoiding the conflict would have to be changed from its present form so that it could be relatively easily understood by pilots and so that it would not create situations in which the conflict is aggrevated. These commands should also include the desired heading and/or altitude. In the case of IFR controlled aircraft, the proposed commands should be made available to the controller first to permit him the opportunity to resolve the conflict before the aircraft reacts on its own. In no case should the legal responsibility for separation of aircraft be exchanged with 30 seconds or less to go to a potential collision.

DABS, with its associated data link, has the potential for providing a number of valuable services to general aviation at very low cost. These include area navigation, ground proximity warning, terrain/obstacle avoidance, weather depiction, and traffic information. All the necessary information to provide these services is available from the DABS sensor and the ATC computer; the data link is adequate to transmit the information to the cockpit. Unfortunately, the only planned use of this capability in the UG3RD is to drive the IPC display. Consequently, the general aviation user who is forced to purchase a DABS transponder with altitude encoder and IPC display will not receive the maximum available benefit from his instruments. Moreover, the ATCRBS transponder and encoding altimeter will provide collision avoidance protection from all controlled aircraft and from those DABS-equipped uncontrolled aircraft. Therefore, the GA user would have little motivation to purchase the DABS transponder and IPC display, since he would gain additional protection only from those uncontrolled aircraft who are equipped with ATCRBS and the encoding altimeter. If the design were modified to include area navigation, then the user would gain more value for his investment.

One primary reason that the present IPC display was adopted (thereby limiting its capability to collision avoidance alone) was the desire to keep its cost low. Consequently, the main deterent to modifying the UG3RD to reduce avionics requirements is the absence of a low cost general purpose display. This is the foremost weakness of the UG3RD; namely, that the capability and potential of the DABS data link is being used only to provide IPC which in its present form is unsatisfactory. A properly designed IPC display should be able to vector an aircraft using computer generated altitude and heading commands transmitted through the DABS data link with the same or better precision than a human controller using voice communications. The general aviation user would then be able to utilize airspace requiring a 3-D RNAV capability whether RNAV equipped or not. With the addition of airspeed commands, the user would obtain a 4-D RNAV capability.

Another modification to the UG3RD concerns area navigation equipment. At the present time the term "area navigation" usually refers to VOR/DME area navigation. However, the RNAV system should be designed to accept any navigational equipment capable of positioning the aircraft to the accuracy requirements specified in Advisory Circular 90-45. The RNAV structure should not be irrevocably tied to the location of the current VORTAC stations. A more universal and flexible approach is to establish waypoints on the basis of latitude and longitude, such that any of the available area navigation systems would be able to identify and store the waypoints easily. A proposal to uplink the waypoint information using the VOR/DME system would clearly be detrimental to the possible implementation of systems such as Loran-C and Omega. The VOR/DME system is noncompetitive in terms of providing area navigation coverage at low altitudes and in remote areas critical to general aviation. The capital investment costs and the operational maintenance costs are an order of magnitude larger for VOR/DME coverage on a per square mile of coverage basis than are those of Loran-C or Omega. That is not to say that the VOR/DME network should be abandoned; but it is not cost effective to attempt to provide universal coverage at low altitude by proliferation of the VOR/DME system. Therefore, any steps taken to implement the RNAV systm should be independent of the VOR/DME network.

The SynchroDABS option could provide a substantial improvement in the capability of the DABS system as it is presently planned. The basic ingredient of SynchroDABS is to time the ground interrogations so that the aircraft always respond at instants of universal time. This permits a one-way range measurement from any DABS equipped aircraft, since any aircraft in the system automatically has a clock kept at universal time. Consequently, each time an aircraft responds, all others which hear the reply can determine their range from it. If each aircraft, in addition, is equipped with an antenna capable of determining the direction from which the transmission is received, then bearing as well as range would be available for determining the location of any other transponder. This would enable an aircraft to obtain range and bearing information from any arbitrary location, by merely placing a transponder at the selected site. For example, transponders could be placed on obstructions, on mountain tops, or at airports in remote areas to provide a very low cost DME, in addition to providing proximity warning or collision avoidance information.

Similar possibilities exist with the semiactive BCAS system. Since the range and bearing to a transponder is geometrically determined by the difference in the time of arrival of the direct signal and the signal via the transponding aircraft, it is possible to create a DME or a navigation beacon by placing transponders wherever they are needed. However, to be meaningful for general aviation, the BCAS must be low in cost, high in reliability, light in weight, and have a good mean time between failures.

Another possible advantage to general aviation using the beacon system is a technique known as PALM (precision altitude landing monitor). The PALM system is essentially another form of MLS where the position of the aircraft is determined by observing with monopulse technology the direction from which the aircraft reply comes. Accuracy has been demonstrated by Lincoln Laboratory to 0.06 degrees, which is more than adequate for precision instrument landings (Reference 108). The major advantage of the PALM system is the elimination of multipath; the time sequencing of the signal is known and reflections from other locations are not close enough in time to contaminate the measurement to the aircraft. Azimuth and elevation information is available on the ground and could be sent back to the airplane over a data link, such as the DABS data link. This data could be presented directly through the IPC display which could give the general aviation user an ILS without having to buy any additional equipment beyond the DABS transponder and IPC. The PALM system is demonstrated hardware which operates similarly to the normal DABS interrogator, except that it interrogates every 1/10 of a second instead of every 4 seconds. It also provides range information to an accuracy of at least 250 feet at a distance of 30 miles. The same concept would also work with the beacon transponder by uplinking the information on a VHF data link or by transmitting commands to the airplane similar to a normal GCA approach. Apparently, PALM has received limited publicity and enthusiasm from the FAA because it is competitive with the MLS system selected by the U.S. to submit to ICAO.

SECTION 6

CONCLUSIONS AND RECOMMENDATIONS

This section outlines the major conclusions and recommendations determined from the study.

6.1 CONCLUSIONS

A proliferation of navigation systems will continue to exist in the 1980's. Any area navigation system meeting the provisions of Advisory Circular 90-45 or equivalent should be considered for operations in the RNAV network. Omega navigation is already available; the ground network is in place and operational, and first generation Omega receivers are operational in general aviation aircraft. However, Loran-C is becoming a strong candidate for future RNAV use, and has been designated the primary navigation system for the U.S. coastal confluence zone. The East Coast chain is in place; the West Coast chain is expected to be on the air in a matter of months; and new stations will complete coverage in the Gulf of Mexico and the Gulf of Alaska. Current construction together with existing Loran-C stations will provide inland coverage over two-thirds of the U.S., and there are pressures to complete coverage to the internal U.S. Several studies have considered replacing the VOR/DME network with Loran-C after the ICAO commitment to VORTAC expires in 1985. While DME offers an accuracy that is equivalent to Loran-C, the capital installation costs and the operating and maintenance costs are far more expensive. Since DME operates line-of-sight, it is of no value far from land, in mountainous areas, or far from the transmitter sites. Although DME is operational in high density areas, Loran-C has such promise that more consideration should be given to developing a general aviation Loran-C receiver.

The system that makes the most sense is a hybrid Loran-C/Omega receiver because the two systems are complementary. They are both hyperbolic systems, and

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about 80 percent of the components are common to both. The only major difference is in the front end; Loran-C operating at 100 kHz and Omega in the 10 kHz band. Since Omega has world-wide coverage with an accuracy of about one mile, it is useful over water and as a backup to Loran-C in the event of outages or lack of coverage. Loran-C can provide the differential capability for Omega which is necessary for Omega to meet the requirements of Advisory Circular 90-45. The combination of Loran-C and Omega together would be better than either one alone in terms of both accuracy and reliability. The hybrid receiver would also be valuable in providing navigation capability during the transition from VOR/DME to Loran-C if such a transition takes place.

For communications our conclusion is that a low-cost general aviation display to operate with data link is of extreme importance. The data link will most likely be the DABS data link; however, even if DABS is not implemented, a separate VHF data link will probably be developed, in which case the display will still be required. The display could have other uses, such as presenting IPC information or to present aircraft attitude and navigational information.

For surveillance, it is anticipated that DABS will be implemented, although the IPC function as presently envisioned is unsatisfactory for general aviation. It could be improved as suggested earlier.

6.2 RECOMMENDATIONS

The first recommendation is to conduct research to develop a low-cost, low-power, cockpit display for general aviation. This display could be used to show alphanumeric information from the data link, to display graphical information such as a readout for area navigation, or to display attitude information. At the present time, a cathode-ray tube is the only viable display available which can present the information at all ambient light levels. However, the cathode-ray tube requires high power and is slightly undesirable from a safety standpoint, in that it requires high voltage and could suffer from implosion in the event of an accident. Also, it is a large device which requires considerable space beyond the instrument panel. The ideal characteristics of a GA display are: a flat shape, taking up relatively little depth; low cost, preferably under a few hundred dollars; lower power, which might be achieved by using ambient light instead of providing its own light; and sufficient resolution to present graphic information. Alternate displays available now fail in one or more of these categories. Besides its imminent need with the data link, the cockpit display would be useful for area navigation, for a traffic situation display, and for an integrated cockpit. The main reason that the prototype IPC display evolved as it did was an attempt to keep the cost low. As a result, it provides less than the total desired amount of information and prevents evolutionary changes to the concept.

The second major recommendation is the development of a Loran-C/Omega hybrid receiver for general aviation. This combination has been justified by a number of studies for their complementary features and their considerable savings in common circuits. Omega is operational, and Loran-C implementation is continuing; yet there is no low-cost Loran-C and/or Omega reciever available for general aviation.

The third recommendation is that a front-end converter be developed which would receive MLS signals and transform them into conventional ILS modulation, thus permitting general aviation users to utilize MLS with existing airborne equipment. The converter should be so designed that the MLS/ILS glideslope and localizers could be selected in combination.

A fourth recommendation, which is predicated on the availability of a cockpit display and data link, is the development of a weather presentation for single-engine aircraft. At the present time, weather radars are only available to multi-engine aircraft, since the airborne antenna is mounted in the nose. A phased array weather radar has been designed and built for single-engine aircraft, but production costs of finite elements are too great for cost-effective production. With a data link and a display, the weather depiction could be uplinked from the ground on request to show the weather as detected by the ground radar. At the present time, the single-engine pilot has to specifically ask the controller for radar weather information, and the request is often denied because the controller is too busy.

Other useful information presently available to the controller is orally relayed to the pilot only randomly or by specific request. An example is the warning displayed to an ARTS controller when an aircraft descends below the minimum enroute altitude for any flight segment. One accident has already occurred in which the controllers were aware that the aircraft was too low for his position, but the information was not reported to the aircraft in a timely fashion. It should be possible to uplink this information automatically, so that the warning available on the ground is also provided in the cockpit.

Another candidate for shared information is the traffic itself; it has already been recommended that IPC be modified to provide traffic information on conflicting aircraft to the general aviation pilot. It is also possible to uplink all the traffic information so that the individual aircraft can selectively display that traffic which might be of interest to him even though it does not constitute a threat. The uplinking of the information presents no technical problem; it can be done simply on a single VHF channel. The difficulty is filtering and processing the data in the aircraft in order to present information to the pilot in a relative format and in an altitude and range band that he might select.

At the component level the most important effort should be to improve reliability in the face of high temperature and vibration. The highest temperatures often occur when the aircraft is parked and the equipment is off. High power solid state transmitters are needed for DME, weather radar and beacon transponders. A low cost gyro-stabilized magnetic compass would be desirable in order to downlink heading.

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