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ADVANCED AIR TRAFFIC MANAGEMENT SYSTEM STUDY
TECHNICAL SUMMARY

MARCH 1975

FINAL REPORT

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PREFACE

This Report culminates a four year (multi-phase) study of advanced air traffic control system concepts by the U.S. Department of Transportation, Office of the Assistant Secretary for Systems Development and Technology. The work was done by the Department's Transportation Systems Center (TSC) in Cambridge, Massachusetts. This Study, part of the Department's long range planning efforts, formulated an advanced air traffic management system concept compatible with the projected 1990 and beyond ATC requirements. Study efforts also resulted in recommended research and development plans, supplementing the present Federal Aviation Administration engineering and development program, for work to support the orderly development and implementation of the concept.

The document, covering the Study's technical and cost analyses, concept definition activities, and research and development planning efforts, summarizes the work of many people. In the Government, the participating organizations include the Transportation Systems Center; Office of the Assistant Secretary for Systems Development and Technology, Office of Systems Engineering; and the Federal Aviation Administration. The primary industry participants in the Study included the Autonetics Division of Rockwell International Corporation, The Boeing Company, TRW Inc., Rand Corporation, Mitre Corporation, Planar Corporation, Stanford Research Institute, Massachusetts Institute of Technology, and Lincoln Laboratories. The contribution of the many individuals within these organizations is gratefully recognized and appreciated. Robert L. Maxwell, Captain William E. Simpson, George H. Webber, and Lt. Col. Jesse W. Halsey of the Office of Systems Engineering, Office of the Assistant Secretary for Systems Development and Technology deserve special thanks for their assistance during the entire study. Their suggestions and guidance helped greatly in the formulation of the concept and plans described in this Report.

Aside from the present author, the principal TSC Study team included David E. Lev, Program Manager during most of the project, Thomas Carberry, Frederick Frankel, David Goldfein, Robert Hagerott, Joseph Hagopian, Sherman Karp, Edmund Koenke, Norman Meyerhoff, Robert Ow, Robert Pawlak, and David Reed, whose support, expertise and dedication were crucial to the successful accomplishment of Study goals. Special thanks is given to James P. Andersen, Calvin H. Perrine, John D. Hodge, Stewart B. Hobbs, and Robert W. Wedan for their guidance and support. James Sterling of Raytheon Service Company deserves special recognition for his excellence in editing this Report and also other study documentation, including elimination of inconsistencies, and clarification of the work of many different authors. The secretaries of the Aeronautical Systems Division are also gratefully recognized for their dedicated help in preparing report manuscripts.

Robert H. Reck
Transportation Systems Center
March 1, 1975

ADVANCED AIR TRAFFIC MANAGEMENT SYSTEM STUDY
EXECUTIVE SUMMARY

The Advanced Air Traffic Management System (AATMS) Study was conducted by the U.S. Department of Transportation, Transportation Systems Center, under the sponsorship of the Office of the Assistant Secretary for Systems Development and Technology. The Study was initiated by the U.S. Department of Transportation in 1970 in response to recommendations by the Department's Air Traffic Control Advisory Committee which published its findings in 1969.(1) The Committee was formed in 1968 to address the pressing need for an improved air traffic control system. The Committee's recommendations formed the basis for much of the present FAA Upgraded Third Generation Air Traffic Control System Engineering and Development Program, including the Discrete Address Beacon System, Intermittent Positive Control, and upgraded automation of ATC facilities.(2) However, the Committee was concerned with potential deficiencies in capacity and coverage of this system in the 1990 time frame and with increasing system operating and maintenance costs. Consequently, the Committee recommended that ". . . A Fourth Generation System should be in orderly development which can supplant the upgraded Third Generation System." In its recommendations the Committee established system and technology priorities for the formulation and definition of an advanced concept of air traffic management:

> ". . . The Committee's review of future possibilities identified space and computer technology as offering the greatest potential advantages."

In acting on the Committee's recommendations, the U.S. Department of Transportation initiated a four-year multi-phased study of concept formulation, to consider future system alternatives; concept definition, to consider specific future system features in detail and develop a supporting technology base; and evaluation leading to selection of a preferred advanced air traffic management system concept and recommendations for research and development activities supplementing the present FAA Engineering and Development Program. Study objectives were that the selected concept handle the projected air traffic estimated for the 1990's, evolve from the Upgraded Third Generation System now in development, maintain system safety, be cost effective, and pose minimal technological risk in concept realization.(3)

The resulting concept for a potential Fourth Generation System, preferable called the Advanced Air Traffic Management System (AATMS), was one of several alternative advanced air traffic management system concepts considered. The selected AATMS concept is characterized by the following features:

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- Use of satellites over the conterminous United States and contiguous oceanic regions as a primary mechanization for universal coverage surveillance, navigation, and data link communication, in conjunction with aircraft avionics integrated at the functional level.
- Continuation of the current philosophy of ground-based air traffic management by Tactical Control, augmented by Strategic Control, a technique emphasizing extensive pre-planned, time-scheduled conflict-free flights, especially in regions of high air traffic density.
- Centralization of the control and data processing network into two or three en route control facilities.
- A high degree of automation to constrain the growth in operational costs.

As shown in Figure 1, the AATMS Concept proposes the application of satellite technology for surveillance, navigation, and data link communication with aircraft, as well as continuation of VOR-DME navigation facilities, VHF voice communication facilities, and the ground-based Discrete Address Beacon System of the Upgraded Third Generation System. The centralization of highly automated air traffic control facilities is also shown. The communication links shown in Figure 1 provide C-band data exchange between the ground control centers and the satellites, and L-band channels for signals between satellites and aircraft. The same satellite constellation used for aircraft surveillance and data link communication would also provide signals for aircraft navigation.

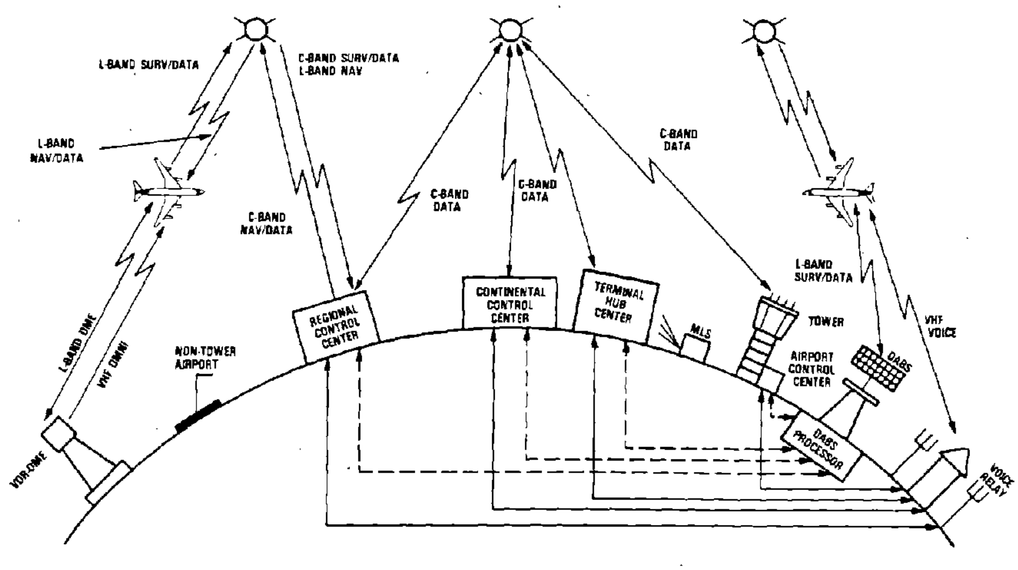

Figure 1. AATMS Surveillance, Navigation, and Communication Concept

Certain research and development efforts are required to support system specification decisions in the early 1980's. This provides the lead time necessary if a modified system concept is to be implemented by the 1990's.(4) Such near term research and exploratory development, augmenting ongoing FAA programs, are required in the areas of satellite surveillance, communication and navigation, compatible avionics, facility centralization, control techniques and automation. The system level aspects of satellites and facility centralization are relatively well understood, so that research and development in these areas can be oriented more toward selective engineering designs and the broader, but critical, economic and operational feasibility questions. For example, technical advancements are required if the low cost avionics necessary for feasible system implementation are to be provided. Such advancements are also required to provide high reliability equipment, and mechanization alternatives to determine acceptable avionics configurations. Study efforts on control techniques will also follow predictable lines of inquiry. The hardware and software aspects of computer technology are well understood, but the application of this technology to the management of the air traffic system will require additional research and development. In particular the relative roles that men and machines would assume in an automated system, the interfaces between men and machines, and the economic feasibility of high levels of automation must be determined. Automation is particularly important since it holds promise of high payoff in terms of either lower operating costs or holding the cost line while meeting increased traffic demands. The primary means for accomplishing this is to improve the productivity of air traffic management personnel which, in turn, will reduce the labor-intensiveness of the system.

Study Description and Results

The existing or Third Generation Air Traffic Control System is currently being extensively modified to keep pace with expanding requirements and, late in this decade, will result in the so-called Upgraded Third Generation System. The improvements to the present system include nine major elements: Intermittent Positive Control, Discrete Address Beacon System, Flight Service Station Automation, Upgraded En Route and Terminal Automation, Airport Surface Traffic Control, Wake Vortex Avoidance Systems, Area Navigation, Microwave Landing Systems, and Aeronautical Oceanic Satellites.(2) These features will improve the system and enable it to handle the forecast traffic loads in an effective manner at least into the late 1980's.

In looking beyond the 1980's, the Advanced Air Traffic Management System Study was concerned with formulating a system concept that could supplant the Upgraded Third Generation System. Consequently, as part of this Study, a Baseline System comprised of the above nine major elements as well as portions of the present system was projected as a point of departure for the AATMS Study. This Baseline System, considered the in-being system for the year 1982, incorporated 106 DABS sites, 1,100 VOR-DME sites, 1,100 VHF voice communication outlets, 20 Air Route Traffic Control Centers, 492 Towers, 407 automated radar terminal systems, deployment of the Microwave Landing System, Flight Service Station automation and other general automation enhancements.

Based on evolution from the Baseline System, the AATMS Study considered various concepts for a system of the 1990's. Figure 2 shows the structure of the AATMS Study, indicating the major system-level studies that were carried out and the contract resources that supported the Transportation Systems Center in the Study. The Study had three

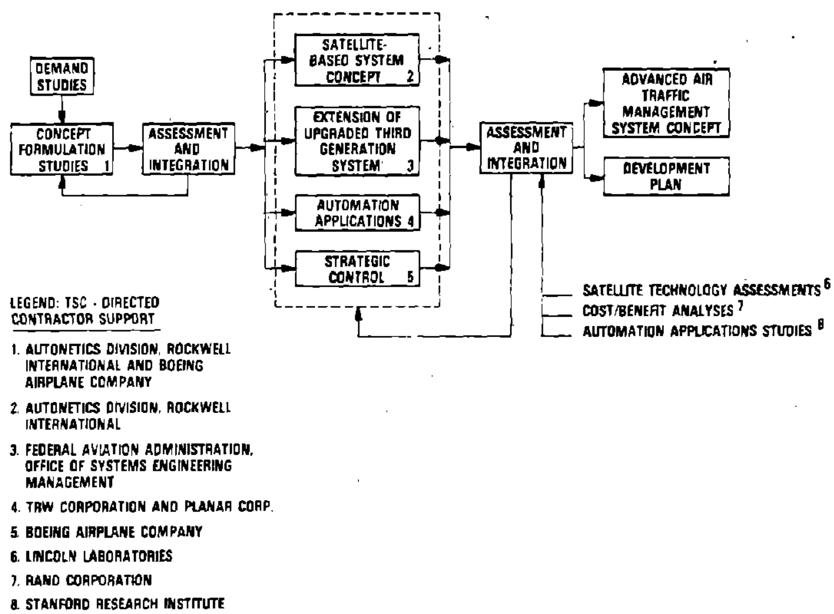

Figure 2. Advanced Air Traffic Management System Study Elements

basic phases. The first phase was the Concept Formulation or "clean sheet of paper" phase in which feasible concept alternatives were considered without imposing the traditional constraint of evolutionary transition from the in-being system. These studies, originally based upon demand estimates made by the Air Traffic Control Advisory Committee and later by refined estimates made by the Transportation Systems Center, considered the relative merits of ground, space, and airborne sensor systems and traffic control techniques for operations in the conterminous United States and contiguous oceanic airspace.[5,6] These alternative concepts were assessed in terms of capacity, safety, adaptability, technical risk, cost, compatibility, and schedule. After assessment and integration of the results, the following guidelines were used in subsequent system considerations and work in the other study phases:

- Continuation of the current philosophy of ground-based control of air traffic, modified by centralized and more extensive pre-planning of flights in regions of high traffic density.
- Centralization of the current distributed data processing network into two or three facilities.
- Use of satellites over the conterminous United States as the primary mechanization for surveillance, navigation, and communications, operating in conjunction with functionally integrated avionics in user aircraft.

In arriving at these guidelines no advantage was seen in abandoning the existing philosophy of centralized ground-based air traffic management. Further, control facility centralization offered the possibility of significant cost savings by reducing the labor-intensive aspects of the ATC system; savings augmented by the use of satellites which provide communication links at less cost than equivalent ground-based links.(7) In addition, satellites provide universal coverage over the area of interest, the conterminous United States.

In the second phase of the Study, shown in the middle of Figure 2, the foregoing guidelines led to the definition of a satellite-based system concept, including a plan to transition from the Upgraded Third Generation System.(7,8) As an alternative to such an All-Satellite System, an extension of the Upgraded Third Generation System into the projected environment of the 1990's was also defined: namely, the Extended Upgraded Third Generation System.(9) In the final Assessment and Integration phase of the Study these two system mechanization concepts were compared and the best features of each were used in determining the final AATMS mechanization concept. Since these alternatives were judged to be comparable in terms of performance (accuracy and functional capability), costs of facilities, equipment, operations and maintenance became determining factors in selecting the AATMS mechanization concept.

In addition to these system mechanization studies, two specific operational studies were conducted during the second Study phase.(10,11,12)

a) Investigation of automation levels beyond incremental improvement to the National Airspace System/Automated Radar Terminal System (NAS/ARTS).

b) Conceptual development of Strategic Control, a technique for use in high traffic density airspace, and characterized by aircraft flying pre-planned, conflict-free routes.

From these study efforts a specific Advanced Air Traffic Management System concept emerged. A concept derived from an evolutionary extension of the Upgraded Third Generation System, it builds on that system's equipment, facilities, and subsystems. As more fully explained and rationalized later in this Study Summary, Flow Control, Intermittent Positive Control, Metering and Spacing, Separation Assurance and Strategic Control are important techniques used in the concept to assist and control aircraft traffic flow. The concept employs highly centralized facilities to provide both control and flight information/assistance services. High levels of automation are used to minimize costs and to permit operators to serve as system managers, acting principally to resolve unusual control situations.

Specifically, the Advanced Air Traffic Management System concept resulting from the Study is characterized by the following:

- A constellation of satellites over the continental United States and contiguous oceanic regions for surveillance, navigation, and data link communications.
- Use of the Discrete Address Beacon System (DABS) in high density airspace regions to obtain aircraft location and identification information and to provide data link communications with aircraft.
- Continued use of the existing ground-based, very-high-frequency (VHF) communications network.
- Precision approach and landing guidance with Microwave Landing Systems and Instrument Landing System equipment.
- Centralized control facilities characterized by three en route centers, twenty terminal-hub control centers, and about 500 airport control centers. The remote control of traffic at some secondary airports will be improved and expanded.
- High levels of automation, with approximately 70% of the tasks being automated, thus permitting air traffic personnel to be more effective and efficient in the management of air traffic since machines carry out more of the routine functions.
- Flight planning, through the use of Strategic Control techniques, to augment the Upgraded Third Generation System techniques of Flow Control, Metering and Spacing, and Separation Assurance.

DABS and the VHF communication networks not only fill AATMS functional requirements, but also conform to the idea of an evolutionary system. The ATCAC recommendation concerning universal coverage is met by the use of satellites, while system capacity and safety requirements are met by techniques such as Strategic Control, in conjunction with increased terminal area navigational capabilities resulting from Microwave Instrument Landing Systems.

The centralization of control facilities as well as the increased levels of automation can provide major cost savings by constraining the continued growth in the number of required air traffic personnel in the face of increasing demands for air traffic services. These savings are expected to be additionally increased by using satellites for interfacility communications and reducing intersite communications dependence on costly ground-based equipment.

Achieving the benefits projected for the Advanced Air Traffic Management System, however, will require additional research and development effort. These activities, supplementing the present FAA Engineering and Development Program, were identified in the final phase of the AATMS Study and are discussed later in this Summary. Basically the research and development activities involve design studies and experiments for satellite-based systems for CONUS air traffic control, continued development of the Strategic Control Concept to enhance system capacity and safety, and extensive research and exploratory development into the introduction of high levels of automation into the air traffic system.

Discussion of Study Results and System Benefits

Current limitations in air traffic control system capacity directly due to the communications, navigation, surveillance or ground control systems should be resolved with the successful implementation of the Upgraded Third Generation System. In addition, it appears that Intermittent Positive Control will significantly reduce the potential for mid-air collisions. Development of a system allowing avoidance of dangerous wake vortices will allow safe reduction of aircraft separations in terminal areas, with resulting increased landing rates.

The demands on the system due to air traffic are expected to continue to grow in the 1980-90 period.[(3)] Air transportation system capacity in the 1990 time period will probably be limited by both the air traffic control system and the ability of major hub airports to handle traffic if no significant changes are made. The peak landing and takeoff rates will depend on the number and configuration of the available runways, runway and taxiway designs, weather, and aircraft traffic spacing constraints. Although one of the objectives of the Study was to assess the air traffic control system capacity in the 1990's, the Study was not defined to address the airport constraints. The Study concluded that the surveillance, navigation, and control elements of all the system concepts considered could be designed so that they do not constrain that inherent capacity.

The AATMS Study, in its final stages, considered two system concepts; the Extended Upgraded Third Generation System and an All-Satellite System. Both offered a number of attractive advantages and the AATMS Concept is a synthesis of the best aspects of the two. The AATMS concept mechanization elements for the surveillance, navigation and communication subsystems, include DABS, satellites, VOR, the existing communications net and the Microwave Instrument Landing Systems. The AATMS control concept derives from that projected for the Upgraded Third Generation System; namely, Flow Control, Metering and Spacing and Separation Assurance Techniques, and from a higher level control concept, Strategic Control. The automation features concerning level of automation and facility configuration result from generic studies that are not dependent on specific hardware configurations and are, therefore, applicable to each advanced air traffic management system concept alternative considered.

The application of advanced automation techniques for controlling aircraft holds high potential for reducing system operating costs. In the area of system operating and maintenance costs, the controller workforce is by far the dominating item, representing, in 1973, about 43% of the National Airspace System annual operating and maintenance costs.[13] The Federal Aviation Administration is presently evaluating state-of-the-art aids to increase controller productivity. Further research into decreasing the controller's involvement in "tactical" control of air traffic, modifying his function to one of system manager, should also be pursued. Current findings indicate that an optimum division of responsibility between the controller and machines might lead to automating about 70% of air traffic management tasks in the system.[10] This is a significant change from the present labor-intensive system which has only about 20% of the tasks automated, and the projected Baseline System that would have about 35% of the tasks automated.

The AATMS Automation Study considered automated system operations and the payoffs of high levels of automation. The potential annual savings in 1995 with a 70% level of automation (70% of the system tasks are performed by machine) appears to be in the range of $600 to $800 million in contrast to a hypothetical capability of continuing the present (Third Generation) concept of labor-intensive air traffic control to meet projected 1995 air traffic demand.[3,7,9,10] More realistically, if the automation techniques associated with the 35% level of automation assumed in the 1982 Baseline System of the AATMS Study are continued into the 1995 timeframe, the potential annual savings of the AATMS Concept (measured against the Baseline System) would be about

$200 million. The design of computer hardware and software systems to achieve these payoffs was not considered in depth in this Study. The present FAA development program addresses some of these problems.

The AATMS Concept also includes augmenting system management in high density airspace with Strategic Control Techniques, under which aircraft fly preplanned, conflict-free routes on a strict time schedule, as illustrated in Figure 3 for the high density terminal application. Strategic Control promises improved airspace utilization and arrival time control which, in conjunction with the higher precision terminal control provided by Microwave Instrument Approach Landing Guidance Systems and the Wake Vortex Avoidance System, will lead to increased airport capacities. Strategic Control was selected as an alternative to currently planned metering and spacing techniques in high density airspace because, although functionally equivalent, it offers a reduction in both air-ground communications and pilot and controller workloads. It also leads to more efficient airspace utilization and, when teamed with higher precision terminal control,

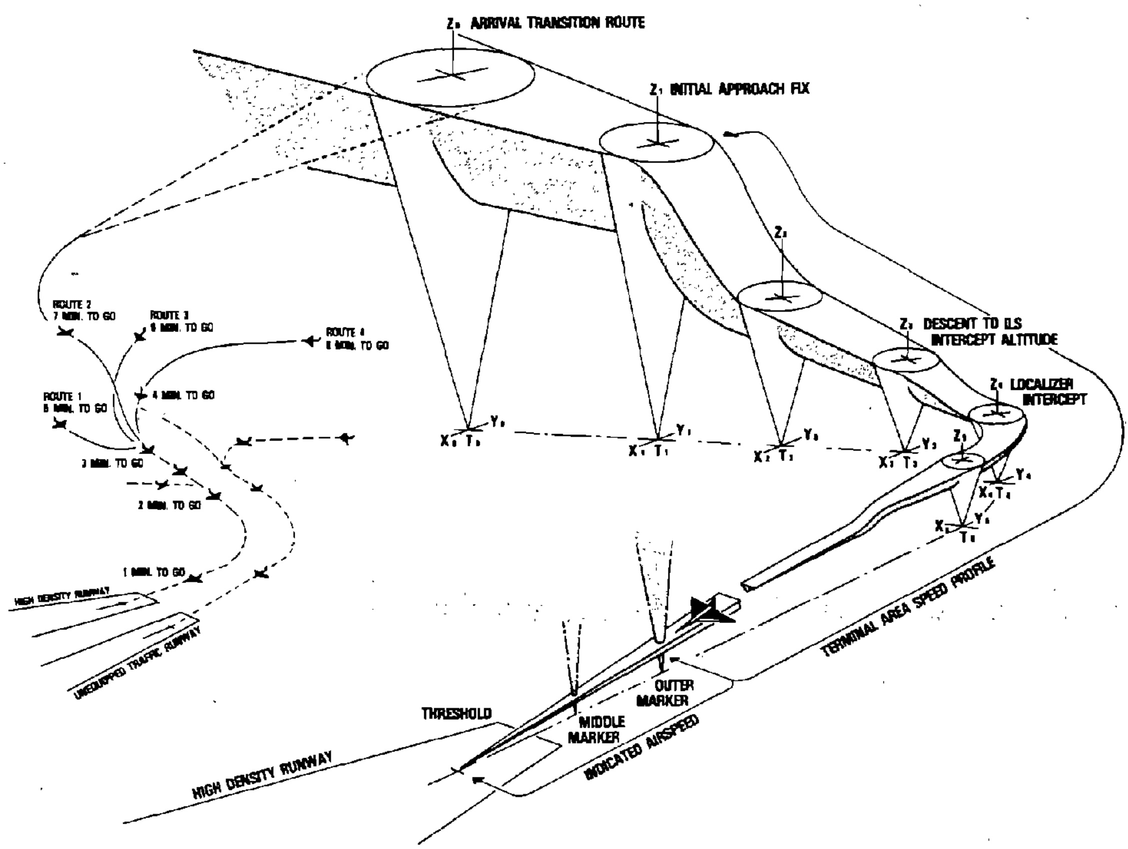

Figure 3. Strategic Control Arrival Trajectory

to increases in airport capacities. Strategic Control minimizes the time dispersion of aircraft, a way of saying that it manages their progess over many paths to arrive at some point such as a runway threshold in an orderly, scheduled fashion. Time dispersion reduction means more aircraft can be safety handled in a given time. This means fewer delays for a given demand level. The benefits of Strategic Control in reducing delays during IFR operations were estimated for one high density terminal (Los Angeles) as an example. Relative to the Baseline System's Metering and Spacing control concept, Strategic Control combined with an effective Wake Vortex Avoidance System appears to have potential for reducing the daily average number of delay minutes by a factor of ten.(12)

The study also indicates that centralization of control facilities for en route air traffic holds potential for reducing operations and maintenance costs over those of the current distributed facility network. Such savings result from equipment sharing, reduction in interfacility communication costs, and reduced personnel requirements related to a projected 1995 demand level. These perceived benefits are based upon comparative evaluation of the AATMS Concept with the Baseline System. However, the benefits due to centralized control facility configurations are not unique to just the configuration selected for the AATMS Concept. Centralization cost benefits however may not be achievable independently of the control techniques or the mechanization of the surveillance, navigation, and communication subsystem.

Satellites are a technically feasible and potentially cost-effective method of extending surveillance and data link coverage anticipated for the Upgraded Third Generation System to all airspace, and of providing universally available navigation signals. The potential cumulative savings of using satellites in the selected AATMS Concept for surveillance, data link communication, and navigation as compared to the Extended Upgraded Third Generation System used in the AATMS Study, is shown in Figure 4. This figure shows two cumulative cost curves associated with the surveillance, navigation, and data link communications mechanization elements of the Extended Upgraded Third Generation System Concept as defined in the AATMS Study, and the selected AATMS Concept. In the Extended Upgraded Third Generation System Concept, the number of DABS sites would be increased from 106 to 291 between 1982 and 1987; 310 special-purpose DABS sites (Mini DABS) are added between 1982 and 1995 to provide air traffic services to airports without towers, nearly all VOR sites are equipped with special DABS-based one-way ranging equipment (Synchro-DABS) and the number of VOR sites is increased to about 1,100 in 1995. In the selected AATMS mechanization concept no DABS or VOR sites are added beyond the 106 and 1025 sites, respectively, projected to be in place in 1982 as part of the Study's Baseline System; 13 to 15 satellites are

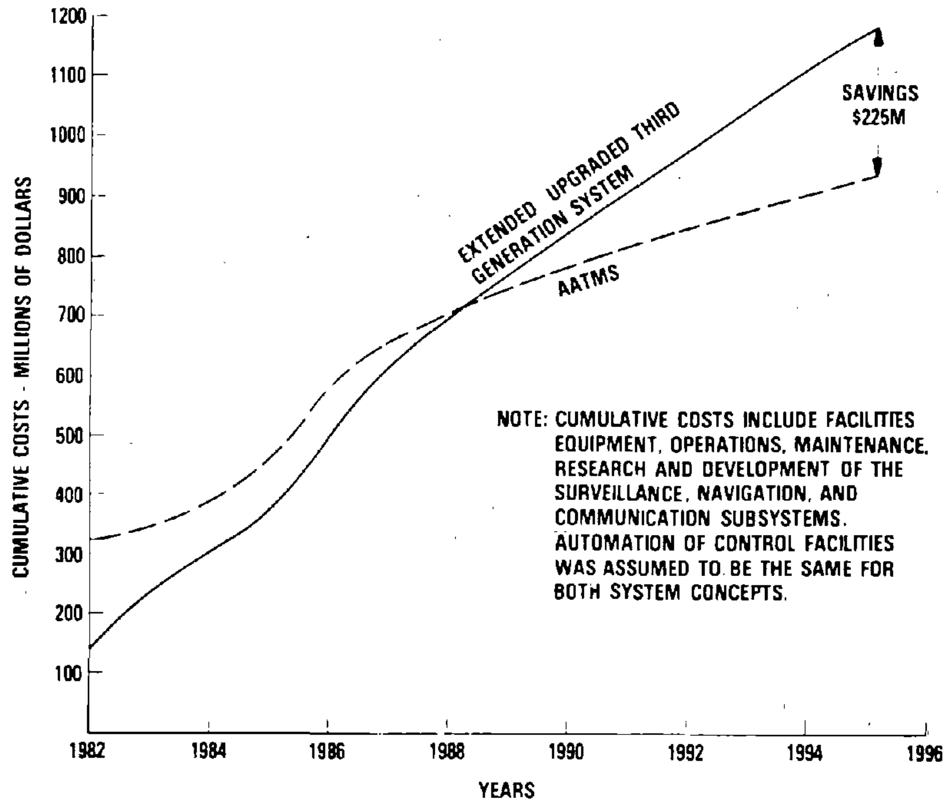

Figure 4. Relative Subsystem Cost - Advanced Air Traffic Management System and Extended Upgraded Third Generation System

placed in orbit during the 1985 to 1990 time period, and the number of VOR sites are incrementally reduced, during the transition phase, from 1,025 in 1990 to 300 in 1995. Initial costs reflected at the start of the plotted time period reflect the investment cost, up to 1982, of the surveillance, navigation, and data link communication equipment of the assumed Baseline System, and an estimated $175 million in expenditures for satellite developments and preliminary operational system deployment for the AATMS Concept. Figure 4 indicates that potential cumulative difference in costs would approximate $225 million by 1995. These include potential savings on facilities, equipment, operations, maintenance, research and development costs. Voice communications costs are not included in the curves since they are common to both system concepts. The space shuttle is assumed available to launch the satellite system elements. If, however, the cost savings associated with use of the space shuttle rather than conventional launch vehicles are not realized and full launch costs must be met, system emplacement costs increase. Cost savings would still be worthwhile, although reduced by about $100 million.

The initial deployment costs for the AATMS Satellite-DABS System would be offset, as contrasted to the Extended Upgraded Third Generation System, by operations and maintenance cost savings within about six years after completion of the research and development program and about three years after deployment of the satellites, again assuming existence of the space shuttle.

The Study also considered the user impact of going to a satellite-DABS system and concludes that functionally integrated, satellite-compatible avionics may be less expensive than the present incremental avionics complement, although research and development will be necessary to realize this potential, especially for general aviation aircraft. The satellite-DABS approach has a number of attractive features including the provision of approach service at all airfields, universal surveillance coverage resulting in the provision of separation assurance service without altitude or geographic constraints, and commonality with the oceanic surveillance and communication systems. Another important benefit is the complete coverage provided by satellites; a latent and minimum cost solution to providing extended coverage as demand for service increases or geographically shifts.

In realizing the attendant benefits from using satellites in the air traffic control system there may be some concern as to their vulnerability, especially in terms of their susceptibility to intentional electromagnetic interference or "jamming". The AATMS Study considered this problem and determined that an adequate range of solutions exist to assure little or no service degradation in all but the most severe electromagnetic environments. Future availability of the satellite-based system should, accordingly, be able to exceed that of contemporary equipment.

Strategic Control, by improving airspace utilization and arrival time control, reduces the random nature of airport arrivals. For the air carrier user, this translates into flight time and delay reduction and a consequent major fuel savings benefit. Figure 5 summarizes the benefits to both the general aviation and air carrier users.

Table 1 summarizes the major cost benefits derived from not only the use of satellites in the air traffic control system, but also from the introduction of the projected 70 percent level of automation, a centralized facility configuration, and Strategic Control techniques. Benefits are stated relative to the extension to 1995 of the Baseline System Concept assumed during the AATMS Study. The importance of automation developments is illustrated in this Table since this potential annual operations and maintenance cost saving is larger than that associated with facility centralization and satellites, although it is closely interrelated to these benefits.

USER	SYSTEM CHARACTERISTIC	USER BENEFITS
AIR CARRIER	REDUCED FLIGHT TIME AND DELAYS THROUGH USE OF STRATEGIC CONTROL TECHNIQUES	FUEL SAVINGS TIME SAVINGS
GENERAL AVIATION	TOTAL COVERAGE THROUGH USE OF SATELLITE	INTERMITTENT POSITIVE CONTROL SERVICE WITHOUT ALTITUDE OR GEOGRAPHIC CONSTRAINTS UNIVERSALLY AVAILABLE SERVICE INCLUDING APPROACH AND DEPARTURE AIDS AT ALL REMOTE AIRPORTS

Figure 5. Primary User Benefits of AATMS

TABLE 1. BENEFITS OF AATMS IN 1995 RELATIVE TO THE BASELINE SYSTEM

- $200 MILLION ANNUAL OPERATIONS AND MAINTENANCE COST SAVINGS WITH THE USE OF ADVANCED AUTOMATION TECHNIQUES
- $100 MILLION ANNUAL OPERATIONS AND MAINTENANCE COST SAVINGS DUE TO CONTROL FACILITY CENTRALIZATION
- $50 MILLION ANNUAL OPERATIONS AND MAINTENANCE COST SAVINGS DUE TO SATELLITE/DABS SENSOR CONFIGURATION
- REDUCED SUBSYSTEM FACILITY AND EQUIPMENT (IMPLEMENTATION) COSTS DUE TO UNIVERSAL COVERAGE PROVIDED BY SATELLITES
- INCREASED AIRPORT CAPACITY AND MORE EFFICIENT HIGH DENSITY POSITIVE CONTROL AIRSPACE UTILIZATION DUE TO USE OF STRATEGIC CONTROL IN PLACE OF TACTICAL CONTROL MODES

The time phasing implementation strategy of the introduction of the various features of the AATMS Concept is shown in Figure 6. Based on results of the research and development program associated with the Advanced Air Traffic Management System Program shown in Figure 7, a decision on system implementation could be made by 1984. The ongoing Upgraded Third Generation System program was assumed to have resulted in the

Baseline System used in this Study by 1982; 106 DABS sites deployed in high density terminal and en route air space regions, 1,025 VOR sites and about 1,100 VHF voice communication outlets. Between 1985 and 1990, 13 to 15 satellites would be used to supplement the Baseline System to complete the AATMS surveillance, navigation, and data link communications mechanization configuration. Satellite data would be distributed initially on existing interfacility communication lines to the facility having jurisdiction over aircraft flying with satellite-based avionics. Control facility modernization, including upgrading of the facility automation, would begin in 1986. The centralized en route facilities would be operational in 1990, while the Terminal-Hub and Airport Control Centers would continue to be upgraded and brought into operational status. By 1995, all AATMS facilities would be operating. Figure 6 also shows the cost associated with mechanization and facility implementation and operation. An estimated $1,200 million is required between 1982 and 1995 for AATMS implementation. Thereafter, operations and maintenance costs for the mechanization elements and facilities and personnel is estimated at $720 million per year. Estimated savings reflected by this last figure are expected to pay back the implementation costs in about a five-year period.

IMPLEMENTATION/COST ELEMENT	IMPLEMENTATION SCHEDULE (FISCAL YEAR) 82 83 84 85 86 87 88 89 90 91 92 93 94 95	1982-1995 F&E COST [1]	1995 O&M COST [2]
APPROVAL FOR AATMS IMPLEMENTATION BASED ON R&D PROGRAM RESULTS	△	-	-
MECHANIZATION SUBSYSTEMS			
● SATELLITES	10-15 SATELLITES DEPLOYED △ — △	$140	$20
● DABS	△ 106 DABS SITES PREVIOUSLY DEPLOYED IN BASELINE SYSTEM	-	5
● VOR NAVIGATION SYSTEM	△ 1025 VOR SITES PREVIOUSLY DEPLOYED IN BASELINE SYSTEM; △ PHASE DOWN TO 300 VOR SITES △	-	5
● VHF VOICE COMMUNICATIONS SUBSYSTEM	△ 1100 VHF VOICE COMMUNICATIONS OUTLETS PREVIOUSLY DEPLOYED	-	30
FACILITIES/AUTOMATION/ OPERATING PERSONNEL			
● CONTINENTAL CONTROL CENTER	△ CONSTRUCTION/ CKECKOUT-1 SITE △	$30	$20
● REGIONAL CONTROL CENTER	△ CONSTRUCTION/ CHECKOUT-2 SITES △	100	60
● TERMINAL-HUB CONTROL CENTERS	△ CONSTRUCTION/CHECKOUT-20 SITES △	300	330
● AIRPORT CONTROL CENTERS	△ CONSTRUCTION/CHECKOUT- 492 SITES △	630	250
COST TOTALS		$1200	$720

1. F&E (FACILITIES AND EQUIPMENT) COSTS REFER TO THE INITIAL EXPENSE TO OBTAIN, INSTALL AND CERTIFY A PARTICULAR SYSTEM ELEMENT. NO DEVELOPMENT COSTS ARE INCLUDED.

2. O&M (OPERATIONS AND MAINTENANCE) COSTS ARE THE RECURRING ANNUAL EXPENSES TO OPERATE, MAINTAIN, RELOCATE, AND MODERNIZE EACH SYSTEM ELEMENT. OPERATING/CONTROL PERSONNEL COSTS APPEAR IN THIS COST FACTOR FOR FACILITIES.

Figure 6. AATMS Implementation Schedule and Costs (Costs in Millions of 1973 Dollars)

There are, of course, hurdles to be crossed prior to implementation of AATMS including the need for research on various elements to more fully determine economic and technical feasibility. The use of satellites for this application, for example, has not been fully demonstrated and such feasibility must be investigated and demonstrated. The determination of methods and levels of automation required for system optimization also calls for research and development efforts; as does the determination of the optimum facility configuration and associated reliability ramifications. Although the Strategic Control Concept promises improved airspace usage by arrival time control, actual methods of optimum implementation must be determined. In particular, better ways of providing accurage route-time navigation to all users must be developed, as well as economically acceptable avionics.

Recommended Research and Development

A system for air traffic management employing satellites, beacons (DABS), centralized control facilities, high levels of automation and Strategic Control techniques is considered attainable. Additional decision-supporting research and development is required in the FY 1976-1984 time period if a Fourth Generation System is to be operational by the mid-1990's.

This research and development would augment current FAA programs and, in addition, would include feasibility studies to further verify certain economic and technical assumptions concerning satellites, automation, control facility centralization, and Strategic Control. In the satellite area, results of ATS-6 and AEROSAT programs will influence what research needs to be done in terms of CONUS satellite applications. Automation and Strategic Control research, discussed below, may require modification as the results of the development program for the Upgraded Third Generation System are obtained in the areas of upgraded automation and Metering and Spacing.

The following research and development efforts are required and are more fully described in the AATMS Study Technical Summary.

(a) Experiments conducted with a network of satellites providing coverage of the conterminous United States are required to verify and further evaluate mechanization approaches for surveillance, navigation and communications over this region, to extend the technology data base to be gotten from currently planned Application Technology Satellite (ATS-6) and the Aeronautical Satellite (AEROSAT) programs, and to validate the economic feasibility of satellites in this application. Development of special avionics compatible with the proposed satellite elements, is also required for purposes of tying the aircraft more directly into the control function. Such avionics development would include airborne data processing equipment and special antennas and transmitters.

(b) Research and exploratory development is required to demonstrate that the high levels of automation incorporated in this system concept are functionally, operationally, and economically achievable. In addition, the development of a data base for the design of an advanced automation system is necessary. To support these efforts functional requirements must be determined and used to define computer systems sizes, architectures and interfaces, software requirements, efficient facility configurations, and appropriate man-machine interfaces.

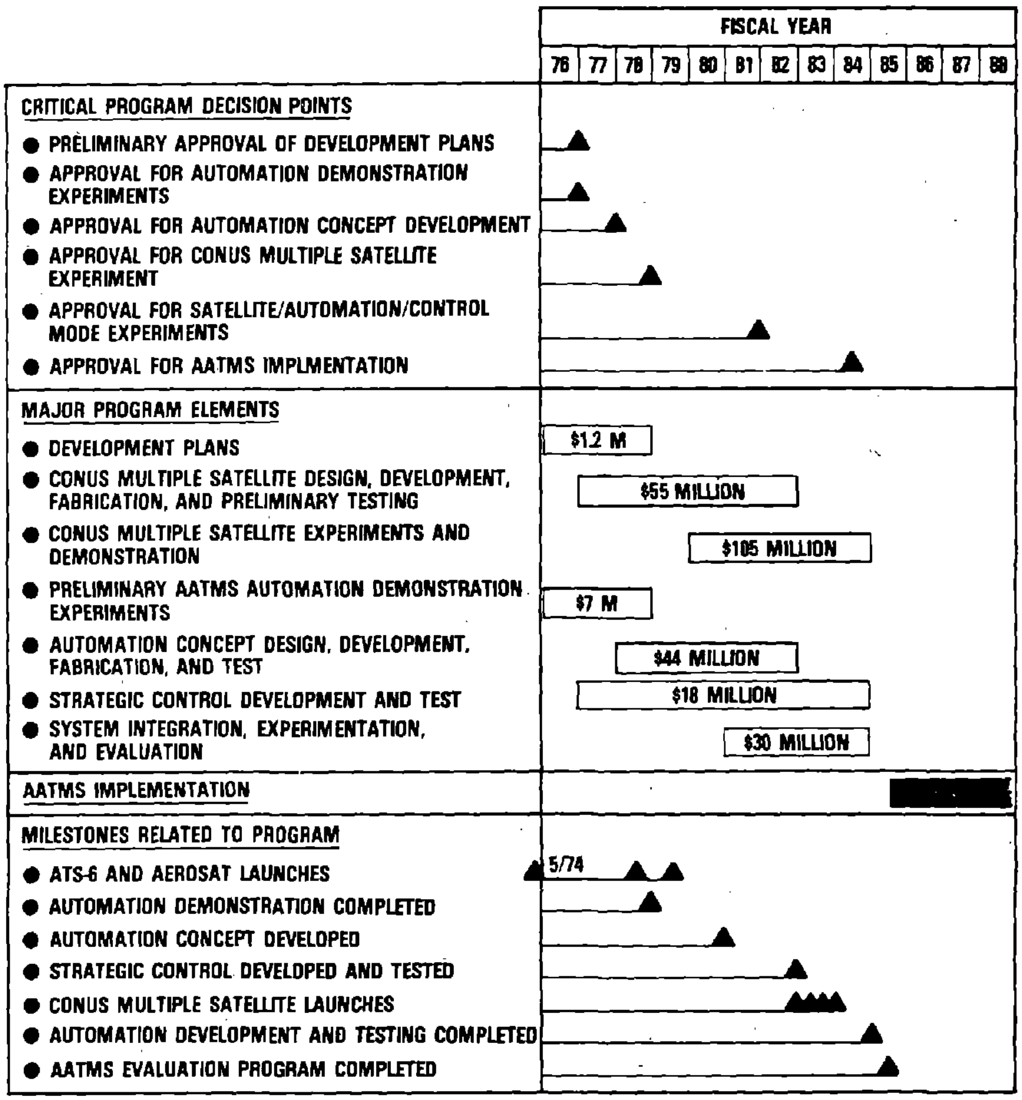

Figure 7. Advanced Air Traffic Management System Development Program

The strategy for coping with failure of the automated and man-operated portions of the system must be demonstrated in order to ensure a high order of safety to all users, and acceptability to the control workforce.

(c) Research is required on better ways to effectively control arrivals at airports, including the provision of combined route (three dimensional) and time navigation capability in high density terminal airspace. Further work to define the Strategic Control Concept, including a comparative assessment with advanced Metering and Spacing techniques, is also necessary.

The following specific research and development should be initiated in FY-1975 and 1976 in order to take advantage of planned and ongoing related programs, and to develop the information on which timely implementation decisions can be made.

- Experiments in conjunction with the currently planned ATS-6 and AEROSAT satellite programs to characterize the aircraft-satellite channel in terms of noise and ionospheric effects, both of which influence system position accuracy. Concurrently, an assessment of the ground-based system and airborne hardware and software required to process satellite-derived signals should be made.
- Development of low-cost, satellite-compatible prototype avionics focusing on advanced, but potentially low-cost components such as surface acoustic wave devices and techniques for improving reliability, e.g., integrated avionics rather than today's multiple element avionics.
- Design studies of system automation including more effective fail-operational concepts, analysis of alternative centralized air traffic control facility designs, feasibility demonstration of automatic air traffic operations, and design analysis and evaluation of advanced air traffic control man-machine interfaces.
- Flight tests under simulated operational conditions to evaluate aircraft capabilities of flying specified routes on pre-set schedules, and the impact that application of such capabilities would have on both the air traffic control system and on users.

Figure 7 summarizes the critical decision points related to the AATMS Program and indicates the timing and costs associated with the various research and development efforts. The total research and development program recommended by this Study is estimated at about $260 million (in 1973 dollars) and spans ten years.

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1. INTRODUCTION

The Advanced Air Traffic Management System (AATMS) Study was conducted by the U.S. Department of Transportation, Transportation Systems Center, under the sponsorship of the Office of the Assistant Secretary for Systems Development and Technology. The Study was initiated by the U.S. Department of Transportation in 1970 in response to recommendations by the Department's Air Traffic Control Advisory Committee which published its findings in 1969.(1) The Committee was formed in 1968 to address the pressing need for an improved air traffic control system. The Committee's recommendations formed the basis for much of the present FAA Upgraded Third Generation Air Traffic Control System Engineering and Development Program, including the discrete address beacon system, intermittent positive control, and upgraded automation of ATC facilities.(2) However, the Committee was concerned with potential deficiencies in capacity and coverage of this system in the 1990 time frame, and with increasing system operating and maintenance costs. Consequently, the Committee recommended that "...A Fourth Generation System should be in orderly development which can supplant the upgraded Third Generation System". In its recommendations the Committee established system and technology priorities for the formulation and definition of an advanced concept of air traffic management:

> "...The Committee's review of future possibilities identified space and computer technology as offering the greatest potential advantages."

In acting on the Committee's recommendations, the U.S. Department of Transportation initiated a four-year, multi-phase study of concept formulation to consider future system alternatives; concept definition to consider specific future system features in detail and develop a supporting technology base; and evaluation to support selection of a preferred advanced air traffic management system concept and recommendations for a research and development program. Study criteria were that the selected concept handle the projected air traffic estimated for the 1990's, evolve from the Upgraded Third Generation System now in development, maintain system safety, be cost effective, and pose minimal technological risk in concept realization.(3) The resulting concept for a potential Fourth Generation System is preferably called the Advanced Air Traffic Management System (AATMS). This Report describes the synthesis of the AATMS Concept and describes the decision-supporting research and development activities recommended for its attainment.

Figure 1-1 shows the structure of the AATMS Study, indicating the major system level studies that were carried out and the contract resources that supported the Transportation Systems Center in the Study. The Study had three basic phases. The first phase was the Concept Formulation, or "clean sheet of paper", phase in which feasible concept alternatives were considered without imposing the constraint of evolutionary transition from the in-being system. These studies, summarized in a separate report, considered the relative merits of ground, space, and airborne sensor systems and traffic control techniques for operations in the conterminous United States and contiguous oceanic airspace. These alternatives were assessed in terms of capacity, safety, adaptability, technical risk, cost, compatibility, and schedule.[14] A necessary quality of the alternatives of this phase and also those of the Concept Definition study phase, was their ability to handle projected 1995 air traffic demand. This Study originally used demand estimates made by the Air Traffic Control Advisory Committee, but later refined them in view of new inputs. Section 2 of this Report summarizes the air traffic projections made in this Study.

In the Concept Definition Phase of the Study, shown in the middle of Figure 1-1, two candidate system concepts were studied: an All-Satellite System concept and a concept

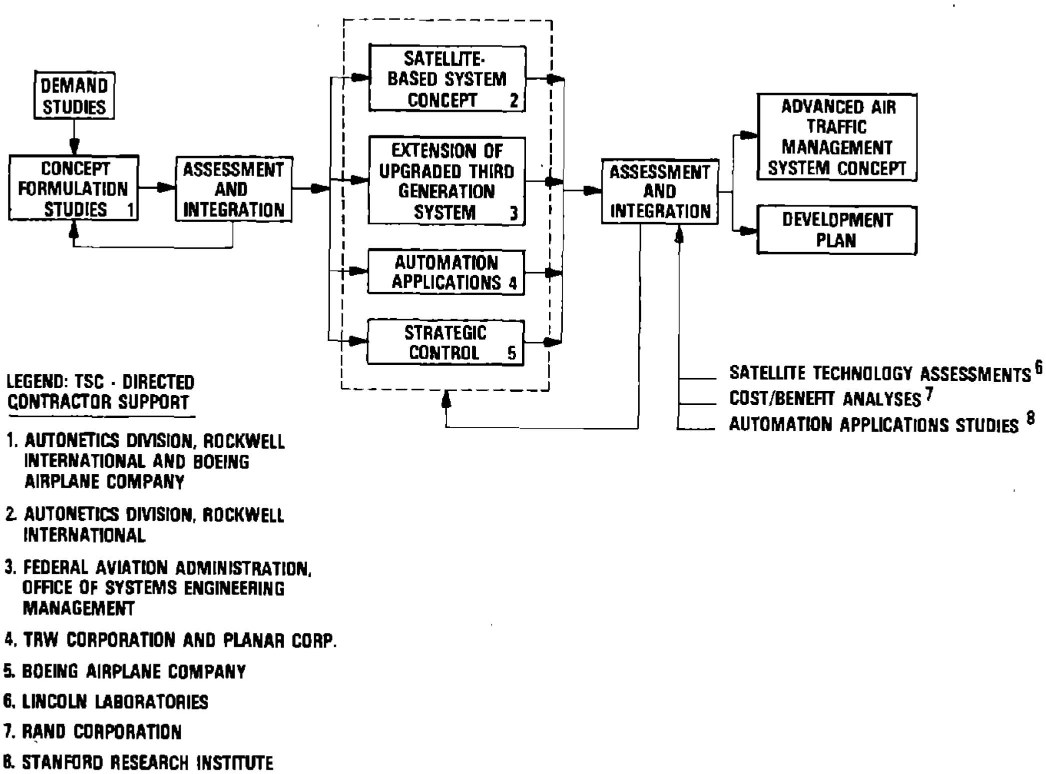


Figure 1-1. Advanced Air Traffic Management System Study Elements

based on extensions of the Upgraded Third Generation System.[7,8,9] These two candidate systems are described in Section 4. These candidate systems and AATMS discussed below were to transition to a 1995 system from an assumed 1982 Baseline System. This Baseline System is described in Section 3. In addition to the candidate system studies, two specific operational studies were conducted during the second Study phase.[10, 11, 12]

a. Investigation of automation levels beyond incremental improvement to the National Airspace System/Automated Radar Terminal System (NAS/ARTS).

b. Conceptual development of Strategic Control, a technique for use in high traffic density airspace, and characterized by aircraft flying pre-planned, conflict-free routes.

From these study efforts a specific Advanced Air Traffic Management System Concept emerged in the third phase of the Study which consisted of synthesis and evaluation. Derived from an evolutionary extension of the Upgraded Third Generation System, AATMS builds on that system's equipment, facilities, and subsystems. Section 5 describes the system concept, its synthesis and the implementation approach. Section 5 also assesses system features. Section 6 describes the recommended research and development activities, supplementing the existing FAA Engineering and Development Program, required to gather decision-supporting information on an Advanced Air Traffic Management System and proposes a plan for its timely development in relation to the implementation approach, presented in Section 5, for operational application by the 1990's.

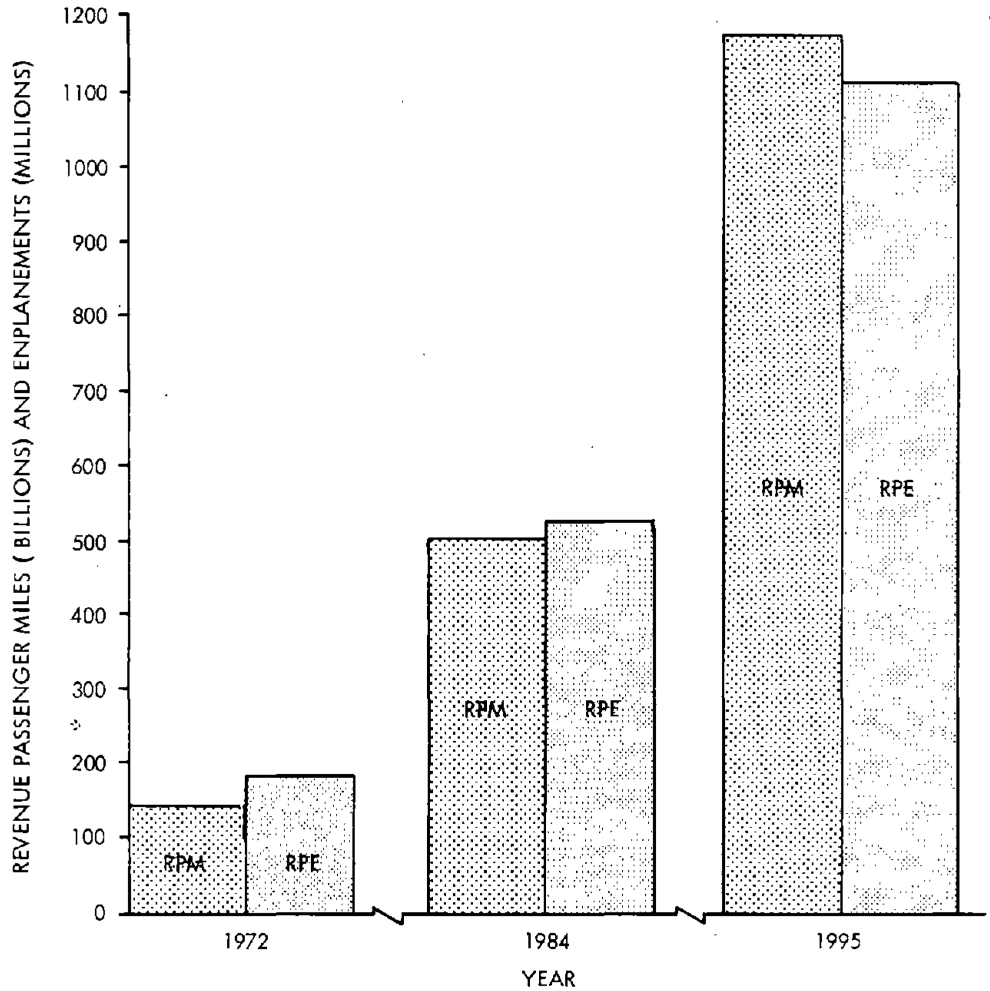
2. AIR TRANSPORTATION GROWTH INTO THE 1990's

In order to do technical and economic analyses during this Study, an estimate of the future demand for air transportation was required[3]. This section summarizes the aviation forecasts, used to estimate the 1995 air traffic environment which, in turn, was used in system concept design to determine subsystem performance requirements. The demand estimates, or forecasts, of air transportation growth in this Study include:

- Public demand for commercial air transportation
- Air fleet size and characteristics
- Peak traffic loading on the ATC system
- Numbers of airports and hubs
- Capacities of future busy airports

The air traffic projections presented here are based on trends forecast by the FAA or found in historical data. Some trends involve such socioeconomic factors as population growth, consumer spending habits, and the gross national product (GNP).[15] Validity of the forecasted demand is highly dependent on the continuing validity of these trends. In addition, although it is too early to assess the long term aviation impact of the Nation's energy balances, it is apparent that changing patterns of fuel availability and consumption will have an impact on aviation traffic levels in the decades ahead. However, the demand projections described in this report assume that an adequate supply of aviation fuel will continue to be available at reasonable prices. Noise or emission control standards may also affect demand forecasts. Lacking definitive information, as in the fuel question, about the impact of these factors on the long-term trends, no specific impact on the forecast used in this Study has been determined. However, both low and high variations to the nominal estimate presented here were assumed.[3]

The public demand for commercial air transportation is projected on the basis of two related quantities: revenue passenger miles (RPM), and revenue passenger enplanements (RPE). The former is the number of miles per year flown by airline passengers; the latter is the number of paying passengers, annually, who embark on commercial flights. The forecasts for domestic and international flights, shown in Figure 2-1, are made periodically by the FAA, which considers such parameters as the GNP, revenue yield per passenger mile, aircraft and seat availability, fare and route structures, passenger trip lengths, and



Source: References 16 and 17

Figure 2-1. Revenue Passenger Miles (RPM) and Enplanements (RPE) By Year a number of socio-economic factors, such as income levels and population distribution*.[16] Between 1972 and 1995, the number of revenue passenger miles and revenue passenger enplanements are expected to increase by factors of about eight and six, respectively. These increases impact on future ATC system concepts in terms of the number and type of aircraft which must be put into operation to adequately meet this demand, as well as the number of operations (or aircraft usage) required to service this demand.

The size of the air carrier fleet necessary to meet the forecast RPE's and RPM's can be estimated. The full impact of the demand upon the air traffic management system, however, is only realized when the forecasts for general aviation and military aircraft are included in the analysis. These are considered below.

The FAA ten year forecast of air carrier aircraft is based on the number of each type of aircraft in inventory or on order, data on how the carriers propose to meet their demand requirements, and operating and performance data for each type of aircraft.[16] This Study extended the FAA air carrier forecasts to 1995 by considering the rate of air carrier fleet growth, the trend to an all-jet fleet, and the revenue passenger miles and revenue passenger enplanements that the air carrier fleet will have to accommodate. The air taxi** segment of the fleet was assumed to be integrated with the air carrier fleet sometime between 1984 and 1995. It is assumed part of the general aviation fleet prior to 1984. The 1995 estimated air carrier operations (takeoffs and landings) were based on estimates of average aircraft utilization and trip length figures and on trends determined from Civil Aeronautics Board Data.[17] These results are presented in Table 2-1.

The general aviation fleet size estimate was based on its historically high correlation with the GNP, whose forecast annual growth rate is 3.8 percent from 1984 to 1995, and 4.3 percent from 1973 to 1984.[15] Extending from the 1972 fleet size of 131,000 aircraft, 217,000 aircraft are projected by the FAA for 1984, and 335,000 are projected by this Study for 1995. The forecast number of operations for general aviation aircraft was based on trends in annual utilization, average flight duration, and the distribution of flight time

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*International U.S. flights in this forecast include those made by U.S. certificated air carriers and which originate or terminate within the United States.

**Air Taxi aircraft are those used by the holder of an Air Taxi Operating Certificate. They are generally short or ultra-short haul aircraft designed for operation from short runways.

TABLE 2-1 FLEET SIZE, ANNUAL OPERATIONS, AND PEAK INSTANTANEOUS AIRBORNE COUNT BY YEAR

	1972	1984	1995
Fleet Size	153,600	240,600	362,000
Air Carrier	2,600	3,600	7,000*
General Aviation	131,000*	217,000*	335,000
Military	20,000	20,000	20,000
Annual Operations (Millions per year)	140	210	327
Air Carrier	10	15	34*
General Aviation	90*	155*	253
Military	40**	40**	40**
Peak Instantaneous Airborne Count	14,890	23,570	37,000
Air Carrier	1,980	2,740	5,350*
General Aviation	12,050*	19,970*	30,800
Military	860	860	860

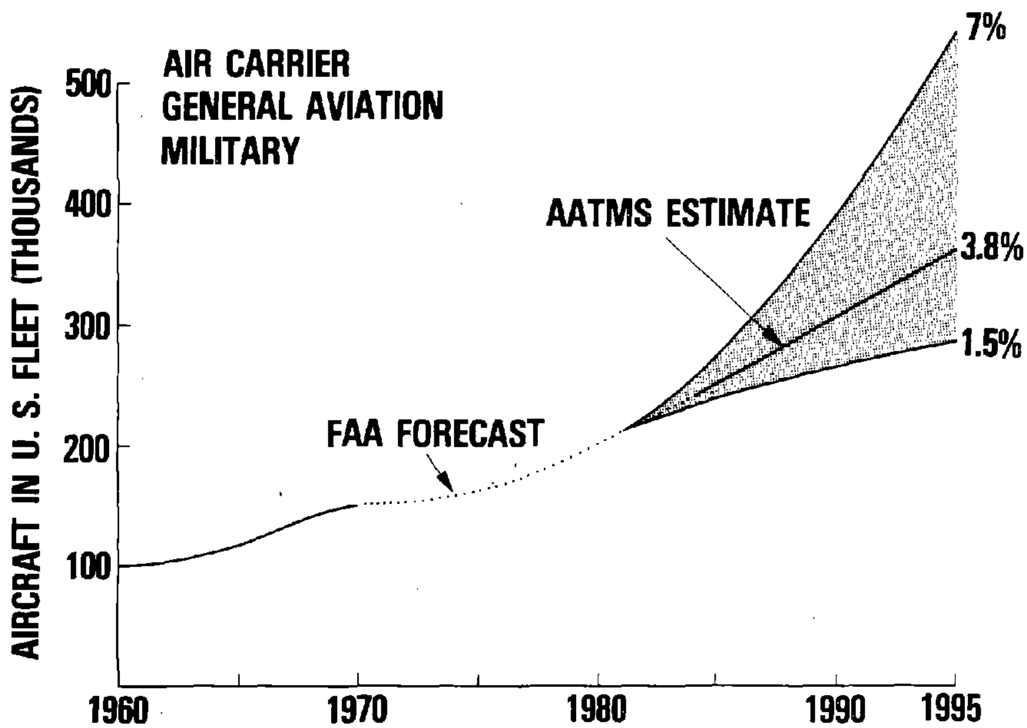
*Includes air taxi fleet, operations, or count, as appropriate
**Includes three million operations at civil airports

Source: References 1, 5, 6, 7, 9, and 15.

between itinerant and local use. Table 2-1 shows the growth in general aviation operations from 1972 (90 million) to 1995 (253 million).

The military fleet and its activity within CONUS are expected to remain nearly constant over the next two decades.(1) These estimates are shown also in Table 2-1. Figure 2-2 illustrates the growth projected by this Study for the combined air carrier, general aviation, and military fleet. The high and low estimates for fleet size are also indicated on the curve with the projected growth rates.

The peak instantaneous airborne count (PIAC) for 1995 represents a demand measure crucial to the design of future air traffic management systems. This count represents the number of aircraft that are expected to be airborne over CONUS during the busiest instant of time in the year. Consequently this number represents the predicted maximum loading on the system and is representative of the actual number of aircraft the system must be capable of handling at any one time. Peak instantaneous airborne count, (PIAC), estimates for 1995 were made for both terminal and en route airspace considering the major



Source: References 3 and 16

Figure 2-2. Airfleet Growth Projections

air route structure and expected number of flights on each route, fleet size and characteristics, revenue passenger miles and revenue passenger enplanements, the type of flight (VFR, IFR, itinerant, and local), and various terminal area and airport characteristics.[9] The nominal PIAC projections for 1972, 1984 and 1995 are given in Table 2-1. A verifiable rule of thumb, based on study data, for estimating the overall PIAC is to take 10 percent of the total aircraft fleet; of this overall PIAC, approximately 60 percent represents the count in terminal airspace.[3]

This Study also forecast the number of hubs and airports in 1995. A hub encompasses the airports and terminal and transition airspace associated with a metropolitan area. The number of hubs was forecast based on an analysis of present hubs including their share of the revenue passenger enplanements and their ability to handle the future demand. Table 2-2 presents the hub classification criteria, the number of hubs in 1972, and those forecast for 1984 and 1995. The number of airports was projected to 1995 in accordance with the activity level classification scheme defined by the National Aviation System Policy Report.[9, 18] Table 2-3 shows the classification scheme and the number of airports for 1972, 1984 and 1995.

These forecasts are based on the present and forecast number of yearly operations expected for each airport without consideration of any growth limitation factors, as well as on the growth trend in the number of airports (National Aviation System (NAS) and other). There is a trend, evident in Table 2-3 and due to increased numbers of operations and enplanements, towards increasing numbers of primary and high density airports.

TABLE 2-2 HUB CLASSIFICATION CRITERIA AND NUMBER BY YEAR

Hub Classification Criteria			Number by Year		
Size	Percent of Nation's RPE in Hub	Approximate Number of RPE's in Hub in 1995	1972	1984	1995
Large	More than 1%	10 Million RPE	23	24	25
Medium	1/4% to 1%	2.5 to 10 Million RPE	37	38	39
Small	1/20% to 1/4%	0.5 to 2.5 Million RPE	80	75	70

Source: References 9 and 18.

TABLE 2-3 CIVIL AIRPORT CLASSIFICATION CRITERIA AND NUMBER BY YEAR

Airport Category	Classification Criteria		Number of Airports		
	Annual Passenger Enplanements	Annual Aircraft Operations	1972	1984	1995
Primary	More than 1,000,000		41	81	133
High Density		350,000 or more	9	27	103
Medium Density		250,000 to 350,000	15	27	19
Low Density		Less than 250,000	17	27	11
Secondary	50,000 to 1,000,000		385	601	784
High Density		250,000 or more	27	129	243
Medium Density		100,000 to 250,000	106	287	342
Low Density		Less than 100,000	162	185	199
Feeder	Less than 50,000		2600	3100	4000
High Density		100,000 or more	50	200	400
Medium Density		20,000 to 100,000	750	900	1500
Low Density		Less than 20,000	1800	2000	2100
Total NAS Airports			3026	3782	4917
Other Airports			9000	11000	14000
Total U.S. Airports			12026	14782	18917

Source: References 9 and 18.

The impact of future aviation demand on the air traffic management system has been estimated based on a study of 29 of the busiest hub airports for 1995.[9, 19] These hub airports in 1971 accounted for 67, 15, and 13 percent of the nation's terminal area delays incurred by air carrier, general aviation, and military users, respectively. The maximum number of 1995 busy hour operations (takeoffs and landings) handled by each airport, i.e., their saturation capacities, was estimated assuming modest changes in the present runway configurations, approach control delivery precision, and flight control safety rules to alleviate congestion problems. The assumed changes included construction of high speed turnoffs, improved taxiways, and both dual-lane and parallel runways. They also included equipment for improving accuracy of threshold delivery times, and for resolving the wake turbulence problem, thereby allowing reduction in the longitudinal spacing between landing aircraft. It has been estimated that these changes can increase individual airport capacity in excess of 165 percent compared to the present system.[1] The saturation capacities, derived for the 29 airports based on these assumptions, were compared to the demand estimates for 1995.[9, 19, 20] The results showed that 12 of the 29 airports will experience busy hour demand* exceeding the projected busy hour saturation capacity, even with the above assumed system and airport improvements. Table 2-4 presents the comparison for all 29 airports.

In summary, this Study has forecast a growth in the demand for air transportation between 1972 and 1995, that will result in the following:

- An eight-fold increase in the number of revenue passenger miles.
- A doubling of the air carrier fleet (excluding air taxi).
- A 150 percent increase in the size of the general aviation fleet.
- A tripling of the number of general aviation operations.
- An increase in the number of IFR operations by a factor of 13.
- A 50 percent increase in the number of civil airports.
- A 150 percent increase in the number of aircraft airborne at the peak instant of time (about a third of these will be IFR in 1995).

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*The number of aircraft expected to request permission to takeoff or land during the busiest hour of operation at each airport.

TABLE 2-4 1995 DEMAND AND CAPACITY AT 29 OF THE BUSIEST AIRPORTS

Airport	Busy Hour Capacity (Operations Per Hour)	Busy Hour Demand (Operations Per Hour)
*Atlanta	182	272
*Baltimore	90	112
*Boston	90	166
*Chicago-O'Hare	185	273
*Chicago-Midway	82	84
Cleveland	157	90
Dallas	255	210
Denver	178	143
Detroit	189	108
Honolulu	162	142
Houston	158	102
Kansas City	126	96
Las Vegas	142	112
Los Angeles	255	214
Miami	255	168
Mineapolis	158	95
*Newark	153	155
New Orleans	152	91
New York-J.F. Kennedy	184	178
*New York-LaGuardia	90	159
Oakland	175	142
*Philadelphia	155	170
*Pittsburgh	146	146
St. Louis	156	141
*San Diego	63	112
*San Francisco	156	202
Seattle	156	103
Washington-Dulles	183	85
*Washington-National	90	131

*Airports at which demand is expected to exceed capacity.

Source: References 9, 12, 19, and 20.

3. BASELINE SYSTEM

The AATMS Study was concerned with defining a system concept capable of meeting the demands that might be placed on the air traffic control system during the 1990 time frame and beyond. This section describes the assumed 1982 Baseline System, defined at the beginning of the Study to provide a basis against which alternative system concepts could be evaluated in developing the final AATMS Concept definition and transition approach.

Although derived from the Upgraded Third Generation System development program, the Baseline System described in this Report as an assumed 1982 system should not be construed to represent FAA implementation plans as several elements are still in various stages of development. However, the features of the Upgraded Third Generation System, currently under research and development, have been defined.[2,9] These include the Discrete Address Beacon System (DABS), Intermittent Positive Control (IPC), Microwave Landing System (MLS), Airport Surface Traffic Control (ASTC), Aeronautical Oceanic Satellites (AEROSAT), Area Navigation (RNAV), Wake Vortex Avoidance Systems (WVAS), Flight Service Station (FSS) Automation, and upgraded en route and terminal area automation (NAS/ARTS).[2] These features are illustrated in Figure 3-1. The general characteristics for each are known. Thus, it was possible to synthesize an assumed Baseline System from these elements with the capabilities anticipated for the Upgraded Third Generation System. This Section describes the 1982 Baseline System in terms of surveillance, navigation, and communications equipment, avionics, control facilities and automation, air traffic control techniques, and system operating modes.

3.1 SURVEILLANCE, NAVIGATION, AND COMMUNICATION EQUIPMENT

The surveillance, navigation, and communication subsystems of the 1982 Baseline System retain substantial portions of the Third Generation ATC System now in existence.[2,9] Table 3-1 summarizes the equipment complement and presents some of the pertinent operating characteristics of these subsystems.

The Airport Surveillance Radar/Air Traffic Control Radar Beacon System (ASR/ATCRBS), and Air Route Surveillance Radar/Air Traffic Control Radar Beacon System (ARSR/ATCRBS), would continue to serve as the primary means for surveillance at low density airports, and in low traffic density en route airspace, respectively. Range and azimuth information for aircraft navigation purposes would be derived primarily from the existing VHF Omni-Range (VOR), Distance Measurement Equipment (DME), and VOR Tacan

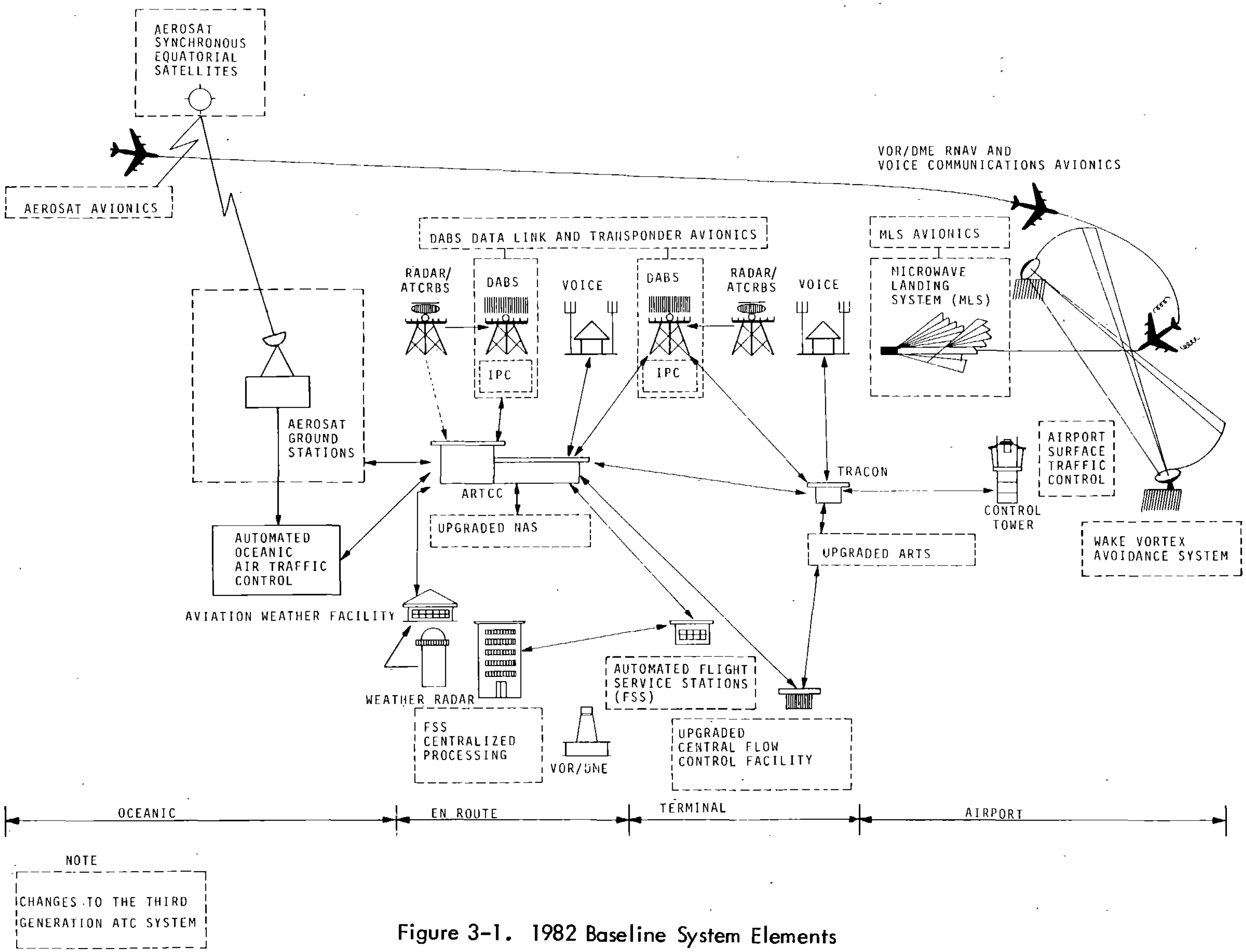

Figure 3-1. 1982 Baseline System Elements

TABLE 3-1 1982 BASELINE SURVEILLANCE/NAVIGATION/COMMUNICATION SUBSYSTEMS

		Surveillance	Navigation	Data Communication	Voice Communication
System Equipment	Terminal	Airport Surveillance Radar-ASR/ATCRBS(268) Discrete Address Beacon-DABS (70 Colocated)	Terminal VOR/DME(133) Precision VOR/DME(70)	Integrated with DABS Surveillance	Ground-Based Remote Trans/Rcvr -RTR (552)
	En Route	Air Route Surveillance Radar-ARSR/ ATCRBS (112) Discrete Address Beacon-DABS (36 Colocated)	VORTAC (465) VOR/DME (120) Precision VOR/TACAN(250)	Integrated with DABS Surveillance	Ground-Based Remote Centers-RCAG (513)
	Oceanic	AEROSAT System Two Way ranging via Satellite Relay (Same as Comm. Satell.)	Self-Contained . Inertial . Doppler Radar OMEGA	AEROSAT System Geostationary Satellites (2)	Same as Data Communications
Accuracy (1σ)	Terminal En Route	ATCRBS:0.25°/370' DABS:0.1°/100' ATCRBS:0.60°/1400'	VOR: 1.7° PVOR: 0.17° DME/TACAN: 600'		
Update Interval	Terminal En Route	ATCRBS:4 Sec. DABS: 1 Sec (min.) ATCRBS: 10 Sec.	Continuous	Same as DABS Surveillance	
Capacity (Per Site)		ATCRBS: 9000 Max. DABS: {6000 Max. 2000 Nom.	VOR: Unlimited DME: 800 Aircraft	Same as DABS Surveillance	
Frequency Band		1030, 1090 MHz (L-Band)	VOR: 108-118 MHz DME/TACAN:1025-1150 MHz	1030, 1090 MHz (L-Band)	118-136 MHz(VHF) 225-400 MHz(UHF)
No. of Channels/ Channel Bandwidth		2	VOR: 200/50 KHz DME/TACAN:126/1 MHz	2 (same as DABS)	UHF: 3500/50 KHz VHF: 720/25 KHz

Source: References 2 and 9.

(VORTAC) network which would be augmented with additional sites and extensive conversion to the precision Doppler VOR configuration. Area navigation techniques in use today would be expanded to incorporate the 1982 RNAV concept.[21] Ground-air-ground voice communications would continue to be routed, as in the current system, to and from the various en route and terminal control centers through remote VHF/UHF transmitter/receiver equipment.

The major new system elements for surveillance, navigation, and communications introduced by the Upgraded Third Generation System are the Discrete Address Beacon System (DABS), incorporating surveillance, data link and Intermittent Positive Control (IPC) capability, and the Aeronautical Oceanic Satellites (AEROSAT) for oceanic surveillance and communication.

The Discrete Address Beacon System is being developed by the FAA for the Upgraded Third Generation System.[2] By 1982, DABS, in the Baseline System, would replace the Air Traffic Control Radar Beacon System (ATCRBS) as the primary surveillance sensor and, in addition, provide a ground-air-ground data link as the primary means of communication, at high and medium density airports (70 units) and in high traffic density en route airspace (36 units). The data link capability off-loads the voice communication channels, making them available for use in unusual situations, for pilot-controller negotiations, or as backup to the data link. DABS sites will have a mini-computer installation that performs the functions of detecting and digitizing aircraft responses, and tracking aircraft; maintaining and ordering the aircraft roll-call; formatting messages; and generating Intermittent Positive Control (IPC) commands.

The experimental AEROSAT System uses two satellites in geostationary (equatorial) orbits providing coverage of the Atlantic Ocean. These two satellites relay two-way voice and data communications between ground locations and aircraft flying over oceanic areas beyond the limits of conventional VHF transmitter/receiver equipment. Communications between aircraft and satellites are two-way at L-band with additional provisions to use existing aeronautical VHF frequencies. The satellite-to-ground and ground-to-satellite communication links are at C-band. Independent aircraft surveillance is done by ground station transmission of an interrogation signal through a satellite to the aircraft. The aircraft then responds to both satellites with a signal which includes aircraft-derived altitude information. The response is relayed by both satellites to the ground station which computes aircraft position from time delay measurements of the aircraft response and knowledge of the satellite locations. Surveillance accuracy in the horizontal plane is expected to be about 1.0 to 2.0 NM (95% CEP) for the most frequently traveled North Atlantic routes (above 40° North Latitude).[22]

3.2 BASELINE SYSTEM AVIONICS

The surveillance, navigation, and communications equipment and the structure of controlled airspace, for the 1982 Baseline System, impose requirements on system users to carry at least a minimum complement of avionics. Table 3-2 summarizes the avionics required in the major airspace categories in 1982.

All participating aircraft carry a DABS transponder for surveillance and data link services or an ATCRBS transponder for surveillance only, and a transceiver for voice communications. Flight in high density, DABS serviced, airspace also requires a data link terminal for display of ATC messages and IPC commands. A full navigation capability requires a VOR receiver for transmitting-sites bearing measurements, DME or TACAN equipment for distance measurement based on transmission to, and receipt of, ranging signals from ground-based transponders, and a processor for area navigation computations. Multiple range measurements, obtained from multiple DME/TACAN equipment, are an alternative to bearing measurement, with computation of a position fix by means of multilateration.

TABLE 3-2 1982 BASELINE AVIONICS REQUIREMENTS

Airspace Category		AVIONICS FUNCTION: Surveillance	Navigation	Data Communication	Voice Communication	Data Processing
High Density Positive Controlled (IFR Only)		DABS Transponder	PVOR-DME	Data Link Terminal	Voice Transceiver	2D Area Navigation Processor
Positive Controlled (IFR Only)		ATCRBS Transponder	VOR-DME	-	Voice Transceiver	2D Area Navigation Processor
Mixed	IFR	ATCRBS Transponder	VOR	-	Voice Transceiver	-
	VFR	ATCRBS Transponder	-	-	Voice Transceiver	-

Legend:
- DABS - Discrete Address Beacon System
- ATCRBS - Air Traffic Control Radar Beacon System
- VOR - VHF Omni-Range
- PVOR - Precision VHF Omni-Range
- DME - Distance Measuring Equipment

3.3 BASELINE SYSTEM CONTROL FACILITIES AND AUTOMATION

The control facilities of the 1982 Baseline System are organized in the same manner as those of the current system, with additional terminal facilities added to handle increased traffic levels at some airports. The level of automation within existing facilities will be increased, and each new terminal facility will incorporate an automation level appropriate to its traffic load.

On the national level, the Central Flow Control Facility (CFCF) will be a semi-automated System Command Center (SCC) performing functions such as analysis of weather effects on traffic, terminal and high-altitude en route flow control, system status monitoring and emergency handling of system outages.

The current twenty Air Route Traffic Control Centers (ARTCC) serving CONUS are equipped with full implementation of NAS upgraded automation including flight plan entry, flight plan completion/revision/updating, IFR flight clearance issuance, separation assurance services, local flow control, and en route metering of traffic into dense terminals.

Terminal area control in the sixty-one large and medium hubs within CONUS, continues to be administered from Terminal Radar Control (TRACON) facilities equipped with upgraded ARTS (Automated Radar Terminal System) equipment. The enhanced ARTS capabilities incorporated in the 1982 Baseline System include automatic tracking of aircraft from both beacon and radar surveillance data; storage of track information; automatic exchange of flight data, track positions, and control information with the associated ARTCC; automated metering and spacing; automatic prediction and resolution of conflicts; and automatic monitoring and control of aircraft making precision approaches to close-spaced parallel runways.

Airports in small hubs, and some major non-hub airports, are serviced by TRACONS equipped with ARTS II equipment, which is a reduced version of ARTS III geared to handle lighter traffic loads. Other terminals, outside of hub areas and with still smaller traffic loads, have airport tower cabs (TRACAB) equipped with a further reduced version of ARTS III, designated TRACAB D. Two-hundred-and-twenty-nine ARTS II and TRACAB D facilities are assumed deployed in the 1982 Baseline System.

Other airports with FAA manned towers, and within radar coverage of the surveillance sites serving the larger TRACONS, are designated as satellite airports. The tower cabs of these manned facilities are equipped with BRITE displays, and receive all the required data for traffic control within the airport's area of jurisdiction from the ARTS III associated with the hub TRACON. There are 117 of this type of facility, designated TRACAB C, in the 1982 Baseline System.

The balance of the 492 airports equipped with an FAA manned tower, approximately 85 in number, either obtain limited radar approach control service from an ARTCC or provide non-radar approach control service.

3.4 BASELINE SYSTEM AIR TRAFFIC CONTROL TECHNIQUES

Air traffic control techniques define the manner in which the air traffic management system uses its control facilities and the airspace to optimally realize system and airport capacity, minimize the length and number of airborne delays, and ensure safe operating conditions for all aircraft. The diverse needs and characteristics of the air fleet require the availability of a number of distinct traffic control techniques for various portions of the airspace and create requirements for a range of avionics capabilities. Control techniques employed in the 1982 Baseline System are described below.

The 1982 Baseline System uses the tactical control techniques of the present system characterized by a single control authority issuing control instructions to IFR aircraft. These instructions are based on continuous flight following, and are only valid for short portions of the flight. Control instructions, intended to guarantee conflict-free movement of a controlled aircraft over a short flight segment, are issued periodically and cover airway routings, altitude, heading, and speed changes. These are based on many factors including the aircraft's flight plan, present position/velocity/heading, relation to other aircraft and the mix of the airborne fleet in the aircraft's vicinity. Two new tactical control techniques are assumed employed in the 1982 Baseline System: Intermittent Positive Control (IPC), and Metering and Spacing.

The deployment of IPC provides a significant new service by the system.[(2)] In the present system, in-flight separation and traffic advisory services are normally provided only to aircraft that have filed IFR flight plans and that are operating under an IFR clearance. VFR pilots may receive in-flight traffic advisories upon request, so long as controller workload permits. IPC is expected to materially aid in reducing the threat of mid-air collisions and in reducing the air traffic controller's load associated with resolving potential collision situations between VFR/IFR and VFR/VFR aircraft. In this concept, suitably equipped aircraft are advised of flight hazards arising from other aircraft, and of positively controlled airspace boundaries and surface obstacles. They are given computer-derived instructions, via digital data link, for appropriate evasive maneuvers. Control is intermittent, intervening into the VFR flight regime only when an aircraft's present course and altitude put it in a conflict situation.

The Metering and Spacing technique is used for merging and spacing aircraft making landing approaches in a terminal area. Its function is to deliver these arrivals to a runway precisely, thereby making more efficient use of runways and minimizing delay. Traffic controlled by this technique is vectored or tactically routed along flight paths with varying length segments to ensure punctual arrival at specific fix points. Flight path changes are generated by computer and transmitted to aircraft on the ATC system digital data link.

Airspace users requiring these services must be suitably equipped with a surveillance transponder, data link terminals and voice communications equipment.

The Baseline System Metering and Spacing concept for Los Angeles International Airport is shown in Figure 3-2. Airspace reserved within the terminal area for adjustment in the sequencing and base leg areas by means of path altering is shown by the dotted areas. The Figure shows nominal paths bracketed by the airspace needed for time adjustments in the threshold arrival time at reasonable aircraft speeds.

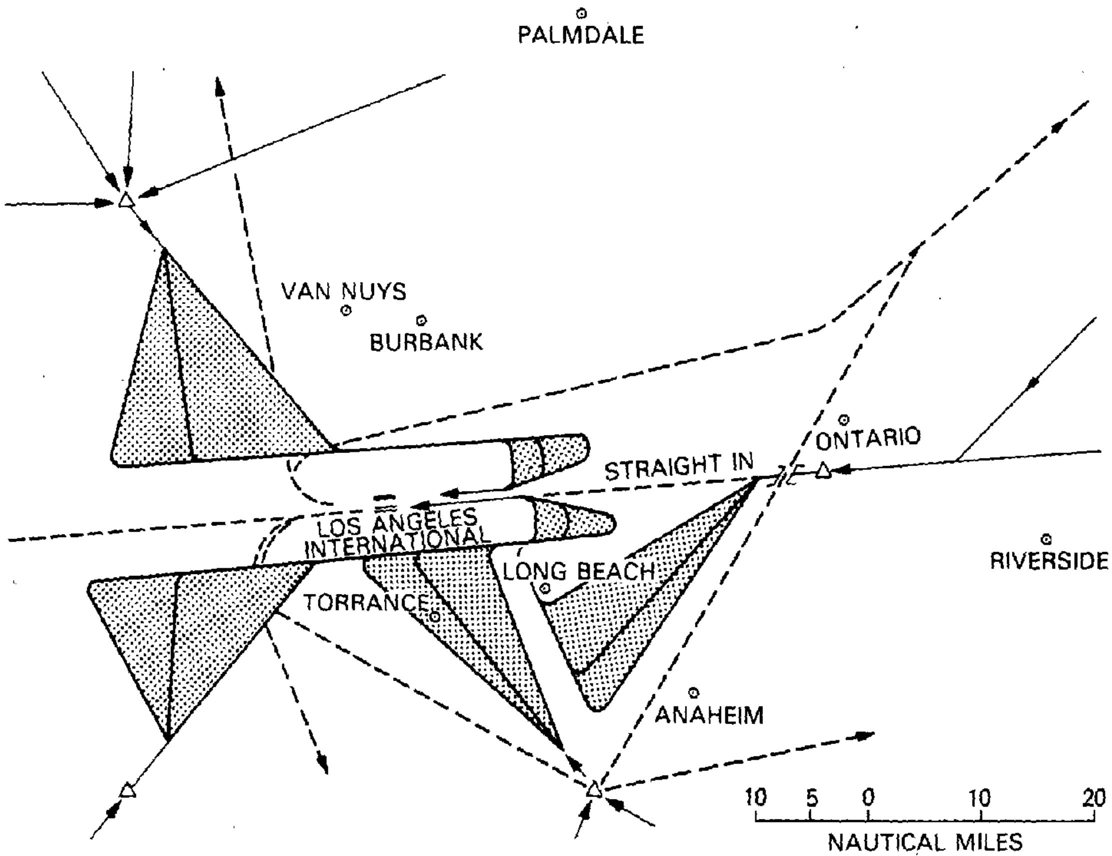

Figure 3-2. Metering and Spacing for Los Angeles International

The 1982 Baseline System is assumed to use centralized flow control to maximize system capacity and minimize airborne delays by establishing optimum long-haul routes, schedules, and altitudes considering wind, weather, and system capacity. Airborne delays are minimized by assignment of arrival times at saturable airports, and coordination of traffic flows between en route centers, and between en route centers and high density terminal areas, on a national basis.

The airspace structure for the 1982 Baseline System is illustrated in Figure 3-3. En route airspace is divided into positive controlled airspace (PCA), mixed airspace, and uncontrolled airspace. Terminal airspace is divided into Terminal Controlled Airspace (TCA) in high density terminal areas; Extended Control Service (ECS) in medium density terminal areas; and airport control zones at low density terminals and at other airports with control towers. The services provided to IFR and VFR traffic in each type of airspace are summarized in Table 3-3. En route flow control is extended to IFR traffic in positive control and mixed airspace. The primary means of providing separation assurance service between aircraft flying IFR flight plans in controlled airspace is via automatic conflict prediction and resolution. Intermittent Positive Control (IPC) is available in high and medium density terminals and in high density en route airspace to provide separation assurance between IFR/VFR traffic, and as a backup to the primary mode of IFR/IFR traffic separation. Metering and Spacing service is provided to all traffic in Terminal Controlled Airspace and in those terminals designated for Extended Control Service. IFR traffic making precision approaches to closely-spaced parallel runways is automatically monitored for approach path conformance. Two-dimensional area navigation routing is available at all controlled airports. Three dimensional area navigation routes are available at high and medium density terminals.

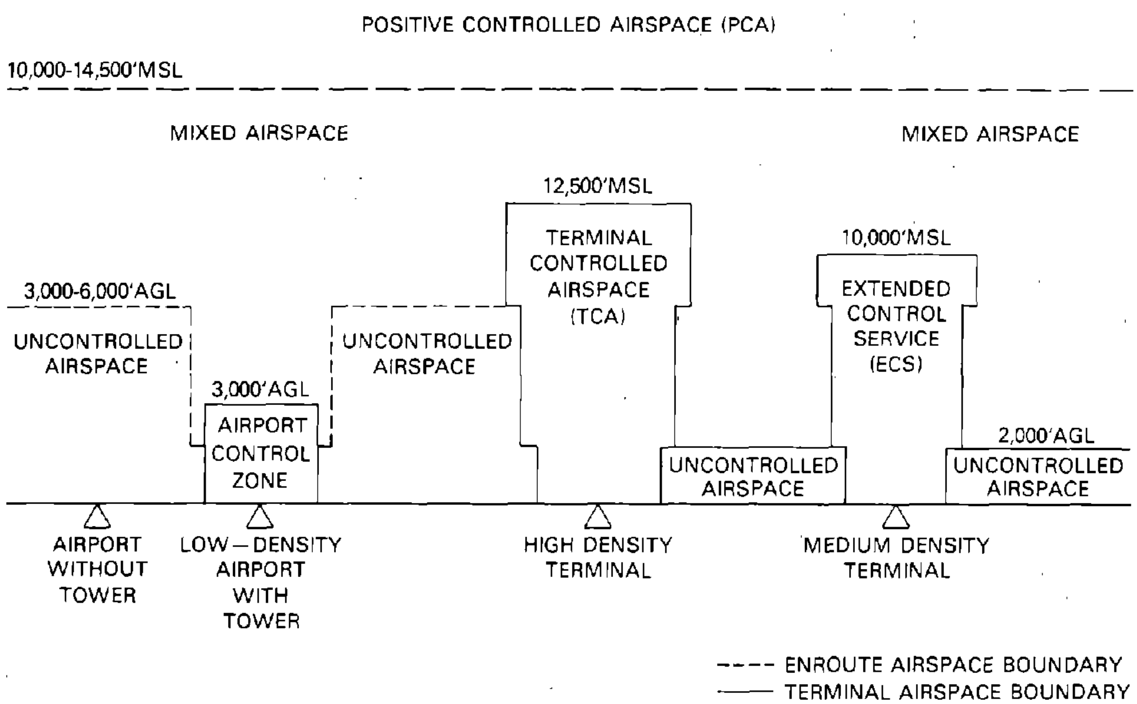

Figure 3-3. 1982 Baseline System Airspace Structure

TABLE 3-3 1982 BASELINE SYSTEM AIRSPACE SERVICES AND USERS

	Airspace Type	Services	Primary Users
EN ROUTE	Positive Controlled	Flow Control Separation Assurance • Conflict Prediction/Resolution • IPC (High density)	Air Carrier - IFR General Aviation-IFR Military - IFR
EN ROUTE	Mixed	Flow Control (IFR) Separation Assurance • Conflict Prediction/Resolution • IPC (High Density)	General Aviation-IFR/VFR Military - IFR/VFR
EN ROUTE	Uncontrolled	None	General Aviation-VFR
TERMINAL	Terminal Controlled Airspace (TCA) (21)	3D/2D RNAV Routing Metering and Spacing Separation Assurance • Conflict Prediction/Resolution • IPC Precision Approach Monitoring	Air Carrier - IFR General Aviation - IFR/Cleared VFR
TERMINAL	Extended Control Service (ECS) (141)	3D/2D RNAV Routing (IFR) Metering and Spacing Separation Assurance • Conflict Prediction/Resolution • IPC Precision Approach Monitoring (IFR)	Air Carrier - IFR General Aviation-IFR/VFR
TERMINAL	Airport Control Zone (Towered Airports) (330)	2D RNAV Routing (IFR) Separation Assurance • Conflict Prediction/Resolution (IFR)	General Aviation-IFR/VFR Military - IFR/VFR
TERMINAL	Uncontrolled	Airport Advisory Services	General Aviation-VFR

3.5 BASELINE SYSTEM OPERATING MODES

The operating modes for surveillance, navigation, and air-ground communication are implemented by the network of DABS, Radar/ATCRBS, VOR/DME/TACAN, and voice communications sites that constitute the 1982 Baseline System.

Surveillance information is obtained in the form of range-angle measurements derived primarily from interrogations of DABS or ATCRBS-equipped aircraft by DABS sites in high density regions and ATCRBS sites in the remainder of controlled airspace. Alternatively, surveillance information is obtained by skin tracking with the primary radar or from on-board navigation position measurements transmitted by the aircraft via the data or voice links. Aircraft under surveillance encode altitude information on their DABS or ATCRBS interrogation responses for ground station use.

The modes used for obtaining navigation information on-board an aircraft depend on the type of avionics carried. Position fixes may be determined using a range-range technique employing measurements from two or more DME's or a range-angle technique using DME and VOR measurements. Ground tracks may be automatically computed by an on-board area navigation processor or manually computed by the pilot/navigator. Minimally equipped aircraft carrying only a VOR receiver can fly selected radials between successive VOR stations.

The primary mode of air-ground communication in high density airspace covered by DABS sites is the digital data link. Air-ground communication in other airspace is accomplished via voice links, which also supplement data links in high density regions.

4. CANDIDATE SYSTEM CONCEPTS

This Section describes two candidate air traffic management system concepts defined in the course of this Study. These concepts formed the basis for the synthesis and definition of the Advanced Air Traffic Management System Concept presented in the next Section of this report.

The two concepts discussed below were selected for concept definition based on the initial or concept formulation phase of the AATMS Study. During this phase, a system employing satellites as a key element in the implementation of the surveillance, navigation, and communication functions was recognized as offering the greatest potential for (1) expanding air traffic services to all airspace, (2) adapting to changes in demand for air traffic services with minimum system impact, and (3) cost savings to the Government and users through integration of the surveillance, navigation, and communication subsystems and avionics.[7] While recognizing the advantages of this approach, there was also concern regarding the large investment of both the Government and users in the Baseline System and the extensive period of dual system operation which would result. These considerations, taken with the expectation of high development costs, avionics cost uncertainty, and areas of technical risk associated with the satellite concept, led to the study and definition of an alternative system concept based on extensions of the Upgraded Third Generation System. The latter system concept is referred to as the <u>Extended Upgraded Third Generation System</u>, and the former as the <u>All-Satellite System</u>*.

These two concepts are described in detail in supporting study documentation; they are described in summary below.[7,9] Their part in synthesizing the final AATMS Concept is described in Section 5.

4.1 EXTENDED UPGRADED THIRD GENERATION SYSTEM CONCEPT[9]

The Extended Upgraded Third Generation System Concept evolved from the premise that the Upgraded Third Generation System could be modified to handle air transportation growth in the 1990's. In order to minimize transitional problems, development cost, and technical risk, the concept was constrained to use Upgraded Third Generation Subsystem

*In the Study and in supporting documentation the <u>All-Satellite System</u> was referred to as System A and <u>The Extended Upgraded Third Generation System</u> as System B for ease of reference.

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technology, incorporating only those modifications required to handle the projected growth in air traffic. The resulting system concept is characterized by the following major features:

- Synchro-DABS, a modification of DABS, which makes possible capabilities such as an air-to-air collision avoidance system, and unsaturable one-way ranging from all DABS and VOR sites.
- Continued use and expansion of the VHF Omni-Range (VOR) network.
- Low-cost DABS installations at non-towered, low density airports (Mini-DABS) to provide surveillance, automated IPC service, and remote IFR control.
- Multiple levels of system redundancy.
- Phaseout of primary radar, air traffic control radar beacon system (ATCRBS) equipment, and two-way distance measuring equipment to a level required to minimally support international or military requirements or agreements.
- Integrated avionics functions.
- Expansion of Baseline System control modes by use of strategic control techniques.
- An increased level of automation incorporated at the control centers.

<u>Extended Upgraded Third Generation System - Surveillance, Navigation, and Communication Equipment</u>

The major surveillance/navigation/communication subsystem innovations introduced by the Extended Upgraded Third Generation System are a modification to the DABS called Synchro-DABS, and Mini-DABS. The VOR, voice communication, and AEROSAT equipments of the 1982 Baseline System would be retained. Other elements such as ASR/ATCRBS, ARSR/ATCRBS, and TACAN/DME would be phased-out of operation.

The 1982 Baseline System would be modified and/or expanded over a period of time until the Extended Upgraded Third Generation System, as it would exist in 1995, has evolved. The 106 DABS sites described in the Baseline System would be modified to incorporate the Synchro-DABS capability, and the number of sites would be increased to 291 to assure adequate coverage of critical airspace regions. The 1025 VOR sites in the Baseline System would be expanded to over 1100 sites, and 1080 of these sites would be equipped with Synchro-DABS, thereby providing air-to-air collision avoidance service and one-way ranging information to properly equipped aircraft. Three-hundred and ten

Mini-DABS installations would be deployed at non-towered airfields enabling the provision of ATC services to IFR aircraft from a remote-control facility. Table 4-1 summarizes the subsystem equipment complement and its major operating characteristics.

The 291 DABS sites in this concept would be used to provide at least double coverage of airspace above 6,000 feet AGL almost everywhere over CONUS.[9] Single site coverage of airspace would be provided down to 3,000 feet or better over more than 90 percent of CONUS, while more than 84 percent of Eastern CONUS would be covered down to 2,000 feet or better (see Figure 4-1). Airspace coverage essentially to ground level will exist at approximately 160 terminals with the busiest national air carrier activity, plus additional airports near which DABS sites will have been strategically located.

Other airports requiring surveillance and data link service to ground level, but too far from an established DABS site to receive adequate coverage, would be equipped with a low-cost, limited-range version of DABS, designated Mini-DABS.[9] This installation includes a rotating directional antenna, a low-powered interrogator, and a surveillance/IPC computer. All DABS-equipped aircraft within the jurisdiction of the Mini-DABS are interrogated, tracked, and receive PWI/IPC service. The surveillance data are transmitted to an appropriate manned air traffic management facility so that participating aircraft can receive positive control/IFR-type service. This remote control concept obviates the need for proliferating control towers and results in control system cost savings. This system concept assumes the deployment of 310 Mini-DABS sites by 1995.

Synchro-DABS, a modification to the basic DABS providing users with air-to-air collision avoidance system services and one-way ranging, is incorporated in all DABS and Mini-DABS sites, and at almost all the VOR navigation sites by 1995. In the Synchro-DABS concept, all DABS ground sites are synchronized with each other. DABS interrogation timing is such that each aircraft responds at a known, precise reference time, T_R, as shown in Figure 4-2. This is possible because the range, and thus the transmission time, to each aircraft is known from prior surveillance cycles, allowing the aircraft to be synchronized to the DABS. Operating modes that become possible by incroproating this feature, e.g., one-way ranging, horizontal position fixing, and an air-to-air collision avoidance capability, are further described later in this Section. A DABS landing guidance capability is also part of this system concept as an adjunct to the Mini-DABS installations at remote airports, thereby allowing further integration of functions into a single avionics package at a lower net cost to the user. However, the technical feasibility and operational utility of this approach requires further evaluation.

TABLE 4-1 EXTENDED UPGRADED THIRD GENERATION SYSTEM SURVEILLANCE/NAVIGATION/COMMUNICATION SUBSYSTEMS (1995)

Subsystem Parameter		System Concept Function: Surveillance	Navigation	Data Communication	Voice Communication
System Equipment	Terminal	Synchronized DABS (291)	VOR (1106) Synchro-DABS DME (1080)	Integrated with DABS/Mini-DABS Surveillance	Ground-Based Remote Trans/Rcvr -RTR (552)
	En Route	Min-DABS (310)			Ground-Based Remote Centers-RCAG (513)
	Oceanic	AEROSAT System Two Way Ranging via Satellite Relay (same as Comm. Satel.)	Self-Contained • Inertial • Doppler Radar OMEGA	AEROSAT System Geostationary Satellites	Same as Data Comm.
Accuracy (1σ)	Cross Track	0.1 Deg.	VOR: 1.7° PVOR: 0.17°		
	Along Track	100 Ft.	Synchro-DABS DME: 200'		
Update Interval		1 Sec (Min.)	VOR: Continuous Synchro-DABS DME: Continuous	Same as DABS	
Capacity (Per Site)		DABS 6000 Max. 2000 Nom.	VOR: Unlimited Synchro-DABS DME: Unlimited	Same as DABS	
Frequency Band		1030, 1090 MHz (L-Band)	VOR: 108-118 MHz Synchro-DABS DME: Same as DABS	1030, 1090 MHz (L-Band)	118-136 MHz (VHF) 225-400 MHz (UHF)
No. of Channels/ Channel Band-width		2	VOR: 200/50 KHz Synchro-DABS DME: 2 (same as DABS)	2 (same as DABS)	VHF: 720/25 KHz UHF: 3500/50 KHz
System Cost (Millions)	Total F&E 1982-1995	DABS: $100 Mini-DABS: $60	VOR-$50 Synchro-DABS DME-$70 Mini-DABS Landing-$25	Included in DABS	VHF Comm-$5
	Annual O&M for 1995	DABS: $15 Mini-DABS: $10	VOR-$20. Synchro-DABS DME-$10 Mini-DABS Landing Guidance System: $3	Included in DABS	VHF Comm-$35

Source: References 9 and 24.

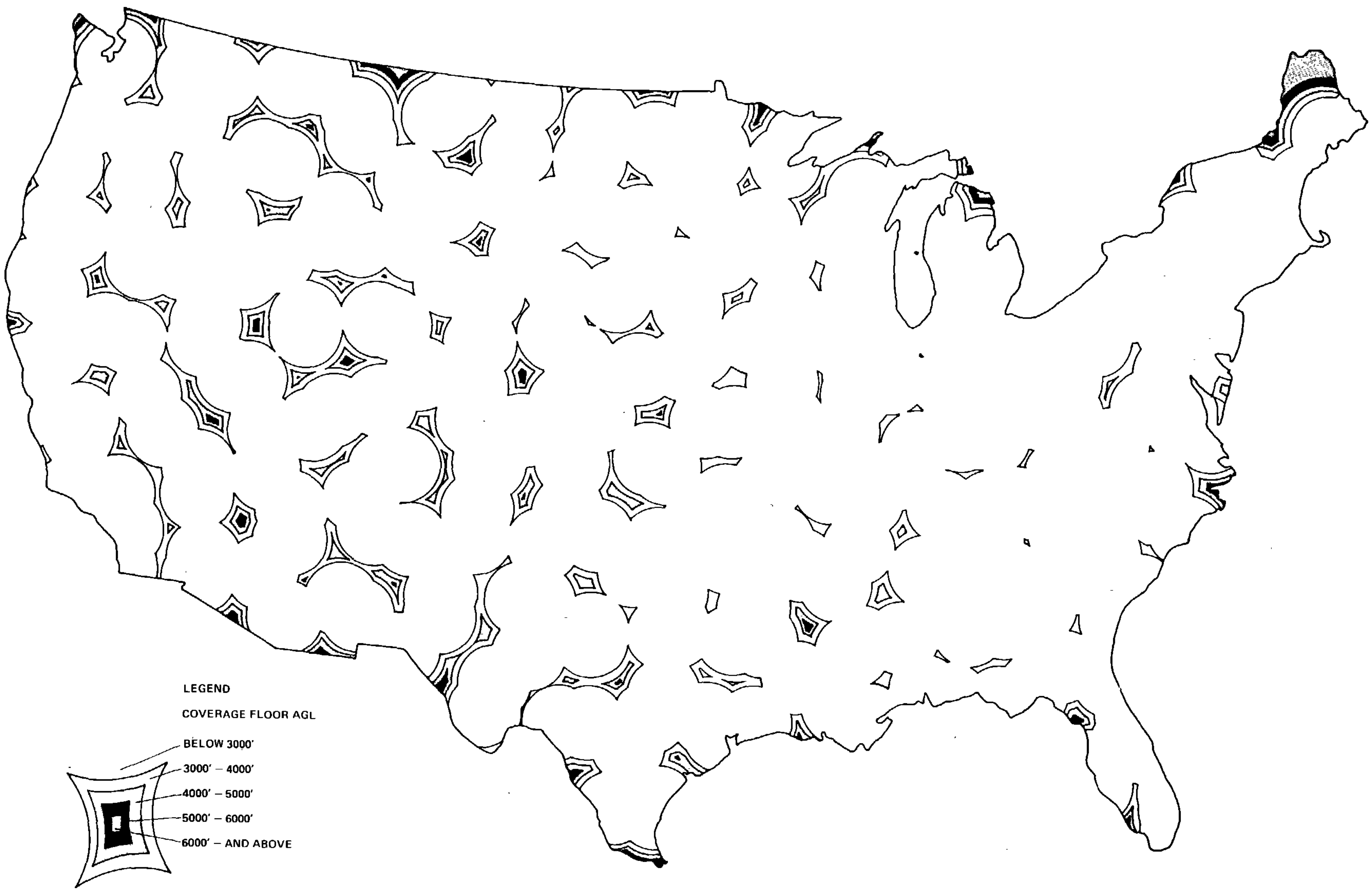


Figure 4-1 DABS Altitude Coverage Contours over CONUS

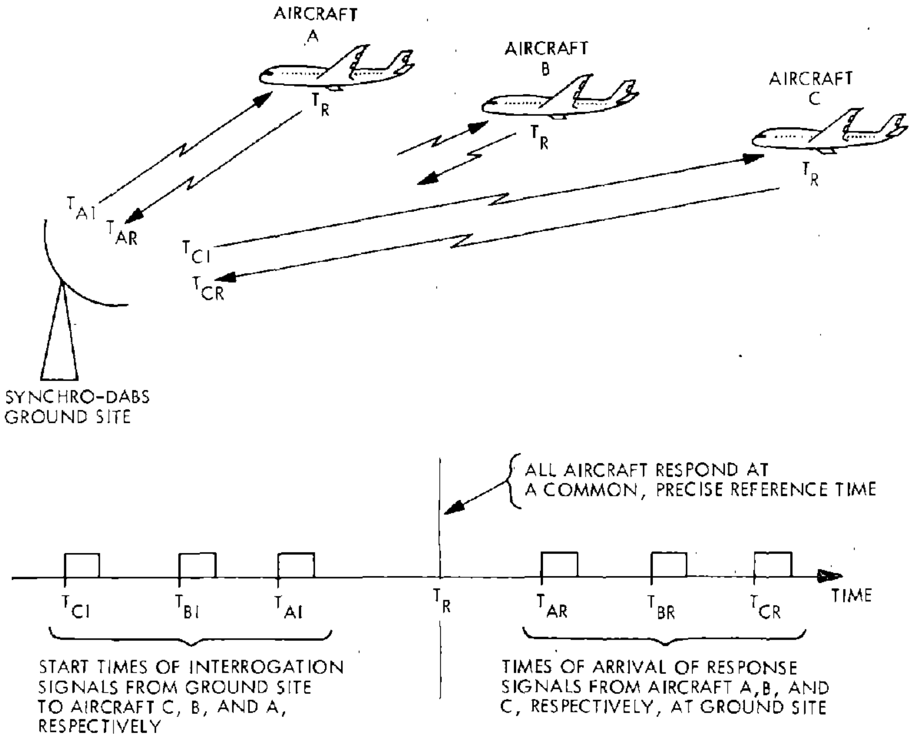


Figure 4-2 Synchro-DABS Interrogation Timing (Simplified)

The facilities and equipment (F&E) costs (defined in Section 5.1) for these elements, and also presented in Table 4-1, reflect the costs for facilities and equipment added to the Baseline System after 1982. Since F & E expenditures are expected to continue indefinitely in this concept due to continued expansion of the system to meet demand, the Table presents the sum of the estimated yearly F & E expenditures from 1982 to 1995. The operation and maintenance (O & M) costs (also defined in Section 5.1) of the subsystem equipment complement are those estimated for 1995 system operation. The total F & E cost for surveillance, navigation, and communication subsystems in this concept is about $300 million. The total O & M cost (in 1995) for the surveillance, navigation, and communication subsystems is about $100 million.

Extended Upgraded Third Generation System Avionics

The avionics for the Extended Upgraded Third Generation System retains most of the Baseline System airborne equipment. The 1995 avionics would be functionally integrated to provide surveillance, navigation, and communication functions, and yet would be incrementally expandable beyond the basic equipment complement to implement additional services.

Figure 4-3 illustrates an approach whereby the additional functions available with the synchronized DABS mechanization are incorporated into the avionics by adding discrete electronic modules. Starting with the Baseline System avionics, the Synchro-DABS DME function is implemented by adding a one-way ranging logic module, and a synchronized clock to the basic DABS antenna, transmitter, receiver and digital logic. If the DABS landing system concept proves feasible, this capability would be incorporated by adding a landing logic module. Incorporating Synchro-DABS DME capability into the avionics allows deletion of the more expensive Baseline System DME avionics equipment. Table 4-2 summarizes the avionics for the major airspace categories suggested in this concept for 1995. The Table also gives cost estimates for individual aircraft avionics required for flight capability in various airspace regions.

The Synchro-DABS Concept also provides the basis for a Collision Avoidance System (CAS) or Proximity Warning Indicator (PWI). With the addition of a 1090 MHz receiver to the avionics complement, a participating aircraft can receive signals from nearby DABS-equipped aircraft responding to interrogations. Since each aircraft is ground-synchronized whenever it is interrogated, an on-board crystal clock can be used in the interval between

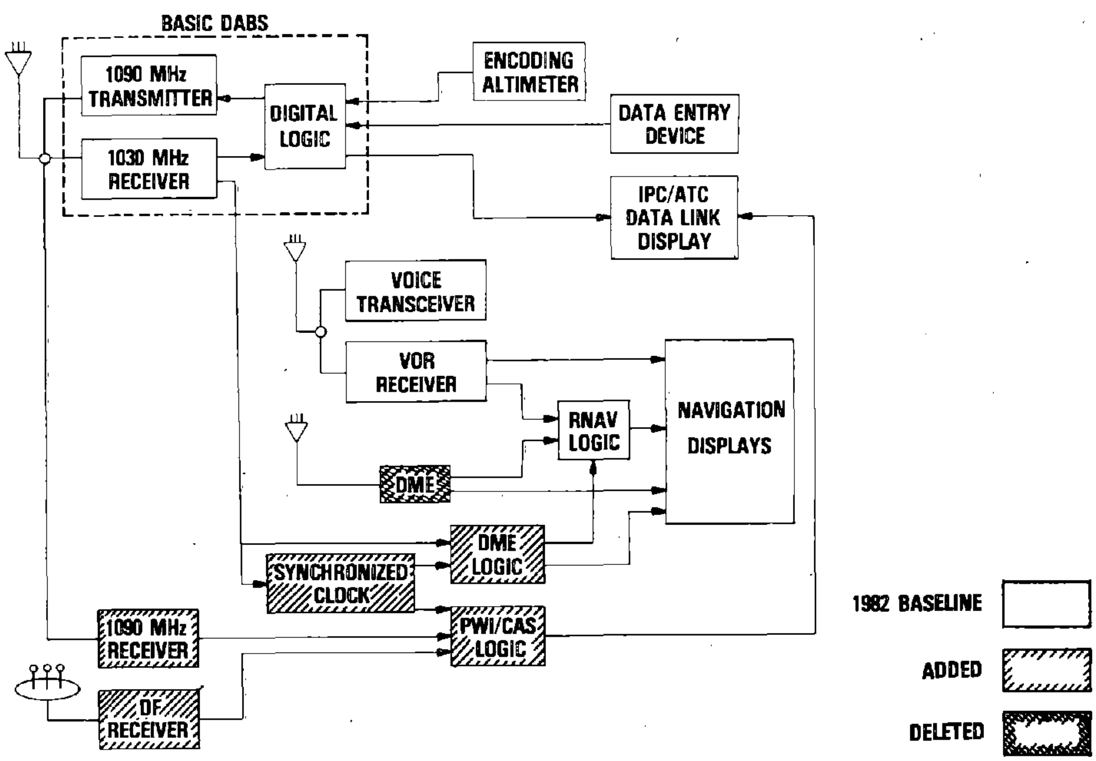


Figure 4-3 Extended Upgraded Third Generation System Avionics Modifications

TABLE 4-2 EXTENDED UPGRADED THIRD GENERATION SYSTEM AVIONICS REQUIREMENTS (1995)

Airspace Category		Function					
		Surveillance	Navigation	Data Communication	Voice Communication	Data Processing	Cost Per Avionics Package
High Density Positive Controlled (IFR Only)		DABS Transponder	Synchro-DABS DME	ATC Data Link Terminal (See Note)	Voice Transceiver	4D RNAV*	$33,570
Positive Controlled (IFR Only)		DABS Transponder	Synchro-DABS DME	ATC Data Link Terminal	Voice Transceiver	2D RNAV	$22,020
Mixed	IFR	DABS Transponder	VOR/VOR	IPC Data Link Terminal (See Note)	Voice Transceiver	2D RNAV	$ 5,570
Mixed	VFR	DABS Transponder	VOR	IPC Data Link Terminal	Voice Transceiver		$ 2,810

Note: Two levels of data link display capability are defined. The IPC data link display would have digital readouts of aircraft flight parameters such as heading, airspeed and altitude, and simple ATC messages in addition to basic IPC commands. This type of display would typically be used in airspace regions where positive control intervention is at a minimum. The ATC data link display would present the same basic information as the IPC display plus a full repertoire of data link messages including ATC directives and clearances, ATC advisories, and ATC responses to pilot requests. This type of display would typically be required in airspace regions where traffic is under control via an automatic data link.

* Costs not included in concept cost estimates

SOURCE: References 9 and 24.

interrogations to maintain synchronization and predict the times of occurrence of the next response. The listening aircraft can then compute the range of other aircraft based upon the time of arrival of their signals. The receiving aircraft could also calculate range-rate by comparing consecutive responses from the same aircraft. The identity and altitude of other aircraft are also known since this information is encoded in their transmissions. An airborne direction finding antenna and receiver would allow determination of relative bearing to the transmitting aircraft. Using this information, the receiving aircraft can determine if any of the aircraft near it are a collision threat. A 1090 MHz receiver, direction finding antenna/receiver, a crystal clock, and a PWI/CAS logic module are required additions to the avionics as shown in Figure 4-3.

Extended Upgraded Third Generation System Control Facilities and Automation

The Extended Upgraded Third Generation System retains the control facility organization structure of the 1982 Baseline System, with terminal automation facilities added to upgrade all manned towers to a radar approach control capability, increased size of computational facilities to handle larger traffic loads, and extension of positive control to Mini-DABS equipped non-tower airports.

Additional terminal automation facilities include 51 ARTS II and TRACAB D installations and 34 TRACAB C installations for a total of 280 and 151, respectively. There are 492 manned towers; the same as in the 1982 Baseline System. The Mini-DABS surveillance and communications facility installation at airports too remote from a DABS site to receive adequate low altitude coverage has been described above. Surveillance data from the Mini-DABS sites are transmitted to a manned air traffic management facility, i.e., ARTCC or TRACON, where normal control functions are performed for all arriving and departing IFR flights. IPC separation assurance services are also extended to DABS-equipped aircraft flying in Mini-DABS serviced airspace. The data processing requirements estimated for the various types of control facilities are presented in Table 4-3.[9] The design instantaneous airborne count (IAC) numbers represent a gross capacity equal to approximately 1.6 times the 1995 forecast presented in Section 2.

En route and terminal controller staffing estimates for the Extended Upgraded Third Generation System for 1995 are 7600 and 10,700 respectively. These estimates were derived from empirical staff estimating functions, using assumed increases in controller productivity for en route sectors, TRACON's, and towers.[9,23] The en route estimate was further tempered by an assumed four percent per year attrition of staff, beginning in 1982 when the Baseline System automation begins to reduce the controller requirements.

TABLE 4-3 EXTENDED UPGRADED THIRD GENERATION SYSTEM CONTROL FACILITIES DATA PROCESSING REQUIREMENTS

Terminal

Control Facility Type	Number of Facilities	Design IAC	MIPS	Storage (30 Bit Words)	
ARTS III	1	800	1.41	117,852	
	5	600	0.75	68,738	
	20	400	0.53	59,608	
	35	200	0.21	37,728	
ARTS II	1	200	0.14	35,726	
	24	125	0.11	33,281	
	90	75	0.08	31,651	
TRACAB D	10	75	0.07	31,363	
	80	50	0.06	30,590	
	75	25	0.05	29,818	
En route				Storage (32 Bit Words)	
ARTCC	5	1300	1.32	1,278,730	
	15	1000	1.06	1,183,410	
				Storage	
National		Annual IFR Oper.		Core (32 Bit Words)	Disk (Bytes)
CFCF	1*	83.4×10^6	1.66	430,735	232,335,000

*Duplex

Source: Reference 9.

Total F&E costs (1982 to 1995) of $450 million are estimated for implementing improvements to the Baseline System control, based on an assumed automation level and on projections of computer and display equipment required for this concept. The 1995 cost (O&M) to operate and maintain both the control facilities and the retained Baseline System interfacility communications equipment, is $200 million. These costs were derived based on O&M costs of today's control facilities and the estimated savings in O&M accruing from the use of new equipment.

The annual cost, in 1995, of the estimated en route and terminal controller staffs of 7,600 and 10,700, respectively, would be about $370 million based on an average annual labor cost (O&M) of $20,000 per controller (salary, benefits, etc.).[9]

Extended Upgraded Third Generation System Air Traffic Control Techniques

The Extended Upgraded Third Generation System retains all of the tactical control techniques of the 1982 Baseline System, adds strategic flight planning and increases the emphasis on monitoring flight plan conformance. The strategic technique introduced in this concept, called Strategic Control, is characterized by advance planning of non-conflicting flight paths and associated clearances by a central control authority. A clearance for each IFR flight under Strategic Control is transmitted to the aircraft is terms of a three-dimensional flight path description which, in high density airspace regions, may be time-scheduled. Separation assurance is achieved by providing for time or distance separation between Strategic Control Clearances based on the assumed accuracy of clearance conformance expected from each flight. Participating aircraft are required to carry two-dimensional or three-dimensional area navigation (2D/3D-RNAV) equipment. Four-dimensional area navigation (4D-RNAV) capability is required to fly certain preferred routes, and at the main runways of busy airports during peak traffic hours.

The airspace structure of this system concept is basically the same as that of the 1982 Baseline System depicted in Figure 3-3, with the following modifications. The en route positive controlled airspace floor is lowered to 12,000 feet mean sea level (MSL). The terminal controlled airspace (TCA) ceiling is raised to 18,000 feet MSL, and the extended control service (ECS) ceiling is raised to 12,000 feet MSL.

The services provided by this system to IFR and VFR traffic in each type of airspace is summarized in Table 4-4, with services added to the 1982 Baseline System indicated in bold type. Additional separation assurance services to IFR traffic are provided by long term, conflict-free, flight planning performed at the Centralized Flow Control Facility, and flight path conformance monitoring performed by the control center having jurisdiction

TABLE 4-4 EXTENDED UPGRADED THIRD GENERATION SYSTEM AIRSPACE SERVICES

	Airspace Type	Services*	Primary Users
ENROUTE	Positive Controlled	Flow Control Separation Assurance . **CONFLICT-FREE FLIGHT PLANNING** . **FLIGHT PLAN CONFORMANCE MONITORING** . Conflict Prediction/Resolution . Intermittent Positive Control . **AIR-AIR COLLISION AVOIDANCE**	Air Carrier-IFR General Aviation-IFR
	Mixed	Flow Control (IFR) Separation Assurance . **CONFLICT FREE FLIGHT PLANNING (IFR)** . **FLIGHT PLAN CONFORMANCE MONITORING** . Conflict Prediction/Resolution (IFR) . Intermittent Positive Control . **AIR-AIR COLLISION AVOIDANCE**	General Aviation-(IFR) General Aviation-(VFR)
	Uncontrolled	None	General Aviation-(VFR)
TERMINAL	Terminal Controlled Airspace (TCA) (30)	**4D/2D RNAV ROUTING** Metering and Spacing Separation Assurance . **CONFLICT-FREE FLIGHT PLANNING (IFR)** . **FLIGHT PLAN CONFORMANCE MONITORING** . Conflict Prediction/Resolution . Intermittent Positive Control . **AIR-AIR COLLISION AVOIDANCE**	Air Carrier-IFR General Aviation - IFR - Cleared VFR
	Extended Control Service (ECS) (145)	**4D/2D RNAV ROUTING (IFR)** Metering and Spacing Separation Assurance . **CONFLICT-FREE FLIGHT PLANNING(IFR)** . **FLIGHT PLAN CONFORMANCE MONITORING** . Conflict Prediction/Resolution . Intermittent Positive Control . **AIR-AIR COLLISION AVOIDANCE**	Air Carrier-IFR General Aviation - IFR - VFR
	Airport Control Zone (Towered/ **REMOTE CONTROL AIRPORTS** (620)	2D RNAV Routing (IFR) **METERING AND SPACING** Separation Assurance . **CONFLICT-FREE FLIGHT PLANNING (IFR)** . **FLIGHT PLAN CONFORMANCE MONITORING** . Conflict Prediction/Resolution . **INTERMITTENT POSITIVE CONTROL** . **AIR-AIR COLLISION AVOIDANCE**	General Aviation - IFR - VFR
	Uncontrolled	Airport Advisory Services/Unicom	General Aviation - VFR

*Bold Face Type (Capitals) indicates services added to Baseline System.

over the portion of the airspace through which the aircraft is flying. An air-to-air collision avoidance capability is available to all air traffic as an optional further backup to the ground-controlled separation assurance services. Four-dimensional area navigation routing is provided for IFR traffic using the main runways at high and medium density terminals. Metering and spacing service is extended to airport control zones either under the jurisdiction of an on-site control tower or receiving control service from a remote facility. Separation assurance services are extended to airport control zones served by remote control facilities.

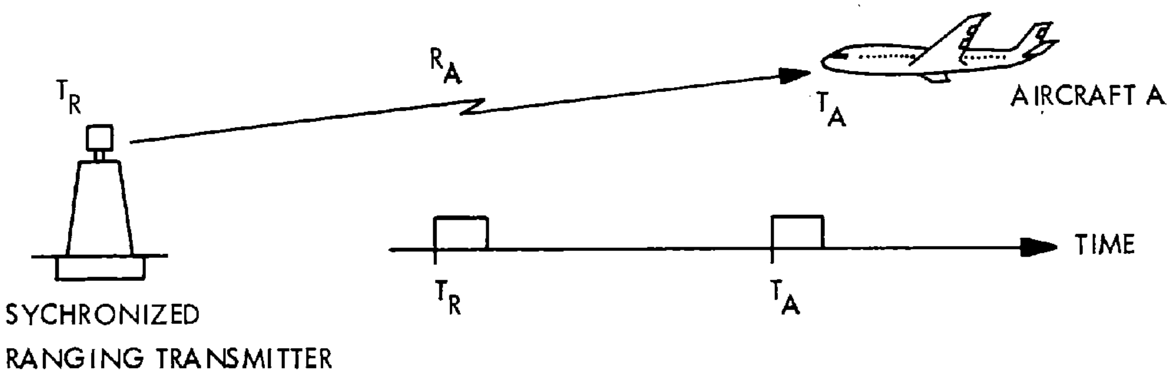
Extended Upgraded Third Generation System Operating Modes

The Extended Upgraded Third Generation System operating modes differ from those of the 1982 Baseline System because of the deployment of additional DABS, the addition of Mini-DABS sites, the adoption of the Synchro-DABS concept enabling one-way ranging and CAS/PWI capability, and the phase-out of the radar/ATCRBS sites.

Surveillance information is obtained from interrogation of DABS-equipped aircraft in all controlled airspace by DABS or Mini-DABS sites. Alternatively, surveillance information can be obtained from on-board navigation position measurements transmitted to the ground by data or voice link. Aircraft altitude for surveillance purposes is obtained, as in the 1982 Baseline System, from encoded aircraft altimetry measurements transmitted by the aircraft in response to DABS interrogations.

In this system concept, on-board measurement of range to fixed ground stations for aircraft navigation purposes is made using Synchro-DABS ranging equipment. In this mode, one-way ranging between aircraft and Synchro-DABS ground stations is possible, since each station transmits omni-directional ranging signals, coded with the identity and three-dimensional location of the site, at the precise reference times (T_R) that are already known to Synchro-DABS equipped aircraft (Figure 4-4). This type of ranging is non-saturable. A range-angle position fix could be made in conjunction with bearing information derived from the VOR, or as an alternative, an accurate unambiguous position fix could be obtained from ranging signals received from three or more ranging transmitter sites (Figure 4-5). Other navigation modes are as described for the Baseline System.

The primary mode of air-ground communication in airspace covered by DABS and Mini-DABS sites is the digital data link. Air-ground communication in other airspace is accomplished on VHF voice links, which also serve as an alternative to the data link in controlled airspace regions.



T_R = INITIATION TIME (IN SECONDS) OF RANGING SIGNAL FROM SYNCHRONIZED STATION; THIS TIME IS KNOWN BY THE AIRCRAFT

T_A = ARRIVAL TIME (IN SECONDS) OF RANGING SIGNAL AT AIRCRAFT A

R_A = SLANT RANGE (MILES) BETWEEN GROUND STATION AND AIRCRAFT A

C = SPEED OF LIGHT (MILES PER SECOND)

$R_A = C(T_A - T_R)$ MILES

NOTE: THE "SLANT RANGE" (R_A) COULD BE CONVERTED TO "GROUND RANGE" BY THE AIRBORNE COMPUTER, SINCE THE GROUND STATION TRANSMITS ITS ALTITUDE AND THE AIRCRAFT MEASURES ITS OWN ALTITUDE.

Figure 4-4 One-Way Ranging Using Synchronized Ranging Transmitter

The air-to-air Collision Avoidance System/Pilot Warning Indication (CAS/PWI) mode provides a backup to ground-managed separation assurance as implemented by control centers, and Intermittent Positive Control as performed by DABS sites. This mode is available to users with the proper avionics modules. A significant feature of synchro-DABS is that only those aircraft desiring the backup CAS/PWI need be equipped with a Synchro-DABS receiver (1090 MHz), provided each aircraft in the given airspace region has a basic DABS transponder, since this capability depends on Synchro-DABS site interrogation. As shown in Figure 4-2, the timing of interrogations from the DABS ground sites is such that all aircraft respond at a precisely known reference time (T_R). Each aircraft equipped with a Synchro-DABS receiver can determine its range and approximate closing velocity with respect to nearby DABS equipped aircraft by measuring the time difference between T_R and when it receives the transponder signals of such aircraft (see Figure 4-6). Properly timed responses from aircraft not within line-of-sight of ground-based DABS or Mini-DABS interrogators, would be obtained from the omni-directional interogators installed at VOR sites.

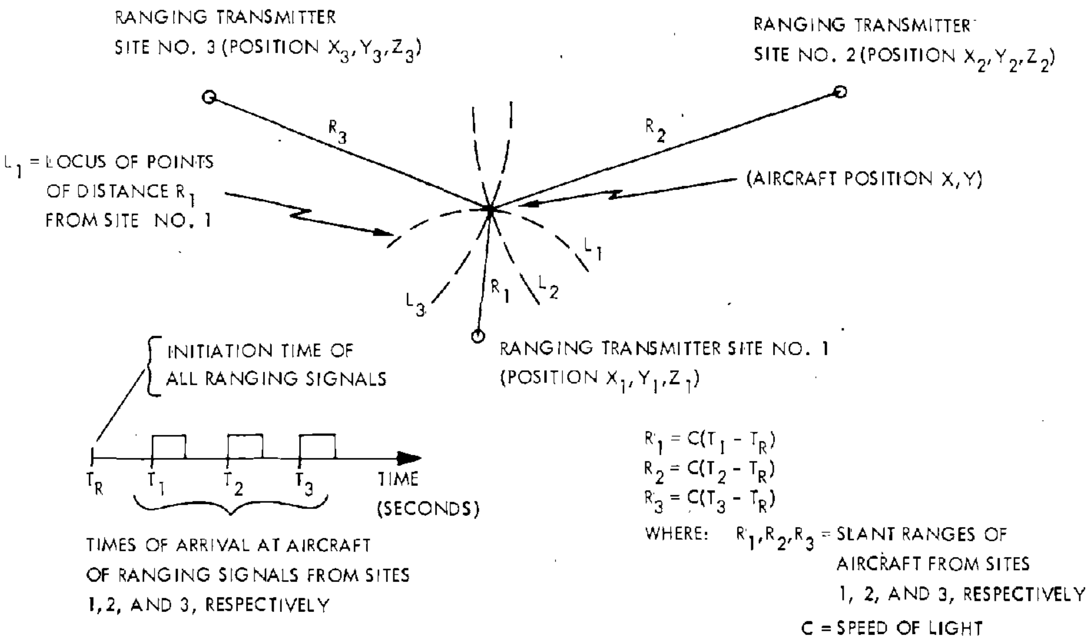


Figure 4-5 Horizontal Position-Fixing by Means of Multilateration

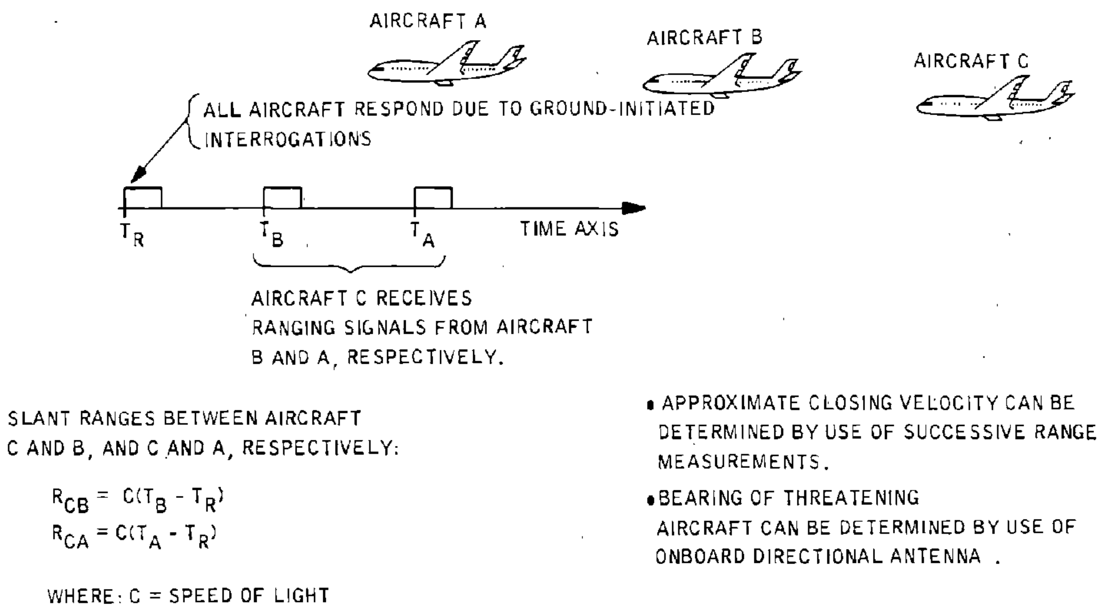


Figure 4-6 Air-to-Air Signal Exchange

Implementation Approach

Figure 4-7 presents an implementation schedule for the Extended Upgraded Third Generation System's ground facilities. In deriving this schedule, it was assumed that the 1982 Baseline System will have been implemented and that this system would transition from the Baseline.

In the period 1983-1985, the number of DABS Sites would increase from 106 sites to 217 sites by conversion of en route (ARSR) and terminal (ASR) radar sites to DABS, while still retaining the primary and secondary radar capabilities. In the period from 1986 to 1988, these same sites would be converted to DABS-only sites and the primary and secondary radars deactivated. Other radar sites (163) would be decommissioned at this time. An additional 74 new DABS sites would be deployed during this period so that 291 sites would exist in 1988. Mini-DABS sites would be put into operation beginning in 1983 at the rate of twenty-five sites per year for twelve years, and thereafter at the rate of ten per year, so that 310 sites would be operational in 1995. All DABS and Mini-DABS sites would have synchro-DABS capabilities.

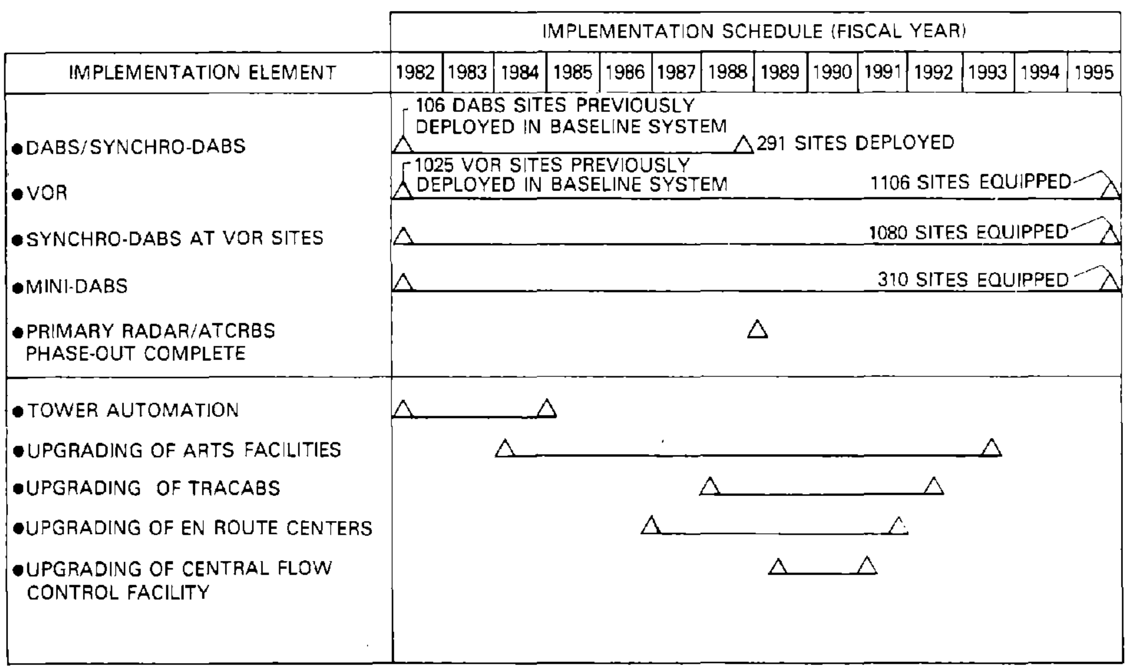


Figure 4-7 Extended Upgraded Third Generation System Ground Facilities Implementation Schedule

After 1982, the Baseline System's VOR network of 1,025 sites would continue to be expanded; initially at an additional nine sites per year rate tapering to four sites per year, so that 1,106 sites would be operational in 1995. Synchro-DABS one-way ranging would be incorporated at VOR sites beginning in 1983 at the rate of 200 per year for five years, tapering to 10 per year thereafter, so that 1,080 sites would be operational by 1995. Allowing a suitable period for user phase-over, full utilization of the Synchro-DABS service would be possible in the mid-1990's enabling the decommissioning of the distance measurement equipment portion of the present VOR network at that time.

Air-ground voice communications would continue to be relayed by the remote outlets carried over from the Baseline System. Additional coverage would be provided by the installation of remote outlets at the Mini-DABS sites in accordance with the Mini-DABS schedule described above.

The Baseline System assumes the completion of the program for automating all towered airports by 1984 with the addition of 14 ARTS II, 37 TRACAB D and 34 TRACAB C facilities. The Baseline System automated control facilities would be updated with new computers and displays sized to handle a traffic load of approximately 1.6 times the 1995 forecast. Updating of the 61 ARTS III centers would occur during the period 1984-1989. The 115 ARTS II facilities would be updated during the period 1987-1993. The 165 TRACAB D and 151 TRACAB C facilities would be updated during the 1988-1992 period. NAS Stage A automation at the twenty ARTCCs would be updated between 1987 and 1991. Computers and displays at the Central Flow Control facility would be updated in 1990.

The phase-in of new ground facilities and phase-out of Baseline System facilities not employed in the Extended Upgraded Third Generation System, is scheduled with a period of dual system operation to allow for user changeover to the DABS/Synchro-DABS avionics. During the period of simultaneous DABS and ATCRBS operation, DABS-equipped aircraft would receive full surveillance/data link service in airspace covered by DABS, and still respond to ATCRBS interrogators elsewhere. ATCRBS-equipped aircraft would be under surveillance in all controlled airspace, as in the 1982 Baseline System. To achieve this compatability, DABS is being designed to operate at the same frequencies as the ATCRBS, i.e., 1030 and 1090 MHz. The initial DABS avionics would also be designed with the capability of being incrementally modified to incorporate the operating modes of the Extended Upgraded Third Generation System Concept. This feature would facilitate user transition at minimum cost since new concept services such as one-way ranging and CAS/PWI may be added incrementally. In 1988, when DABS is fully deployed and the primary and secondary radars phase out of operation, all aircraft flying in controlled airspace would be required to carry a DABS transponder and data link display. IFR flight in positive controlled airspace would require Synchro-DABS ranging capability on-board aircraft by the mid-1990's, when the conventional distance measuring equipment ground network would be phased out of operation.

4.2 ALL-SATELLITE SYSTEM CONCEPT[7]

This Section describes the All-Satellite System Concept developed in the concept formulation phase and further defined in the concept definition phase of the AATMS Study.[7] This candidate Advanced Air Traffic Management System Concept employs a constellation of satellites as a key element in the implementation of surveillance, navigation and communication functions. Surveillance data processing and en route control are performed by two regional facilities with system flight planning and flow control managed from a single Continental Control Center. The remainder of this Section summarizes the salient features of this concept.

All-Satellite System Surveillance, Navigation, and Communication Subsystem Equipment

The surveillance, navigation and communication functions of the All-Satellite System Concept employ a common constellation of fifteen satellites, providing coverage over conterminous United States and contiguous oceanic airspace, plus ground-support facilities consisting of two surveillance data processing centers, a satellite tracking and calibration network, and direct air-ground communication links with Airport Control Centers. Table 4-5 summarizes the subsystem equipment complement and its major operating characteristics.

Surveillance in this system concept is accomplished via unsynchronized periodic transmissions from participating aircraft to the satellites in view of the aircraft, which relay the information to data processing centers on the ground. Each signal is encoded with the originating aircraft's unique identification code. The relative times-of-arrival (TOA) of an aircraft's signal at the various satellites are used by a ground processing center to compute aircraft position. Signals relayed to the ground processing center from four or more satellites are required to calculate each aircraft's three-dimensional position.

Aircraft entering the system transmit a surveillance signal once every two seconds until acquisition by the ground station. On acquiring an aircraft, the ground-based surveillance computer performs a position computation and initiates a tracking function for that aircraft. During the tracking phase, surveillance signals are transmitted once every eight seconds. More frequent aircraft transmissions may be initiated by the control center, particularly in high density terminal areas.

TABLE 4-5 ALL-SATELLITE SYSTEM SURVEILLANCE/NAVIGATION/COMMUNICATION EQUIPMENT

		Surveillance		Navigation		Data Communication	Voice Communication
System Equipment	Terminal	Satellite-Based Transponders (a)		Satellite-Based Transmitters (a)		Terminal-Based Transmitters (700) / Satellite-Based Transponders (a)	Terminal-Based Transmitters/ Receivers (700)
	En Route	Calibration Stations (High Density Regions)		Satellite-Based Transmitters (a) / Ground-Processed Course Guidance		Satellite-Based Transponders (a)	Satellite-Based Transponders (a)
	Oceanic	Data Processing Centers (3)		Ground-Processed Course Guidance		Satellite-Based Transponders (a)	Satellite-Based Transponders (a)
Accuracy (1σ)	Cross Track	380 Ft.	23 Ft. (b)	230 Ft.	1200 Ft.	-	-
	Along Track	120 Ft.	20 Ft. (b)	115 Ft.	600 Ft.	-	-
	Altitude	160 Ft.	13 Ft. (b)	115 Ft.	(d)	-	-
Update Interval	-	2 Sec. (Acquisition) 8 Sec. (Tracking)		3 Sec.	8 Sec. (Min.)	-	-
Capacity	Regional Center	20,000	64,000 (c)	Unlimited	Max. - Surv./ Data Comm. Capacity	G-A: 90KBS/Channel A-G: 50 KBS/Aircraft	-
	Continental Center	35,000	100,000 (c)	Unlimited	Max. - Surv./ Data Comm. Capacity	G-A: 90KBS/Channel A-G: 50 KBS/Aircraft	-
Frequency Band/ No. of Channels/ Channel Bandwidth (MHz)	Air-Sat.	L / 1 / 20		-		L / 1 / 15	L / 150 / .025
	Sat-Gnd.	C / 5 / 20		L / 1 / 20		C / 1 / 15	C / 150 / .025
	Gnd.-Sat.	-		C / 1 / 15		C / 3 / 5	C / 150 / .025
	Sat-Air	-		L / 1 / 20		L / 3 / 5	L / 150 / .025
	Air-Term	-		-		-	L / 400 / .025
	Term-Air	-		-		L / 1 / 5	L / 400 / .025

(a) All Satellite-Based Transponders/Transmitters are Contained in a Common Constellation of 15 Satellites

(b) Within 50 Mi. of Calibration Stations

(c) Expansion Capability

(d) Not Applicable

The surveillance mechanization is projected to have one sigma position location accuracies of 380 feet cross track, 120 feet along track, and 160 feet altitude[7]. Position error contributions due to ionospheric and tropospheric delays and satellite ephemeris errors are reduced by use of a network of Calibration Stations, each consisting of a surveillance transmitter identical to the airborne unit, installed at known geographic locations on the ground. Transmissions from a Calibration Station are used by surveillance data processing centers to compute the Calibration Station location. This computed location is compared to the true, known location, to provide a correction factor which can be applied to position computations for all aircraft in the region surrounding the Calibration Station. One sigma position accuracies for aircraft within 50 miles of a Calibration Station are projected to be 23 feet cross track, 20 feet along track, and 13 feet altitude. Calibration Stations would typically be located in high density traffic regions where the improved accuracy may be required to maintain system capacity and safety standards.

Processing of surveillance signals for position determination and tracking is performed at two centers servicing conterminous United States and contiguous oceanic regions. The eastern and western regional centers are located so that, between them, this CONUS and oceanic tracking coverage is possible. Each regional center is capable of tracking 20,000 aircraft simultaneously with provisions for expanding each site, by reconfiguration of processing equipment to handle 64,000 aircraft. A continental center is centrally located so as to view all of the satellites required for CONUS coverage, thereby providing backup to either, or both, of the regional centers by virtue of its capability to track all CONUS aircraft. The continental center is capable of tracking 35,000 aircraft simultaneously with provisions for expansion to handle 100,000 aircraft.

The navigation function is implemented in two ways: a satellite navigation mechanization, independent of the surveillance function, requiring a data processing capability on-board the aircraft; or a mechanization employing surveillance data and ground-based data processing to provide navigation and course guidance to participating aircraft. In the first mechanization, the satellites transmit time-ordered signals which include a precisely timed marker pulse plus satellite ephemeris data. By measuring the time-of-arrival (TOA) of signals from at least four satellites, the aircraft can compute its three-dimensional position. The satellite-transmitted navigation signals used by the aircraft are also used by ground stations to predict the satellite ephemeris data. The computed ephemeris data for each satellite are transmitted to that satellite for retransmission as an integral part of its navigation signal. This satellite navigation mechanization is projected to yield one sigma position accuracies of 230 feet cross track, 115 feet along track, and 115 feet altitude.[7]

The alternative mode of navigation in this system concept is designated Ground-Computed Area Navigation (GC-RNAV). Aircraft position data derived from the surveillance subsystem, and aircraft destination or intermediate way point data transmitted via data link to a Regional Control Center, are used to compute course guidance commands which are transmitted via data link to the participating aircraft. On-board the aircraft they are displayed to show either bearing and range from the aircraft's present position to a previously selected destination or way point, or distance-off-track, where the ground track is defined as a great circle path between way points.

Data and voice communication between control centers and aircraft in en route and oceanic airspace are relayed via satellites. In terminal airspace served by an airport control center (approximately 700 are assumed to exist in this system), aircraft-to-airport center voice communications are via direct link. Data communications from airport-center-to-aircraft are also via direct link, but aircraft-to-center data messages are relayed via satellite. Use of direct links at airports, where communications loading is highest, serves to relieve the satellite link communications load. Table 4-6 summarizes the communications links for the All-Satellite System.

The satellite constellation selected to implement the surveillance, navigation, and communication functions of the All-Satellite System Concept consists of six geostationary and nine geosynchronous satellites. Figure 4-8 shows the orientation of the subsatellite points for the constellation at a given instant. The satellites are all of the same basic design although they differ in the amount of communications equipment carried. All of the satellites carry the electronic equipment required to relay surveillance signals, transmit navigation signals, and relay digital data transmissions from control centers to aircraft and from aircraft to control centers. In addition, all six geostationary satellites carry equipment for relaying voice communications between control centers and aircraft in en route or oceanic airspace; of these, the four which are centrally located with respect to CONUS carry additional equipment for relaying digital data transmissions between control centers.

The selected constellation configuration provides complete down-to-the-ground coverage over conterminous United States and over contiguous oceanic areas. The number of satellites employed is sufficient to insure the simultaneous visibility of at least four, from all points in the region of coverage, as required for surveillance and satellite navigation purposes. The number is also sufficient to maintain an adequate level of performance in case of individual satellite failure, or of aircraft signal degradation due to aircraft maneuvers or reduction in transmitted energy levels.

TABLE 4-6 ALL-SATELLITE SYSTEM COMMUNICATIONS LINK DESCRIPTIONS

Function	Path		Band	Bandwidth	No. of Channels	Channel Bandwidth	Type of Data	Comments
Surveillance	A-S	Uplink	L1	20 MHz	1	20 MHz	Surveillance Pulse	Independently transmitted by all aircraft
	S-G	Downlink	C1	21 MHz	5	20 MHz	Surveillance Pulses	Five overlapping channels separated by 0.25 MHz
Navigation	S-A S-G	Downlink	L2 + L3	20 MHz	1	20 MHz	Navigation Pulses (also used for tracking)	Time ordered and shared with digital data transmission to aircraft
	G-S	Uplink	C2	15 MHz	1	15 MHz	Ephemeris Insert Data	Time ordered and shared with digital data uplink to the satellite
Communication - Data and Voice	A-S	Uplink	L4	15 MHz	1	15 MHz	Digital Data	Asynchronous aircraft-to-ground data link
	S-G	Downlink	C3	15 MHz	1	15 MHz	Digital Data	
	G-S	Uplink	C2	15 MHz	3	5 MHz	Digital Data	Ground-to-aircraft data link, time ordered and shared with navigation links
	S-A	Downlink	L2	15 MHz	3	5 MHz	Digital Data	
	T-A	Local LOS	L3	5 MHz	1	5 MHz	Digital Data	
	G-S	Uplink	C4	3 MHz	600	5 kHz	Digital Data	Ground-to-ground link interconnecting RCC's and ACC's; employs four equatorial satellites with space diversity to achieve 2,400 channel capability
	T-S	Uplink	C4	3 MHz	600	5 kHz	Digital Data	
	S-G	Downlink	C5	3 MHz	600	5 kHz	Digital Data	
	S-T	Downlink	C5	3 MHz	600	5 kHz	Digital Data	
	G-S	Uplink	C6	5 MHz	150	25 kHz	Voice	Ground-to-aircraft voice link
	S-A	Downlink	L5	5 MHz	150	25 kHz	Voice	
	A-S	Uplink	L6	5 MHz	150	25 kHz	Voice	Aircraft-to-ground voice link (two channels reserved for air-to-air mode)
	S-G	Downlink	C7	5 MHz	150	25 kHz	Voice	
	T-A	Local LOS	L7	10 MHz	400	25 kHz	Voice	Local traffic voice links with ACC's
	A-T	Local LOS	L7	10 MHz	400	25 kHz	Voice	

Notes: 1. Path abbreviations: A = Aircraft, S = Satellite, G = Ground (RCC), T Tower (ACC or Remote Site)
2. Total spectrum usage: L-Band = 75 MHz, C-Band = 67 MHz
3. RCC = Regional Control Center
4. ACC = Airport Control Center

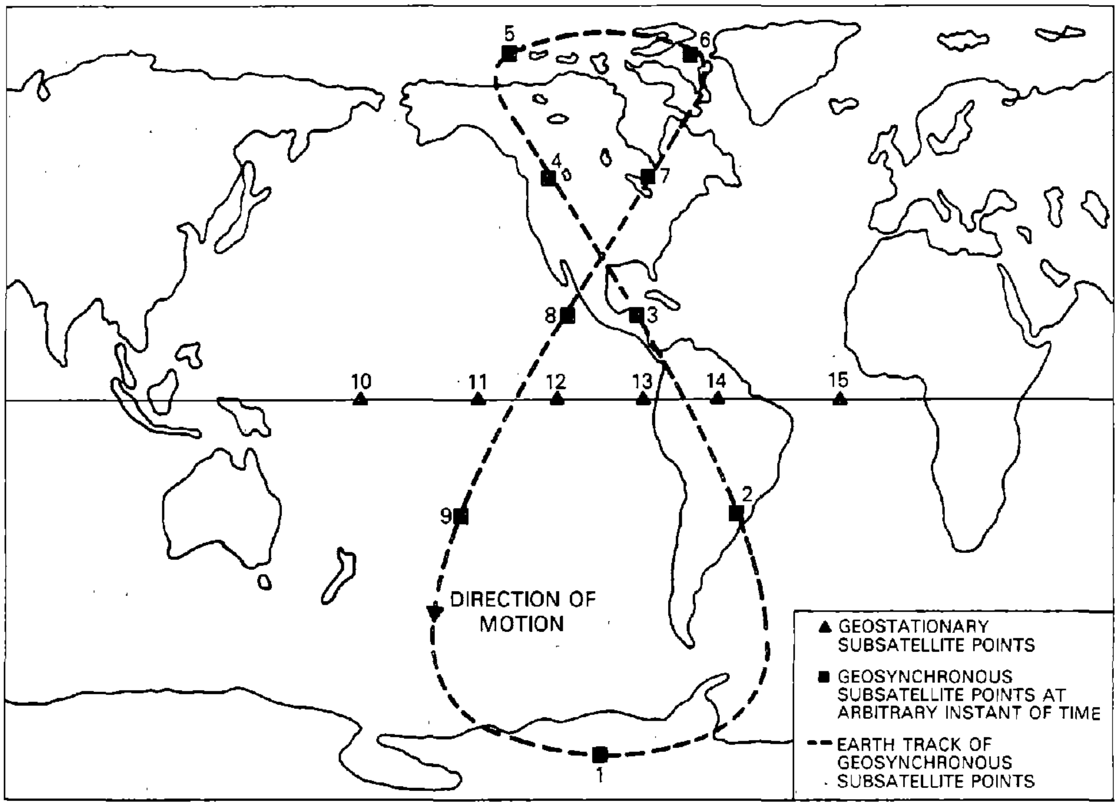


Figure 4-8 Constellation Subsatellite Points

Each of the six geostationary satellites is estimated to cost \$5.4 million. The nine geosynchronous satellites are estimated to cost \$2.4 million each. The entire network of 15 satellites could be placed in orbit with three Space Shuttle/Tug launches, each costing \$12 million. The total estimated implementation cost for the space-based elements is therefore \$90 million.(7,24)

The O&M costs associated with the satellite system were determined by considering the anticipated lifetimes of the space-based equipment. Based on historical data concerning space sensor reliability, a satellite lifetime of seven years was assumed, and the annual O&M costs are taken as one-seventh of the initial space vehicle and launch costs. The estimated 1995 annual O&M cost for the satellite elements is therefore \$13 million.

All-Satellite System Avionics

The surveillance, navigation, and communication mechanization requires participating aircraft to carry a compatible set of avionics. Figure 4-9 is a schematic representation of the avionics modules required for operation with the satellite and ground-based elements of this system concept.

The transmitter section performs the integrated surveillance and digital data functions, transmitting asynchronous, L-band signals at a nominal eight second interval. The section includes the electronics required to generate the aircraft's surveillance identification code, to encode pilot-generated messages, and to provide the timing mechanism for signal transmissions.

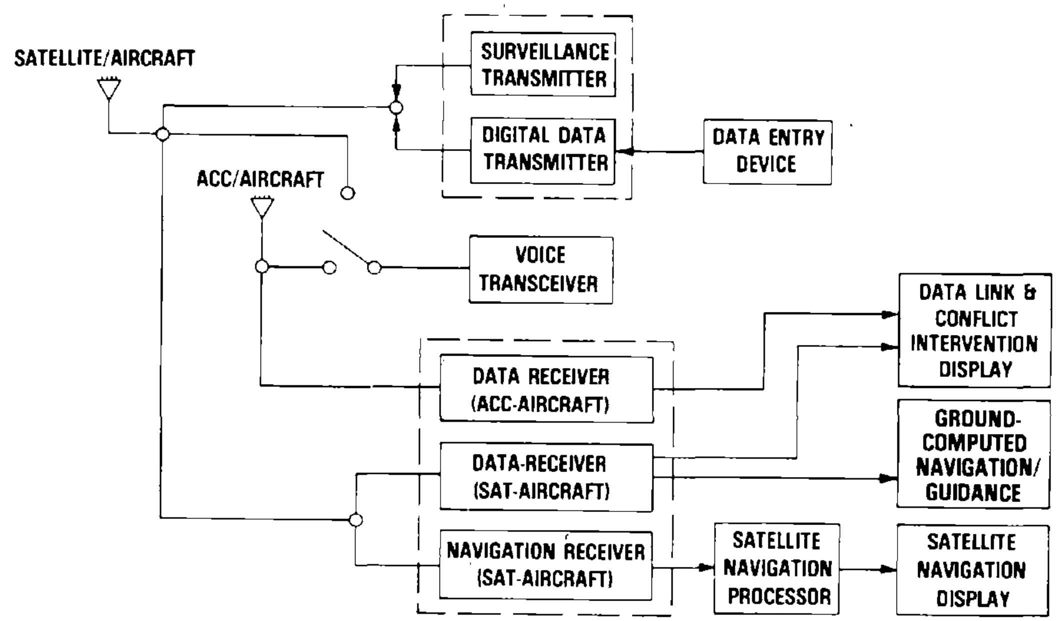


Figure 4-9 All-Satellite System Avionics

The voice transceiver includes the electronics for channel selection, modulation/demodulation and amplification of voice messages transmitted and received at L-band. These signals may be routed via satellite relay or via direct link to Airport Control Centers (ACC).

The receiver section processes digital data messages relayed through satellites or transmitted directly from Airport Control Centers, and pre-processes navigation signals received from all satellites in view of the aircraft. Digital data messages, including traffic advisories, clearances, and conflict avoidance commands, are decoded and displayed to the pilot. Ground-computed navigation/guidance data are also displayed. Satellite navigation signals are processed on board the aircraft where the received data are corrected for aircraft and satellite clock errors and for ionospheric and tropospheric delays. The multilateration equations are solved using Kalman filter techniques, and position/steering data are displayed to the pilot.

An aircraft flying in controlled airspace is required to carry avionics capable, at a minimum, of performing the surveillance and data/voice communication functions. A satellite navigation and data processing capability is required in all positive controlled airspace and for all aircraft flying with IFR clearances.

An air-to-air collision avoidance and proximity warning (CAS/PWI) capability, independent of ground-based separation assurance services, may be realized by the air-to-air exchange of navigation position information between aircraft. This would require additional avionics for the transmission, receipt, and display of navigation data for proximity warning purposes. Additional airborne processing capability is also required for a collision avoidance capability. Air-to-air data transmissions for CAS/PWI consisting of aircraft identity, latitude, longitude, altitude, speed, heading, and intent would be sent in digital format over a voice channel using a low-power, line-of-sight (non-satellite) link.

The All-Satellite System Study defined three basic user classes and projected the number of aircraft in each class in 1995.[7] Two of the classes are in general aviation; the first, called "low cost" and based on aircraft purchase price, includes aircraft which typically fly under visual flight rules; the second GA class is called "sophisticated" and typically includes business aircraft and aircraft equipped for instrument flight. The third class, air carrier and military aircraft, make-up the remainder of the fleet and are equipped with redundant, high quality units to perform instrument flight. Equipment procurement and installation costs were estimated from preliminary subsystem designs for the various modules. Estimated costs for submodule parts were translated into purchase price by using industry conversion factors and historic trends. Estimated avionics cost for the equipment complements are: "low cost" general aviation - $3,625; "sophisticated" general aviation - $15,000; and air carrier - $38,640.[7,24]

All-Satellite System Control Facilities and Automation

This system concept employs three types of facilities for control of air traffic in various jurisdictional areas. A Continental Control Center (CCC) serves as an executive command and monitor center for the entire system during normal operation. Two Regional Control Centers (RCC) have primary tracking responsibility of all aircraft within their respective regions and have control responsibility for all aircraft in en route, transition, and oceanic airspace. Approximately 700 Airport Control Centers (ACC) have command and control responsibility of all aircraft within their jurisdiction.

The unique function of the CCC is the planning and maintenance of traffic flow in controlled airspace throughout CONUS. This includes the tasks of strategic and tactical flow planning and complilation of weather service data, historical flight data, and flight schedules for use in this planning process. The CCC also includes the data processing capability required to perform satellite tracking and ephemeris computations. A secondary function of the CCC is to provide full backup to the surveillance and aircraft control processing functions normally performed at the RCC's, in case of complete or partial failure of one or both of these facilities.

The principal data processing functions performed at a Regional Control Center (RCC) include:

- Acquisition of aircraft surveillance signals, separation of newly acquired aircraft from those already being tracked, and computation of newly acquired aircraft position.
- Computation of tracked aircraft position.
- Maintenance of a tracked aircraft file.
- Prediction and resolution of conflicts between aircraft.
- Prediction and resolution of impending intrusions into restricted airspace.
- Handoff to the other RCC or to an ACC
- Computation of transition and arrival flight plan, conformance monitoring, and control commands.
- Computation of course guidance commands for aircraft navigation.
- Computations necessary to satellite tracking

The two RCC's would probably be located near the east and west coasts of the United States, and would have jurisdiction of their respective CONUS region and contiguous oceanic airspace.

Airport Control Centers (ACC's) would be located at all airports with manned control towers. These centers have command and control responsibility for aircraft within their jurisdiction, a region which extends approximately five miles from each airport. All airport surface surveillance/control and airport arrival/departure control falls under the responsibility of the ACC's. The principal data processing functions are concerned with communications, handoffs, and displays. Four ACC's will also perform satellite tracking computations, transmitting data to the CCC, where the satellite ephemeris computation is performed.

The data processing subsystem at each RCC is sized to handle 20,000 aircraft, requiring an estimated computer processing speed of 23.5 million instructions per second and memory capacity of 5.8 million 32-bit words. The CCC is sized to handle 35,000 aircraft, requiring an estimated computer processing speed of 33.9 million instructions per second and memory capacity of 40 million 32-bit words. Data processing requirements at each ACC is a function of the number of aircraft within its jurisdiction. The busier ACCs require a mini-computer with a capacity of up to 32,000 words of main memory. At some small airports the main memory requirement would be as low as 8,000 words.

The number of en route controllers required in 1995 is estimated at 3500 per site, or a total of 10,500 for the CCC and two RCCs. This estimate is based on an instantaneous airborne count of 35,000 and a capability of monitoring 40 aircraft per two-man sector. The seven hundred ACC's, even with a high degree of automation, are estimated to require a staff of 8,000 controllers due to the minimum staff levels needed at each airport tower. The staff would be comprised of system operators or controllers, their supervisors, and a data processing support staff. It is estimated that the salary for personnel in each category would be $20,000, $25,000, and $18,000, per man per year, respectively. The annual control staff cost, in 1995 is therefore estimated to be $400 million.

The F&E and O&M costs for the control facilities of the All-Satellite System Concept are derived from detailed estimates of the costs for land, buildings, equipment, software, installation and checkout, equipment replacement, maintenance, and flight inspection.[7,24] Total control facility F&E costs have been estimated in this Study as $800 million; O&M costs in 1995 were estimated as $180 million.

All-Satellite System Air Traffic Control Techniques

The All-Satellite System Concept provides the same generic services described for the Extended Upgraded Third Generation System Concept. Differences exist, however, in the mechanizations used to implement the specific control techniques. Intermittent Positive Control, which is an independent backup to conflict prediction/resolution computations for aircraft with IFR clearances and the primary means of separation assurance for aircraft flying VFR in the previously described concept, is not implemented in this system concept. In this system, automatic conflict prediction and resolution service is provided by the RCC's to aircraft flying in controlled airspace, with computational backup provided by the CCC. Responsibility for flight plan conformance monitoring is delegated to the aircraft except in the transition-arrival flight phase where the RCC performs this service. Terminal area services relating to 4D/2D RNAV routing, metering and spacing, and conflict-free flight planning are implemented by the transition and arrival control processing function at an RCC.

All-Satellite System Operating Modes

The operating modes for surveillance, navigation, and air-ground communication in the All-Satellite System Concept are implemented by the satellites, the ground-based data processing centers, and the network of airport-based communication terminals. Three-dimensional surveillance information is obtained from multilateration techniques using measurements of differences in time-of-arrival of each aircraft's asynchronous transmissions relayed through a minimum of four satellites. An alternative means for obtaining surveillance information is by data link/voice transmission, from aircraft-to-ground, of position information derived on-board the aircraft from measurements of difference in times-of-arrival of satellite transmissions. A variation of this alternative is the relaying of the time of arrival measurements themselves for ground computation. This alternative is available only if the aircraft carries avionics suitable for receiving satellite navigation signals and, in the first technique, the data processing capability required to perform position computations.

The modes used for obtaining navigation information on-board an aircraft depend on the type of avionics carried. A three-dimensional position fix may be obtained by aircraft carrying a navigation receiver and a processor to compute position from differences in the times of arrival of signals received from at least four satellites. An alternative is to use ground-computed guidance signals based on surveillance data and knowledge of the aircraft's next destimation.

The primary mode of air-ground communication is the data link through satellite relay en route, and by direct line-of-sight channels from Airport Control Centers. The alternative air-ground communication mode is voice channels either through satellite relay or directly to and from Airport Control Centers.

All-Satellite System Implementation Approach

Figure 4-10 presents an implementation schedule for the All-Satellite System's space-borne and ground facilities. It is assumed that the 1982 Baseline System will have been implemented and that the All-Satellite System will transition from that system.

It is anticipated that six to ten fully-equipped satellites will have been placed in orbit prior to 1982 as part of the All-Satellite System development and test program. The Continental Control Center will also be in partial operation with capabilities for satellite tracking and ephemeris computation, surveillance processing, air-ground data and voice communication, ground-computed course guidance, flow control, and inter-facility communications. Thus, CONUS-wide down-to-the-ground surveillance coverage will be available in 1982 for all aircraft equipped with the required surveillance transmitter.

Partial oceanic coverage will be available from those satellites within view of the Continental Control Center. Surveillance data on aircraft equipped with Baseline system avionics will be obtained by ATCRBS or DABS for CONUS traffic, and from the AEROSAT system for traffic over the Atlantic Ocean.

In 1990, most of the fleet will be equipped with satellite system-compatible avionics, and the primary surveillance processing responsibility will have been transferred from the CCC to the two RCC's, which will have become operational. Decommissioning of the ATCRBS and DABS sites will begin at this time. In 1995, ATCRBS and DABS will be completely decommissioned and all participating aircraft will be required to carry a satellite system-compatible surveillance transmitter.

The full satellite system navigation service, both satellite navigation and ground-computed course guidance, will be available CONUS-wide in 1982 to properly equipped aircraft. Aircraft equipped with Baseline System avionics would continue to use the VOR/DME/VORTAC network to fly radials or area navigation routes over CONUS. Aircraft in oceanic airspace will continue to use inertial or hybrid radio-inertial navigation techniques.

In 1990 most of the fleet will be equipped with satellite system-compatible avionics, and phase-out of the VOR/DME/VORTAC network will begin. Primary responsibility for

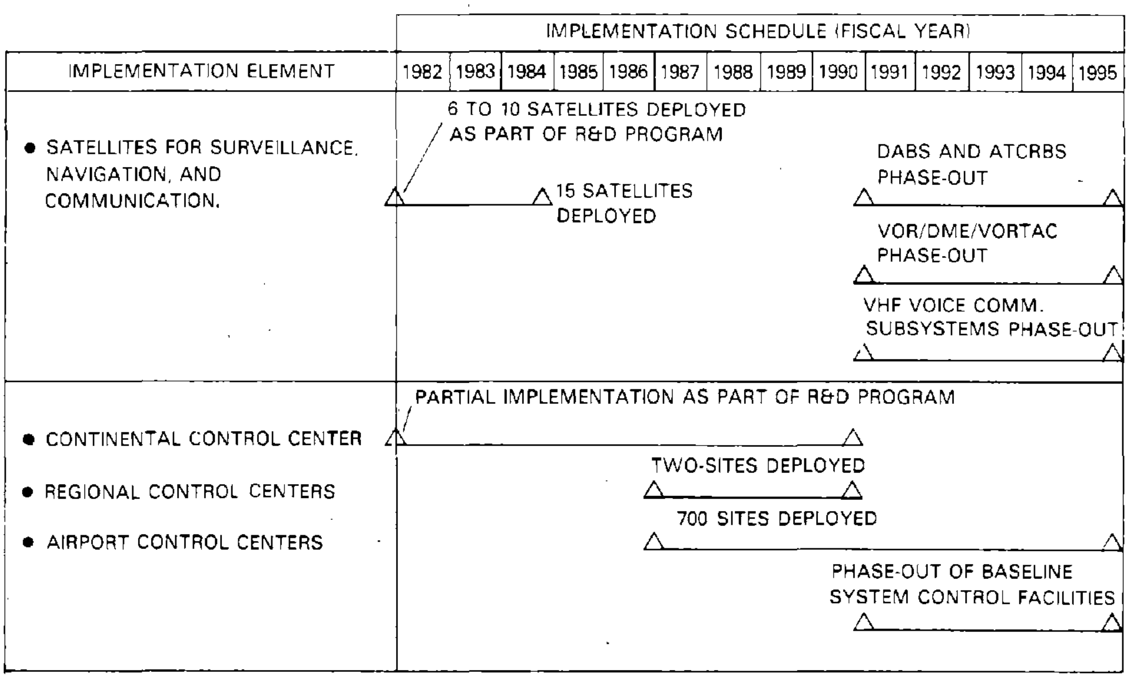


Figure 4-10 All-Satellite System Facilities Implementation Schedule

ground-computed course guidance will have been transferred to the RCC's by 1990. By 1995, phase-out of the VOR/DME/VORTAC network will be complete, and all aircraft flying in controlled airspace will carry the avionics needed to implement the appropriate navigation mode.

In 1982, air-to-ground communications between aircraft equipped with All-Satellite System avionics and the ground-based control centers will be via satellite relay to the Continental Control Center and thence to the cognizant Baseline System control facilities. Ground-to-air communications to these aircraft will follow the reverse path. Air-ground communications with aircraft equipped with Baseline System avionics, will be via VHF voice or the DABS data link over CONUS, and via the AEROSAT system over the Atlantic Ocean.

In 1990, most of the fleet will be equipped with satellite system-compatible avionics and the VHF voice outlets and DABS sites will start to be decommissioned. Air-ground communications with aircraft equipped with satellite system avionics will be routed to the RCC's, except in the vicinity of airports equipped with an ACC, where a direct line-of-sight link will be used. By 1995, all air-ground communications will be via the satellite-RCC link or direct ACC link, and the VHF voice/DABS data link network will be completely phased-out.

From 1982 to 1990, the control facilities of the Baseline System (ARTCC's, TRACONS, and TRACABS) will be maintained in normal operation. Some satellite-relayed ground-to-ground communication capability will be added at these facilities to enable communication with the Continental Control Center and Regional Control Centers. Flow planning and flight planning functions will continue to be performed by the Central Flow Control Facility, the Flight Service Station network, and the ARTCC's.

Phase-in of the Satellite System spaceborne and ground facilities, and phase-out of the Baseline System facilities is scheduled with a period of dual system operation to allow for user changeover to a completely new set of avionics equipment. Satellite system avionics will be designed to offer varying degrees of shared electronic elements, and have the flexibility to allow incremental addition of avionics capability. Shared electronics minimizes overall avionics cost, while the possibility of incremental add-ons allows increasing avionics capability at the option of the user without requiring a large initial investment.

Certain functions such as surveillance/digital data transmission, and navigation/digital data signal reception can be implemented with a significant percentage of common elements. Other functions, such as voice transmission/reception, satellite navigation processing/displays and ground computed course guidance displays require the addition of independent modules. The manner in which the avionics are implemented in an individual aircraft depends upon the aircraft's existing avionic complement, the new services or air-space accessibility desired, and the size of investment the user is willing to make. All aircraft operating within an airspace region will be controlled by a single jurisdictional authority, although the surveillance data will be obtained from either the Continental Control Center or individual DABS/ATCRBS sites. Initially, control authority will be retained by the ARTCC's, TRACONS, and TRACABS. The Continental Control Center and Regional Control Centers will perform the control functions over limited regions, as they are implemented; perhaps over one or more ARTCC sectors at a time. This will be done off-line until the facility and its personnel are checked-out. On-line control by the system facilities will be implemented on a staged, region-by-region basis. A similar procedure will be followed in the activation of Airport Control Centers at selected primary airports.

During the period 1990 to 1995, the primary control authority of the remaining regions will be transferred to the RCC's and ACC's at an accelerated rate. CONUS-wide flow and flight planning functions will be transferred to the CCC, which will operate in conjunction with the Flight Service Station network. ATCRBS or DABS derived surveillance data will be transmitted to the cognizant RCC's and thence to the ACC's via appropriate satellite or land-line communication links. The decommissioning of the remaining ARTCC's and TRACON's will be completed by 1995.

5. THE ADVANCED AIR TRAFFIC MANAGEMENT SYSTEM (AATMS) CONCEPT

This Section describes the surveillance, navigation, and communications mechanization, user equipment, the control facility and staffing configurations, and the control modes for the selected Advanced Air Traffic Management System (AATMS) of the 1990's. The system configuration was synthesized from the All-Satellite and the Extended Upgraded Third Generation System Concepts described in Section 4 of this Report, the assumed 1982 Baseline System described in Section 3, and supporting AATMS studies on control techniques and system automation described in other documents.[10,12] The 1982 Baseline System was considered as the point of departure for transition to an advanced system design for application in the 1990's. The All-Satellite and the extended Upgraded Third Generation System Concept represented alternative ways of meeting Air Traffic Control System demands in the 1995 time frame.[7,9] The evaluation resulting from these two studies led to the definition of a mixed ground and space-based system concept capable of meeting the projected demands for air traffic control service in a cost-effective manner. The following paragraphs present the elements of the recommended concept, including surveillance, navigation, and communication equipment, user equipment, control facilities, control automation, estimated costs, implementation approach, and operating modes. An assessment of the selected system concept is also presented.

5.1 AATMS SURVEILLANCE, NAVIGATION, AND COMMUNICATION EQUIPMENT

Table 5-1 lists the major spaceborne and ground-based elements required to implement the surveillance, navigation, and ground-air communication functions of the selected AATMS Concept. Avionics required to interface with these equipments are described later in this Section.

Subsystem Equipment

Surveillance and Data Link Communication Equipment - The AATMS concept employs 106 DABS sites to service high density en route and terminal airspace regions as the primary surveillance sensor and data link interface. These sites will have Synchro-DABS capability so that one-way DME and CAS/PWI functions can be provided to suitably equipped users within the coverage of the sites. They are expected to be able to handle up to 73 percent of the 1995 peak instantaneous airborne count because of their site placement relative to projected traffic distributions.

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TABLE 5-1. SURVEILLANCE, NAVIGATION, AND COMMUNICATION SYSTEM EQUIPMENT

Function	Airspace Region			
	Terminal		En Route	
	High Density	Low Density	Domestic	Oceanic
Surveillance	DABS/Synchro-DABS	Satellites	Satellites (1)	Satellites
Communication (Air-Ground-Air)				
Data	DABS	Satellites	Satellites (1)	Satellites
Voice	Ground-based Transceivers	Ground-based Transceivers(2)	Ground-based Transceivers(2)	Satellites
Navigation (3)				
IFR	Satellites	Satellites	Satellites	Satellites
VFR		GC-RNAV	GC-RNAV	

Notes: (1) Certain high-density en route regions would be served by DABS sites deployed prior to 1982.

(2) Satellite-based voice links may prove to be a lower cost means of providing service to the widely dispersed users operating in low traffic density regions.

(3) Selected VOR sites may be retained to provide navigation service in uncontrolled airspace.

The AATMS Concept also incorporates a constellation of satellites to provide redundant surveillance/data link coverage in the regions covered by the DABS sites, and surveillance, navigation, and data link communication capabilities in other terminal and en route regions outside DABS coverage. About fifty Calibration Stations, distributed throughout the United States at various airports, would aid in reducing bias errors in position determination from both the surveillance and navigation subsystems. The satellites cost-effectively extend the coverage of ground-based sites and provide services in low-density traffic regions throughout the conterminous United States and contiguous oceanic regions.

The satellite constellation consists of geostationary and geosynchronous satellites. The geostationary satellites remain at fixed locations over the earth's equator. The geosynchronous satellites trace a repetitive figure-eight pattern over North and South America. The satellites are tracked by ground tracking centers, and since their positions are known, they can serve as signal sources (or receivers) to enable accurate surveillance and navigation measurements to be made. The equipment on board the satellites includes antennas, transmitters, receivers, and electronic equipment for signal conditioning. The satellite subsystems operate at the following frequencies:

- L-band (near 1600 MHz) for signals between satellites and aircraft
- C-band (near 5200 MHz) for signal exchanges between satellites and ground control centers.

Navigation Equipment - Two navigation techniques are proposed for use with the AATMS Concept. The first technique enables users to determine their position based on a sequence of signals received from the satellites. The same satellite constellation used for surveillance and data link communication provides signals for aircraft navigation. These signals include satellite location and calibration data. The second technique uses the data link to transmit ground-determined position and navigation guidance information to aircraft equipped with a surveillance transponder and data link terminal modem. The transmitted information is based on surveillance data on the aircraft's position and a knowledge of the pilot's intended flight path. These two navigation modes are described later in this Section in more detail.

About 300 conventional VHF Omni-Range (VOR) sites may be retained from the Baseline System. These sites will provide navigation capability to users that retain some Baseline System avionics and will also help satisfy military and international agreements. Navigation information would be in the form of bearing-from-the-site. The volumetric coverage of the 300 VOR sites was estimated using information from a recent study concerning a line-of-sight sensor network.[9] With 300 VOR sites, about 90 percent of the conterminous United States will be covered by at least a single site down to an altitude of 3,000 feet above ground level (AGL) or better, and more than 84 percent of the eastern United States (where most flights occur) may be covered down to an altitude of 2,000 feet AGL or better. Redundant site coverage occurs in airspace above 6,000 feet AGL. Near each site, the minimum altitude at which VOR signals may be received decreases and thus, near VOR-equipped terminals, navigation service continues to be available.

Voice Communication Equipment - AATMS retains the Baseline System's direct air-ground-air voice links operating in the VHF portion of the frequency spectrum. This equipment, like the VOR equipment just mentioned, permits communication with users retaining avionics from the Baseline System (generally those that are minimally equipped). There will be about 1,100 ground-based transmitter-receiver sites in terminal and en route areas and these will be sufficient, together with the data link, to handle future CONUS communication system requirements. Satellite-relayed voice links will be used for oceanic airspace regions. These may also prove to be a cost-effective means of serving users operating in low density terminal and domestic en route airspace. These satellite-based links could also serve as a backup to the direct air-ground-air voice links retained from the Baseline System.

Equipment Cost Estimates - The estimated costs for the selected satellite and ground-based surveillance, navigation, and communication subsystem described above are presented in Table 5-2. These estimates are based on preliminary designs for subsystem equipment and consider the impact of current and anticipated technological advances, as well as costs for similar existing equipment.[7, 9, 24] These estimates include initial implementation and checkout expenses for newly deployed equipment (F&E) of the proposed system, but do not include costs associated with implementing the 1982 Baseline System or phase-out of equipment not included in the AATMS Concept. O&M costs include the annual expenses to operate, maintain, relocate, and modernize all subsystems anticipated to be operational in 1995. Costs accruing to surveillance and GC-RNAV data processing equipment are included with control facility cost estimates (see Section 5.2).

Two independent studies have estimated the costs associated with deploying satellite constellations during the late 1980's. The costs associated with the All-Satellite System

TABLE 5-2. SURVEILLANCE, NAVIGATION, AND COMMUNICATION SUBSYSTEM COSTS
(Costs in Millions of 1973 Dollars)

Subsystem	No. in Place in 1995	Unit Cost	Total F&E Cost 1977-1995 (2)	Annual O&M Cost in 1995 (1)
DABS/Synchro-DABS	106	-	-	$4
SATELLITES				
Geostationary Satellites (3)	5-7	$5.4 - $11.8	$55 - $100	$5 - $10 (4)
Geosynchronous Satellites (3)	5-9	$2.4 - $5.5		
Launch of Satellites (5)	3	$12.0	$35	$5 (4)
Satellite Tracking Centers	7	-	$2	$2
Calibration Stations	50	-	$2	-
Ground-based Communications Voice Transceivers	1,100	-	-	$34
VOR	300	$.280	-	$5
COST TOTALS			$90 - $135	$55 - $60

(1) Includes Relocation and Modernization (R&M) costs which also recur annually.

(2) Does not include implementation cost of 1982 Baseline System equipment.

(3) Cost estimates determined from two studies (see text).

(4) Satellite lifetimes of seven years were assumed.

(5) Three launch missions costing $12 million each are assumed required to place the entire constellation in synchronous orbit. The Space Shuttle/Tug combination is used.

Concept were estimated in connection with that study (see Section 4).[8] Another recent study estimated the costs associated with a satellite system designed to be DABS-compatible and consisting of a constellation of seven geostationary and six geosynchronous satellites.[9] In this Study, four of the satellites, called transmit/receive satellites, relay surveillance interrogations. They were estimated to cost $11.8 million each. The other nine satellites called receive satellites, were less complex and were estimated to cost $5.5 million each. The data from these two studies were used to estimate a cost range for the AATMS Concept geostationary and geosynchronous satellites.[7,9,24] Annual O&M costs accruing to the satellites were based on an average seven-year lifetime for each satellite, and assume that one-seventh of the implementation cost will be required each year for constellation replacement. Both satellite concept studies determined that orbital deployment of the full satellite constellation could be accomplished by three dedicated missions of the Space Shuttle/Tug, each costing $12 million. Annual O&M costs accruing to satellite launches, also based on the seven-year lifetime of the satellites, were estimated at an average of $5.2 million.

Ground-based equipment includes DABS, VOR, and air-ground voice transceivers. Beyond 1982, no additional sites are recommended for these subsystems. The 106 DABS sites, installed at high and medium density terminals and in en route regions, were estimated to cost $4.3 million annually to operate and maintain. Starting about 1991, sites from the Baseline VOR network (about 900 sites) are about $30 million. By 1995, the installation of improved equipment and use of an integrated approach to achieve maintenance productivity increases, should result in annual operating costs for the remaining 300 VOR sites of about $5 million. Data link, the primary means of communication in 1995, will reduce the demand on air-ground voice communication channels for all but extraordinary and emergency communications, enabling the retained Baseline System air-ground voice communication equipment to adequately service the 1995 airfleet. The annual O&M costs in 1995 for the approximately 1,100 ground-based voice transceivers will be about $34 million, a figure close to that of the present system.[9] The use of satellites for air-to-ground voice communication over the conterminous United States, and intersite data exchange and communications, is a promising area for operating cost reduction. A thorough analysis of air-ground voice and ground-to-ground communications through a satellite network and system backup modes is needed in future system design activities.

Avionics Equipment - This study defined six user classes to represent the expected range of 1995 user requirements and needs for flight services. These classes represent levels of capability and, in total, the diversity of avionics complements that the future fleet may be expected to install and use. Table 5-3 shows the general equipment types for each of the user classes. It is expected that different users would carry avionics of different quality, redundancy, and degree of sophistication based on the cost, safety, and level of service they chose, and the airspace in which they wish to fly. The six user classes are also representative of today's stratification of avionics capabilities, a trend expected to continue into the future. The six classes of users are described below.

Class A

- IFR capability in all controlled (mixed, positive control, and high density) airspace regions of the National Airspace System under instrument meteorological conditions (only VFR flights may be conducted in uncontrolled airspace).
- Equips with dual, high quality avionics characteristic of air carrier and military aircraft.

Class B

- IFR capability in all mixed and positive controlled airspace regions (requiring 3D-RNAV), except where Strategic Control procedures (requiring 4D-RNAV equipment) are in effect.
- Equips with dual, high quality avionics characteristic of expensive general aviation aircraft.

Class C

- Typically operates IFR in mixed airspace regions.
- Has nonredundant, medium quality avionics of limited navigation (2D-NRAV) and data link communications capability.

Class D

- Generally operates VFR in all low density terminals and mixed en route airspace.
- Has low cost avionics without area navigation equipment.

TABLE 5-3. AVIONICS BY USER CLASS

Avionics Descriptors	Avionics Classes					
	A	B	C	D	E	F
1. General Features						
Interface Compatibility						
Ground-only					•	•
Ground and Satellite	•	•	•	•		
Redundant Equipment						
Dual Equipment Units	•	•				
Single Equipment Units			•	•	•	•
2. Avionics Elements						
Surveillance/Data Link						
DABS Beacon (Ground-only)					•	
DABS Beacon (Ground-Satellite)	•	•	•	•		
IPC Data Link/Display	•	•	•	•	•	
ATC Data Link/Display	•	•				
Altitude Encoder					•	
Voice Communications	•	•	•	•	•	•
Navigation						
VOR				•	•	•
GC-RNAV (2D-dependent RNAV)	•	•	•	•		
2D-RNAV/Satellite Nav. (independent)			•			
3D-RNAV/Satellite Nav. (independent)		•				
4D-RNAV/Satellite Nav. (independent)	•					
CAS/PWI: Synchro-DABS	•	•	•			

Class E

- Typically operates VFR in mixed airspace only if within line-of-sight of a DABS site, otherwise operates in uncontrolled airspace.
- Has low cost avionics with VOR navigation equipment.

Class F

- Operates in uncontrolled airspace with ground-based voice communications and minimum VOR navigation capabilities.

Users are classified as "cooperative" when they carry the minimum required equipment to enable them to fly in mixed airspace, namely a surveillance transponder, data link (IPC) logic and displays, a voice communications transceiver, and some type of navigation equipment. Users can choose to install duplicate sets of equipment to increase reliability, interfacing with either the ground or ground and satellite system elements depending on their choice of equipment. Optional collision avoidance or proximity warning system equipment may also be added. The flexibility of obtaining ATC services through a range of system-compatible equipments, reflected in the Extended Upgraded Third Generation Concept, has been retained in the AATMS Concept. The continued use of DABS and the IPC and ATC data links assures transition compatibility with many elements of the Baseline System, while the additional features offered by satellites are available to suitably equipped users.

The DABS-compatible avionics, including IPC and ATC data link logic and display equipment, have been discussed in Section 3. The services provided by DABS should also be available from satellites by using an add-on module with the ground-compatible avionic subsystems. The availability of a full range of navigation capabilities to future AATMS users is apparent from Table 5-2. Extensively equipped aircraft use satellite-based navigation techniques, deriving their position from signals sent via the satellites. This position information can be additionally processed by the aircraft's area navigation equipment. Users expecting to fly in strategically controlled airspace equip with four dimensional area navigation equipment (4D-RNAV), while other users, not expecting to fly in this airspace, equip with that (area) navigation system best serving their needs. Satellite-based navigation using the Ground-Computed Area Navigation (GC-RNAV) technique, described in Section 4, offers less complex and less expensive navigation service to suitably equipped users. Minimally equipped users could continue to obtain an inexpensive, but limited, navigation capability by using VOR navigation equipment.

The proposed avionics for the AATMS mechanization concept is integrated at the functional level, i.e., surveillance, navigation, and data link communications. The Synchro-DABS concept forms a basis for achieving this integration. An interface with satellite subsystems is achieved with a simple add-on to the avionics complement.

Avionics Costs Estimates - The cost of avionics necessary to interface with the AATMS elements have been estimated using the results of several independent studies.[7,9,24] These studies assessed preliminary equipment designs, and then assessed the fabrication and installation costs based on current equipment practices. The study results were used to indicate a range of costs for each of the six user classes defined earlier. This was done to reflect the uncertainty associated with projecting future avionics costs. Representative avionics costs for the six user classes for a DABS-compatible satellite system are presented in Table 5-4. A wide variety of Microwave Landing System avionic subsystems is assumed to meet the range of user landing requirements. Estimated costs of these avionics, not included in Tables 5-4 or 5-5, lie between $2,000 for a minimum capability for general aviation aircraft and $15,000 for airline quality equipment.[25] The estimated costs for avionics to interface with a system based on asynchronous aircraft surveillance transmissions are presented in Table 5-5. Such a system concept should also be compatible with ground-based DABS.[7] An integrated complement of avionic subsystems is proposed for this system concept resulting in lower equipment costs for most user classes. Separate CAS/PWI modules would be used by the better equipped users as a backup to the control system separation assurance services. The estimate presented in Table 5-5 assumes that the minimally-equipped, cooperative user employs GC-RNAV equipment.

It is anticipated that a wide variety of avionic subsystems will be available, enabling users to assemble a functional complement of equipment with considerable cost latitude. Technological advances in aircraft antenna systems, L-band components and modular subsystems, voice communication subsystems, navigation processors, and display subsystems offer potential cost reductions.

The potential fleet investment in system compatible avionics was estimated by considering the estimated demand for ATC services in 1995, and subsequently the number of users in each hypothesized equipment class. The Study assumed class populations as follows: Class A-27,000; Class B-62,500; Class C-84,000; Class D-93,000; Class E-62,500; and Class F-33,000 aircraft. The overall 1995 fleet investment for the equipment complements presented in Tables 5-4 and 5-5 was determined to be between $5,300 and $6,100

TABLE 5-4. AATMS AVIONICS COSTS BY USER CLASS BASED ON ESTIMATES FOR A DABS-COMPATIBLE SATELLITE SYSTEM

CLASS	AVIONICS	UNIT COST	PACKAGE COST
A*	Dual Ground/Satellite DABS Transponders and Satellite Navigation Receivers	$24,400	
	Dual IPC/ATC Data Link Logic and Displays	8,500	
	Dual Voice Communications	10,000	
	Dual 4D-Area Navigation Equipment	21,000	$63,900
B*	Dual Ground/Satellite DABS Transponders and Satellite Navigation Receivers	$18,800	
	Dual IPC/ATC Data Link Logic and Displays	3,800	
	Dual Voice Communications	6,000	
	Dual 3D-Area Navigation Equipment	10,000	$38,600
C*	Ground/Satellite DABS Transponder and Satellite Navigation Receiver	$9,300	
	IPC Logic and Display	900	
	Voice Communications	2,000	
	2D-Area Navigation Equipment	2,000	$14,200
D	Ground/Satellite DABS Transponder	$2,800	
	IPC Logic and Display	900	
	Voice Communications	900	
	VOR Receiver	500	
	Ground-Computed Area Navigation Logic and Display	900	$6,000
E	Ground-only DABS Transponder	$700	
	IPC Logic and Display	$900	
	Encoding Altimeter	600	
	Voice Communications	900	
	VOR Navigation Receiver	500	$3,600
F	Voice Communications	900	
	VOR Navigation Receiver	500	$1,400

*Does not include CAS/PWI avionics.

TABLE 5-5. AATMS AVIONICS COSTS BY USER CLASS BASED ON ESTIMATES FOR AN ASYNCHRONOUS ALL-SATELLITE SYSTEM

CLASS	AVIONICS	UNIT COST	PACKAGE COST
A	Dual Surveillance, Digital Communications, Voice Communications, Navigation Receiver and Processor (4D-RNAV)	$22,200	
	Dual High Quality Displays	20,200	
	Dual Air-to-Air CAS/PWI	10,100	$52,500
B	Dual Surveillance, Digital Communications, Navigation Receiver and Processor (3D-RNAV), Voice Communications	$17,000	
	Dual High Quality Displays	7,900	
	Air-to-Air CAS/PWI	1,400	$26,300
C	Surveillance, Digital and Voice Communications, Satellite Navigation Receiver and Processor (2D-RNAV)	$ 8,500	
	Displays	4,000	
	Air-to-Air CAS/PWI	1,400	$13,900
D	Surveillance, Digital and Voice Communications	$ 6,900	
	Displays (including logic and display for ground-computed area navigation data)	1,400	
	VOR Receiver	500	$ 8,500
E	DABS Transponder	$ 700	
	IPC Logic and Display	900	
	Encoding Altimeter	600	
	Voice Communications	900	
	Ground-Computed Area Navigation Logic and Display	900	$ 4,000
F	Voice Communications	$ 900	
	VOR Navigation Receiver	500	$ 1,400

million. Some of these costs represent the retention of equipment from the Baseline System that will be compatible with the recommended system concept. A phase-in period will permit users to interface with new system features in consonance with avionics equipment lifetimes and amortization periods.

AATMS Mechanization Concept Synthesis and Evaluation

The surveillance, navigation and communication concept for the Advanced Air Traffic Management System was derived after making a comparative assessment of the All-Satellite and the Extended Upgraded Third Generation System Concepts. The control facility and automation features of the selected system configuration evolved principally from other supporting studies.(7,10)

Table 5-6 lists the evaluation factors considered to have a bearing on the selection of the surveillance, navigation, and communication mechanization approach. As shown in the Table, the candidate systems were ranked relative to one another for each evaluation criterion; the system with the superior qualities being given a rank of one. The last three factors were not addressed by the candidate system concept definition studies, and although important, were not considered in the evaluation. Including these factors in the analysis should not change the results. Quantitative data was used in assessing the factors relating to cost, coverage, accuracy, capacity, update rate limitations, and backup capability. The other factors were qualitatively assessed.

The first twelve factors were considered to be of major concern and were the basis for selection of the mixed ground and space-based system. These factors may be separated into two categories: the first six factors pertaining to implementing the particular candidate system concept, and the next six factors pertaining to the operational characteristics of the equipment. Several of these factors, such as susceptibility to intentional interference and susceptibility to natural interference, were eliminated from further consideration. Intentional interference appears to be an institutional problem, and since no set of requirements exists for the present system, this factor was eliminated from consideration. Natural interference was eliminated because there is little discernible difference between the two concepts with regard to this factor. The impact on total system costs was eliminated since insufficient tradeoff data was available for quantitative assessment of this factor. This Study does conclude, based on a qualitative assessment, that the use of satellites for surveillance and communications tends to foster facility centralization, and hence induce savings in system operations costs. This Study also determined that the total 1995 fleet investments in

TABLE 5-6. CANDIDATE SYSTEMS EVALUATION

Evaluation Factor	Definition	Ranking* All Satellite System	Ranking* Extended Upgraded Third Gen. System
1. Gov't F&E Costs	Estimated cost of procuring, installing, and certifying equipment.	1	2
2. Gov't R&D Costs	Estimated cost to complete the definition, engineering design, experimentation, and evaluation phase.	2	1
3. Risk	Probability of meeting projected capabilities within projected costs and schedules	2	1
4. Transition Time	Time to fully implement the new system, phase-out the initial system, and achieve a high-level of user participation and confidence.	2	1
5. Impact on Total System Costs	Characteristics of the surveillance, navigation and communications equipment configuration that can lead to a reduction in costs of other segments of the air traffic management system.	1	2
6. User Costs	Estimated investment of the equipped 1995 airfleet for AATMS avionics.	1	1
7. Gov't O&M Costs	Estimated cost for operating, maintaining, relocating, and modernizing equipment.	1	2
8. Airspace Coverage	Volume of conterminous United States and contiguous oceanic airspace in which the functions of surveillance, navigation, and communication are performed or available.	1	2
9. Demand Sensitivity	Extent of system reconfiguration and investment required to accommodate variations in fleet operating characteristics, traffic distribution, or level of traffic activity.	1	2
10. Backup Capability	Availability of alternate means of performing system functions.	1	2
11. Susceptibility To Intentional Interference	Ease by which the system may be intentionally disrupted, leading to performance degradation.	2	1
12. Susceptibility To Natural Interference	Degree to which self-interference and that due to natural phenomena, cause performance degradation.	1	1

TABLE 5-6. CANDIDATE SYSTEMS EVALUATION (Cont.)

Evaluation Factor	Definition	Ranking*	
		All Satellite System	Extended Upgraded Third Gen. System
13. Subsystem Capacity	Number of aircraft each functional subsystem can accommodate in one update cycle.	1	1
14. Accuracy	Projected three-dimensional position accuracy of the surveillance and navigation subsystems.	1	2
15. Update Rate Limitations	Limitations of the rate at which position information may be derived, or air-ground communications may take place.	1	1
16. Baseline System Compatibility	Ability of new equipment to operate jointly with 1982 Baseline System equipment without compromising system safety or capacity.	2	1
17. Spectrum Utilization	Frequency band requirements for the surveillance, navigation, and communication equipment.	1	2
18. Environmental Impact	Potential degradation of the environment due to deployment of new equipment.	1	2
19. Workload	Impact of subsystem characteristics on aircrew or controller operating efficiency.	-	-
20. Equipment Unique Services	Ability of equipment to provide user services exclusive of the primary subsystem function.	1	1
21. Configuration Sensitivity To Control Modes	Adaptability of equipment configuration and operating characteristics to new requirements imposed by alternate traffic control philosophies, separation assurance strategies, and airspace structures.	-	-
22. Reliability	Achievable mean time between failures of the system equipment.	-	-
23. Intermodal Implications	Adaptability of equipment configuration and operating characteristics to non-aviation users.	-	-

*A rank of 1 indicates superiority on an evaluation factor over a rank of 2. A rank of 1 on both systems on the same factor indicates equivalency.

avionics were comparable for either system concept. The comparison of the remaining eight major factors may be summarized as follows:

Evaluation Factors	Relative Ranking: All-Satellite System	Relative Ranking: Extended Upgraded Third Generation
Factors Relating to System Operation		
Government O&M Costs	1	2
Airspace Coverage	1	2
Sensitivity to Demand Variations	1	2
Backup Capability	1	2
Factors Relating to System Implementation		
Government F&E Costs	1	2
Government R&D Costs	2	1
Risk	2	1
Time Needed to Transition	2	1

The All-Satellite System was evaluated as operationally superior to the Extended Upgraded Third Generation System. However, it is more diffucult to obtain. The relative ranking of the two system concepts with respect to Government F&E Costs may be time dependent. If the All-Satellite System implementation is delayed and future deployment of the Baseline System or its ground-based extensions take place, F&E costs for the Extended Upgraded Third Generation System would decrease, and the ratings on this factor may reverse.

The AATMS surveillance, navigation and air-ground communications configuration was selected by incorporating the features of the All-Satellite System yielding operational superiority, and retaining segments of the Baseline System which contribute to ease of system implementation. The risk and transition time of the All-Satellite approach is due in large part to the uncertainty of realizing low-cost satellite-compatible avionics, and the requirement for users to completely replace Baseline System avionics. The Extended

Upgraded Third Generation Concept on the other hand, incorporates Baseline System-compatible avionics with a broader cost range and less development risk, assuring system services to the general aviation user at reasonable equipment prices. This Study concluded that the selected system should therefore retain the user flexibility incorporated in this approach. Consequently, the AATMS Concept incorporates satellites but includes key elements of the Baseline System, namely DABS, VHF voice communications, and VOR equipment. The Baseline DABS System of 106 sites, located near high density terminal and en route airways, is retained in the AATMS Concept because it provides an adequate level of surveillance and data link service to approximately 73 percent of the airborne fleet in 1995 without requiring the replacement of Baseline System avionics. The Baseline System VHF voice communications network is retained as a low risk, adequate coverage capability, also allowing the retention of Baseline System avionics. Three-hundred selected VOR sites are retained in the AATMS Concept because this number assures adequate coverage of both controlled and uncontrolled airspace, and also provides a reasonably priced avionics navigation system for the users. Retention of these system elements also allows continued meeting of commitments under present international agreements.

5.2 CONTROL FACILITIES

The AATMS Concept control and data processing facilities provide traffic management and flight service functions efficiently and at low operating costs. This will be achieved by automation of routine traffic control and management operations and by centralization of control and data processing facilities. This Section contains a summary description of the proposed facility configuration, including the allocation of control functions in primary and backup modes of operation. In addition, estimates of initial and operating costs are given.[5,10,24]

Facility Configuration

The AATMS control and data processing facility configuration includes one national and two regional en route control centers, twenty terminal-hub area control centers, and terminal facilities at primary and secondary airports. This configuration integrates control and flight service functions in a parallel, hierarchical structure, as shown in Figure 5-1. The allocation of functional responsibilities to the various facilities for normal and backup modes of operation is shown in Table 5-7.

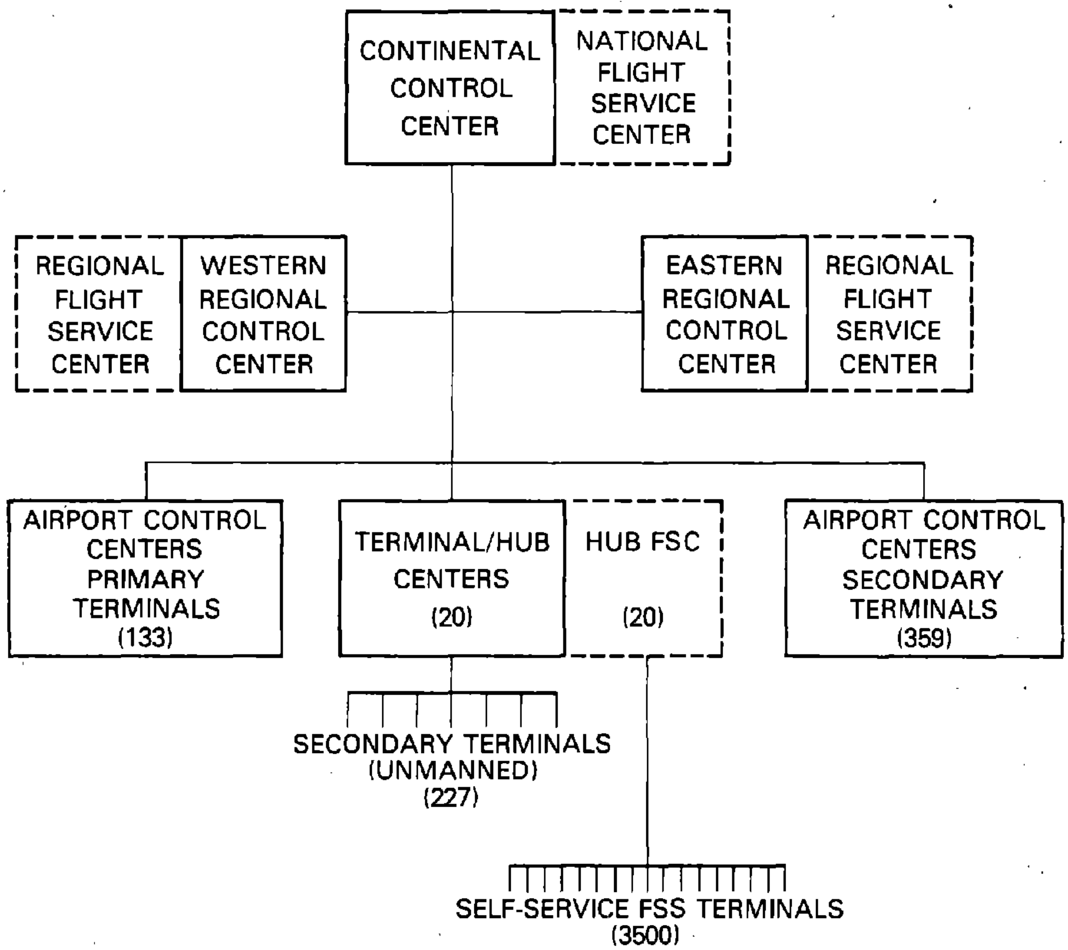


Figure 5-1. AATMS Facility Configuration (1995)

TABLE 5-7. FACILITY RESPONSIBILITIES IN NORMAL AND BACKUP MODES OF OPERATION

Control Facility	Functional Responsibilities		Flight Service Facility	Functional Responsibilities	
	Normal Operations	Backup		Normal Operations	Backup
Continental Control Center (CCC)	• National Flow Control • Management of system resources • Coordination with colocated NFSC	• En route traffic services for RCC (extreme cases)	National Flight Service Center (NFSC)	• Maintenance of system data base • Provision of flight service data • Coordination with RFSC	• Processing and distribution of flight plans for HFSC • Flow control for CCC
Regional Control Center (RCC)	• En route traffic services for CONUS • Coordination of traffic with adjacent oceanic region • Coordination with colocated RFSC	• En route traffic services for other RCC • Terminal air traffic services for ACC or THC	Regional Flight Service Center RFSC	• Flight service data support for oceanic traffic • Flight service data support for RCC operations • Coordination of HFSC activities	• NFSC operations • Flight service data support for ACC or THC • Processing and distribution of flight plans for HFSC
Terminal - Hub Center (THC)	• Air traffic services for unmanned secondary airports • Coordination with RCC for en route transition • Coordination with co-located HFSC	• Air traffic services for adjacent THC (extreme cases)	Hub Flight Service Center (HFSC)	• Flight service data in support of ACC and THC operations • Processing and distribution of flight plans • Operation of remote FSS terminals	• Operation of remote FSS terminals for adjacent HFSC
Airport Control Center (ACC)	• Air traffic services for primary and secondary airports with manned towers • Coordination with RCC for en route transition	• Air traffic services for adjacent ACC (extreme cases)	FSS Terminals (self-service)	• Weather data and flight planning assistance for users • Flight plan acceptance and processing	

A single Continental Control Center (CCC) performs national flow control functions and serves as the central point for management of system resources. The CCC coordinates with the National Flight Service Center (NSFC) to acquire the data on weather and system capability and the status needed for national flow planning. In addition, the CCC serves as a backup to the two Regional Control Centers in cases of computer failures or during periods of abnormal operation.

There are two Regional Control Centers (RCC) in the AATMS Concept. They are assigned responsibility for the eastern and western continental regions respectively. In its area of jurisdiction an RCC provides air traffic services for domestic en route traffic. The RCCs consolidate, in two facilities, the services presently provided by twenty Air Route Traffic Control Centers (ARTCC) and the Oceanic Control Centers. Each RCC also provides traffic advisories and performs handoff coordination for aircraft in adjacent oceanic control regions. The RCC coordinates with the colocated Regional Flight Service Center (RFSC) to obtain environmental data and system capability and status information as required for regional-level air traffic management. The RCCs back each other up insofar as possible, in en route operations. Each also serves as backup for Terminal-Hub Centers (THC) and Airport Control Centers (ACC) within its region, and as a backup to the Continental Control Center (CCC).

At the next level below the Regional Control Centers are two types of facilities which provide air traffic services in terminal areas: Airport Control Centers (ACC) and Terminal-Hub Centers (THC). It is estimated that by 1982 approximately 492 Air Traffic Control Towers would be installed (133 at primary airports and 359 at secondary airports).[9] After 1982 no new control towers would be added. In the AATMS concept the 492 manned towers would be designated Airport Control Centers (ACC). Each ACC provides air traffic services for aircraft within that ACC's terminal area jurisdiction and coordinates with the RCC in its region concerning aircraft in transition to and from the en route portion of the system. For short flights between nearby terminals, the ACCs coordinate the handling of traffic directly. This direct linkage among close-by terminal facilities also permits them to support each other in backup modes of operation.

An innovative feature of the AATMS Concept is the Terminal-Hub Center (THC), which provides terminal air traffic services for remote secondary airports in major hub areas, but outside the control zones of ACCs. These secondary airports will not have manned towers, and control of traffic at these sites will be accomplished remotely by the THC. It is estimated that there will be approximately 227 such airports in 1995, which will be handled by a total of twenty THCs. Centralization of terminal air traffic services for these secondary airports is desirable because their relatively low volume of operations does not justify the level of on-site personnel that would be required to individually staff them. The level of automation proposed in the AATMS Concept makes remoting of air traffic control not only a practical but also a more efficient utilization of the workforce. The level of automation proposed in the AATMS Concept makes remoting of air traffic control not only a practical but also a more efficient utilization of the workforce. The present twenty ARTCC sites would be converted to serve as THC facilities. The location of most of the ARTCCs in major traffic areas makes this conversion readily feasible. As discussed below in the description of AATMS flight service facilities, the converted ARTCC sites would also serve as locations for centralized flight service station activities.

The configuration of flight service facilities in AATMS, adapted from the DOT-proposed flight service station concept and depicted in Figure 5-1, reflects the need for future improvement in the areas of providing weather data and flight planning assistance for users, and of processing and distributing flight plans.[26] The National Flight Service Center (NFSC), which is colocated with the CCC, contains the central data processing facility and data base for the entire system. This data base includes not only that data needed to conduct flight service station activities throughout CONUS and adjacent oceanic regions but also all the information on the environment, system capability, and system status needed to carry out normal air traffic control operations. The NFSC also acts as a clearinghouse for incoming environmental and operational information: weather, NOTAMS, PIREPS, etc. As the highest data processing facility in the flight service hierarchy, the NFSC acts as coordinator of activities at Regional Flight Service Centers (RFSC) and Hub Flight Service Centers (HFSC). The NFSC has two major assignments as a backup facility: assumption of national flow control functions on behalf of the CCC, and flight plan processing and distribution to backstop any Hub Flight Service Center which has sustained extensive failure of data processors.

The two Regional Flight Service Centers (RFSC), which are colocated with the eastern and western RCCs, have three major functions. As an operational facility, the RFSC provices flight services for oceanic traffic. The RFSC also acts as a support facility to the RCC by providing environmental and operational data needed to perform air traffic services for en route aircraft. Finally, the RFSC acts in a coordinative and managerial capacity for the HFSCs within its region. Each RFSC is capable of acting as a partial backup to the NFSC to support any individual HFSC within its region.

The AATMS Concept incorporates twenty Hub Flight Service Centers (HSFC), which are colocated with Terminal-Hub Centers in sites formerly occupied by ARTCCs.[26] Each

HSFC supports approximately 175 remote, unmanned FSS terminals. These 3500 self-service terminals are situated at airports or other locations convenient for users. The HFSC-FSS network processes pilot-entered requests for weather and flight planning data, provides displays of the requested information, assists in flight plan filing, and processes and distributes accepted flight plans. In addition to pre-flight data and planning services, the HFSC also acts as a centralized point for dissemination of flight advisories and for in-flight assistance to pilots.

AATMS Control Facility Costs

The Study estimated the initial investment cost (F&E) to realize the control facility configuration just described, and also estimated what the annual cost to operate and maintain (O&M) these facilities in 1995.[7,24] These costs were based on cost estimates for the installation and checkout of equipment and facilities, and other required resources such as land, buildings, support equipment, and software. The costs were heavily influenced by the results of the Control Automation Study described in the next Section.

The CCC and RCCs are assumed to be completely new facilities, including buildings and equipment. The THCs, which are nearly identical to the CCC in terms of size and building requirements, are assumed to be located at the already existing buildings of the present ARTCCs, and the ACCs are assumed located at already existing (in 1982) tower facilities. Building cost for the THCs and ACCs are thus minimal, and only reflect modernization. The building costs were assumed proportional to the size of the staff at each facility, and the building and support equipment costs in the All-Satellite Study were so scaled.[7] The costs for displays and controls (work station consoles) and computer equipment were estimated for each facility based on the results of the Automation Applications Study.[10] The total software cost for the system was estimated in several studies to be $100 million and this result was used here, with the amount split between the facilities according to estimates on the future complexity of each facility type.[7]

Operations and maintenance costs of the control facilities do not include the control workforce or the staff, whose costs are discussed in the next Section. The facility O&M costs are dominated by the costs associated with the control/display and computer O&M costs. These estimates were based on the initial F&E expense projected for these items and on the projected equipment life.[24] Interfacility communication equipment O&M cost was also estimated.[9,24] In the AATMS Concept this cost reflects retention of the 1982 Baseline network.[9] Considerable savings may be possible by carrying out interfacility communication through the system satellites. The desirability of performing these critical functions by a satellite-based system thus needs to be assessed further, especially in relation to backup modes of operation. Interfacility communication subsystem O&M costs were apportioned according to the number of control personnel at each type of facility.

A summary of AATMS control facilities costs is presented in Table 5-8, including a breakdown of site costs in terms of F&E and O&M expenses, and also the numerical size of the staff at each site and the resulting manpower costs, as derived in the following Section. A total of $1.1 billion is required to acquire the capabilities offered by the recommended facility configuration; $174 million is required annually (in 1995) to operate and maintain these facilities, and $486 million is required to pay the control-related staff salaries. Salaries for controllers, support personnel, and managers account for about three-fourths of the annual operating and maintenance costs.

5.3 CONTROL AUTOMATION

Historically, the air traffic control system has been a labor-intensive activity. As demand (the number of aircraft requiring services) has increased, there has been a corresponding increase in the number of controllers needed to operate the system. However, the relationship of controllers to demand is not linear. As shown in Figure 5-2, the controller workforce has grown more rapidly than the national aviation fleet, and projections indicate that it would continue to do so if the largely manual Second Generation System of the 1960-1970 period were retained unchanged until 1995.

The best estimates of projected improvements to result from increased automation in the Third Generation (NAS/ARTS) system, and later in the Upgraded Third Generation System (shown by the broken line in Figure 5-2) indicate that the traditional relationship of manpower and demand can be altered by assigning a greater share of air traffic control tasks to machine resources. Even so, estimates of the number of controllers needed to man the system beyond 1985 remain high.

It is evident from Figure 5-2 that automation of air traffic control processes can produce gains in productivity and reductions in system manpower requirements. For these reasons, higher levels of automation beyond those of NAS/ARTS have long been proposed. The AATMS Study approach was a direct outgrowth of the Air Traffic Control Advisory Committee recommendation for:

> "...the prompt initiation of a system study that determines whether the higher levels of automation achieved by the incremental additions to NAS/ARTS would be fundamentally different from an automation program that was derived from basic considerations of air traffic flow capacity and safety."[1]

TABLE 5-8. FACILITY COST SUMMARY
(COSTS IN MILLIONS OF 1973 DOLLARS)

Facility (3)	No. Of Sites	Unit F&E	Total F&E	Annual O&M (1995) For Facilities	No. Of Personnel (1)	Annual O&M (1995) For Personnel (2)	Total Annual (1995) O&M
CCC	1	$33	$ 33	$ 3	660	$ 13	$ 16
RCC	2	49	97	11	2,170	45	56
THC	20	16	315	47	13,750	284	331
ACC	492	- (4)	635	112	6,920	144	256
TOTALS	-	-	$1,080	$173	23,500	$486	$659

Legend

CCC - Continental Control Center

RCC - Regional Control Center

THC/FSC - Terminal-Hub Center and Flight Service Center

ACC - Airport Control Center (primary or secondary airport)

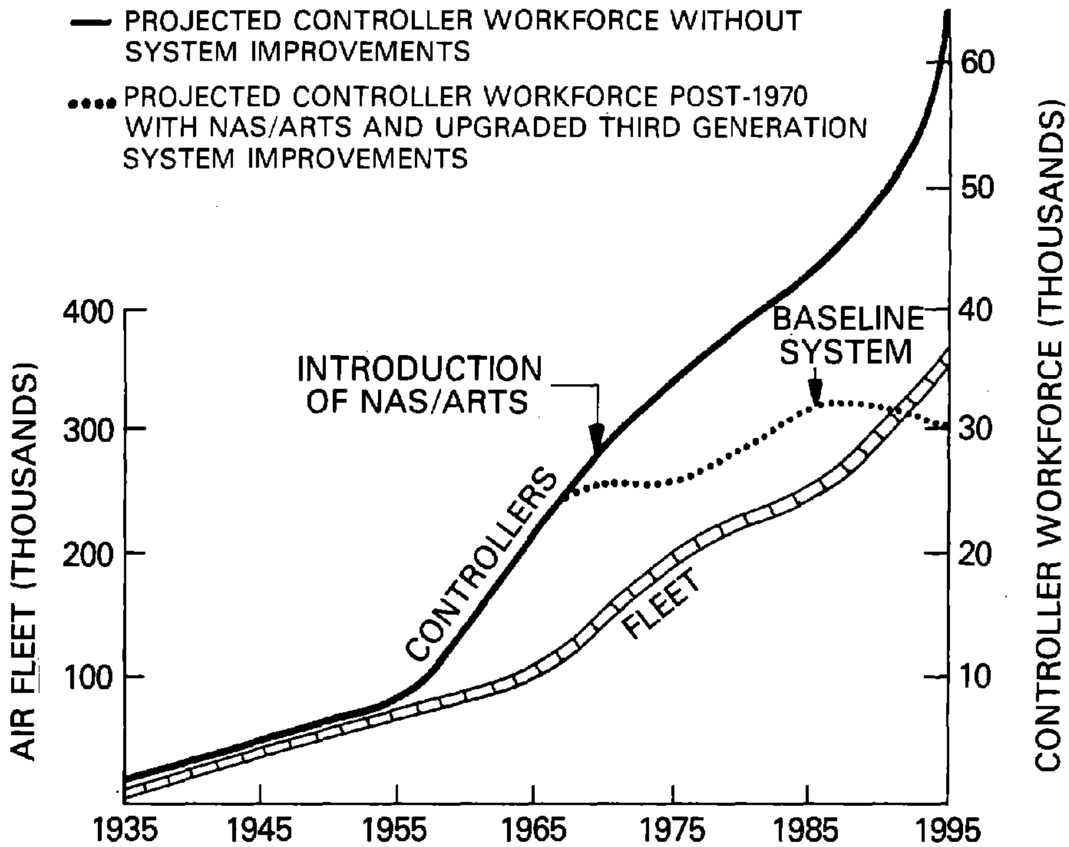
Notes

(1) Includes controllers, support, and managerial personnel.[10]

(2) These personnel levels are contingent upon achieving a substantial increase in productivity through automation.

(3) Includes colocated flight service facilities.

(4) Unit site F&E highly variable among different sites.



Source: References 11, 12, 13, 15, 19

Figure 5-2. Relationship of Fleet Size to Controller Workforce

The AATMS Study specifically considered the automation of air traffic control functions; allocating tasks between man and machine on the basis of their respective and unique capabilities. The high degree of automation conceived for the AATMS is described in this Section, as well as the man-machine task allocation and the associated rationale.(10)

Study Methodology

The methodology for assigning air traffic management tasks to human and machine resources was developed by this Study in response to a need for an objective and quantifiable allocation technique. This methodology, synthesis of three separate disciplines - systems engineering, human factors, and psychometrics, was brought to bear on a detailed analysis of air traffic control operations that defined a complete set of functions, subfunctions, and tasks necessary to meet service demands of airspace users.(10) To assure that automation benefits could be defined in a manner as free as possible from the influence of mechanization and equipment concepts, task descriptions and relationships were stated in generic terms. The emphasis was on what had to be done to perform air traffic services and not on how it was to be done. The answers to the latter question were, however, found in the Study.

In a complex surveillance and control system the greatest benefits of automation begin to emerge when the machine is effectively introduced into the decision and control process itself. Significant productivity gains are achieved when machines assume a substantial role in making routine decisions and in translating decisions into control commands. For this reason, the study of automation applications concentrated on the internal processes of air traffic control.

The list of generic air traffic control tasks derived from the functional analysis was examined considering the performance capabilities required to carry out each task and whether best accomplished by man or machine. The tasks, based on this analysis, were arbitrarily combined into five groups that indicated the extent to which automation could be applied in the system. Man and machine resource requirements for each candidate grouping were estimated. Some of these groups appeared unachievable and unrealistic because of excessive numbers of controllers or excessive dependence on machines. An initial level of automation was selected, however, considering the desired goals of safety and capacity, as well as a judgemental, complementary balance between human and machine assignments.

The selected level of automation was subjected to further analysis and a detailed statement of the responsibilities of men and machines was developed. Computer requirements for normal and failure modes of operation were compiled and strategies to allocate reserves and to reconfigure the system in response to equipment failures were devised. Estimates of controller productivity at the recommended level of automation were developed. The man-machine interface for each system operator was defined in terms of control and display requirements. Figure 5-3 shows the flow of the Study methodology in deriving the recommended automation level.

Advanced Level of Automation

Major air traffic system functions that appear as candidates for full or partial automation are comprised of tasks which are interrelated in complex ways. Because of these complexities, assignments of man and machine responsibilities were not made at the functional level, as in the past, but at the task level where specific performance requirements could be more accurately assessed. Among the factors influencing the selection of the recommended automation level were:

- Input-output information characteristics
- Decision and action requirements
- Man-machine performance capabilities
- Task relationships induced by automation
- Man-machine interface requirements
- Failure mode effects and requirements
- Safety and capacity considerations
- Software feasibility
- Operational evolution
- Control concepts
- System mechanization

Consideration of these variables indicated that system automation should be implemented in discrete steps, where each step represents a viable (and internally consistent) combination of man and machine resources.

Analysis of the respective, calculated man and machine resource requirements for each task grouping indicated that the most favorable extent of automation was when 64 percent to 86 percent of the air traffic control tasks were automated or machine performed. In this range of percent-of-tasks-automated, the Study determined that there was a cost-effective mix of men and machines, safety considerations were adequately handled, capacity optimization was achievable, and the level of automation selected appeared feasible.

Based on these initial and tentative findings, subsequent study was directed towards two ends. The first was to refine and adjust the allocation of tasks within the range of 64

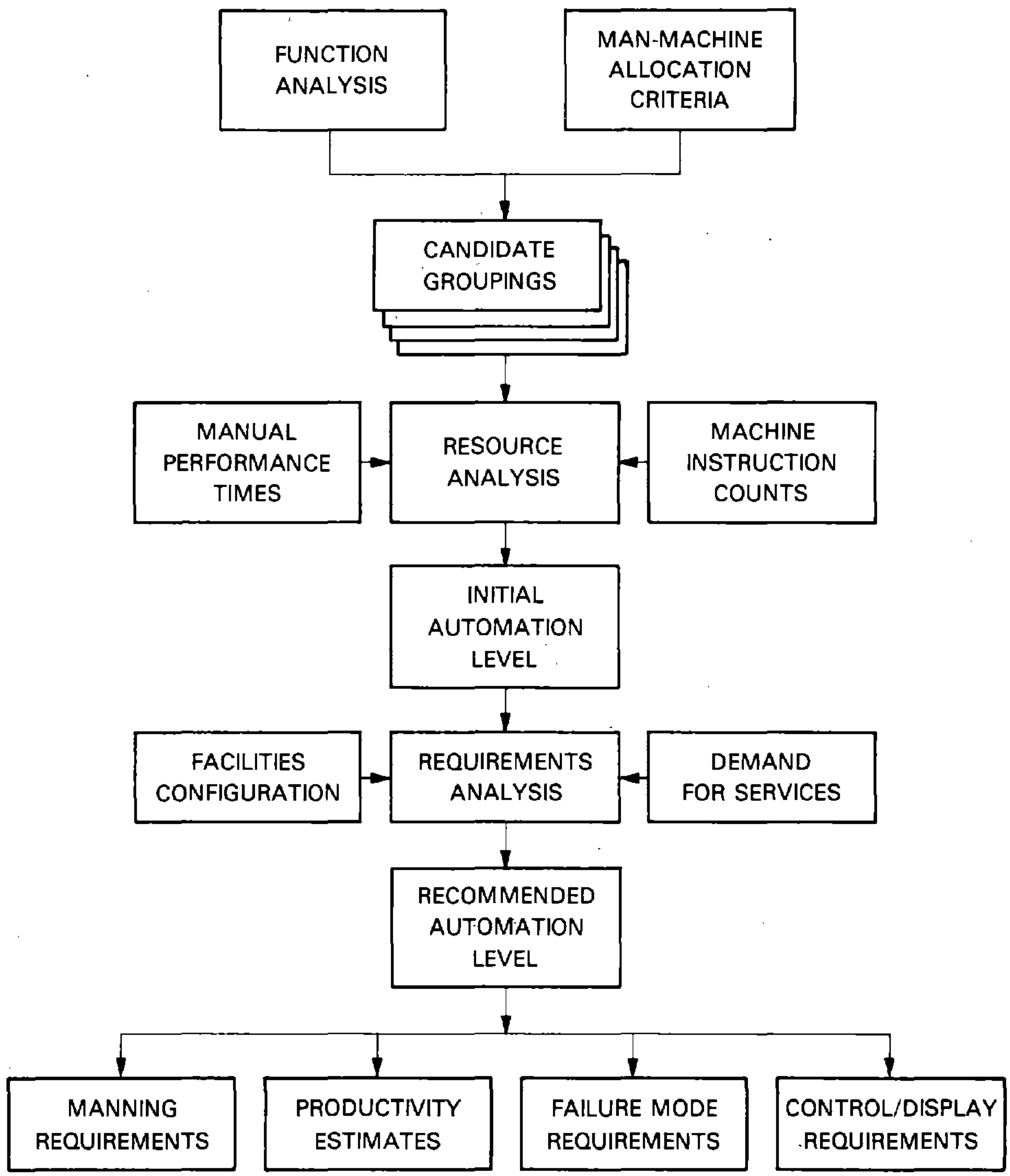


Figure 5-3. Methodology Flow for Derivation of Recommended Automation Level

percent and 86 percent so as to find a set of functionally coherent man-machine assignments which made best use of man's capabilities. The second was to test the task groupings previously defined, but outside the 64 to 86 percent range of task automation, to verify the desirability of this range. It was found that lower percentages of task automation produced manpower requirements that were greater than those envisaged for the 1982 Baseline System when handling the projected peak 1995 demand of about 37,000 aircraft, i.e., in excess of 30,000 controllers.[13] The magnitude of the control workforce at low percentages of system task automation rises due to the number of induced tasks created by traffic sectorization and machine interface requirements. When more than 86 percent of the air traffic control tasks are automated, reductions in the workforce are achievable, at least theoretically. However, system failure recovery potential and man's proper functioning within such a system are unacceptable.

Approximately 70 percent of air traffic control tasks are assigned to machines in the recommended automation level based on the Study findings. This selected level of automation is an average and is not uniform across all the major functions of the system. Some functions are fully automated, and others are performed wholly by human operators. Figure 5-4 shows the selected degree of automation by individual function and by five major classes of functions. It can be seen that functions involved in active control of aircraft and in maintenance of the system data base are nearly completely automated. On the other hand, data services to users are less than 50 percent automated, while special and emergency services are not automated at all. The automated tasks are those requiring computation, data processing, or routine and repetitive actions. Routine decision-making has also been delegated to machines. The tasks assigned to the operators are those calling for interpretive judgement or complex decisions. The operators retain responsibility for tasks which require non-routine, communications interaction with pilots or negotiation concerning intent and authorization. Emergency services are exclusively a human responsibility. The role of the machine in these areas of the system is to serve as a decision aid or to supply automatic alerts and prompts to the controller. Emergency services are the air traffic services provided in response to air failures.

Future Man-Machine Complement

In today's system, the role of the controller is to interpret data acquired and processed by system sensors, to make decisions, and to direct individual aircraft movement by means of voice communication with the pilot.

The operator's role in AATMS is away from the labor intensive, direct control of aircraft, and toward more information management and process control. The degree of direct

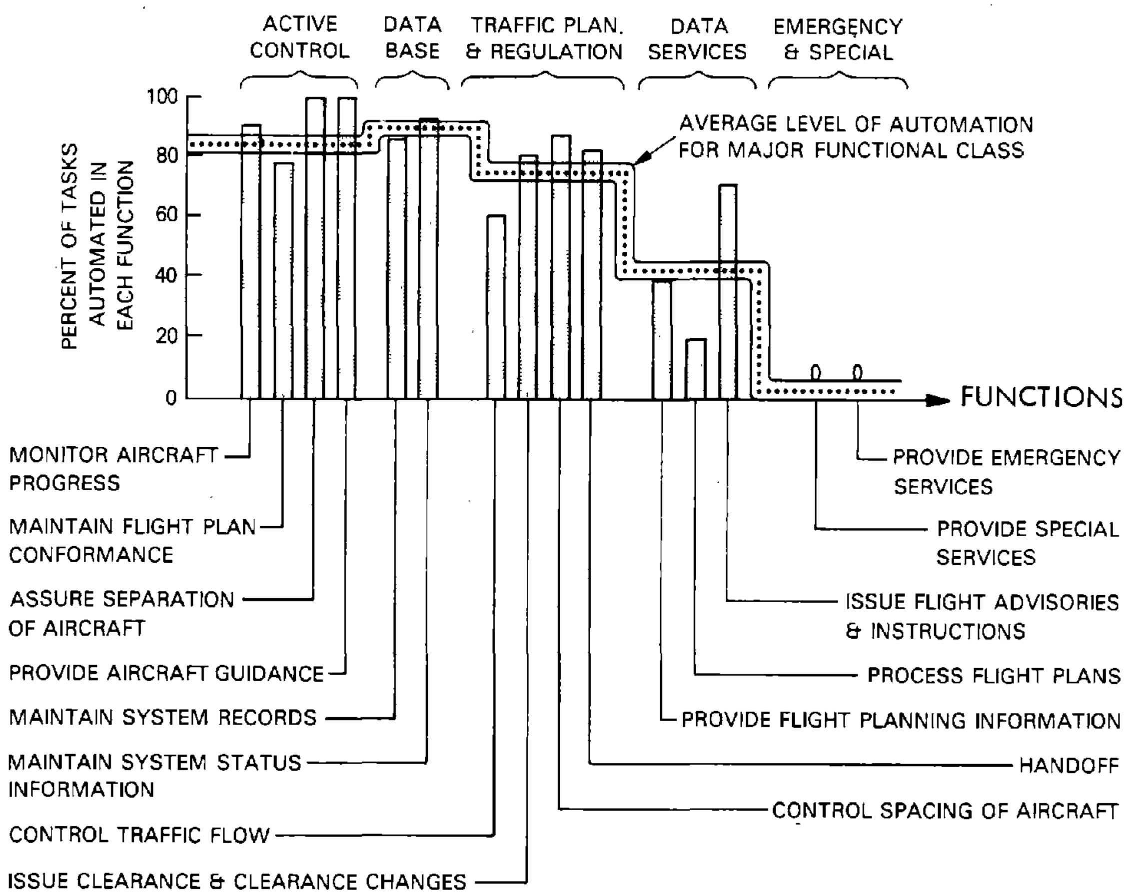


Figure 5-4. Recommended Level of Automation by Function

involvement with aircraft is diminished. Routine surveillance, decision making, communication and control activities are allocated to machines whose operation is supervised and coordinated by man. The managerial role of the operator also includes responsibility for assessing the need for corrective action in situations such as imminent congestion, equipment failure, and adaptions to changing flight and weather conditions. Man is also charged with responsibility for intervention and remedial action in special and emergency situations. In the new situation the controller is manager of an equipment complex which monitors and controls individual aircraft and the traditional relationship between air traffic demand and controller workforce is broken. This Study identified five classes of operators to staff the system. The responsibility and duties of each operator position are outlined in Table 5-9, which also indicates the types of facility to which they are assigned. Only the Flight Surveillance and Control Officer position corresponds directly to a contemporary air traffic controller position. The functional responsibilities of this position parallel those of the present terminal and en route positions rather closely but are required only for anomalous situations. The flight Service position of the present system has a very indirect counterpart in AATMS. In AATMS, Flight Service Station duties are divided between two positions; Flight Information Services and Flight Plans, both of which have expanded responsibilities in comparison with today's FSS personnel. Flow Control and Data Base are new positions, whose duties reflect the added importance of strategic planning and data processing in the highly automated AATMS.

The equipment configuration of AATMS reflects a similar functional realignment of resources. Facilities are considerably more centralized, particularly for en route traffic control and flight service activities. Computers located in the Eastern and Western Regional Control Centers, together with those of the Continental Control Center, form the major data processing nodes of the national air traffic management network. The Terminal-Hub Centers and terminal computing systems are connected to the network through the en route facilities. This computer network arrangement offers several advantages:

- Cost savings due to linked computer systems sharing workloads, information, programs, and specialized hardware,
- Large data bases, residing at one location, but shareable by other elements of the network,
- Ready access by network participants to special equipment located at other facilities,
- Rapid response and reconfiguration of the system in the event of equipment failure anywhere in the network.

TABLE 5-9. RESPONSIBILITIES AND ASSIGNMENTS OF AATMS OPERATORS

Position	Functional Responsibilities	Facility Assignment
Data Base Operator	Maintain system capability and status information Maintain system records	CCC
Flight Information Services Operator	Provide flight planning information Provide flight advisories and instructions	THC RCC*
Flight Plans Operator	Process flight plans Provide ancillary and special services	THC RCC*
Flow Control Operator	Plan and control traffic flow	CCC
Flight Surveillance and Control Operator	Issue clearances and clearance changes Monitor aircraft progress Maintain conformance with flight plan Assure separation of aircraft Control spacing of aircraft Provide aircraft guidance Perform handoffs Provide emergency services	RCC Primary terminals Manned secondary terminals THC (for remotely manned secondary terminals)

*Oceanic flight services

Legend:

CCC - Continental Control Center
RCC - Regional Control Center
THC - Terminal-Hub Center

The computer architecture for AATMS consists of a large number of multi-purpose modules, distributed widely throughout the system but linked in a mutually supporting arrangement. Computations for system functions with similar basic characteristics and data processing requirements are performed by a common computer within a facility. However, the computer has multi-purpose capability and can be assigned one set of functions in normal operating modes but yet be capable of assuming others in failure states. This form of computer architecture permits intra-facility and inter-facility backup. Backup, within a facility, is achieved through internal reallocation of resources and reordering of functional priorities. External backup is possible by commitment of centrally located reserves to aid the affected facility. Figure 5-5 is a functional illustration of arrangements for backup within and among facilities.

A distributed, multi-purpose data processing arrangement offers several advantages. Distribution avoids the dangers of a massive and centralized system, which has a high vulnerability to failure unless it also has extensive built-in redundancy. Multi-purpose capability helps to eliminate the need for costly redundancy since system elements can be reassigned with great flexibility. A distributed, multi-purpose network also has the advantage of allowing functions to be assigned to those data processing elements best suited to performing the various tasks, but without irreversible commitment as would be the case with special-purpose computers. The proposed AATMS computer architecture is well suited to the needs of an evolutionary system since it allows modular development and incremental integration of automated functions into the system. Modularity can be applied to storage capability as well, thus permitting the system to continue operation in a degraded mode by reallocation of memory modules.

AATMS automation reflects a fail-operational design philosophy. The system can sustain the loss of individual processing elements and continue to operate for a short time at normal levels of safety and capacity. The system can also suffer multiple, simultaneous failures and yet maintain safe operations; in some cases at normal or near-normal capacity, although for a somewhat shorter period of time than in the single-failure circumstance. The capability of the data processors and memory modules to provide mutual backup within and between facilities prevents sudden degradation of safety and capacity and allows sufficient coast time to redeploy system resources or to redistribute demand.

The failure mode philosophy of AATMS has two other important features. First, the interlocking arrangement of multi-purpose computers greatly reduces the need for redundancy. Continuity of service is assured by reallocation of resources rather than by the more costly method of providing spares and standby processing units through the system.

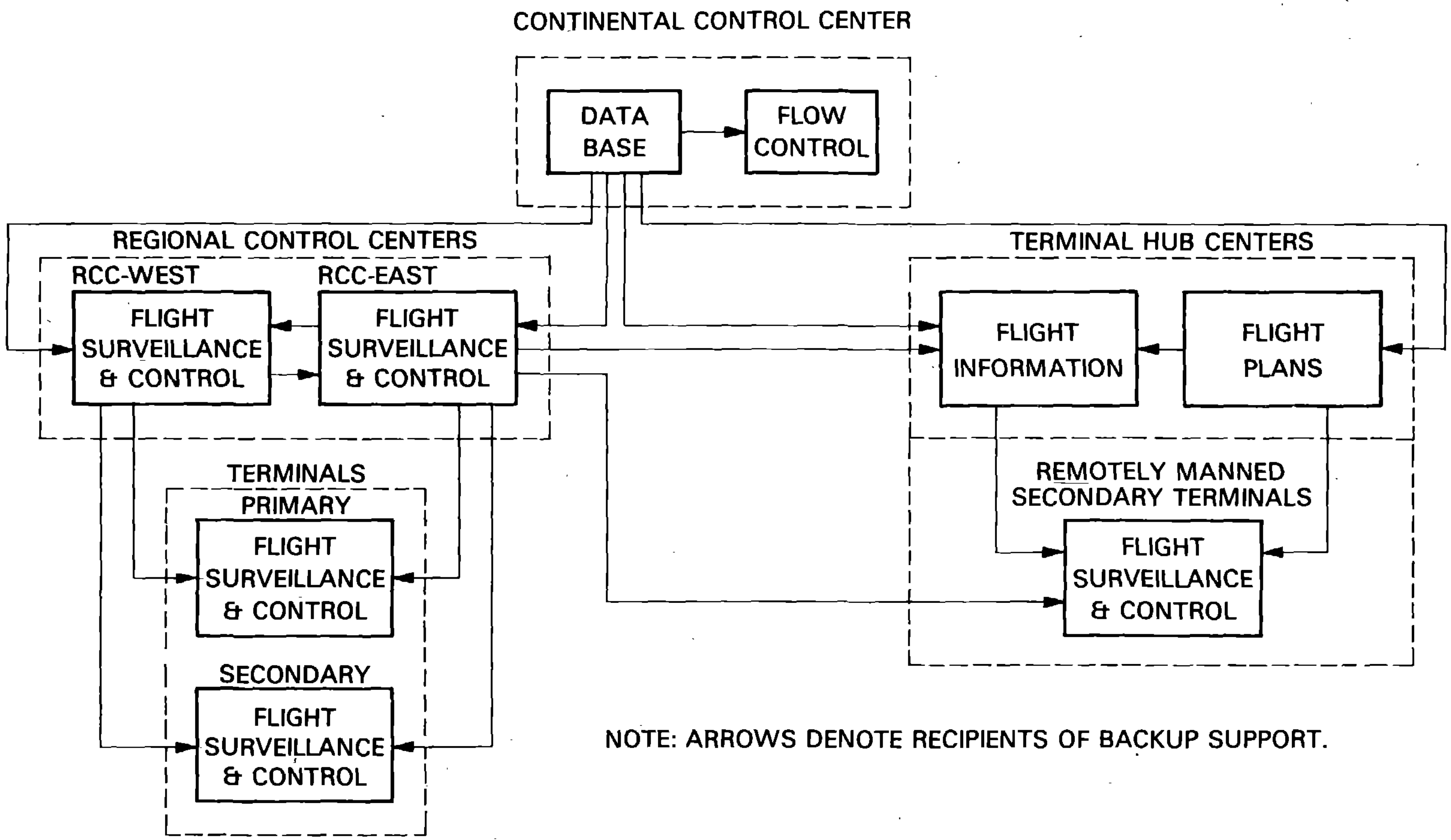


Figure 5-5. Backup Arrangements Within and Between AATMS Facilities

The second feature is that the system does not rely on manual modes of operation in degraded states. In a highly automated system such as AATMS, manual backup is neither practical nor safe. The operator has no effective and sure way to enter critical, automated control loops. Therefore, the philosophy of failure mode operation requires that automated elements be backed up by automated elements. Assessment of failure mode requirements and selection of response strategies remains a human responsibility, but backing up automated functions in failure states is a continuing task for machines.

Staffing of AATMS

The workforce to operate and maintain AATMS is made up of three major personnel positions: Operators, Support Personnel, and Managers.

Operators, like present controller and flight service staff, are the personnel required to perform the manual tasks in AATMS. As previously described, there are five types of positions which together with automated components, are needed to carry out the on-line operational tasks associated with maintaining the system data base, providing flight information services, controlling traffic flow, processing flight plans, and providing flight surveillance and control. Operator positions represent almost two-thirds of the total AATMS staff.

Support Personnel positions are the second largest AATMS staff element. There are two general types of support staff; maintenance and automation specialists. The maintenance staff, as in the present system, is responsible for the upkeep and repair of equipment and for the restoration of equipment to service in the event of malfunction. The new position, automation specialists, involves responsibility for overseeing the status of automated resources and aiding or correcting machine performance. The automation specialist ensures the completeness, consistency, and adequacy of automated operations. The skill requirements for this position are not those of air traffic operations but of computer science, programming, and automation technology.

The third element of the AATMS workforce is Managers. These personnel positions are an outgrowth of the increased system automation, and involve control over the automation process and coordination of resources to meet demand for services. Three levels of management are seen as necessary in AATMS. First is the direct supervision of the human and automated resources carrying out operational tasks. This level is called supervisory and is roughly equivalent to the present system's Watch Supervisor. The areas of responsibility for these positions are: load control (matching resource application to demand on a dynamic basis), resource assignment (distributing resources equitably across available demand), and services assurance (monitoring the quality and adequacy of services to airspace users).

The second level of manager functions is executive in nature. The concern is with the overall coordination and management of all resources within a given facility, both in normal modes of operation and in degraded states. Its concern is not with the direct supervision of individual resources. The position responsibilities are the same as at the supervisory level (load control, resource assignment, and services assurance) but the scope of concern is facility-wide.

At the topmost level of management are the system directors, whose responsibilities extend across regions or even all of CONUS. The director level is concerned with the overall management of system resources and with the interrelationships of all facilities within the respective jurisdictions. Director-level personnel will most likely be assigned only at the Regional Control Centers and the Continental Control Center, which by virtue of their centralized nature will be the location of higher management authority.

Quantitative staffing requirements for AATMS at the recommended level of automation were made based on an analysis of operator activities essential to deliver the required services to airspace users at the nominal demand level. Performance times for each manual operator task, and computing requirements for automated tasks, were estimated and combined with the number of times each task would be performed in providing services for the expected 1995 demand level. This calculation served as the basis for estimating the size of the operator workforce needed to man AATMS facilities. Personnel requirements in the support and managerial categories were estimated as fractions of the operator staff.[10]

Table 5-10 summarizes the AATMS staffing requirements by facility and personnel category. This estimate is based upon the nominal 1995 airborne count of 37,000 aircraft as presented in the AATMS Demand Study.[3] Support personnel requirements are assumed to be 20 percent of the operator workforce for automation specialists. The managerial complement is estimated at 25 percent of the operator workforce.

Table 5-11 is a summary of annual manpower cost estimates derived from the anticipated staffing levels for AATMS. The estimates are stated in 1973 dollars and are based on arbitrarily assumed nominal manpower cost levels for each personnel category as listed in the Table. The manpower costs, which amount to about $485 million, were used in arriving at the estimated annual operating cost presented in the earlier discussion of AATMS facilities costs.

5.4 AIR TRAFFIC CONTROL CONCEPT FOR 1995

This Study proposes that Strategic Control, a ground-based traffic management technique, be incorporated in the 1995 control concept in all IFR airspace, augmenting the

TABLE 5-10. ESTIMATED AATMS FACILITY STAFFING FOR 1995

Facility	No. Of Sites	Per Site Per Shift			All Sites Per Shift			All Sites All Shifts[c]		
		Operator	Support[a]	Manager[b]	Operator	Support	Manager	Operator	Support	Manager[d]
CCC	1	115	35	60	115	35	60	400	130	130
RCC	2	200	60	70	400	120	135	1,400	420	350
THC	20	10	5	2	180	60	40	630	210	120
THC (HFSC)	20	120	35	30	2,380	720	620	8,320	2,520	1,900
Primary Airport	133	-[e]	-[e]	-[c]	530	160	200	1,850	560	700
Secondary Airport	359	2	-[f]	-[f]	720	215	180	2,500	760	600
TOTAL					4,325	1,310	1,235	15,100	4,600	3,800
					6,870			23,500		

(a) Assumed to be 30% of operator staff (20% maintenance, 10% automation specialist).

(b) Assumed to be approximately 25% of operator staff.

(c) Shift size x 3.5 to account for three working shifts, schedule irregularities, vacation and sick leave.

(d) Not all managerial positions are staffed on a shift basis.

(e) Variable from site to site.

(f) Not assigned on a local basis.

Legend:

CCC - Continental Control Center

THC - Terminal-Hub Center

RCC - Regional Control Center

HFSC - Hub Flight Service Center

TABLE 5-11. ESTIMATED ANNUAL MANPOWER COST SUMMARY FOR 1995

Staffing Category	No. Personnel	Percent of Workforce	Estimated Annual Cost Per Position* (Thousands)	Annual Manpower Cost* (Millions)
Operator	15,100	65	$20	$300
Support Maintenance	3,100	13	18	55
Automation	1,500	6	16	25
Manager Supervisor	2,100	9	25	55
Executive	1,600	7	30	50
Director	100	-	40	-
Totals	23,500	100	-	$485

*1973 dollars

Flow Control and Metering and Spacing traffic management strategies retained from the 1982 Baseline System.[2] This addition is proposed because of the benefits described below, the most important of which is the optimization of airport and air route capacity while maintaining the inherent safety of the system, particularly in high air traffic density airspace.[12]

Strategic Control is a centralized management control concept in which nonconflicting flightpaths are predetermined for all flights. The clearance for each flight is transmitted to the airplane in terms of a three-dimensional flightpath description, to be flown according to a time schedule. Usually this clearance consists of a series of waypoints defined in altitude, longitude, and latitude (or with respect to the range and bearing from a navigation aid) and the time for making each waypoint. Separation planning is performed by providing time or distance separation between clearances based on the accuracy with which a flight can achieve its assigned route-time profile. The responsibility for executing the clearance rests with the pilot of the aircraft. It will be potentially in the best interest of each aircraft to fly its assigned clearance accurately since the route-time profile will be computed so as to optimize some flight parameter such as fuel consumed or flight time, in addition to providing a conflict-free path through airspace. A representative Strategic Control terminal arrival path is presented in Figure 5-6. It is assumed that a sequence of positions (X, Y), altitudes (Z), and times (T) have been issued in a single communication to the landing aircraft. The aircraft navigates so as to fly through each three-dimensional waypoint at the required time of arrival.

Strategic Control, characterized by dynamic, advance planning of nonconflicting flight paths and issuing of associated clearances by a central control authority, is an extension of the traffic control system presently used in the North Atlantic organized track system. It is a concept in which an entire flight could be scheduled from assigned takeoff time to landing time. Strategic Control is most effective when applied in high density airspace where it increases capacity, minimizes delay, and improves the inherent safety of the air traffic control system by reducing uncertainties about future events and the need for tactical or short-term control intervention by the ATC system. It requires 4D-RNAV equipment; so, to decrease user impact of this concept feature, areas of application would be initially restricted to the terminal airspace of the twelve airports projected to be saturated in 1995, and to en route airspace on routes where busy hour traffic is expected to exceed 25 flights per hour.[12] Strategic Control can, however, be used to advantage in all airspace where IFR flights take place and could be extended to service VFR flights following a standard flight plan route. Strategic Control would be the most stringent level of control in the air traffic control system. As such, it would be used at those times and places where

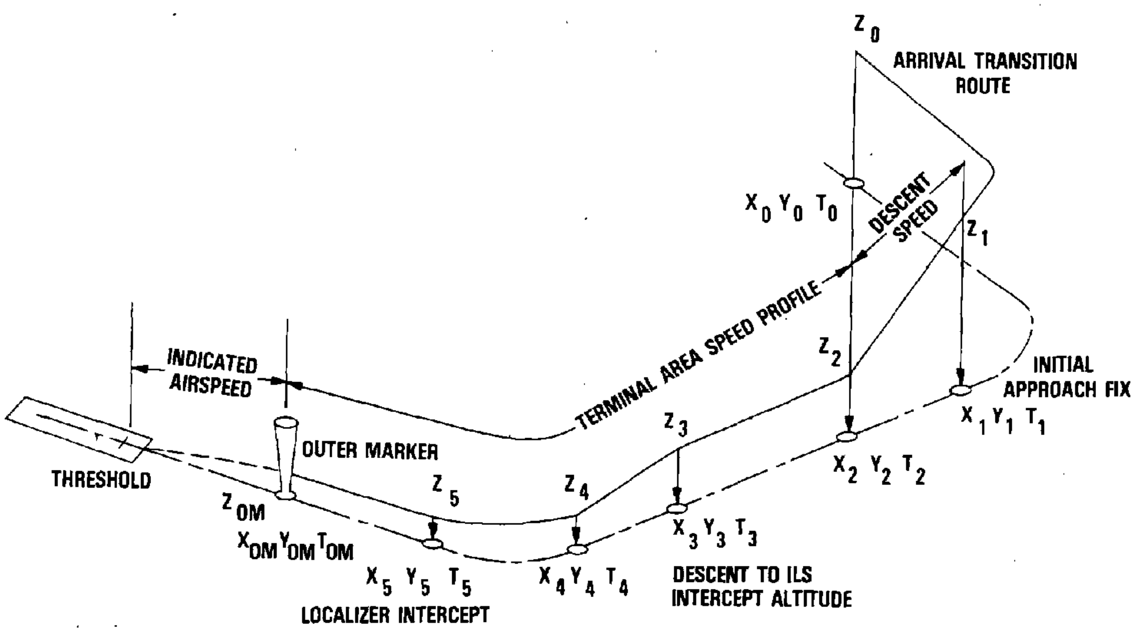


Figure 5-6. Strategic Arrival Path Example

increased ATC system capacity is needed to handle the traffic demand. This would be during peak periods for those runways and air routes that consistently operate at capacity with air carriers and the more sophisticated, high-performance general aviation aircraft.

Strategic Control is proposed as the primary method for air traffic management in high density positive control airspace for the following reasons. Potential conflicts between controlled aircraft can be readily identified and resolved; intruders on an aircraft under Strategic Control can be dealt with tactically; the flow, and hence density, of traffic at any particular point in space or time can be adjusted and optimized; and the extent of airspace required for terminal area positive control and the length and number of delays incurred in flight can be reduced. Flight time and fuel consumption can be minimized through use of optimized routes and, due to the long-term nature of the control technique, controller workload and communication channel loadings are reduced from those of the more tactically directed control methods. There is a greater opportunity for each flight to fly the most desirable path from the controller's point of view. There is also more flexibility in use of the available airspace since the technique may be selectively applied to allow for traffic density, or specific geographic area characteristics. Under this concept, both equipped and unequipped traffic can operate from the same runway. (Equipped traffic means airplanes having the avionics necessary to operate in a Strategic Control environment).

Under the Strategic Control Concept, four-dimensional flight path assignments are made that allow for geometric, environmental, and airplane performance considerations. Strategic Control flight paths and operations accomplish the following:

(a) Define desired airplane flight path in terms of horizontal position, altitude and time.

(b) Provide paths that are nonconflicting with safe separation between aircraft.

(c) Sequence and space aircraft for operation onto and off the runway.

(d) Make efficient use of available airspace and control capacity.

(e) Minimize flight penalties by using paths and profiles that match the desired route and aircraft performance envelopes as closely as practical.

The flight requirement is for each strategically controlled aircraft to maintain its scheduled position as a function of time with an error that is small compared with the planned spacing between flights. Sixty second longitudinal separations of aircraft in terminal areas therefore require that airplanes be able to maintain their assigned schedule to an accuracy of two to five seconds (one sigma).

If conflicts, system changes, or schedule slippages do not occur, each flight proceeds according to its Strategic Control clearance, i.e., its route-time-profile. As a practical matter, perturbing influences will occasionally occur and require resolution during the flight. The benefit of Strategic Control is that preplanning and use of airplanes equipped to achieve accurate path/time compliance removes variables that otherwise introduce considerable randomness into system operation. The necessity for revising a flight plan results from an airplane not being able to meet its next fix or fixes on schedule, or its inability to proceed to its intended landing without conflicting with other strategically controlled aircraft. If the airplane cannot make good its schedule to a fix, or if conflicts arise, the problem is resolved by generating a new route-time-profile that can accommodate the aircraft. This may require the resequencing of adjacent aircraft scheduled for specific times over nearby fixes or runways.

Strategic Control relies on ground equipment for surveillance position determination (including altitude), capability for providing navigation signals-in-space, a digital data link, and a central data processor; capabilities obtainable in a variety of equipment. The primary use of ground equipment will be for surveillance to enable the ground sites to monitor flight progress and conformance with the Strategic Control clearance. Short-term updates to the wind model for the area and altitude of each flight are obtainable from this ground equipment data, and are used in the generation of other route-time-profiles through the region. The aircraft equipment complement required by Strategic Control includes a surveillance transponder, data link modem, display, four-dimensional navigation capability, and a guidance computer. The potential liabilities of high cost user equipment are offset by the benefits of being able to operate in high density air traffic environments with increased safety at reduced costs and with reduced potential for unexpected delays. A potential may exist for using ground controlled-area navigation (GC-RNAV) features of the proposed system concept to supply the four-dimensional system guidance to strategically controlled aircraft. The application of GC-RNAV navigation techniques may be desirable from a cost-benefit standpoint in enabling the users and system to realize many of the benefits of Strategic Control, while minimizing the required user investment. Air carrier and general aviation aircraft that frequent high density airports during peak hours of traffic operation are expected to be the primary users.

Strategic Control would be used in particular portions of positive controlled airspace, designated as High Density Positive Controlled Airspace, when flow, traffic density, or other conditions dictate its use. Figure 5-7 shows the anticipated airspace structure for the 1995 system concept. The possibility of using Strategic Control procedures outside of high density positive controlled airspace exists through the use of tactical control to reroute aircraft that might impinge on the flight profile of a strategically controlled aircraft. This technique could be applied in Positive Control and Mixed Airspace where all aircraft must have a surveillance transponder and a data link modem (capable at a minimum of receiving IPC instructions). In uncontrolled airspace, many aircraft may not be under surveillance and thus it is not possible to assume conflict-free-flight. Figure 5-8 correlates airspace regions with proposed control techniques. The primary operating mode and, in descending order, the backup modes of operation are shown for each airspace category. Tactical control modes back up strategic control modes. The avionics of the typical users in each airspace region are also shown in the chart.

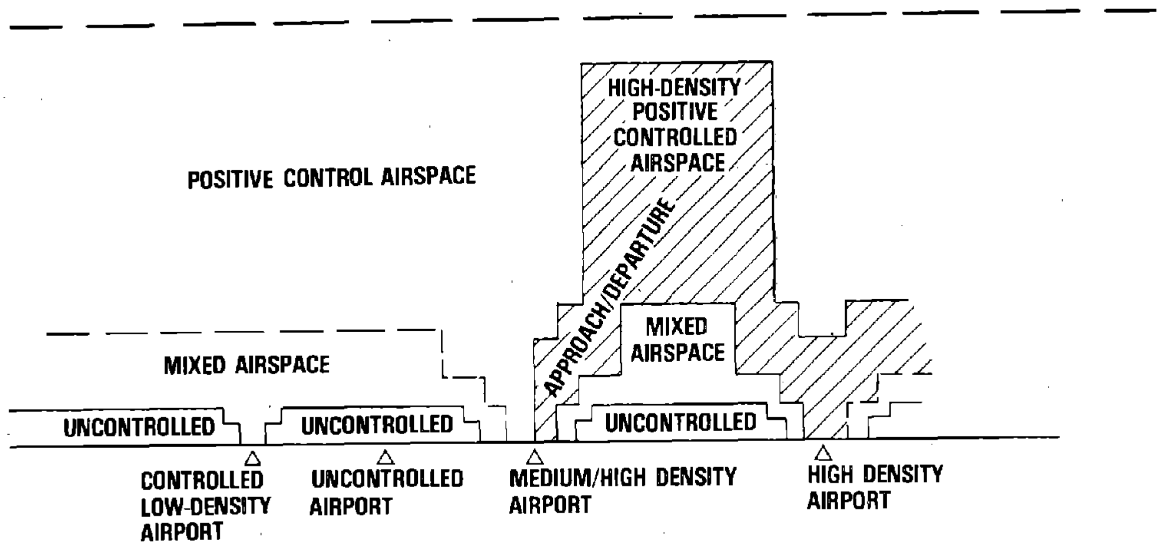


Figure 5-7. Airspace Structure

	AIRSPACE REGIONS		
	HIGH-DENSITY POSITIVE CONTROL	POSITIVE CONTROL	MIXED
OPERATING MODES	← STRATEGIC CONTROL →	← CONFLICT-FREE FLIGHT PLANNING →	
		← CONFORMANCE MONITORING	→
		← FLOW CONTROL	→
	← METERING AND	SPACING →	
	← CONFLICT	INTERVENTION	→
	← INTERMITTENT	POSITIVE CONTROL	→
	← AIR-DERIVED	SEPARATION ASSURANCE	→
AVIONICS	• 4D-RNAV • SURVEILLANCE TRANSPONDER • ATC DATA LINK • VOICE COMM • (CAS/PWI)	• RNAV • SURVEILLANCE TRANSPONDER • ATC DATA LINK • VOICE COMM • (CAS/PWI)	• NAVIGATION UNIT • SURVEILLANCE TRANSPONDER • IPC DATA LINK • VOICE COMM • (CAS/PWI)

Figure 5-8. Selected 1995 Operation Modes, Airspace and User Equipment

5.5 OPERATING MODES

The spaceborne, ground-based, and airborne equipment for the Advanced Air Traffic Management System has been described in Section 5.1. This Section describes the primary and backup modes of surveillance, navigation, and communication available with these equipments. Primary modes describe the normal or preferred means for implementing a functional capability. Backup modes describe alternative means for implementing a function, generally when equipment used in the primary mode has failed.

Primary Modes of System Operation

Surveillance - The primary means by which position information is obtained on each aircraft in the system depends on the equipment carried by each aircraft and the airspace region in which the aircraft is flying. Generally, satellite surveillance techniques would be used to obtain aircraft position information in en route and low density terminal airspace, and DABS would be used in high density terminal airspace. Because of the AATMS capability to coordinate data from several different surveillance systems, aircraft capable of replying only to interrogations from ground-based DABS sites would not be precluded from operating, with an appropriate clearance, in any airspace with DABS coverage. Depending on the estimated surveillance position errors, however, increased separation standards may be applied between aircraft operating with different surveillance techniques.

Within en route positive control airspace, at low density terminals, and within oceanic airspace regions, all aircraft would normally be located through the satellite surveillance system. This information would be processed in the Continental and Regional Control Centers and would be distributed to other appropriate control centers. DABS-derived surveillance information relating to aircraft flying in en route airspace would be appropriately distributed. Aircraft equipped to interface with the satellite surveillance subsystem would not need encoding altimeters since the satellite system provides three-dimensional position information for each aircraft.

Three viable techniques for satellite-based surveillance have been identified and warrant further investigation to determine system tradeoffs and the extent of compatibility with ground-based DABS that can be achieved. Each satellite surveillance technique employs ground-based computer processing in order to determine the three-dimensional position of an aircraft. The relative times-of-arrival of signals transmitted by that aircraft and received by several satellites are used in this process. The three surveillance techniques may be summarized as follows:

(1) Asynchronous transmissions by each aircraft are relayed by at least four satellites to ground processing centers (Figure 5-9).

(2) Responses to satellite interrogation of aircraft-borne surveillance transponders are relayed back through the satellites to ground centers (Figure 5-10).

(3) Satellite navigation signals emitted by the satellites and received by aircraft are transmitted to the ground centers over the satellite data link (see Figure 5-11).

Calibration stations are used in conjunction with the satellite surveillance techniques to aid in determining and reducing position location errors.[7] These calibration stations would be located at carefully surveyed ground sites. Simulating a precisely located aircraft, the site's surveillance-derived position is compared with the actual (known) position to determine and compensate for surveillance or navigation system bias errors. Aircraft position location accuracies on the order of less than a hundred feet (1σ) are expected with the satellite-based subsystem.

The Discrete Address Beacon System, augmented by the capabilities incorporated in the Synchro-DABS concept, is the primary surveillance system at high density terminals. It is supplemented with independent altitude and position information obtained via the satellite system. DABS, by providing an alternate means for performing the surveillance and data link functions, reduces satellite system loading in these functional areas and makes possible effective, side-by-side implementation of DABS and satellite systems.

Navigation - The AATMS Concept provides four alternative modes of navigation to users. These are:

- Satellite Navigation
- Ground-Computed Area Navigation
- Ground Ranging (Synchro-DABS DME)
- Omnirange Navigation (VOR)

Satellite-based navigation, discussed in Section 4 and illustrated in Figure 5-12, enables each aircraft to determine its three-dimensional position from on-board processing of differences in the times-of-arrival of signals from at least four satellites. Additional information in the downlink-to-aircraft signals enable the aircraft to remove a portion of the bias errors and determine its own position to accuracies on the order of a hundred feet (1σ) relative to the geodetic reference system and on the order of a few tens of feet with respect to nearby aircraft (or calibration stations) using the same navigation technique. Satellite navigation techniques may prove acceptable for precision landing guidance at all

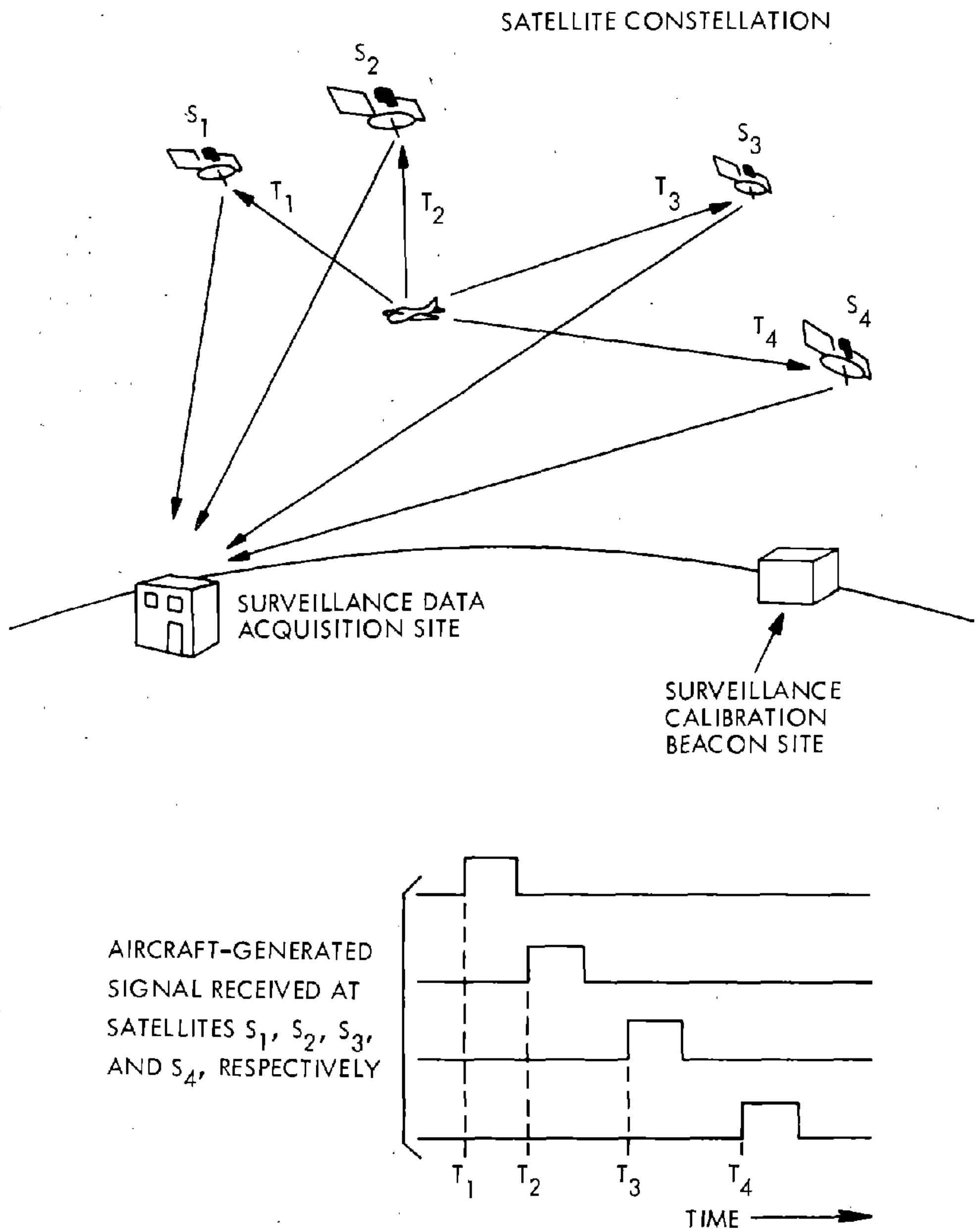


Figure 5-9. Satellite-Based Surveillance Method Using Asynchronous Transmissions From Aircraft

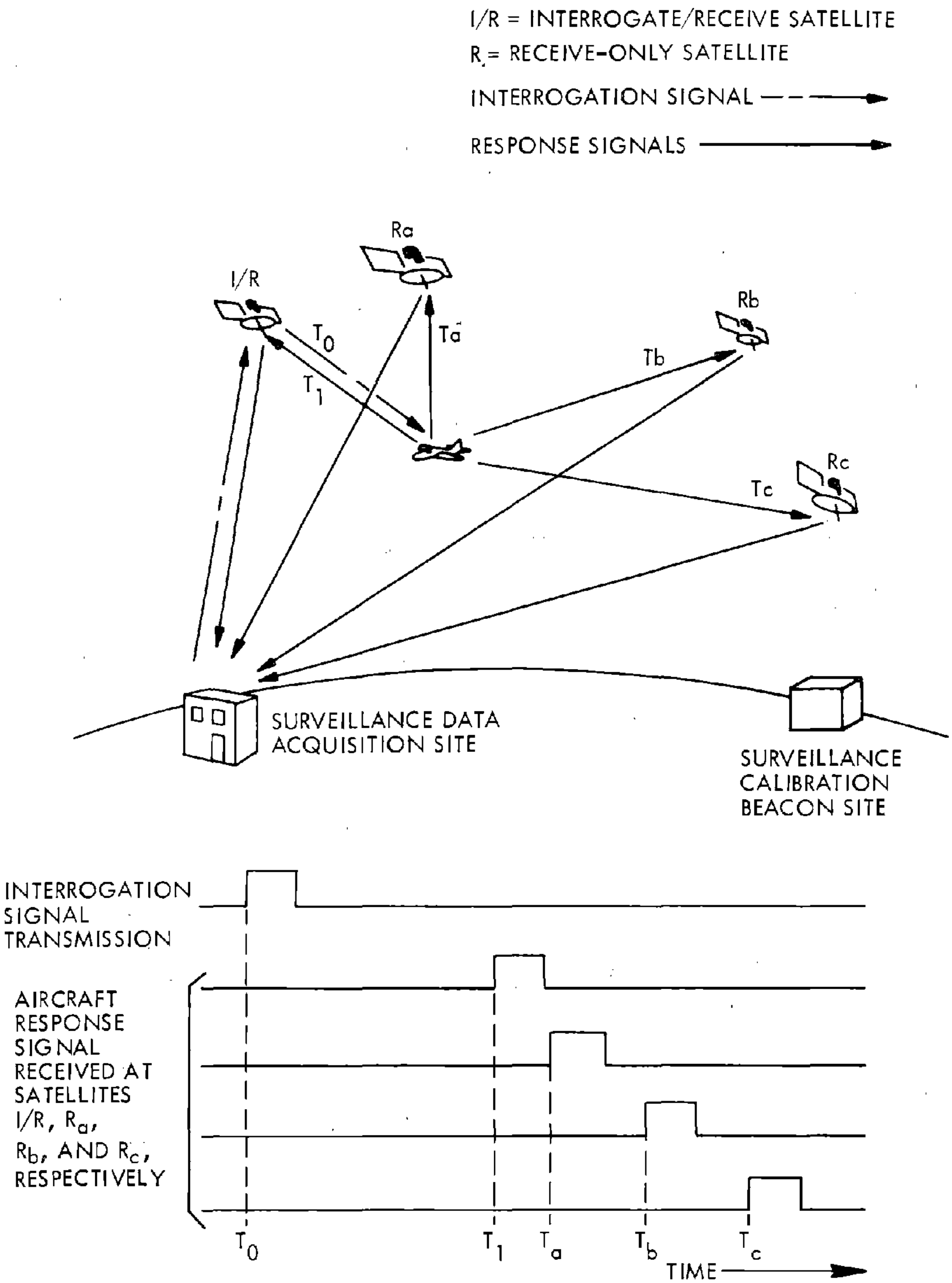


Figure 5-10. Satellite-Based Surveillance Method Using Interrogated Beacons on Aircraft

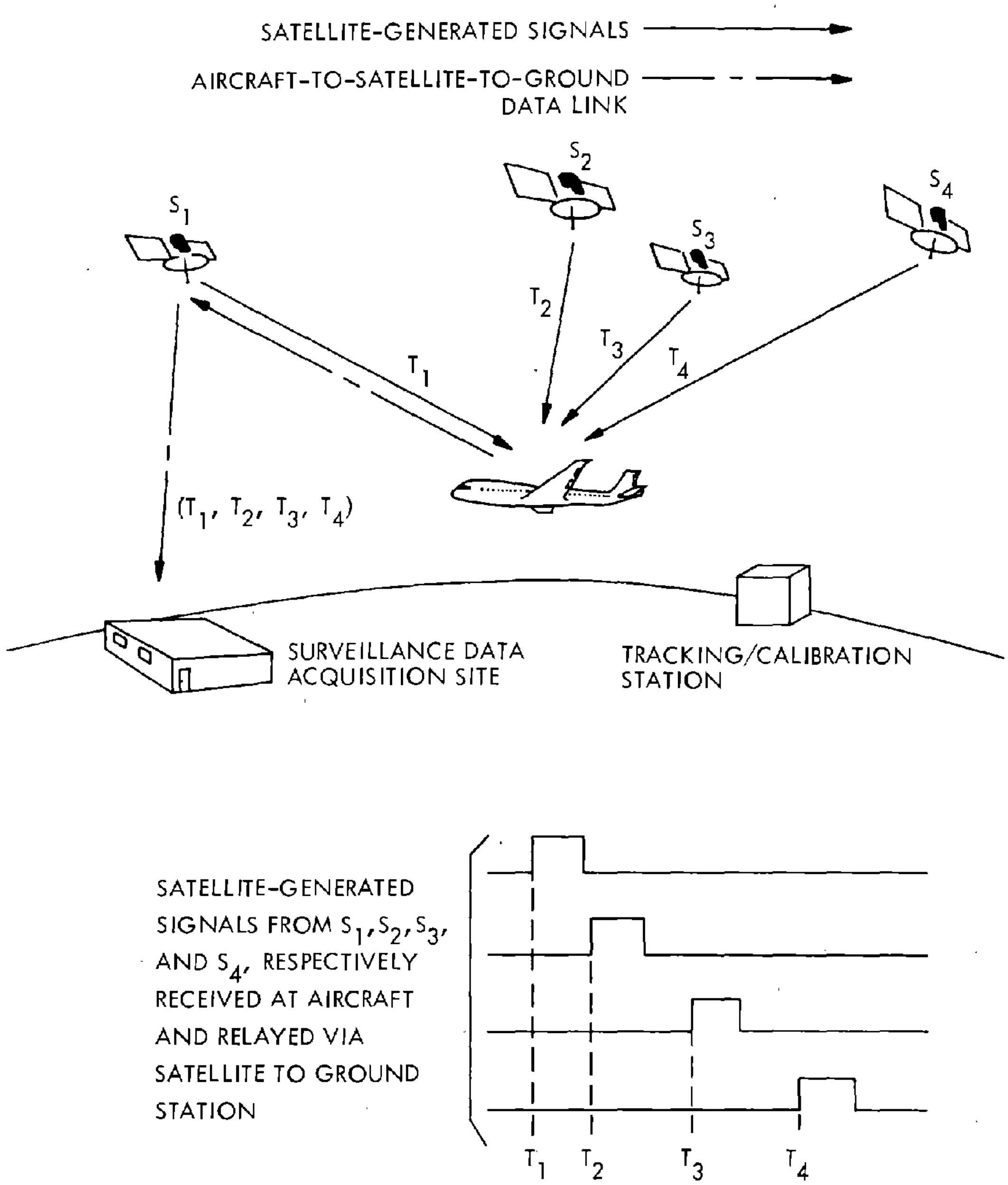


Figure 5-11. Satellite-Based Surveillance Method Using Satellite-To-Aircraft-To-Ground Signaling

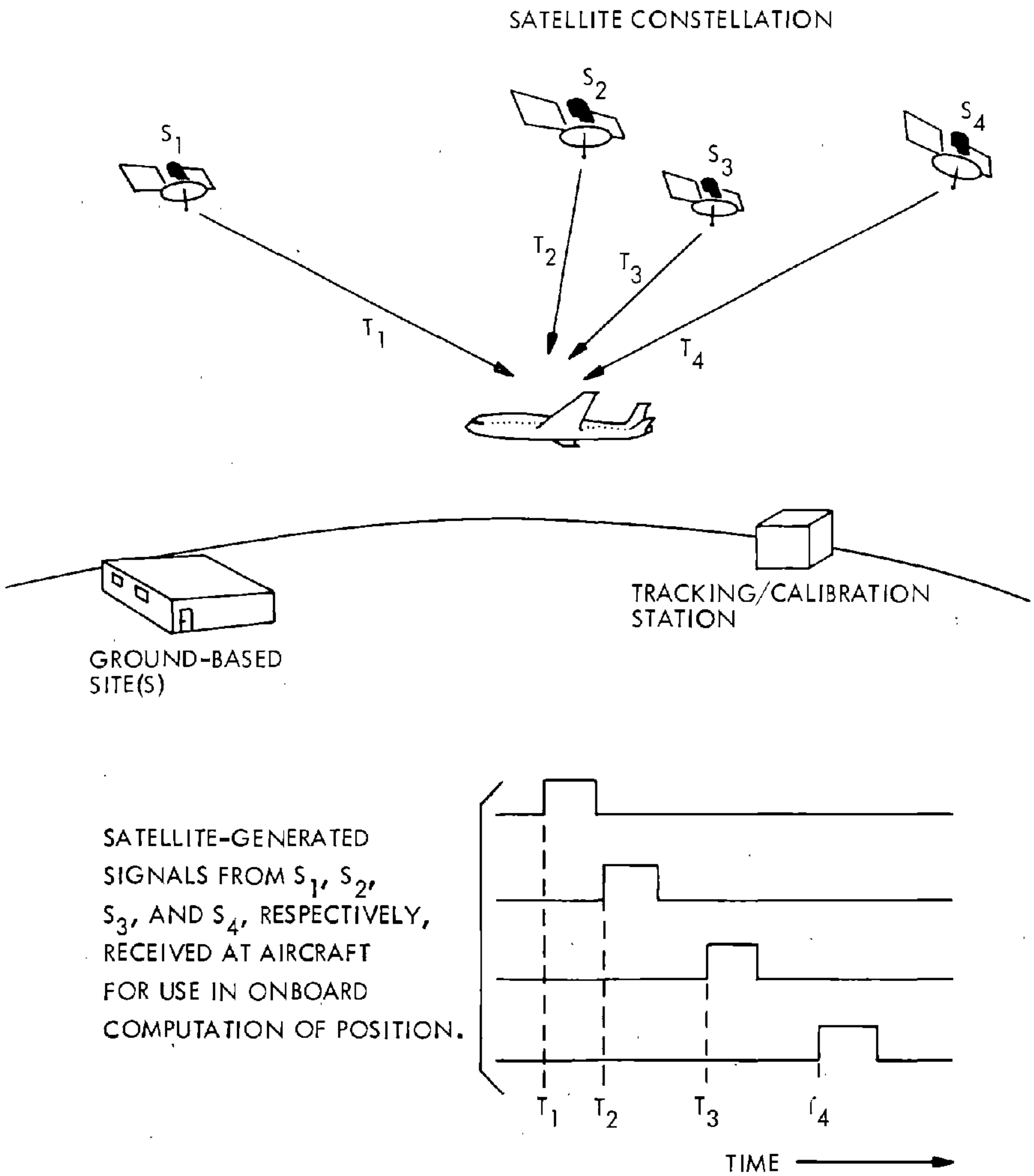


Figure 5-12. Satellite-Based Navigation Method

airports or at airports near a calibration station.[8] It is anticipated that users equipping to use satellite navigation will also use area navigation equipment since the computational logic for positional determination and area navigation are easily integrated.

The Ground-Computed Area Navigation (GC-RNAV) technique provides users with a low cost, navigation capability which is more flexible than the present VOR navigation system. This navigation technique, a cost-effective adjunct to the satellite surveillance and data link functions, depends on the surveillance and digital data link subsystems, and ground knowledge of aircraft destination. Using surveillance information from either the satellite subsystem or DABS and the coordinates of the aircraft's destination, transmitted via data link from the aircraft, the ground system computes navigation parameters such as position, bearing and range to the destination (or next intermediate waypoint), and cross-course deviation; periodically sending this information to the aircraft, where it is displayed. Further study is needed to determine GC-RNAV suitability for IFR navigation, including airport approach and departure guidance. The issues to be resolved include achievable accuracy, update rates, reliability, and cost of computational loading upon the system computers.

The third navigation technique for the Advanced Air Traffic Management System involves the one-way ranging to Synchro-DABS sites (see Section 4). This equipment is incorporated in the selected concept to accommodate those users retaining Baseline System equipment. Since users of this navigation technique must receive one-way ranging signals from three-sites to enable an unambiguous position fix, this navigation mode will most likely be used either in conjunction with other low-altitude navigation aids such as VOR, or at higher altitudes with some type of area navigation equipment.

A fourth type of navigation technique, enabling aircraft to fly bearings to known locations, would be provided in the future system by the retention of approximately 300 conventional VOR sites from the Baseline System. This mode of navigation would be used primarily by aircraft not having satellite navigation, Synchro-DABS ranging, or GC-RNAV capability, and which seek a minimum cost avionics complement to operate in uncontrolled airspace regions having VOR coverage.

Precision landing guidance signals at high and medium density airports would be provided by the Microwave Landing System, or conventional Instrument Landing Systems, retained from the Baseline System. Satellite navigation may prove acceptable for precision landing guidance at all airports, but the operational aspects of this technique require further investigation.

Backup Modes of System Operation

Provision of alternative means for performing air traffic management functions or backup modes are an important consideration in defining a system concept. Maintenance of air traffic safety and minimization of delays are of primary concern. Weighed against these concerns is the added implementation and operating and maintenance costs incurred by the operators and users of the system. An optimum, cost-effective balance should be sought between functional backup and cost.

For surveillance and data link functions, the highest order of backup would be provided by redundant equipment or overlapping coverage of the airspace, for the primary modes of operation. In the AATMS Concept, primary surveillance/data link backup, for aircraft carrying satellite-compatible avionics would be achieved by deploying redundant satellites. Retaining the DABS sites in high density regions, thereby providing overlapping coverage of this airspace (which accounts for approximately 73% of the instantaneous airborne traffic), provides a backup surveillance/data link capability for those aircraft carrying DABS/satellite-compatible avionics. Some overlap of airspace coverage between adjoining DABS sites would also exist, thereby providing an airspace-limited backup capability for aircraft carrying DABS-compatible avionics.

A degraded form of surveillance/data link backup is afforded by the independently implemented voice link. Messages normally transmitted via the data link could be handled by the voice link at a reduced rate. Aircraft-derived navigation data could be transmitted to control centers via voice link to replace a lost surveillance/data link capability, maintaining system safety, albeit with reduction in capacity and increased delays.

As in the case of the surveillance/data link function, primary navigation backup, for aircraft carrying satellite navigation avionics, would be achieved by the deployment of redundant satellites. Primary backup for Ground Computed-Area Navigation equipped aircraft would be realized through surveillance/data link backups. Aircraft equipped with a ground-ranging navigation capability would have a backup capability by virtue of overlapping airspace coverage of the DABS/Synchro-DABS and VOR/Synchro-DABS interrogators. Aircraft equipped with the ground-steering capability provided by the VOR network would have a primary mode backup to the extent that VOR site airspace coverage overlaps.

From the user's viewpoint, additional navigation backup capability could be achieved by carrying the avionics for two or more alternative modes of navigation. Most typically, a satellite navigation equipped user would also carry the avionics required for a GC-RNAV capability, and a ground-ranging equipped user would also carry a VOR receiver to enable a ground-steering capability. Alternatively, users operating in controlled airspace could be provided aircraft position information by data-linking ground-derived surveillance data to the aircraft, given that the loss of navigation capability was not due to a surveillance/data link malfunction in the first place (e.g., an aircraft equipped for GC-RNAV only).

As another backup, a user that has lost all primary navigation modes, and does not have a surveillance/data link capability, would be provided navigation/guidance information via the voice link using current air traffic control/navigation system procedures.

Where a mixed ground-based and satellite-based system exists, serving users that have a variety of capabilities, the backup modes available are conditioned by two important factors; first, the service coverage of ground systems employed in this concept is limited by line-of-sight restrictions, and the use of such ground systems as backup units requires the tacit assumption that aircraft remain within the coverage of the backup facility; and second, users must be equipped compatibly with the backup subsystem.

Allowing for the line-of-sight limitations, ground subsystems functionally backup adjacent ground subsystems and similar satellite subsystems. Satellite subsystems back up similar ground functions. Voice communications units back up data links, and vice versa. Failure of surveillance and navigation subsystems is met by relaying navigation and surveillance data, respectively, on either voice or data link channels, to the affected system element. Additional assurance results from the fact that the failure of some system elements may not be catastrophic. As an example, degradation of one or more satellites in the constellation may only result in the degradation of the system's ability to provide accurate three-dimensional surveillance or navigation information, leaving, at worst, a two-dimensional capability for both functions.

Users are afforded at least the same level of backup as the present system offers, and frequently, depending on their equipment complement, a higher level. Surveillance module failures can be accommodated through use of navigation and communication subsystems, and vice versa. Some coordination with system control elements may be necessary to effect these modes. Independent data link and voice communications subsystems provide the user a high degree of reliability in maintaining communications contact with a control authority. Users equipped with both satellite and ground-based interface avionics can supplement one capability with the other; redundant equipment also offers increased user reliability. As in the present system, minimum equipped users may suffer some degradation in navigation or communication if the equipment fails. However these users will be operating under visual meteorological conditions (flying VFR) and the loss is not critical.

5.6 IMPLEMENTATION APPROACH

The Study assessed the implementation of AATMS in terms of the associated system and user costs, conversion requirements, and attendant system benefits and disbenefits. The assumptions used are listed below.

- AATMS will evolve from the assumed Baseline System.
- Transition to the new system will not cause any degradation in system safety or capacity.
- Transition will take place so that users do not have to carry two different sets of functionally identical equipment.
- Elements of the ground system in place in 1982, but not part of AATMS, will be retained in parallel operation for a ten year period to allow sufficient time for implementation of new avionics.

The mixed ground and space-based system concept proposed in this Study offers a cost effective approach to air traffic control. This characteristic is particularly evident in the concept's ability to adapt to changes in the characteristics of the fleet, its ability to remain insensitive to fluctuations in demand and hence avoid proliferation of multiple ground sites to meet changing demand, and its ability to foster a cost-effective centralization of system services. In addition, the concept offers a balance of user and system cost advantages. More impressive savings beyond those indicated here may be possible if intersite and air-to-ground voice communications through satellites prove feasible. However, if satellite implementation for CONUS surveillance, navigation and communication is delayed in favor of continuing the deployment of the ground-based system beyond the Baseline System date of 1982, the potential savings estimated by this Study for a hybrid ground and space-based mechanization may no longer be available, being counterbalanced by the increased investment in the ground-based system beyond 1982. The time phased implementation of AATMS, and the related costs, are summarized in Figure 5-13.

Surveillance/Data Link Subsystems

The satellite experimental program will result in the deployment of several satellites compatible with the design of the future satellite subsystem, and at least partial implementation of data processing and satellite tracking facilities. With a decision to implement satellites during the 1978 to 1982 time period, the operational capability of the system concept would be achieved between 1985 and 1989 with the launch of additional satellites. When the satellite subsystems are operational, users equipped with the basic DABS avionics can procure satellite-compatible add-ons to receive satellite-based services throughout CONUS

IMPLEMENTATION/COST ELEMENT	IMPLEMENTATION SCHEDULE (FISCAL YEAR) 82 83 84 85 86 87 88 89 90 91 92 93 94 95	1982-1995 F&E COST [1]	1995 O&M COST [2]
APPROVAL FOR AATMS IMPLEMENTATION BASED ON R&D PROGRAM RESULTS	△	-	-
MECHANIZATION SUBSYSTEMS			
● SATELLITES	10-15 SATELLITES DEPLOYED △——△	$140	$20
● DABS	△ 106 DABS SITES PREVIOUSLY DEPLOYED IN BASELINE SYSTEM	-	5
● VOR NAVIGATION SYSTEM	△ 1025 VOR SITES PREVIOUSLY DEPLOYED IN BASELINE SYSTEM; PHASE DOWN TO 300 VOR SITES △——△	-	5
● VHF VOICE COMMUNICATIONS SUBSYSTEM	△ 1100 VHF VOICE COMMUNICATIONS OUTLETS PREVIOUSLY DEPLOYED	-	30
FACILITIES/AUTOMATION/ OPERATING PERSONNEL			
● CONTINENTAL CONTROL CENTER	△ CONSTRUCTION/ CHECKOUT-1 SITE △	$30	$20
● REGIONAL CONTROL CENTER	△ CONSTRUCTION/ CHECKOUT-2 SITES △	100	60
● TERMINAL-HUB CONTROL CENTERS	△ CONSTRUCTION/CHECKOUT-20 SITES △	300	330
● AIRPORT CONTROL CENTERS	△ CONSTRUCTION/CHECKOUT- 492 SITES △	630	250
COST TOTALS		$1200	$720

1. F&E (FACILITIES AND EQUIPMENT) COSTS REFER TO THE INITIAL EXPENSE TO OBTAIN, INSTALL, AND CERTIFY A PARTICULAR SYSTEM ELEMENT. NO DEVELOPMENT COSTS ARE INCLUDED.

2. O&M (OPERATIONS AND MAINTENANCE) COSTS ARE THE RECURRING ANNUAL EXPENSES TO OPERATE, MAINTAIN, RELOCATE, AND MODERNIZE EACH SYSTEM ELEMENT. OPERATING/CONTROL PERSONNEL COSTS APPEAR IN THIS COST FACTOR FOR FACILITIES.

Figure 5-13. AATMS Implementation Schedule and Costs (Costs in Millions of 1973 Dollars)

at any altitude. The DABS avionics would continue to operate at 1030 and 1090 MHz. The satellite-compatible add-on would operate near 1600 MHz, in a frequency band already allocated for signaling between aircraft and satellites.

Ten years after satellite system deployment, service previously provided by the primary radar and ATCRBS network would be phased out. System-compatible avionics would therefore be required in controlled airspace after that time (1995 to 1999). It is assumed that weather and military requirements for primary radar data can be met with other means, and that commitments under all international agreements relating to air traffic control subsystems can be met without retaining the primary radar or ATCRBS.

Navigation Subsystems

The current civil aviation navigation plan continues to use the VORTAC network through 1982[27]. Once the satellite system is deployed, users can obtain satellite navigation service by adding a satellite navigation receiver and processor to their avionics.

With deployment of the Continental Control Center and the Regional Control Center, the Ground-Computed Area Navigation (GC-RNAV) service will become available to users equipped with system surveillance-data link, and GC-RNAV logic and display avionic modules. Synchro-DABS one-way ranging will also be available to suitably equipped users when near a DABS site after 1982.

Users not equipping for satellite navigation or GC-RNAV would continue to use the VORTAC network. By 1994 to 1998, satellite navigation and GC-RNAV will be the primary means of navigation. The number of VOR sites may gradually be reduced during this transitional period until approximately 300 sites remain. These remaining sites would serve as navigation aids in uncontrolled airspace. Significant reductions in the cost of DABS/Satellite avionics, especially navigation modules, would result in eventual decommissioning of any remaining VOR sites.

Communication Subsystems

By 1982 the complement of voice communications equipment assumed for the Baseline System will be complete. This equipment will continue in use throughout CONUS in the Advanced Air Traffic Management System. Those users expecting to fly in oceanic regions will need satellite-compatible voice communications equipment. When voice communications through satellites proves to be a cost effective, low risk, and reliable communications technique, users eventually may be expected to convert from the present VHF equipment to satellite-compatible equipment.

Control Facilities

In the 1982 Baseline System, en route CONUS air traffic is controlled from twenty ARTCCs, major and medium hub air traffic is controlled from approximated 63 Terminal Radar Approach Control (TRACON) facilities; airport traffic is controlled from 492 control towers; and national flow is monitored from one center. The AATMS Concept requires a shift in the en route and hub control authority from this distributed approach to a centralized concept employing a Continental Control Center (CCC), two Regional Control Centers (RCC), and 20 Terminal-Hub Centers (THC). The number of airport control facilities would remain 492 in 1995. To assure safety during the transition period, all aircraft operating within the same region would have to be under a single control jurisdiction although the surveillance data used for control might be obtained from different sources, viz. ATCRBS, DABS, satellites.

The surveillance, navigation, and communication mechanization approach described above enables initiation of transition in the mid to late 1980's, after completion of Regional

Control Centers and deployment of satellites. Initially the Air Route Traffic Control Centers and Terminal Radar Approach Control facilities would exercise control with satellite-derived surveillance data transferred from the processors of the Regional Control Centers. Control intervention commands would be initiated by the Air Route Traffic Control Centers and the Terminal Radar Approach Control facilities and transmitted to suitably equipped users via the Regional Control Center's satellite link. Users not having satellite-link capability would be served through retained 1982 Baseline subsystems.

Control authority would be transferred to the Regional Control Centers and Terminal-Hub Centers on a staged, region-by-region basis. Control staff from Air Route Traffic Control Centers and Terminal Radar Approach Control facilities would be transferred to operate the Regional Control Centers and Terminal-Hub Centers respectively. Transfer of control authority from the Air Route Traffic Control Centers and Terminal Radar Approach Control facilities should be complete by 1995. Implementation of the Airport Control Centers at selected airports would begin in the mid-1980s. Initially, these Airport Control Centers would operate off line, with their processors and displays receiving surveillance position data from ATCRBS and DABS sites as well as from the RCC facilities. After a satisfactory checkout period, the ACCs would assume control over the aircraft within the airport regions. Deployment of the Airport Control Centers would be completed by 1995.

5.7 SYSTEM ASSESSMENT

Assessment of Proposed Mechanization

The AATMS surveillance, navigation, and communication mechanization concept has advantages and disadvantages which affect both system operators and system users. The major advantages include:

- Surveillance, navigation, and communications coverage provided down to the ground throughout conterminous United States.
- Air traffic management services provided more economically than the Baseline System or its extensions.
- Air traffic management services available at all air fields, however remote their locations.

Somewhat offsetting these advantages are:

- A shortage of definitive test data related to the performance of satellite-based surveillance, communications, and navigation subsystems and associated avionics.

- Inability to spread the satellite facilities and equipment (F&E) costs over a number of years, since the full constellation would be needed coincident with initiation of satellite-based service.

Of the concepts that have been examined, there appears to be no cost effective and viable alternative to the employment of satellites to meet future air traffic management operational requirements.[14] Additional definitive information and test results are desirable to support detailed considerations and decisions in determining actual system design. This data requires additional R&D which is described in Section 6 of this report.

The DABS/Satellite system mechanization concept provides a well-balanced system approach. The DABS sensors cover large numbers of aircraft in relatively small regions where system reliability must be high. The satellite constellation provides extensive, supplementary coverage of the larger but lower traffic density airspace regions, thus minimizing the number of ground-based sites needed for coverage of en route airspace and remote, low density terminals.

Additional benefits derived from a satellite-based system include improved surveillance and navigation accuracy and universally available coverage. These features maintain safety while increasing en route capacity because separation standards can be reduced.* Other user benefits include universally available terrain and obstacle avoidance warning, emergency locating (search and rescue) service, and a form of approach and departure guidance to and from all airports and airfields. Although these benefits have their greatest impact on general aviation, they could also foster the development of short-haul commercial service in low density traffic regions.

Another feature made possible by use of satellites is aircraft altitude determination without reliance on airborne barometric altimeters, or on altimeter encoders. Additionally, a satellite constellation provides a common grid for surveillance and navigation, minimizing coordinate conversion and sensor registration problems.

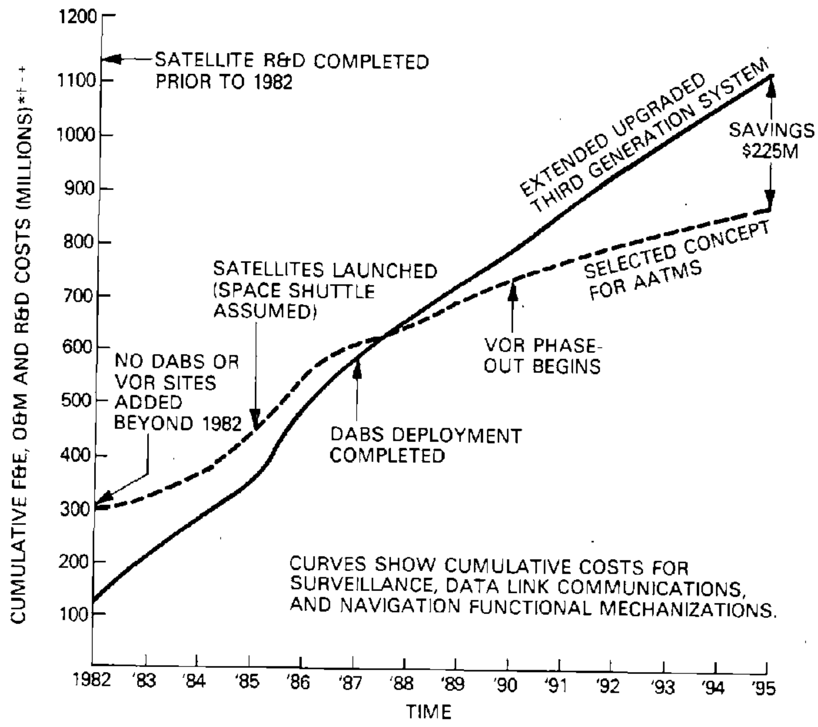
The system backup modes draw on the strength of two compatible, but independent systems each of which can provide the functions of the other in particular regions of the airspace. As part of the system backup, CAS/PWI capability is available in all airspace via the space-based system elements. A satellite-based surveillance mode employing aircraft-to-satellite-to-ground signaling may be vulnerable to intentional, sophisticated

*The importance of this feature is somewhat less than it may initially appear since the major future capacity problems are expected in terminal regions, resulting from lack of runway availability and other factors independent of air traffic control equipment and their operational characteristics.

jamming. However, the system has adequate backup modes, as described in Section 5.5, to handle this improbable situation.

The pilot's workload is reduced in the system through the use of new avionics which require little frequency changing. Further user benefits result from the introduction of a new navigation technique, Ground-Computed Area Navigation, which can provide direct routing information to any suitably equipped aircraft. The requirements for integrated avionics, designed to interface with the satellite system and at an acceptable user cost, should present no insurmountable attainment problems.

The cost benefits of the selected mechanization approach** for surveillance, navigation, and communication were estimated by comparing the AATMS approach to that for the Extended Upgraded Third Generation System, whose costs were discussed in Section 4. Figure 5-14 summarizes the results of a cumulative, year by year comparison of the two mechanization approaches beyond 1982. Since the voice communications subsystem for the



+ NO VOICE COMM COSTS. COMMON TO BOTH ELEMENTS.
* O&M FROM 1982 TO TIME.
÷ INITIAL F&E INCLUDES 1977-1982 EXPENDITURES (SEE REFERENCE 9).
- SATELLITE R&D ESTIMATED AS $175M PRE-1982

Figure 5-14. Potential Cost Savings of Satellite-DABS Mechanization Over The Extended Upgraded Third Generation System

**Costs for managers, operators, control facilities, and overhead expenses are not included in this discussion.

two approaches was identical the costs for these elements were deleted from the comparison. The Extended Upgraded Third Generation System costs reflect no R&D expenditures since such expenditures would have already been charged off against developing the Upgraded Third Generation System, i.e., they are sunk costs. The Extended Upgraded Third Generation System curve starts in 1982 at about $125 million, which reflects the initial implementation costs for the system. The curve increases from 1982 to 1995, reflecting accumulating implementation, operation, and maintenance expenses for the sensor elements. The AATMS cost curve starts in 1982 at about $300 million, reflecting the Extended Upgraded Third Generation System's initial expenses plus an additional $175 million estimated for satellite system research and development (assumed completed prior to 1982). No further ground-based sensors are added after 1982, but operational satellites are implemented in 1985 and 1986, and the number of VOR sites is reduced from about 1,000 to 300, beginning in 1990 and ending in 1995.

By the year 1995 the AATMS mechanization will have saved an estimated $225 million over the equivalent costs of the Extended Upgraded Third Generation System were it operational at that time. Mechanization O&M costs for 1995 are $35 million less for AATMS than for the Extended Upgraded Third Generation System. However, even more important, the slope of the cost curve for the Extended Upgraded Third Generation System is $63 million per year, while for AATMS it is only $28 million per year. The latter difference includes the fact that in the AATMS Concept it is not necessary to continually deploy subsystem equipment to meet system requirements since system coverage is already complete in all relevant airspace areas.

Assessment of Proposed Control Facility Configuration

It is expected that the consolidation of the en route air traffic control facilities into two Regional Control Centers will improve efficiency and lower system operating and maintenance costs. These advantages result from the following facts:

- Peak instantaneous load requirements for the two regional control centers are lower than the sum of the peak instantaneous load requirements of the twenty Air Route Traffic Control Centers. This is because reserve capacity to handle peaks can be time shared by the RCCs whereas each ARTCC must have its own reserve to handle peak busy hour traffic for its individual region. Staffing requirements are reduced by this averaging of demand.
- Greater flexibility is possible in allocating the centralized pool of controllers, computers, and data resources to air traffic management tasks as they arise throughout the entire en route CONUS region.

- Information exchange and aircraft handoffs will be greatly simplified in the RCCs, in comparison to the intercenter coordination among today's ARTCCs, due to the proximity of controller stations.
- High operating efficiency and reliability is achieved in AATMS through the hierarchical structure and interlocking backup modes of control and flight service facilities.

The benefits of centralizing the control facilities were difficult to estimate in this Study because there were no decentralized system concepts to use for comparison purposes. Rockwell International Corporation, using an assumed automation level and centralized control facility configuration estimated annual savings of over $100 million.[7] An independent analysis by the Rand Corporation arrived at similar conclusions based on the same assumptions. The AATMS Concept facility configuration, selected as reasonable based on the data obtained by this Study, may not be optimum when all factors are taken into consideration including the impact of centralization on the interfacility communications network. The proposed AATMS R&D Program addresses the design of the future control facility configuration.

The primary benefit of centralization is the smaller workforce that results from more efficient use of system resources. Rockwell International estimated that inability to centralize would result in a twenty-five percent increase in the en route workforce due to the necessity of providing complete redundancy for all facilities. If the AATMS facilities were not centralized, the equivalent of at least a second Continental Control Center and Regional Control Center would be required to compensate for the lack of control facility centralization.[24] This would represent an additional staff complement of 1,742 people at an annual cost, in 1995, of $37 million. In addition, the facilities for these people would, in 1995, cost over $8 million per year to operate and maintain. To provide a comparable capability to the THCs in a decentralized system concept, at least five more sites would have to be added. The annual cost for these sites in 1995 would be $12 million for the facilities themselves and $70 million per year for the additional staff. Decentralization has little impact on the Airport Control Centers. Thus, a non-centralized concept would entail annual costs of approximately $127 million over the costs of the centralized concept.

It is worthwhile noting that centralization would be more costly to achieve and difficult to continue in the face of demand growth without a highly automated system and without satellites as primary surveillance and communications sensors. AATMS inherently, by virtue of the characteristics of the satellite surveillance and communications subsystems, has the full availability of surveillance and communications data on all aircraft in the system at several, centralized locations, rather than partial availability at each of many widely distributed geographic points, as at present. This data availability largely explains why control facility centralization is a highly desirable and cost-effective element for the future air traffic management system.

Assessment of Proposed Control Automation

The high level of automation recommended by this Study for the Advanced Air Traffic Management System results in a number of advantages. Automation permits attainment of the optimum mix of men and machines to provide safety and system services efficiently, and economically. Features of the proposed 70 percent level of automation include a multi-purpose resource sharing computer network, more substantive career opportunities for the system staff, and a fail-operational design philosophy. The computer network (described in Section 5.3) offers several advantages:

- Cost savings due to sharing workloads, information, programs, and specialized hardware, possible with a linked computer system.
- Large data bases, residing at one location, but sharable by other elements of the network.
- Ready access by network elements to special equipment located at other facilities.
- Rapid response and reconfiguration of the system in the event of equipment failure.

Distributed, multi-purpose data processing has several important advantages. Its distributed nature effectively provides inherent redundancies, thus reducing vulnerability to failures. Multi-purpose capability helps reduce the need for costly equipment redundancy per se since there is great flexibility in reassigning system elements. Functions can thus be carried out by those data processing elements best suited to performing the various tasks, but without irreversible commitment as would be the case with special-purpose computers. The computer architecture proposed for AATMS is well suited to the needs of an evolutionary system since it allows modular development and incremental inclusion of automated functions. Modularity can be applied to storage capability as well, and the system can continue to operate in a degraded mode by reallocation of memory modules.

The manpower savings achievable with a high level of automation were determined by comparing the staff and productivity estimates given in the FAA's Ten Year Plan to the staffing estimated for the Advanced Air Traffic Management System.[10,13] The FAA's

Ten Year Plan estimates that between 1972 and 1984 the en route, terminal, Flight Service Station and related ATC personnel staff would increase in productivity. Maintaining the same rate of productivity increase until 1995 would result in a control workforce of 30,000 people to handle the projected demand. A comparable 1995 staff complement based on the AATMS Automation Study was estimated to be 18,790 people (Section 5.3) consisting of supervisors, operators, and automation specialists. The cost benefit of AATMS automation was estimated simply by assuming that the average salary per individual is $20,000 per year. This was multiplied by the staff difference* between the two potentially comparable system automation techniques.[24] The result indicates potential annual savings of about $225 million.

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*30,000 - 18,790 = 11,210

6. RESEARCH AND DEVELOPMENT PLAN

The objective of the proposed Research and Development Program, described in this Section, is to obtain the necessary information to support the most cost-effective air traffic management system design and related system implementation decisions. Key features of such a system, beyond those currently planned for the Upgraded Third Generation System, have been described in the preceding Section. They include

- Satellites to provide extended surveillance/data link coverage, and navigation services in all airspace.
- Strategic Control for spacing control and separation assurance in high density positive controlled airspace.
- Centralized management of en route air traffic through use of two national en route facilities coordinated with hub facilities.
- Automation of approximately 70% of air traffic management functions, with the controller managing computer-directed, real time control of air traffic under normal operating conditions.
- Functionally-integrated avionics, in which the basic package is also designed for minimum cost.

In consonance with early Study objectives, this work is directed to carrying out the definition, development, and validation of the key features of the AATMS Concept to the point where implementation decisions can be made.

To further place the contents of this Section in the appropriate perspective, the following points must be kept in mind:

(a) This plan supplements current, on-going FAA Engineering and Development programs.

(b) Estimates of resources needed to accomplish the program are necessarily tentative, being based on experience in analogous and, where applicable, related programs, and will require continual refinement and updating.

6.1 MAJOR PROGRAM ELEMENTS

Multiple Satellite Tests and Experiments

Comprehensive satellite tests and experiments provide the only realistic basis for certain system design decisions and for preparing the ground, airborne, and space equipment specifications. Section 6.2 contains the Program's six major tasks necessary to establish the design and operational validation of these elements. The associated avionics need to be developed so that each user can choose his desired level of service.

Strategic Control

This Program element contains the tasks necessary to support operational and technical system design decisions in implementing the Strategic Control Concept. Equipment to demonstrate the benefits of four dimensional navigation and guidance and to enable performance estimation flight tests needs to be developed and tested together with a Strategic Control algorithm for use in high density, positive controlled airspace regions.

Automation

Automation studies need to be directed toward further development of computer-directed real-time control of aircraft under nominal operating conditions. This concept, assuming approximately 70% of air traffic management functions automated, needs to be validated through design and test of appropriate computer hardware/software and displays, with a major criterion being controller and pilot acceptance.

Cost

The estimated cost of the Research and Development Program from FY 1976 through FY 1984 is $260 million. The cost breakdown is as follows:

Multiple Satellite Tests and Experiments	-	$ 175 million
Strategic Control	-	$ 20 million
Automation	-	$ 65 million

These costs are based on 1973 dollars and the use of equipment and facilities beyond those either currently available or part of present FAA Program developments. Figure 6-1 summarizes the program in terms of critical decision points, schedules, and major milestones. Table 6-1 summarizes the estimated yearly expenditures for the three major activities in this Plan. The following sections describe plan activities and costs in more detail.

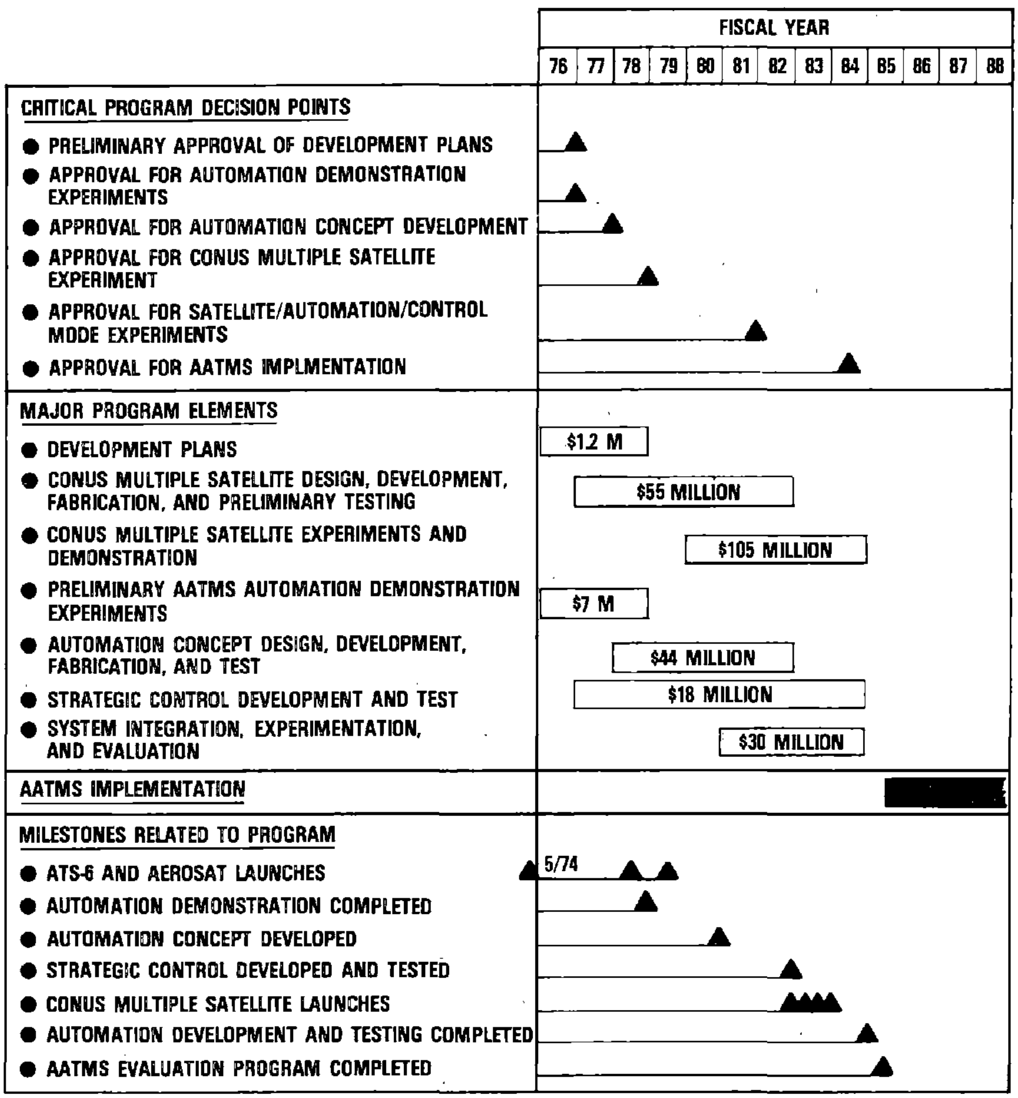

Figure 6-1. Advanced Air Traffic Management System Development Program

TABLE 6-1. AATMS RESEARCH AND DEVELOPMENT PLAN FUNDING BY YEAR BY ACTIVITY AREA
(Costs in Thousands of 1973 Dollars)

Activity Area	Fiscal Year									Task Cost Totals
	1976	1977	1978	1979	1980	1981	1982	1983	1984	
Multiple Satellite Tests and Experiments	400	2,400	9,900	14,500	43,000	35,300	45,700	12,000	12,000	175,200
Strategic Control	-	700	1,200	2,850	4,270	3,540	2,820	2,200	900	18,480
Automation	1,625	3,775	3,375	10,225	14,900	13,300	7,700	6,000	6,000	66,900
Total Cost	2,025	6,875	14,475	27,575	62,170	52,140	56,220	20,200	18,900	260,580

6.2 MULTIPLE SATELLITE TESTS AND EXPERIMENTS

The AATMS Study considered three surveillance approaches employing satellites, and two different navigation techniques. It was concluded that a system incorporating some of these approaches could lead to a reduction in the number of surveillance, communications, navigation, and air traffic management facilities currently installed to serve CONUS and oceanic areas, with resulting operation and maintenance economies. An extensive experimentation and evaluation program is necessary, however, to provide the information for specifying, and eventually procuring, a satellite-based system. This Section describes the technical problems and uncertainties which must be resolved through tests and experiments, defines the major task areas, and presents schedule and funding estimates for these tasks.

ATS-6 and AEROSAT are current experimental programs whose results will be important to future AATMS considerations. Table 6-1 lists the satellite tests and experiments of these programs that support this Research and Development Program. The AEROSAT experimental satellites, with presently planned wideband channels and eastern CONUS coverage, are especially important test resources. The second column in Table 6-1 indicates the experiment areas projected for wideband channel test and evaluation that bear directly on the future application of satellites to CONUS air traffic control. Column 1 indicates the similar, but limited, tests of applicability anticipated from the ATS-6 Program. Both of these programs are inherently limited in their ability to validate the viability of satellites in CONUS air traffic control, ATS-6 since it is only a single satellite with limited capabilities, and the two AEROSAT satellites since they are primarily placed for North Atlantic coverage and cannot be used in three-dimensional position location experiments.

While the ATS-6 and AEROSAT programs will provide important technical information to further define the feasibility of satellite applications in air traffic management, the most important technical information will be obtained from CONUS multiple satellite tests and experiments. These experiments would require four or more satellites over CONUS for surveillance and navigation position determination experiments in operational air traffic environments. Column 3 of Table 6-2 lists the experiment areas that these satellites should be used to address. The most critical area, and the one addressed in Task V of this R&D program, is an operational evaluation.

The AATMS mechanization concept employs a constellation of satellites to enable surveillance, navigation and aircraft position location through multilateration techniques,

TABLE 6-2. SATELLITE TESTS AND EXPERIMENTS

ATS-6 Tests And Experiments	AEROSAT Wideband Channel Tests And Experiments	CONUS Multiple Satellite Tests And Experiments
Initial Multipath	Oceanic Multipath	CONUS Multipath Experiments
Channel Characterization (Partial)	Channel Characterization	Channel Characterization
Time of Arrival Measurements	Time of Arrival Measurement Evaluation	Time of Arrival Measurement Accuracy
Aircraft Antenna Patterns	Aircraft Antenna Patterns	Aircraft Antenna Patterns
Satellite Tracking	Surveillance Waveform	Navigation Waveform
	Communications Waveform	Surveillance Waveform
	Multiple Access	Communication Waveform
	Preliminary Surveillance Mechanization	Multiple Access
	Satellite Tracking	Synchronous and Asynchronous Acquisition and Tracking
	Operational Concept Evaluation	Surveillance Mechanization
	Avionics Evaluation	Navigation Mechanization
		Communication Mechanization
		Operational Concept Evaluation
		Control Software Evaluation
		Satellite Tracking
		Integrated Avionics Evaluation
		Limited AATMS Operational Tests

and communication between ground control centers and aircraft. Three basic surveillance techniques were identified in this Study.[9] These techniques have been discussed in Section 5. One of the major results of this Research and Development Program will be the determination of which of these techniques will best accomplish air traffic management functions. Both independent and dependent navigation modes are a recommended part of the AATMS Concept and the test program should explore the capabilities and limitations of each technique in regard to those modes. Digital data and voice communication between aircraft and ground control centers through the satellites also requires investigation.

The multiple satellite tests and experiments supporting the Research and Development Program and shown in Table 6-1 can provide answers to questions on spectrum utilization and on electromagnetic compatibility of systems in the selected portion of the spectrum. Uncertainties about the effects of ionospheric dispersion, multipath, signal bandwidth and aircraft antenna gain, which account for approximately 15 dB variation in the power budgets of typical satellite system designs, can be resolved. These satellite tests can also provide information for evaluating selected subsystem mechanizations and for making a preliminary evaluation of possible control concepts. Results of these tests would support the initiation of engineering development and the deployment of a satellite-base system.

A summary of the tasks and schedules for the multiple satellite tests and experiments is shown in Figure 6-2. Six major task areas are scheduled over a ten-year period as the Program progresses from design and development to flight test using multiple, orbiting satellites. The highlights of each of these major tasks are described in the following paragraphs.

6.2.1 Task 1 - CONUS Satellite Program and Test Planning

Program and test plans need to be prepared between FY 1975 and FY 1978 to provide the technical and management documentation necessary to conduct CONUS multiple satellite tests and experiments (see Table 6-2), and obtain optimum data from available test resources. Particular attention needs to be paid to coordinating the test plans with those of other programs, such as ATS-6 and AEROSAT, so that the information available for a CONUS ATC-applications satellite decision is maximized. Initial work in this area during FY 1975 should concentrate on planning for the use of the wide bandwidth channels of the Aeronautical Oceanic Satellites (AEROSAT). This effort should identify the experiments to be performed, including the technical rationale and data acquisition and reduction techniques, and should detail the required resources. Efforts in subsequent years should build on this initial effort to plan the multiple satellite tests needed to verify the operational

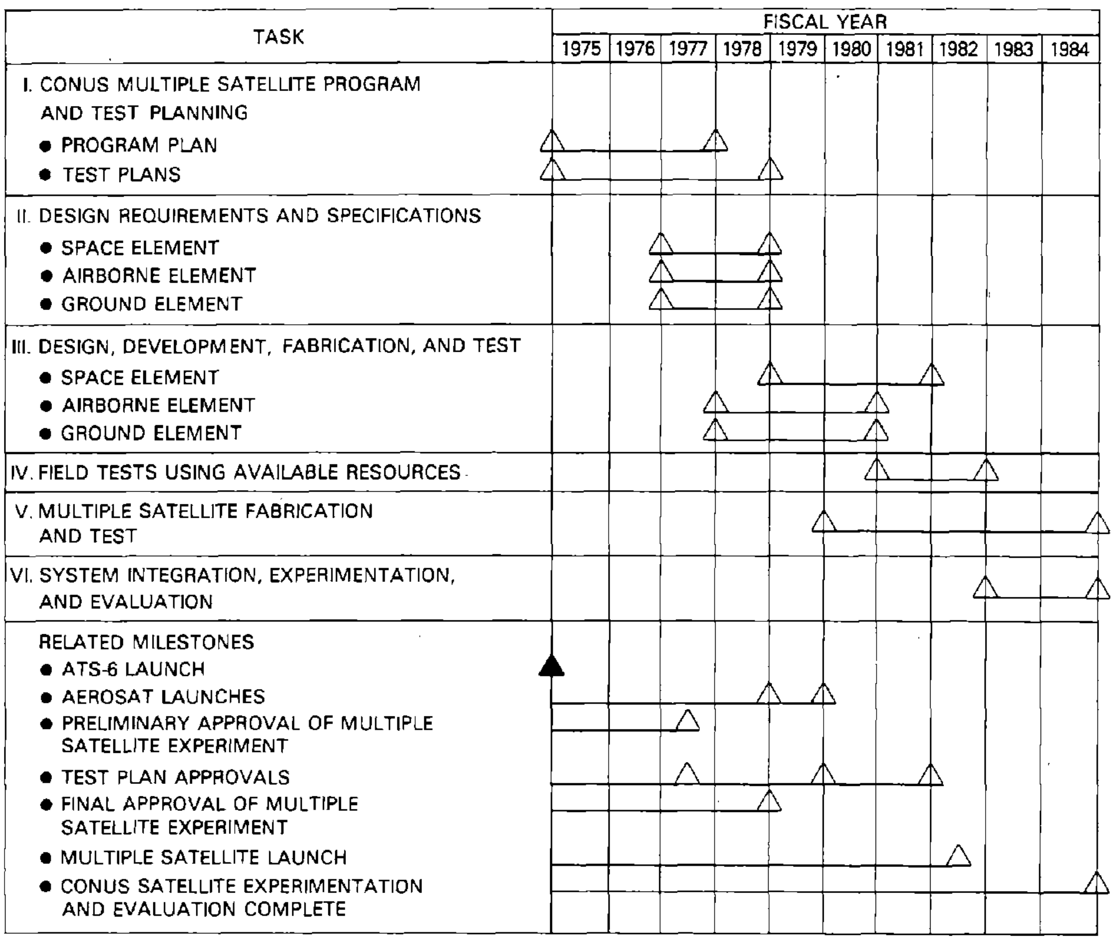

Figure 6-2. CONUS Multiple Satellite Tests and Experiments - Task Schedule

application of satellites for CONUS air traffic control. In addition to technical analyses supporting the test planning effort, the management documentation structuring the entire multiple satellite experimental program should be created. These plans can be updated during the development program as additional data becomes available. This task has been estimated by this Study to cost $400,000 per year in FY 1976, 1977 and 1978. AEROSAT Wideband Channel Test Planning activities supporting this task in FY 1975 are under way and will cost about $300,000.

6.2.2 Task 2 - Design Requirements and Specifications

A series of design studies and analyses must be performed to derive the specifications for the space and airborne elements. The generation of specifications for ground equipment required in the satellite tests is part of this effort. This task will take about two years (with balanced funding) and should be started in FY 1977 to take advantage of the ATS-6 test results. Design studies and analyses to be performed include the following efforts.

Satellite Design Requirements and Specifications

(a) Satellite Orbit and Constellation Analyses - A detailed model for analyzing the dependence of the surveillance, navigation, and communications functions on the satellite orbit and constellation geometry is needed and should be developed by this effort. The model should consider aircraft/satellite factors such as antenna patterns, received signal energy, platform stabilization, and look angles as well as satellite/space factors such as multiple body gravity, nonspherical earth, and solar pressure. The major model outputs should be relationships between satellite constellation geometry and surveillance and navigation functions, satellite visibilities to aircraft and ground stations, system performance effects of different aircraft antenna patterns and maneuvers, and user effects degradation. Costs for this effort are estimated at $375,000. Completion time is estimated at two years. In this Plan, this effort and subsequent parts of the satellite design effort are scheduled for performance in FY 1977 and FY 1978.

(b) Satellite Launch Vehicle Study - The interrelations among the space shuttle and other potentially available launch vehicles, system satellites, and the proposed orbits and constellations being analyzed above will be considered in this effort to determine the cost and technical tradeoffs of the various vehicles, and to determine the most efficient and effective means of inserting the system satellites into orbit. Study estimates for this effort are $185,000 in resources and two years (FY 1977 and FY 1978) to complete.

(c) Satellite Attitude Control - This effort covers the design and development of the satellite attitude stabilization subsystem. The work should include the generation of attitude stabilization requirements, an attitude stabilization performance analysis, and an attitude stabilization subsystem design specification. It is estimated that $250,000 is required to complete this task over a two year (FY 1977 and FY 1978) period.

(d) Satellite Link Characterization - A model to study the effects of the ionosphere and troposphere on propagation needs to be developed. The model would be used to determine the characteristics of errors introduced into the satellite link due to propagation anomalies and time and geography factors. The effects of these errors on both absolute and relative measurement accuracies and the means of reducing the errors need to be analyzed. Some preliminary data for this task will be developed during the ATS-6 satellite tests. More detailed information to refine this modeling effort will be available from the AEROSAT test program, and from potential field tests recommended by this Study (Task 4). This effort leads to completed ionospheric and tropospheric propagation models, analysis of surveillance and navigation accuracies as affected by satellite link errors, and error reduction techniques. This effort supplies critical design data to the Task 3 effort discussed below. This Study estimates that $375,000 is required to complete this effort over a two-year period. In this Study, this effort is proposed for completion in FY 1978.

(e) CONUS Multipath Analysis - The CONUS multipath environment and its effects on the surveillance, navigation, communication functions also needs to be studied in detail. Techniques for minimizing the deleterious effects of multipath should be identified. This effort recommends work which includes analysis and laboratory studies of both multipath effects on satellites and ground subsystem effectiveness. Preliminary data of use to this study will be obtained from the ATS-6 tests and refined in the AEROSAT satellite test program. This effort should include analysis of pseudo-noise waveforms over various terrains at different evaluation angles, multipath model development, and analysis of pseudo-noise waveforms versus other candidate waveforms. Critical design data needed in Task 3 (below) would be generated in this effort. It is estimated that $375,000 and two years are needed to perform this work. This Study recommends that this work be carried out simultaneously with the other efforts connected with the satellite system design requirements and specification study.

(f) Time-of-Arrival (TOA) Measurement Techniques Analysis - The surveillance and navigation techniques selected by this Study are based on measurements of signal times of arrival from various system mechanization elements. This effort provides for analysis of the different techniques, including performance and implementation tradeoffs in order to select the best way to make these measurements. The analysis should consider the state of the art in implementation hardware, costs, and performance capability. This Study estimates that \$185,000 and two years concurrent with the other satellite design requirements studies, will be required to complete this effort.

(g) Satellite Tracking Algorithm Development - Computational programs necessary to predict satellite locations need to be developed, tested and operationally coded in connection with this program. The work should include analyzing various satellite tracking mechanizations, defining and describing their error sources and performance, and selecting the optimum mechanization. A detailed simulation and exercise of the satellite tracking and prediction software should be performed, with programs modified as necessary based on simulation results. This effort generates the satellite tracking prediction mechanization, the tracking program description, and simulation results, required for Task 3 (below). It is estimated that two years and \$250,000 are required to complete this effort.

(h) Satellite Navigation Algorithm - This effort covers the development, simulation, and operational coding of the satellite navigation algorithms. Different navigation techniques and mechanizations, including different suboptimal filters, should be analyzed and tested. The sensitivity of navigation accuracy to equipment (satellite and avionics) and to system errors should be determined. This work produces a software requirements document and an algorithm accuracy sensitivity analysis needed in Task 3 to complete the system synthesis. It is estimated that two years and \$375,000 are needed to complete this effort. As with the other elements of this task, this work is proposed for performance during FY 1977 and 1978.

(i) Satellite Error Analysis - An evaluation of different competing techniques needs to be made and the subsystem, and ultimately system, performance determined. A complete and detailed set of error models should be developed; updated as a result of simulations and satellite field and operational tests; and used to complete a detailed error budget for the satellite subsystem and its individual end items and components. This effort will produce a satellite surveillance error model, a satellite navigation error model, and a satellite communications error model necessary to complete Task 3 (below). Other models which should be generated include a ground surveillance error model, a ground navigation error model, and a ground communications error model, as well as preliminary subsystem performance information. This effort has been estimated as requiring two years and \$185,000 to complete, with the funds allocated uniformly over the time period.

Avionics - Design Requirements and Specifications

The avionics equipment associated with any new subsystem must meet the acceptance of a large and diverse group of users. Avionics for use with AATMS must be of low or moderate cost and perform a service clearly evident and necessary to the users. To achieve this objective, functionally-integrated avionics at minimum cost must be designed. The addition of compatible add-ons to the basic airborne surveillance equipment will allow user capabilities to be extended as desired. The three concurrent efforts described below for performance during FY 1977 and FY 1978 should produce avionics subsystem and system-level requirements specifications.

(a) Surveillance Subsystem Requirements - The surveillance subsystem avionics requirements need to be determined and used to produce system-level avionics specifications. The requirements for low-cost avionics, integrated designs with communications and navigation subsystems, and the range of capabilities that users may require should be considered. Technology areas with potential impact in satisfying requirements in the design activities of Task 3 should also be identified. Tradeoffs relating avionics requirements and designs to the particular surveillance technique (see Section 5) will also need to be determined. This effort is estimated as requiring two years and $250,000 to complete.

(b) Communication Subsystem Requirements - The requirements for the communications subsystem avionics, and their potential impact on the hardware and software that may satisfy these requirements, needs to be determined. Information flow rates, candidate waveforms and modulation techniques, on-board interfaces with other subsystems, controls and displays, and voice and digital data techniques should be included in this effort. Requirements specifications should be produced. The work requires about $250,000 and two years to perform.

(c) Navigation Subsystem Requirements - The requirements for the navigation subsystem avionics, and requirements specifications on which the avionics designs in Task 3 will be based, need to be produced. Requirements studies should be done for the two alternative navigation techniques (independent and dependent or GC-RNAV) that have been identified. Consistent with system considerations for high accuracy and low cost avionics, tradeoffs should be made to reduce the number of Task 3 design possibilities which would satisfy the range of user needs. This effort requires about $250,000 and two years to complete. The results of this work are needed in Task 3 for the design of avionics equipment.

Ground Equipment - Design Requirements and Specifications

Several different types of ground stations and equipment are required for use with the satellite system recommended by this concept. Satellite tracking stations are needed to maintain current knowledge of satellite location; ground stations are needed to compute aircraft surveillance and navigation location corrections; communications relays are needed; and various supporting computer elements are needed. In the AATMS Concept, these stations may be colocated and may actually involve common computer elements. This effort will determine design requirements for all of the ground equipment complexes needed in connection with the satellite system in both support and control modes. The work in this effort should be performed during fiscal years 1977 and 1978 in coordination with other tests proposed in this plan, and functionally segmented into surveillance, navigation, and communication subsystem support studies.

(a) Surveillance Subsystem - Ground Equipment Analysis - The requirements for ground equipment to support the surveillance function of the system need to be determined and translated into a ground equipment - surveillance subsystem - specification. This effort is dedicated to just that objective. The analysis should include determining the impact of the various alternative surveillance techniques on the ground equipment complex. It is estimated that $250,000 will be needed to complete this task over a two year interval.

(b) Communication Subsystem - Ground Equipment Analysis - The requirements on the ground equipment to support the communications function of the satellite based system need to be determined and translated into a ground equipment - communications subsystem - specification. This effort covers that need. A detailed study of communications requirements for both air-ground and ground-ground (inter-center) subsystems, including an assessment of interfacility communications through satellites, should be included in this work. Consideration should also be given to voice and data link communications requirements and their potential system impacts. The results of this effort, and of other elements of this task, impact directly on the system design effort described in Task 3. This work element is estimated as requiring $375,000 and two years to complete.

(c) Navigation Subsystem - Ground Equipment Analysis - This effort is dedicated to determining the requirements on the ground support equipment for the system navigation function, and the translation of these requirements into a system-level specification which can be used as the basis for designs in Task 3 (below). This effort should consider the two navigation schemes suggested for the AATMS Concept, determining any significant differences in impact on ground equipment requirements of ground-computed area navigation as contrasted to communications and surveillance subsystems should also be studied in this effort. This work is estimated as requiring two years and $185,000 to complete.

6.2.3 Task 3 - Design, Development, Fabrication and Test

The initial hardware and software connected with the CONUS multiple satellite test program will be designed, developed, fabricated, and tested under this effort. The effort will encompass one fully-tested satellite ready for launch, fully-equipped experimental aircraft, satellite control and tracking centers, calibration stations, and facilities for performing the tests and evaluations. Specific developments in this task are described below.

Satellite System Design, Development, Fabrication, and Laboratory Test

(a) Ground Support Equipment - The requirements and specifications for satellite system ground support equipment and software generated in Task 2 need to be translated into equipment designs and subsequently into fabricated hardware for laboratory test by this effort. The ground support facilities should include satellite control and tracking centers and calibration stations. It may be possible to reduce the test configuration requirements for such facilities where existing facilities can be adapted and used. Test and measurement facilities, including mobile units and channel simulation equipment, should be included under this effort. Preliminary checkout and testing of these facilities, with, when possible, available space-based resources such as ATS-6 and AEROSAT, will be an element of Task 4. The ground equipment developed in this effort should be compatible with these other test resources, thereby enabling the use of existing valuable test resources in connection with this program. It is estimated that the effort to design, fabricate, and preliminary-test the ground support facilities for the experimental program will cost $10 million and should be done during fiscal years 1978 to 1980, with the initial effort spent on the lower cost design activities. Costs per year are estimated as $2 million during FY 1978, and $4 million for each of the two subsequent years of this effort.

(b) Satellite Antennas - C and L-band satellite antennas need to be designed, selected, developed, and laboratory tested. This effort is directed to such work. Minimum antenna weight should be a prime criterion. The integration of the antennas, wherever possible, through the use of multiple feeds or other design techniques is another important consideration. This work results in antenna design requirements, an antenna test plan, antenna design specifications, prototype antenna fabrication, and subsequent laboratory test of the antennas. In item f, below, this subsystem and the ones developed in subsequent efforts should be integrated and used to fabricate one test satellite. This effort is estimated to cost $2 million, and require three years to complete. In detail, this program element is seen as requiring $500,000 in FY 1978 and $750,000 in both FY 1979 and 1980.

(c) Satellite Transmitters - The transmitters required for the satellite need to be designed, developed and tested. This effort is directed to this end. The results of the effort are a completed transmitter design, with preliminary equipment necessary for inclusion in the satellite systems integration effort (below). The primary objectives are high reliability and the long life-time necessary for the ATC-applications satellite usage. The following transmitters should be considered:

- L-band, high peak power and high average power
- L-band, medium peak power and high average power
- C-band, low peak power and high average power

The output of this work should include determination of transmitter subsystem design requirements, generation of the transmitter subsystem test plans and transmitter subsystem design specifications, and fabrication of the transmitter subsystem. Initial laboratory tests and evaluations should also be accomplished under this effort. This effort is estimated to require $4 million and three years to complete. The estimated funds required for the proposed schedule are $1 million in FY 1978, and $1.5 million in each subsequent year. The FY 1978 work should cover the design and specification portion of the effort.

(d) Satellite Transponder - The transponders necessary for the satellite subsystem should be designed, developed and tested in this effort. Two transponders are required. The first receives aircraft L-band transmissions, converts them to C-band, and retransmits them to the ground. The second receives ground transmitted C-band signals, converts them to L-band and retransmits them to the aircraft. This effort should include generating receiver design requirements, integrating the receiver-modem-transmitter designs, developing a suitable test plan and design specifications, fabricating the subsystem, and performing related laboratory tests. This Study estimates this effort will require the following resources: $1 million in FY 1978 during initial design and specification efforts, and $1.5 million in FY 1979 and 1980 during fabrication, test and checkout of the transponder equipment.

(e) Satellite Power Sources - Satellite power sources for the satellites discussed in this concept need to be developed and tested and integrated into a unified satellite design. This effort concerns these activities, and results in a power subsystem design for the satellites. The input power requirements for the satellites are expected to be between 7 and 10 kW. The development of a solar cell array capable of meeting this requirement should be an important step in establishing satellite and concept feasibility. Other alternatives should also be considered. This effort should include the determination of generating source requirements (iteratively with the systems engineering effort), translation of these requirements into subsystem designs and specifications, test plan generation, test source fabrication, and laboratory tests independent of integrated testing. This effort is estimated to require the following resources: $1 million in FY 1978 during initial requirements, design, and specification activities, and $1.5 million per year for two years to cover development, fabrication, and test activities.

(f) Satellite System Engineering and Fabrication - The results of the preceding satellite directed efforts need to be integrated to produce a complete design, a unified specification, and one satellite ready for laboratory testing. This effort covers the necessary systems engineering, integration, and fabrication activities. By virtue of laboratory tests on each satellite subassembly, the unit should have been thoroughly tested prior to integration. This effort should complete the integration, subsystem documentation and specification, the preparation of test plans, and related laboratory test activities. This effort is seen spanning four years and is estimated to cost about $11 million. About $2 million per year is estimated, for allocation in FY 1978 and FY 1979, when design, requirement, and specification activities are underway. Thereafter, $3.5 million per year would be required during the integration and test activities. This effort should highlight any potential problem areas associated with the development of the four demonstration spacecraft discussed in Task 5. The satellite fabricated in this effort should also serve as a backup spacecraft in case of problems with any of the spacecraft fabricated in the later task.

Avionics Equipment Design, Development, Fabrication and Laboratory Test

The avionics associated with the satellite system concept will be designed, developed, fabricated, and tested in the same manner as the ground and satellite subsystems previously described, in this effort. Subassembly requirements studies, design activities, test program formulation, and specification and program documentation activities should be covered by these efforts which should be accomplished during FY 1979. Subassembly development, fabrication, and test are estimated as taking place during FY 1980 and 1981. The final effort, described below, is systems engineering and integration which spans all three years of this avionics project with principle emphasis in FY 1981. The following paragraphs describe the efforts associated with the development of avionics necessary to assess satellite-based system concepts for decisions on the use of satellites in air traffic control.

(a) Frequency Generator - An avionics clock network, possibly supplemented by a frequency synthesizer, should be developed for future system avionics in this effort. Both analog and digital techniques should be investigated. Particular attention should be paid to factors such as stability and output power. This effort is estimated to require $500,000 and two years to complete with equal funding in each year of effort.

(b) L-Band Amplifiers - The design, development, fabrication, and test of a solid-state transmitter subsystem and demonstration of its feasibility in meeting surveillance subsystem requirements is needed and is the subject of this effort. An L-band amplifier chain and transmitter are required for the avionics system. This should be a high power, low duty cycle subsystem. Several methods are presently available for meeting the potential system requirements. They include traveling wave tubes (TWT), cross field amplifiers (CFA), planar triodes, and solid-state amplifiers. Although solid-state amplifiers are still in the development stage, serious consideration is warranted because of their potentially high reliability, ease of manufacture, and potentially low cost. This effort is estimated to cost $1 million and span three years: $300,000 in FY 1979, $400,000 in FY 1980, and $300,000 in FY 1981. This work is integrated into a single systems design in effort g, below.

(c) L-Band Aircraft Antenna - An efficient and cost effective L-Band aircraft antenna is needed for the aircraft satellite link. This effort is directed to studying alternative antenna designs and specifically covers the design, development, test, documentation, and evaluation of a suitable antenna. Antenna design requirements should be available from the satellite subsystem studies. Resource estimates for the effort are $300,000 for FY 1979, $500,000 for FY 1980, and $200,000 for FY 1981.

(d) Displays - Displays that meet the data link and navigation requirements should also be developed, tested and evaluated. The displays should be designed to take maximum advantage of the highly centralized digital processing features of the integrated avionics. Most of the display processing should be accomplished in the avionics data processor rather than in the display itself for simpler and less costly displays. Maximum use should be made of solid-state components, such as liquid crystals, to reduce power requirements, costs, weight, and volume. Estimated resources required for this effort are: $300,000 in FY 1979, $400,000 in FY 1980, and $300,000 in FY 1981.

(e) Integrated Surveillance and Communications Equipment - The avionics surveillance equipment, comprising a clock and transmitter, should be developed and tested in this effort. This preliminary step is required prior to total avionics package integration. Careful consideration should be paid to aircraft-to-ground communications system requirements and modulation techniques. This effort includes integration of clock and transmitter modules, test planning, test, and subsequent evaluation. This effort is estimated to require $500,000 and three years to complete, with equal funding assumed in each year of the development effort.

(f) Navigation Equipment - The navigation processor for the aircraft would be developed under this effort. Calling for careful coordination with the display and on-board computer, and consideration of accuracy requirements, this equipment complex should be designed, fabricated, tested, and integrated with the avionics received in this effort. The receiver subassembly represents a major portion of this activity. This effort is seen as requiring about $1.5 million and three years to complete, with funds evenly distributed over the estimated schedule time.

(g) Avionics Systems Engineering and Fabrication - This effort is directed to taking the results of the preceding subtasks and producing several avionics complements installed on test aircraft and ready for use. The development work on frequency generators, L-band amplifiers, antennas, displays, integrated surveillance and communications equipment, and navigation subsystems should be incorporated in this integrated design. This effort coordinates these activities, documents the development program, integrates the avionics subsystems into various complements of user equipment, and performs laboratory tests on the resulting avionics. The resources estimated for this effort are: $1.5 million in FY 1979, and $2 million per year in FY 1980 and 1981.

6.2.4 Task 4 - Field Tests Using Available Resources

The objective of this Task is to test ground support hardware and software, and avionics in an operational environment approximating that of the final mechanization. This task assumes use of available satellite resources to test the equipment developed in connection with the CONUS ATC-Applications Satellite Program.

Tests in this Task should aid in defining follow-up test activities in Task 5, and should provide preliminary data on the operational features of the AATMS satellite subsystems. The tests should serve to check out and evaluate measurement techniques and ground equipment and software, as well as avionics technology developments during the time that test satellites of Task 5 are being fabricated. Emphasis in this task should be on use of wideband channels in the ATS-6 satellite, if it is still available, and AEROSAT satellites. The following paragraphs identify the areas suggested for investigation under this Task.

(a) Ground System Checkout - The Task 3 ground equipment would be tested and evaluated in this effort. The ground system may be comprised of satellite tracking centers, calibration stations, and communications terminals. The hardware and software at these sites as well as measurement techniques, data collection and reduction techniques, and interfaces need to be tested and evaluated. The test standards should reflect operational and functional specifications and requirements. Tests should be conducted against available resources such as ATS-6 and AEROSAT. Particular emphasis should be placed on the ground-satellite control loop, ephemeris determination hardware and software, and other tracking and control hardware and software. These tests are estimated as requiring $300,000 in FY 1981 for preliminary planning and set-up of test resources, and $1.7 million in FY 1982 for test performance, data collection and analysis, and system evaluation. This test prepares for the orderly use of the test satellites fabricated and launched in Task 5.

(b) Avionics Experimentation and Evaluation - The avionics fabricated in Task 3 need to be operated in conjunction with ATS-6 and AEROSAT to test, as far as possible, the avionics operability and to check out, in operational environments, the antennas, receivers, transmitters, modulators, and airborne processing equipment. Software necessary to simulate the large number of users anticipated in future air traffic environments should be developed under this effort, and should be used in the Task's flight test experiments to test and evaluate the avionics equipment. Flight tests should be performed relating to future CONUS satellite applications. This effort should investigate satellite-CONUS aircraft channel characteristics, including multipath, scintillation, and multiple-access noise problems; waveforms and modulations as they relate to the channel characterization; functional system requirements for ranging, navigation, and communication; preliminary evaluation of the three satellite-aircraft surveillance techniques; navigation subsystems, including airborne processor and software; and access control communication channel control and utilization. The resources for this effort have been estimated to be $1 million in FY 1981 for planning and experimental set-up, and $2 million in FY 1982 for performance of test activities (including flight tests), data collection and reduction. The completion of this program phase sets the stage for pre-operational, multiple satellite tests in Tasks 5 and 6.

6.2.5 Task 5 - Multiple Satellite Fabrication and Test

Four satellites, in addition to the one fabricated under Task 3, need to be fabricated and launched into selected orbits for full-scale testing as a satellite constellation over CONUS. Four satellites are required to resolve the technical uncertainties associated with the various three dimensional position location (surveillance and navigation) concepts to be investigated, and also to convincingly demonstrate the feasibility of using satellites for CONUS ATC applications. Reliability considerations dictate the availability of a fifth satellite to replace any one of the four original satellites in the event of failure. Navigation of civilian aircraft throughout their entire flight profile by means of a satellite navigation system should be demonstrated and evaluated in this effort. The test avionics developed earlier can be used in these tests. The control of aircraft by employing satellite surveillance and data link subsystems should also be evaluated and demonstrated. The resources for this activity have been estimated as $105 million over a five-year period. The bulk of the money is involved with fabrication of the satellites and subsequent launch (one Space Shuttle/Tug mission costing $15 million in 1982 was assumed). It is estimated that $80 million over FY 1980, 1981 and 1982 is required for satellite fabrication and $10 million is required in FY 1983 and 1984 (half in each year) for completion of test planning, test, data collection and reduction, and evaluation activities.

6.2.6 Task 6 - System Integration Experimentation and Evaluation

The space and airborne elements need to be integrated with the elements of the automation and control mode development programs to fully test and evaluate the AATMS concept. This Task is directed to the two-year long integration and operational demonstration activity to attain this goal. Resources for this effort were estimated at $7 million per year in FY 1983 and 1984, and would include making the systems engineering activities support system implementation decisions.

6.2.7 Funding Allocations

Table 6-3 shows the funding estimates for this portion of the proposed AATMS research and development program. A total budget of about $175 million is required over the ten-year period. Approximately $95 million of this funding is required for the five satellites and their launches.

6.3 STRATEGIC CONTROL

This Section describes the R&D effort to develop Strategic Control capability in AATMS for controlling aircraft along the high density air routes and in high density terminal areas.

TABLE 6-3. CONUS MULTIPLE SATELLITE TEST AND EXPERIMENTS FUNDING BY YEAR BY TASK
(Costs in Thousands of 1973 Dollars)

Task/Element	Fiscal Year									Task Cost Totals
	1976	1977	1978	1979	1980	1981	1982	1983	1984	
I. CONUS Multiple Satellite Program and Test Planning	400	400	400							1,200
II. Design Requirements and Specifications		2,000	2,000							4,000
III. Design, Development, Fabrication and Test			7,500	14,500	17,000	7,000				46,000
IV. Field Tests Using Available Resources						1,300	3,700			5,000
V. Multiple Satellite Fabrication and Test					26,000	27,000	42,000	5,000	5,000	105,000
VI. System Integration, Experimentation and Evaluation								7,000	7,000	14,000
Total Cost	400	2,400	9,900	14,500	43,000	35,300	45,700	12,000	12,000	175,200

The objectives of this program element are to

- Establish the feasibility of Strategic Control to a higher confidence level.
- Determine the limits of the operational performance capabilities of Strategic Control.
- Develop and validate the Strategic Control Concept to a confidence level sufficiently high to justify and support its implementation.

The proposed research and development program for Strategic Control consists of four major tasks directed toward developing Strategic Control to successively higher levels of capability. The tasks are successively dedicated to:

(1) The basic Strategic Control capability to control arriving airplanes from multiple entry points to one or more parallel runways. Other terminal area control operations will be accomplished tactically.

(2) The capability to control all terminal area arrival operations to any runway configuration. Strategic Control techniques are used to handle system distrubances, i.e., go-arounds, diversions, runway reversal/changes, etc.

(3) Strategic Control capability over all terminal area operations by adding control of departures.

(4) Extension of Strategic Control capabilities and further optimization of operations and application to en route control.

Accomplishment of each task involves (1) an analysis effort to perform planning and mathematical formulation; (2) development of software to implement each capability in a real-time simulation environment; (3) evaluation of each capability in a real-time simulation; and (4) a flight test program integrated with the simulation to substantiate airborne equipment and Strategic Control performance feasibility.

The overall plan is shown in Figure 6-3. Task 1, development of the basic arrival control capability, encompasses seven subtasks. The analysis of basic arrival control should provide the basis for software development and test and should include a functional definition of how a completely strategic controlled terminal area functions. The software should be tested in a real-time simulation which includes multiple simulated airplanes, a cockpit simulator, and an airplane. Four-dimensional navigation and guidance equipment for Strategic Control needs to be specified, built, and flight tested to enable an operational performance capability description to be generated. The description should be used in the simulation. The test avionics need to be refined to provide the required basic

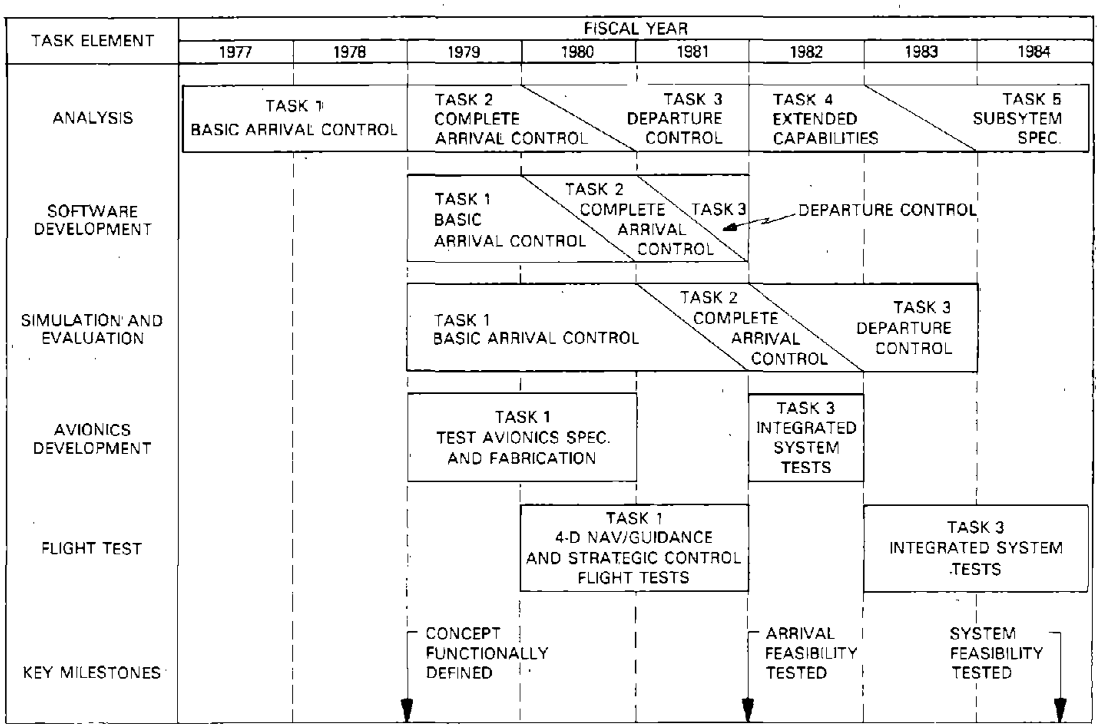

Figure 6-3. Strategic Control Development Plan

arrival control capability, tested in an operational terminal (metering and spacing) environment to disclose operating environment requirements and then used in a live airplane in an integrated, real-time simulation for capability analysis and validation.

The Task 2 analysis defines the method for complete Strategic Control of all arrival operations. Software to implement this method should be developed, building on the Task 1 effort, and tested in a real-time simulation.

The Task 3 analysis should define the method for departure control and provide a complete strategic terminal area control system. Task 2 software needs to be extended to incorporate departure control and provide an integrated capability. Both departure control and the integrated capability should be tested by real-time simulation. The test avionics should be upgraded in Task 3 to include both complete arrival and departure capabilities.

Task 4 is designed as a purely analytical effort to investigate further refinements to terminal area control and the extension of Strategic Control into en route airspace.

Task 5 is dedicated to providing a system specification towards initiating acquisition of Strategic Control operational capability.

The program has a continuing set of program checkpoints. The completion of each subtask provides significant items for review and evaluation. The key milestones are:

- Completed functional definition of the Strategic Control concept at the end of the Task 1 analysis.
- Completed testing of the Strategic Control arrival control capability at the end of Task 1.
- Completed Strategic Control system testing at the end of Task 3.
- System specifications produced at the end of Task 5.

The development efforts leading to these milestones are described in the rest of this Section.

6.3.1 Task I - Development of Basic Arrival Control Capability

In Task I a basic arrival control capability for the Strategic Control of arriving airplanes from multiple terminal area entry points to single or parallel runways needs to be developed. The Task includes the analysis, simulations, and flight tests to demonstrate and evaluate this capability.

Basic Arrival Control Analysis

The objectives of this effort are to develop the logic for the complete Strategic Control concept, define algorithms for arrival control, and plan the simulations and experiments required to evaluate the basic arrival control capability. The major items of work are:

(a) Basic Arrival Control-Mathematical Formulation - Airplane performance, arrival control requirements, and runway demand schedules need to be analyzed to mathematically define the algorithm for Strategic Control of arrivals. A fast-time terminal area simulation should be used in generating the algorithm. The resources for this task are estimated to be $200,000 per year for FY 1977 and 1978.

(b) Test Avionics Functional Requirements - The functional capability required in the airplane to accomplish strategic arrival control need to be defined. This effort should complete this definition, providing support for subsequent test and evaluation efforts. Resource estimates for this work are $100,000 and one year (FY 1978) to complete.

(c) Data Processing System Requirements - An initial estimate of the level and characteristics of the ground-based data processing required to accomplish Strategic Control needs to be developed. This effort should develop these estimates. Time and cost estimates for this work are one year (FY 1978) and $100,000.

(d) Complete Strategic Control Functional Concept - A description of how functionally, Strategic Control can be used to accomplish all of the terminal area arrival and departure operations needs to be developed. This concept definition effort builds on other work done as part of this Study and is estimated to require $150,000 per year for FY 1977 and 1978.

(e) Arrival Control Performance Analysis - The terminal area performance achievable by Strategic Control needs to be assessed in terms of capacity, peak flow rates, and control communication workload using data from a fast-time simulation (Item a, above). This assessment is addressed by this effort. Resource estimates are $100,000 per year for two years (FY 1977 and 1978).

(f) Flight Test Requirements - The flight test conditions and data collection requirements for the four-dimensional navigation and guidance performance tests and for the terminal (metering and spacing) environment flight tests should be defined in this effort. A test plan should be prepared considering potential test conditions and data collection and analysis requirements. It is estimated that this effort will cost about $300,000 and be accomplished in FY 1977 and 1978.

(g) Communication System Requirements - The communication capabilities required to support Strategic Control need to be defined using the Strategic Concept functional description and results of the fast-time simulations. Consideration should be given to other functional requirements of the communications system. This effort also supports subsequent concept development efforts. It is estimated that this effort will cost $100,000 per year for FY 1977 and 1978.

Basic Arrival Control Simulation Software Development

The detailed computer program for mechanizing the basic Strategic Control arrival control capability needs to be developed. The program should be in a form suitable for implementation and testing by the basic arrival control simulation. The inputs for this effort should be a mathematical description of the geometry, scheduling strategy, route-time profile generation technique, demand requirements, aero-performance definitions, and simulation objectives from the basic arrival control analysis. Development of the simulator hardware/software interfaces is also part of the simulation effort.

The effort should involve: defining a suitable programming strategy; developing the required logic flowcharts, timing diagrams, software checkout procedures, memory format and utilization; and developing a coded algorithm suitable for simulator implementation. The program should allow for the future addition of complete arrival control and departure control capability. This subtask is estimated to cost $450,000 per year for two years (FY 1979 and 1980).

Basic Arrival Control Simulation and Evaluation

The capability to test and evaluate basic strategic arrival control by real-time simulation needs to be developed. The simulation should be capable of working with flight test airplanes as part of the real-time test mechanization. This effort is divided into three distinct items.

(a) Simulation Design - A simulator hardware and software implementation plan needs to be prepared, and specifications formulated to define the interface requirements for the basic arrival control program and the flight test airplane. This should be based on the simulation experiment requirements developed from the basic arrival control analysis. A test plan should be prepared to satisfy the experimental requirements and specify the test data reduction requirements. All simulation software requirements to test the basic arrival control program should be delineated. The scope of the simulation should include computer simulated airplanes, a cockpit simulator with characteristic commercial airplane response, and the capability of substituting a real, flight-test airplane. This capability should include an instrumented test range and air-ground data link capability. The simulation should model an extended terminal area from en route altitudes to runway exit. This work should require about $400,000 to complete. The work should be done in FY 1979.

(b) Test Implementation - All necessary hardware and software needs to be prepared to execute the simulation test plan. Simulation data acquisition, and test data reduction software should be prepared and integrated with the basic arrival control program. This work is estimated to cost $500,000 per year for two years (FY 1980 and 1981).

(c) Test Evaluation - The simulation capability prepared during design and implementation will be used to execute the simulation test plan for basic arrival control. The simulation should include tests using simulated airplanes, including ground-based cockpits, and tests using flight test airplanes. The work will require $700,000 to complete and should be done in FY 1981 to properly phase evaluation results with other program elements.

<u>Four-Dimensional Navigation/Guidance Avionics Analysis and Specifications</u>

Specifications need to be developed for four-dimensional navigation/guidance test avionics which can be used to determine, by flight test, the potential performance capability of an airplane flying time scheduled three-dimensional paths. These specifications should be modified and kept current with strategic arrival and departure capabilities defined by subsequent analyses. The major items of work are

(a) Test Avionics Functional Design - A determination of how each basic avionics function will be accomplished needs to be made. This work should be done in FY 1979. The estimated cost to be $200,000.

(b) Guidance Algorithm Definition - The guidance algorithms need to be selected and the software program designed based on analysis and evaluation of alternative guidance concepts. This work and the following effort should cost about $100,000 and require one year (FY 1979) to complete.

(c) Flight Control Definition - Autopilot design criteria, control laws, and functional features for four-dimensional airplane control need to be developed. Emphasis should be on precise along-track position control. This work requires resources identical to those of the previous effort.

(d) Avionics Performance Analysis (Four Dimensional) - The accuracy with which the selected four-dimensional navigation/guidance configuration can follow assigned four-dimensional flight paths needs to be studied. This work should consider the effects of winds, flight paths, and navigation aid location and errors. This effort is estimated to require $200,000 and one year (FY 1979) to complete.

(e) On-Board Computation Requirements - The required software for four-dimensional navigation/guidance performance flight tests needs to be developed. This software should be tested on a real-time simulation. An estimate should be made of the total avionics software requirements that will eventually be needed for complete Strategic Control operation. This work should be done in FY 1979. The cost is estimated as $100,000.

(f) Flight Test Avionics Subsystem Specification - A design/procurement specification for the avionics to be used in the four-dimensional navigation/guidance flight test needs to be prepared. The specification should provide for growth or modification to accommodate total Strategic Control. Specifications should include (1) interface requirements to the communication data link, display system, and flight control system; (2) data processing hardware requirements (storage, speed, architecture, and special-purpose equipment); and (3) the guidance and flight control software requirements. This effort requires resources identical to those in the previous effort.

Four-Dimensional Navigation/Guidance Flight Test

The capability of an airplane, using a four-dimensional navigation/guidance system, to fly a predefined four-dimensional track needs to be measured. These results should be used in further analyses of Strategic Control System performance and as inputs to the simulator airplanes representing strategically controlled airplanes. The major items of work are:

(a) Test Avionics Fabrication - A four-dimensional navigation/guidance system needs to be fabricated based on the flight test avionics specification. Existing avionics and equipment should be used whenever practical. Flight test plans and appropriate aircraft modifications should also be developed and specified. It is estimated that $300,000 spent over two years (FY 1979 and 1980) should complete this effort.

(b) Flight Test Preparations - The test avionics should be installed in a test airplane, and modified as required for the test. The flight test instrumentation, both ground and airborne, should be obtained, prepared, and tested. This effort and the following one are estimated to each require $300,000 per year for two years (FY 1979 and 1980) to complete.

(c) Flight Test - The planned flight tests need to be flown at an appropriately instrumented range. Test data should be collected and reduced to the form required by flight test experiment evaluation requirements.

Arrival Control Avionics Analysis and Specification

A specification for modifying the avionics to provide the capabilities required for strategic arrival control needs to be generated. The major items of work, each estimated as costing $200,000 and scheduled for performance in FY 1980 in this plan, are:

(a) Arrival Control Avionics Definition - The guidance software, control/display configuration, and flight control system need to be developed to meet the arrival control avionics requirements. This effort should include real-time simulation and crew workload studies as required to select the desired configuration. The modifications to the guidance and flight control systems necessary to provide improved capability should be determined using the findings from the four-dimensional navigation/guidance flight tests.

(b) Avionics Performance Analysis (Strategic Arrival) - The performance expected from the arrival control avionics configuration, considering the arrival paths to be flown, wind effects, and quality of the navigation aids, need to be determined.

(c) Arrival Control Avionics Specification - A specification needs to be prepared for the test avionics reflecting the results of the four-dimensional navigation/guidance flight tests and the arrival control requirements.

Four-Dimensional Metering and Spacing and Basic Arrival Control Simulation Flight Tests

The objective of this effort is to comparatively test and evaluate four-dimensional navigation and guidance techniques in metering and spacing and Strategic Control environments. Each of the following efforts have been estimated to cost $900,000. They should be done in FY 1980 and 1981. The two major items of work are:

(a) Four-Dimensional Metering and Spacing Flight Test - The test aircraft and avionics used previously need to be modified to the arrival control flight test avionics specification described in the preceding paragraph. Flight tests should be made with data acquired according to the specifications. A terminal with (advanced) metering and spacing should be used as the test site for these evaluation experiments. The arrival route and schedule, developed in the Metering and Spacing computer, may be sent to the aircraft on a digital data link and then the performance monitored on radar. Comparisions of this technique with Strategic Control are part of the next effort.

(b) Basic Arrival Control Simulation Flight Test - The airplane and avionics used in the preceding flight test should be modified for use with the basic arrival control simulation. The airplane should fly similar paths according to the flight test plan developed under Basic Arrival Control Simulation and Evaluation. The Metering and Spacing and Strategic Control tests results should be comparatively evaluated as part of this effort.

6.3.2 Task 2 - Development of Complete Arrival Control Capability

A complete strategic arrival control capability needs to be developed by this task including operations with crossing runways, go-arounds, runway changes, "pop-up" demand, dynamic rerouting, and optimal scheduling. The work extends that recommended under Task I.

Complete Arrival Control Analyses

The objectives of this task are to develop the logic for Strategic Control of all terminal area arrival operations, mathematically define the algorithm for the software to accomplish complete arrival control, and define the simulation tests and experiments required to evaluate the software program. The following three major work areas are each estimated to require $150,000 per year for two years. The work should be done in FY 1979 and FY 1980.

(a) Complete Arrival Control-Mathematical Formulation - Airplane performance and control requirements need to be analyzed to mathematically define the Strategic Control algorithm for all arrival operations. The algorithm should be tested in a fast-time simulation. This work builds on that developed in Task 1 of the recommended Strategic Control research and development program.

(b) Simulation and Evaluation Requirements - The test conditions and data collections and analyses required for the real-time simulation experiments need to be defined. This effort is directed to this activity.

(c) System Analysis - The system performance, concept, and subsystem requirements definitions of arrival control need to be extended to include complete arrival control. This effort is directed to making these extensions to the system concept.

Complete Arrival Control Simulation Software Development

A detailed computer program for mechanizing the complete strategic arrival control capability should be developed under this effort. The program should be suitable for implementation and testing of the complete arrival control simulation. The work builds on a mathematical description of the geometry, scheduling strategy, route-time profile generation techniques, demand requirements, aero-performance definitions, and simulation objectives from the complete arrival control analysis. These inputs specifically involve improvements to the previously programmed basic arrival control capability, including capability for operations with crossing runways, go-arounds, runway reversals, rescheduling of path assignments, and other perturbations. A suitable programming strategy should be defined to generate flowcharts, timing diagrams, software checkout procedures, memory formats and usages, and an algorithm suitable for implementation on the simulator. This algorithm includes the basic arrival capability as a subset. This software development effort is estimated as costing $320,000 per year during FY 1980 and 1981.

Complete Arrival Control Simulation and Evaluation

The real-time simulation capability to test and evaluate the complete arrival control mechanization needs to be developed. This simulation effort should be an extension of that used for the basic arrival control simulation. The effort should include only simulated airplanes; flight tests are deferred to the integrated system simulation and flight test efforts (below). The simulation design is assumed to be the same as the basic arrival control simulation. Each effort has been estimated to cost $600,000 and the work should be done in FY 1981 and 1982.

(a) Simulation Implementation - The simulation test plan necessary for testing the complete arrival capability needs to be prepared and the software/hardware integration and checkout performed. This test plan should be designed to accomplish the work delineated by the simulation experiment requirements which were determined by the complete arrival control analysis. The software input needs to be the coded complete arrival control program. The effort should also include the preparation and checkout of necessary test data reduction software.

(b) Simulation and Evaluation - The simulation capability resulting from the previous effort should be used to execute the simulation test plan for complete arrival control. The resulting simulation test results should be reduced to a form suitable for further analysis for the complete arrival control capability.

6.3.3 Task 3 - Development of Departure Control Capability

The capability to strategically control departures, integrated with the complete control of arrivals, needs to be developed by this effort.

Departure Control Analysis

The objectives of this task element are to develop the logic for Strategic Control of departures and the complete control of arrivals, mathematically define the algorithm for the software to accomplish integrated departure and arrival control, and define the simulation tests and experiments required to evaluate the integrated departure and arrival control software. There are three major parts of this effort. The first two parts are estimated to cost $200,000 and one year (FY 1980) to complete. The systems analysis effort is estimated to cost $200,000 per year and should be done in FY 1980 and 1981.

(a) Departure Control-Mathematical Formulation - Airplane performance and departure control requirements need to be analyzed and the algorithm for integrated Strategic Control of departures with arrival control needs to be mathematically defined. The algorithm should be tested in a fast-time simulation.

(b) Simulation and Evaluation Requirements - The test conditions and data collection and analyses required for the real-time simulation experiments need to be defined.

(c) System Analysis - The system performance, concept and subsystem requirements definitions need to be extended to include departure control.

Departure Control Simulation Software Development

The computer program for mechanizing strategic departure capability should be developed under this effort. Results of this work, when added to those of a basic and complete arrival control, will form the basis for a total integrated Strategic Control capability. The coded computer program should be in a form suitable for implementation and testing of both departure control capabilities and a totally integrated control system for arrivals and departures. The work should include defining a suitable programming strategy; developing the required program flowcharts, timing diagrams, software checkout procedures, memory formats and utilization requirements; and developing a coded algorithm suitable for simulator implementation. This algorithm should include integrated departure and arrival control capability. This effort is estimated to cost $300,000 and require one year to perform (FY 1981).

Departure Control and Integrated System Simulation and Evaluation

The real-time simulation capability to test and evaluate the departure control capability and the totally integrated Strategic Control capability should be developed under this effort. This integrated capability should include all features of arrival control as well as departure control. A flight test airplane should be used during the integrated system tests. The separate departure control simulation experiments should only use simulated airplanes. This simulation effort is made up of three parts: implementation; departure control test and evaluation; and integrated system simulation and flight test. Each effort is scheduled in this plan to span two years - FY 1982 and 1983.

(a) Implementation - The simulation test plan needs to be prepared to meet the experimental requirements for both departure control and integrated system testing as defined by the departure control analysis. The departure control program should be integrated into the simulator and checked out. At this point the simulator should encompass the whole integrated system capability. Necessary test data reduction software and flight test range interface software should be prepared and checked out. It is estimated this work will cost $170,000 per year for the two year duration of this effort.

(b) Departure Control Test and Evaluation - The portions of the simulation test plan pertaining to strategic departure control need to be executed on the simulation prepared in (a) above. The resulting departure control experimental results should be reduced to a form suitable for further analysis. This effort is estimated to cost $350,000 per year for the two year period (FY 1982 and FY 1983).

(c) Integrated System Simulation and Flight Test - The fully integrated Strategic Control System to execute the experiments as required by the simulation test plan needs to be tested and evaluated. Tests with a strategically equipped flight test airplane should be made in conjunction with simulated airplanes. The total system capability and technical feasibility should be established at the completion of this effort. The simulation test results should be reduced to a form suitable for total system specification. This work is estimated in this Study to cost $500,000 per year for the two year period (FY 1982 and FY 1983).

Departure Control Avionics Analysis and Specification

A specification for modifying the avionics to provide the capabilities required for complete arrival control and departure control needs to be developed. This effort accomplishes this development with three major items of work, each estimated as costing $200,000. This work should be done in FY 1982.

(a) Complete Arrival and Departure Avionics Definition - The guidance software, control/display configuration, and flight control system to meet these requirements need to be developed using the complete arrival control avionics requirements and the departure control avionics requirements. The effort should include real-time simulation and crew workload studies as required to select the desired configuration.

(b) Avionics Performance Analysis (Strategic Departure) - The performance expected from the complete arrival and departure avionics configurations need to be determined considering the paths to be flown, wind effects, and quality of the navigation aids.

(c) Departure Control Avionics Specification - A specification should be prepared for the avionics to be flight tested in the departure and integrated system flight tests. This effort prepares this specification.

Integrated System Simulation Flight Test

The departure and integrated Strategic Control capabilities need to be tested in this effort using a real airplane. Each of the following two parts of this effort were planned in this study for accomplishment in FY 1983 and 1984, to coordinate with other program activities. The first effort is estimated to cost $700,000 to complete; the second about $800,000.

(a) Airplane and Avionics Modification - The airplane and avionics from the basic arrival control flight tests need to be modified by this effort to the flight test departure control avionics specification.

(b) Integrated System Flight Test - The airplane in (a) should fly in the departure and integrated system real-time simulation according to the experimental test plan developed in the Departure Control and Integrated Systems Simulation and Evaluation effort.

6.3.4 Task 4 - Analysis of Extended Capabilities

This Task should determine Strategic Control growth and improvement potentials. Airplane performance and control requirements should be analyzed to determine potential extended Strategic Control capabilities. Areas of investigation should include scheduling arrivals and departures with complete flexibility as to the paths to be flown by each individual flight without reference to any predetermined track system; use of Strategic Control in en route airspace to solve traffic routing and conflicts; use of advanced techniques for scheduling arrival and departure operations at any airfield; and use of strategic scheduling and control techniques for a network of airports and air routes. This work, building on previous research and development activities, is estimated to cost $450,000 per year. The work should be done in FY 1982 and 1983.

6.3.5 Task 5 - Subsystem Specification

This Task should generate the Strategic Control subsystem specification necessary to enable system acquisition. This work should include performance requirements specification for the data processing hardware, software, communications, and avionics subsystems. Resource estimates for this Task are shown in Table 6-4.

6.3.6 Funding Allocations

In general, the R&D costs for Strategic Control were estimated from similarities between the Strategic Control program and programs already in existence. An estimate of the probable number of program instructions provided a method of arriving at an esimate of man-months of effort required to develop software and produce the simulation program.[12] Man-months, computer hours, and flight test hours were converted to dollars and allocated over the estimated time required to complete the recommended efforts. Table 6-4 shows the time-phased cost estimates. Total resources required for the Strategic Control Development Program are about $18.5 million.

6.4 AUTOMATION

This Section describes a research program to determine and validate automation techniques and implementation methods for a highly automated air traffic management system. The potential benefit, discussed earlier in this Report, included savings in excess of $200 million potentially possible compared to conventional automation approaches. How these benefits might be achieved, how the system functions, and what man's role in this future system would be were discussed in Section 5.

The development of a highly automated ATC system will require extensive effort in both the hardware and software areas. This development must be based on a prior research program which establishes detailed operational requirements and delineate system hardware and software specifications. After these preliminary tasks have been completed, providing system-level specifications, the designs should be tested and evaluated.

A summary of the R&D automation program plan is shown in Figure 6-4. Five major task areas are scheduled over a nine-year period. These tasks cover extension of earlier definition studies and the development of evaluation techniques; demonstration of the effects of automation and the feasibility of automated ATC operations; concept development; development, fabrication, and test of automation hardware and software; and subsequent software reconfigurations, design, development, and operational test. These tasks are detailed in the following paragraphs:

TABLE 6-4. STRATEGIC CONTROL DEVELOPMENT PROGRAM
RESOURCES BY YEAR BY TASK
(Costs in Thousands of 1973 Dollars)

Task/Element	Fiscal Year								Task Cost Total
	1977	1978	1979	1980	1981	1982	1983	1984	
I. Development of Basic Arrival Control Capability	700	1,200	2,400	2,900	2,100				9,300
II. Development of Complete Arrival Control Capability			450	770	920	600			2,740
III. Development of Departure Control Capability				600	520	1,770	1,600	750	5,240
IV. Analysis of Extended Capabilities						450	450		900
V. Subsystem Specification							150	150	300
Total Cost	700	1,200	2,850	4,270	3,540	2,820	2,200	900	18,480

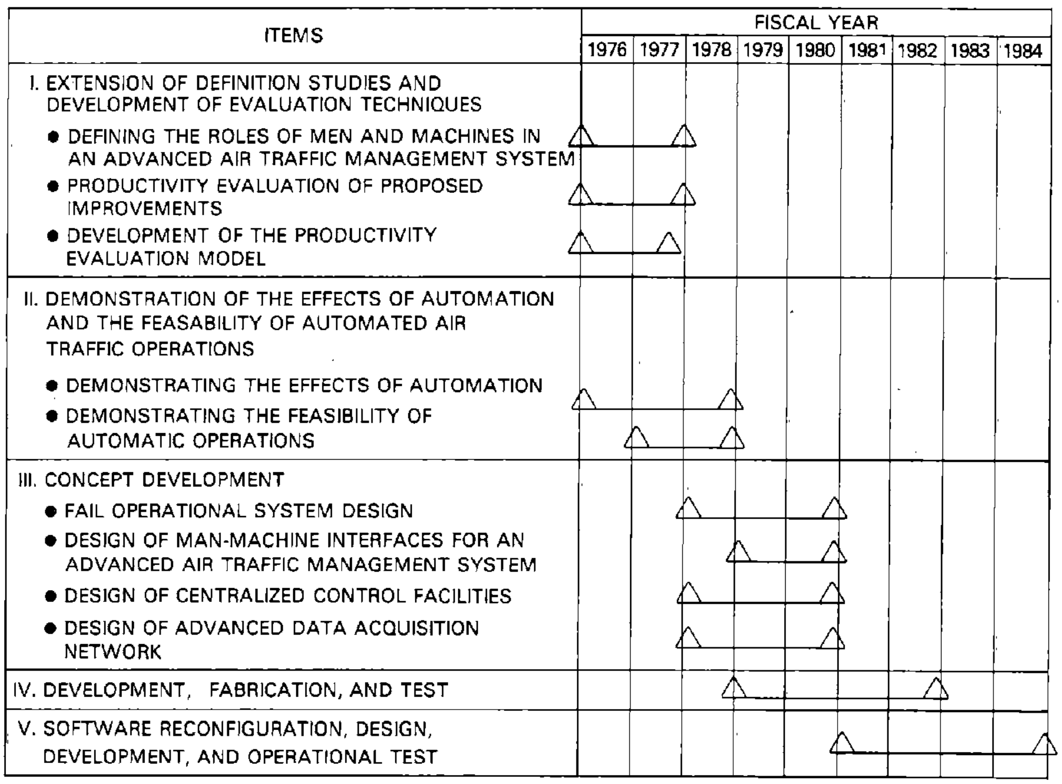

Figure 6-4. Automation Development Schedule

6.4.1 Task 1 - Extension of Definition Studies and Development of Evaluation Techniques

This Task encompasses three major efforts to extend earlier work on the application of automation techniques to advanced air traffic control systems. The three efforts are to define the relative roles of men and machines in the management and maintenance of the Advanced Air Traffic Management System, to develop and apply techniques to credibly determine the productivity payoff of system improvements, and to develop a sophisticated productivity evaluation model. These efforts are follow-on's to automation applications studies done under the AATMS Study.[10] The specific work to be done is summarized below.

Role Definition

The roles and functions of men and machines in the management and maintenance of AATMS need to be further defined. The resulting information, taken with similar information from the AATMS Program, should form the basis for initially specifying the physical design of the advanced system. This task element should also define and detail the tasks in the management and maintenance of an advanced air traffic management system with respect to internal or control processes and allocation of these tasks between man and machine. The result when combined with operations definitions from the AATMS Program, should be a documented, overall concept (operations, management, and maintenance) that enables firm design specifications to be produced. The four parts of this effort, described below are each estimated by this Study to require $250,000 and two years to complete. This plan recommends this work be done in FY 1976 and 1977.

(a) Definition - A study of the nature and scope of the management and maintenance concepts, in terms of the performances required in system management and system maintenance, needs to be produced. This effort will produce these element descriptions.

(b) Function/Subfunction Task Analysis - The functions that must be carried out in order to achieve the required performances in system management and system maintenance need to be specified as well as the subfunctions and work making up the functions.

(c) Man-Machine Task Allocations - A recommended level of automation in system management and maintenance, through allocation of tasks to men or machines, needs to be determined. This result should be used in subsequent program efforts.

(d) Specification of Machine Aids - The definition of machine requirements in the system needs to be completed through the specification of machine-aiding in system operations, management, and maintenance. The result should be a comprehensive description of all tasks, man/machine allocations, machine-aiding, and functional display/control requirements for the management, operations, and maintenance of an advanced air traffic management system. This information is needed as the basis for the demonstration task and the design studies task.

Productivity Evaluation of System Improvements

Future automation concepts presently under development and of potential use in an advanced air traffic management system include automated metering and spacing, conflict prediction and avoidance, flow control, and the use of data link for communications. However, the extent to which increased controller productivity can actually be attained by these improvements has not been quantified. This effort aims at developing a technique for quantifying the relationships among control team workload, system capacity, and controller productivity. Using such quantified measures, the total-system productivity payoff from future ATC automation improvements can be assessed. Included in this task would be an assessment of potential automation-related improvements to the Upgraded Third Generation System.

A comprehensive and definitive common terminology needs to be developed to facilitate the comparison of system concepts in terms of operational efficiency. Productivity evaluation procedures developed under this effort should be sensitive to system hardware and the operational functions performed at control positions.

Productivity potential determinations of certain ATC improvements will require that the components of productivity be isolated and quantified. These efforts depend on the availability of the productivity evaluation model described later in this Task description. A computer program for determining quantitative values of certain factors related to productivity needs to be developed. This work is encompassed in seven separate efforts, the first three planned here for FY 1976 and 1977, and the last four for FY 1977.

(a) Development of a Sector Productivity Evaluation Procedure - The procedures or techniques for determining sector productivity needs to be developed. The approach of this effort is to (1) review the functional analysis done under the AATMS Study, (2) formulate a method to determine the sector productivity, (3) develop a data base on the factors influencing sector productivity. Cost estimates for this effort are $150,000.

(b) Development of a Sector Efficiency Evaluation Procedure - A procedure needs to be developed to evaluate that sector efficiency factor which bears directly on the determination of system productivity. An analytical model to evaluate the variations in control position workload as a function of traffic demand should also be developed. Those analyses which require the use of computer models developed under the AATMS Study should be identified. It is estimated that this effort will cost $150,000.

(c) Development of a Manning/Staffing Factor Evaluation Procedure - Scaling relationships, and workload and staffing relationships need to be developed that permit evaluation of the manning/staffing factor, a factor necessary in the evaluation of system productivity. Costs for this effort are $150,000 over a two year period.

(d) Model Application - The results of the preceding three efforts should be used to quantify certain parameters, and to derive complex relationships among productivity parameters that cannot be accomplished by analytic means. The Delta Model, developed under the AATMS Study and modified by the effort described below, can be used in this effort.[10] About $100,00 is estimated as needed to do this work.

(e) Procedure Validation - The productivity evaluation procedure needs to be validated. The above techniques should be applied to at least two existing air traffic control facilities and the results evaluated. The productivity evaluation procedure should be modified to reflect the validation findings. It is estimated that $50,000 is needed to complete this effort.

(f) Development of Application Plans - The candidate ATC system improvements which need to be evaluated with respect to productivity should be identified. Candidate improvement selection should be based on the assessment of each improvement itself, and on the probability of productivity gains if a particular improvement were to be implemented. This effort and the following one are each estimated to require $200,000 to perform.

(g) Productivity Evaluation Procedure Application - The productivity evaluation procedure developed above should be used to evaluate the selected improvements determined as described in item (f) above. For each application, a detailed assessment of the productivity potential of the evaluated improvement should be made, together with supporting rationale and recommendations.

<u>Development of the Productivity Evaluation Model</u>

A computer model needs to be developed to provide specific parametric data and to explore complex relationships among productivity parameters which cannot be accomplished by direct analytic means. This effort should use the Delta resource allocation model developed for the AATMS Automation Study.[10] Delta (Determine Levels of Task Automation) Model was developed to generate resource utilization data used in selecting appropriate degrees of automation. The Delta Model should be modified for use in the productivity evaluation of proposed improvements described earlier and in subsequent investigations of automation improvements. Six distinct efforts are projected for this model development effort. The first two are estimated to cost $100,000 each; this plan suggests they be done in FY 1976. The next two cost the same; this plan suggests they be done in FY 1977. The last two are projected to cost $50,000 in the same period (FY 1977).

(a) Determination of Model Modification Requirements - Revisions to the Delta Model need to be specified that would permit its use for productivity evaluation. General requirements for the model should be generated as part of the Productivity Evaluation effort, and these requirements should be translated into a specification which would delineate required software changes.

(b) Modification of the Model Structure - The Delta Model needs to be restructured to be a multi-level simulation tool capable of handling complex multi-dimensional problems on a statistical basis. The restructuring should include a high-level traffic flow model.

(c) Model Modifications - The required changes would be made in the Delta Model, consistent with the specification (item (a), above), and the restructuring requirements (item (b), above). Model element testing and check out should be included in this effort.

(d) Software Testing - The revised and new software developed under the preceding efforts needs to be tested and evaluated. These tests should use the complete program with all revisions and additions. A test plan and schedule should be prepared and used during the test cycle to assure that a comprehensive test is performed.

(e) Model Validation - The revised Delta Model needs to be validated. The model should be tested against known scenarios, using a test plan prepared at the start of the effort, to establish its validity and region of utility. Modification recommendations resulting from the validation tests should be made and tested.

(f) Model Documentation - The Delta Model developed in this project needs to be documented. Documentation should include a programmer's and user's manual, and should cover the model validation procedure.

6.4.2 Task 2 - Demonstration of the Effects of Automation and the Feasibility of Automated Air Traffic Operations

This Task encompasses two different demonstrations, each the basis for subsystem designs of an automated air traffic management system. The first demonstration is of the effects of automating the air traffic system to a level where most tasks are assigned to machines. The second demonstration is to determine the technical feasiblity of actually attaining a system with such a level of automation. The demonstration of effects will be of crucial importance since its outcome determines whether or not man can and will accept a computerized system for directing traffic while he acts in a managerial and monitoring capacity. If it can be shown that man can function effectively in this role and will accept it, then the second demonstration will consider the technical feasibility of achieving this capability. The two efforts that comprise this Task are described below.

Demonstrating the Effects of Automation

This effort is designed to determine, through use of a "proto-simulator", an experimental tool described below, some insight into the characteristics of a highly automated air traffic management system. This work involves determination of the operational end point to be attained in a highly automated air traffic system. The demonstration should provide a common understanding, within the aviation community, of automated systems and goals. It should also provide a means for defining the steps and milestones for achieving these goals.

The demonstration should use an operational analog which will allow the future ATC system to be defined, and studied in a dynamic and realistic fashion. Actual demonstrations of automation in air traffic control are far more useful than paper studies, but neither the hardware nor the software for an advanced ATC system exist. To overcome these present shortcomings and enable the effects of advanced automation to be studied, a "proto-simulator" needs to be developed. This unit is not really a simulator, hence the use of the term "proto-simulator". The effects of automation can be demonstrated by having test controllers work with "machines" that appear highly automated. These "machines" can in fact, be other controllers who are allocated the same tasks as machines would have in the future ATC system. The effect, insofar as the test controllers are concerned, is the same as if the tasks were truly automated.

The topics to be studied in this effort include alternative implementation strategies, man-as-a-controller and man-as-a-manager roles (assignment of men and resources), and man-machine interface characteristics. First priority in the demonstrations needs to be given to study of operations at the recommended automation level in the active control area. Once firm data is obtained on the operational viability of the high level of automation envisioned for the advanced system (or a suitable alternative automation level found), then the proto-simulation should be used to study other operational resources, management function automation, and system performance in abnormal modes (bad weather, failures, etc.). Items (a) and (b) are essential to the demonstration effort since they incorporate the experimental planning activities that ultimately determine the utility of the results from this effort.

(a) Scenario Specification - This effort should produce design specifications for the proto-simulator based on the functional requirements the simulator must meet. These functional requirements need to be determined by enumerating each of the major kinds of demonstration scenarios and determining its characteristics with sufficient precision to enable stating the performance requirements. The output of this effort should be scenario specifications. This work is estimated to cost $200,000 and should be done in FY 1976.

(b) Experimental Designs - Demonstration experiments need to be designed based on the scenarios above. The independent and dependent variables should be specified and the parameters and methods of measurement determined. This effort should cost about $200,000 per year for two years and be done in FY 1976 and 1977.

(c) Proto-Simulator Hardware Analysis and Design - The proto-simulator facility should be specified in this effort. The specification should include the requirements for work stations for controller machines, and managers, and for special personnel stations required to operate the proto-simulator, for example, video system operators, experimenter's observation stations and data recording stations. (A flexible, modular configuration is envisioned to provide demonstration scope, necessary in part, because the iterative nature of the investigations that may take place.) This effort is estimated to cost $300,000 per year in the same time frame as the preceding effort.

(d) Facility Acquisition, Installation, and Test - The demonstration facility needs to be built and tested according to the design generated by the preceding efforts. Maximum advantage can be taken of off-the-shelf equipment items because of the generalized equipment requirements. One million dollars is the estimated cost for this effort. It is recommended that this work be done in FY 1977.

(e) Demonstrations and Proto-Simulations - The scenarios specified in item (b) above should be run on the proto-simulator and the results measured, documented, and used as a basis for further design activities concerning automated systems. About $800,000 is estimated as the cost of this effort. The work should be done in FY 1978.

Demonstrating the Feasibility of Automatic ATC Operations

The feasibility and practical extent of removing the controller from the tactical control loop needs to be demonstrated. This work needs to focus on controller functions which are a part of the tactical control loop. The characteristics of these tactical functions should be determined preparatory to conducting a credible demonstration. An en route center controller uses primarily the conflict prediction and resolution tactical function and, to a lesser extent, sequencing, metering, and spacing at en route merge points. The tactical functions of the terminal area controller are mainly sequencing, metering, and spacing. However, conflict prediction and resolution are still important functions. A brief description of each of the items in this effort is given below. The first three parts of this effort are estimated to cost $50,000, and should be done in FY 1977. Resources for subsequent tasks are presented below.

(a) Analyze Previous and On-Going Research - This task should obtain and analyze relevant data from recent studies with the object of finding material pertinent to setting up a successful demonstration.

(b) Extrapolate Characteristics of Overlapping Responsibility Levels - Based on data from item (a) this effort needs to determine overlapping levels of responsibility of the following tactical control functions with the object of identifying ways to off-load the controller.

- Strategic Flow Control
- Flight Plan Conflict Probe
- Airborne Situation Display
- Intermittent Positive Control (IPC)
- Collision Avoidance System/Pilot Warning Indication (CAS/PWI)

(c) Determine Requirements of Conflict Prediction and Resolution - This work will determine the functional requirements of the conflict prediction and resolution function in accord with the function characterisitcs determined in item (b).

(d) Develop Man-Machine Design of Conflict Prediction and Resolution - Based on the requirements determined in item (c), a tentative man-machine design of the conflict prediction and resolution function needs to be developed. Demonstration algorithms and man-machine interfaces should also be developed using available resources wherever possible. This work and that in the following effort are estimated to cost $200,000 and should be done in FY 1977 and 1978.

(e) Design/Implement Man-in-Loop Simulation of Conflict Prediction and Resolution - A demonstration test facility needs to be designed and fabricated based on the preceding specifications. The conflict prediction and resolution function should be studied.

(f) Evaluation Demonstration of Conflict Prediction and Resolution - The results of the conflict prediction and resolution function demonstration need to be evaluated using such criteria as evolvability, control acceptability, cost, legal accountability, failure modes, and engineering production feasibility. This effort is estimated to cost $100,000; both this work and the following effort should be done in FY 1977.

(g) Determine Requirements of Sequencing, Metering and Spacing - The functional requirements of the sequencing, metering and spacing function should be determined in accord with the subfunction characteristics determined in item (b). About $50,000 will be required to perform this work.

(h) Develop Man-Machine Design of Sequencing, Metering and Spacing - Based on the requirements determined above, this effort should develop a man-machine design of the sequencing, metering, and spacing function. Demonstration algorithms and man-machine interfaces should be developed, using available resources wherever possible. This effort and the following one should cost about $200,000 and be done in FY 1977 and 1978.

(i) Design/Implement Man-in-Loop Simulation of Sequencing, Metering, and Spacing - This effort should design, and fabricate in the item (e) demonstration facility, the necessary elements to demonstrate the extent to which the controller can be removed from the sequencing, metering, and spacing function. The demonstration tests should be performed in this effort.

(j) Evaluate Demonstration of Sequencing, Metering, and Spacing - The results of the sequencing, metering, and spacing function demonstrations should be evaluated using such criteria as evolvability, controller acceptability, cost, legal accountability, failure modes, and engineering production feasibility. The evaluation effort is estimated to cost $100,000 and should be done in FY 1978.

6.4.3 Task 3 - Concept Development

This task is comprised of four subsidiary efforts to specify a highly automated advanced air traffic management system. These efforts translate the system from a conceptual state to a specific set of plans for controls and displays, facilities, and computer architecture, all so integrated that the system functions effectively in normal and degraded states. The separate efforts should be closely coordinated because of the interrelationships among these four areas of design.

Fail Operational System Design

The failure effects in an advanced air traffic management system need to be determined by employing an interactive design process. A specific and systematic fail operational design based on the notions of coast time, failure recognition time, and backup activation time should be developed and evaluated by considering transient and steady-state capability and safety characteristics. The required resources, e.g., hardware and software equipment, mechanization techniques, resource configuration flexibility, system deployment, and how to measure safety and capacity levels should be defined for a proposed system design.

A safe automated system needs to be designed and analyzed considering transient safety, steady-state safety, failure recognition time, and backup activation time. This design should couple closely with the Data Acquisition Network design activities described later in this Task, and aid in the development of system computer architecture which will both affect the recommended degree of automation and support the requirements for failure operations. The work should include the following elements:

(a) Development of Techniques for Determing the Coast Time of Subfunctions - The methodology for determining the coast time associated with the failure of a particular subfunction needs to be developed. Coast time is the time period after a failure during which system operation remains essentially unaffected. It depends on such factors as subfunction, performance frequency, performance duration, interrelationships with other subfunctions, and existing operational conditions such as traffic level and weather conditions. Different techniques should be developed to handle the overall range of subfunction complexities and natures. Computer simulation should be used. Resource estimates for this effort and also the following effort are $200,000 each; the work should be done in FY 1978.

(b) Development of Techniques for Determining the Backup Activation Time - Techniques need to be developed to determine backup activation time; that is the time required to activate a backup after a failure has occurred. The backup activation time depends on what the system does in response to the failure. The results of this effort also depend on the data acquisition network design since details of the system mechanization influence the activation time and the determination of this time.

(c) Coast Time Determination - The tools developed above should be used to determine the coast time for various subfunction failures. Analyses of the coast time sensitivity to the factors identified in item (a) and to the system mechanization should be performed. This work and the following are estimated to cost $300,000 each. This work and the following three subtasks should be done in FY 1979.

(d) Backup Activation Time Determination - The backup activation time for various subfunction failures needs to be determined using the approach developed above. Details of the computer architecture must be available to this effort before the backup activation time can be determined, in contrast to coast time determination. In those cases where a backup alternative is available, its activation time should also be determined. Analyses should be performed to determine the sensitivity of backup activation times to mechanization factors.

(e) Determination of Failure Recognition Times - Requirements for the failure detection mechanism in terms of the failure recognition time need to be derived using results of the coast time and failure recognition time studies. This work is estimated to cost $200,000.

(f) Analysis of Failure Related Times - The coast, failure recognition, and backup activation time durations need to be analyzed to ascertain whether the mechanization design can meet the system backup requirements. An iterative design and analysis of the backup system should be carried out jointly in the fail operational design and data acquisition network design efforts. This effort is estimated to cost $500,000.

(g) Specification of the Failure Design Mechanization - Top level specifications of the failure operations subsystem need to be developed. This is the subsystem responsible for failure detection and resolution including transitioning normal operations to failure operations, and backing up the primary system. This work, estimated to cost $300,000, should be done in FY 1980. These specifications should cover the following:

- Failure recognition times for the failure detection subsystem
- Backup activation times
- Transitioning procedures
- General mechanization details of the backup system
- Interfacing requirements between the primary system mechanization and the failure detection subsystem
- Interfacing requirements between the failure detection subsystem and the backup system

(h) Design of Failure Operations Subsystem - The complete design of the failure operations subsystem including fault detection algorithms, fault resolution algorithms, system monitor and control interfaces, and computational requirements need to be developed. This work design is estimated to cost $500,000 per year for two years - FY 1979 and 1980.

Design of Man-Machine Interfaces for AATMS

Design data need to be developed on the man-machine interfaces in an advanced air traffic management system. These data, together with other information from this research program, should support the determination of the overall design specifications for the system prototype. A basic assumption of this effort is that efficient, automated air traffic management is based on an effective partnership between men and machines, and that this relationship depends on appropriate, effective and efficient interfaces between men and machines. This effort is dependent on Task 1 efforts in which the roles of man and machines in system management, maintenance, and operations are specified. The work to be undertaken under this effort should, in general, be performed for each operator position identified for the future system. The interactive effects across control position types should also be examined as part of each of the five elements making up the effort and described in the following paragraphs.

(a) Control/Display Information Analysis - An analysis needs to be made of the detailed system concept and system procedures alternatives, to specify the requirements for candidate control/display items and formats for each major procedural alternative. As a parallel effort, control types and preliminary control console designs should be developed. Scenarios of system operations should be prepared so that effects analyses of candidate control/display concept choices and between major system alternative choices can be conducted. This work, and the following effort, should cost about $200,000 and be performed in FY 1979.

(b) End-Effects Testing - The end-effects of particular choices in man-machine interface design need to be examined at system and sub-system level using the proto-simulator facility and the scenarios for system operations developed in item (a) above. A tabulation should be prepared for each major system alternative on the utility of each defined control/display item. These tabulations should serve as data sources for the tradeoffs involved in the preliminary physical design of the man-machine interface itself.

(c) Preliminary Interface Design - Displays and controls, both those generic to the jobs of each operator and manager and those specific to the hardware which has been tentatively selected for the system need to be evaluated and final selections recommended This work should cost about $750,000 to complete and like the next effort, should be performed in FY 1979 and 1980.

(d) Simulation Testing - The control-display subsystem needs to be simulated in operator work stations and detailed evaluations of system operations, management, and maintenance activities should be carried out to aid the preparation of man-machine interface specifications. This effort assumes the availability of an appropriate simulator, and is estimated to cost $500,000 to complete.

(e) Integrated Specifications Development - The data derived above should be consolidated with the data for computers, software and system facilities produced in the other areas of this effort to produce not only the specifications for prototype man-machine interfaces, but also specifications for other aspects of the system prototype itself, in preparation for prototype system testing. This effort is estimated to cost $500,000 and should be done in FY 1980.

Design of Centralized Control Facilities

The operational relationships which arise from a centralized facility configuration and the design features and operational characteristics of future control facilities need to be defined. Detailed design requirements and specifications for air traffic control, flight service, and data base facilities in an advanced system should be developed. This effort should also examine the facilities configuration proposed by this Study, considering the nature and degree of centralization necessary to meet the goals of safety, operational efficiency, and manpower economies. This effort should establish detailed requirements for the internal configuration of individual facilities and for the interconnections among facilities. The requirements should be formulated so that they are compatible with the fail operational character of the system and the level of automation designed into the data acquisition and processing network.

The proto-simulator, developed as part of Task 2, and other simulation facilities, if available, should be extensively used in this project. The following efforts delineate the research and development activities to be performed in this area. Each of the first three of the seven efforts are estimated to cost $200,000. The work should be done in FY 1978.

(a) Develop Preliminary Facility Configuration - A detailed description of each type of facility in the advanced system needs to be generated. The starting point for this exercise should be the facility concept and position descriptions available from this Study. The preliminary facility configurations should include descriptions of the internal site arrangements, work force organization, personnel assignment and duties, and working relationships among facilities in normal and failure operating modes.

(b) Specify Operational Procedures - The preliminary facility configurations designed above should be analyzed to create a specification of the operational procedures to be employed at each facility. The specification should include a detailed blueprint of the way each facility carries out its operational functions in providing services to aircraft, and its internal management and maintenance activities. The blueprint should be made up of operations and procedures handbooks to be used by personnel at each facility. Among the topics to be covered are sectorization rules, workload distribution and task assignment procedures, methods for monitoring and assuring the quality of service, reconfiguration and back-up procedures, and lines of authority and coordination.

(c) Develop Operational Scenarios - In preparation for testing and evaluation of the facility configuration, scenarios of air traffic operations which fully tax the proposed system should be developed. The scenarios, based on nominal and peak demand estimates for the 1995 time frame, should cover a representative sample of normal and contingency conditions. The latter should include adverse weather conditions, runway reversals, airport closings, and navigation/communication system outages. A separate set of scenarios should be prepared to cover various failure modes of equipment performing system internal data processing functions.

(d) Test Facility Operation in Normal Modes - The preliminary facility configuration and associated operational procedures should be evaluated and refined using the proto-simulator facility, and other simulation facilities as available. Initial tests should concentrate on operations at individual facilities, e.g., RCC, THC, CCC, to assess the effectiveness of the internal organization and evaluate the appropriateness of centralization in meeting system goals. After individual facility tests have been completed, interfacility relationships should be considered by assessing such problems as handoff procedures, relationships of the THC-located Flight Service Centers to the CCC data base activity and to control facilities, and flow control (CCC) interactions with local terminal metering operations. This effort should be concerned solely with normal modes of system operation. It is estimated to cost $350,000 and should be performed in FY 1978 and 1979.

(e) Revise Facility Configuration - This effort should be undertaken only if the foregoing tests indicate that the basic facility configuration design requires substantial modification. It would be the equivalent of item (a) above, and would consist of iterative steps to arrive at an optimum control facility configuration. This plan estimates the cost of this iterative process as $250,000. It should be done in FY 1979 when test results are available.

(f) Test Facility Operation in Failure Modes - The suitability and effectiveness of the backup and support arrangements which have been built into the facility network to deal with equipment failures need to be determined. As in item (d), the order of treatment should be individual facility designs followed by system-wide tests. Initial evaluations should consider the "internal reserve", "lateral borrowing", and "reduce to essentials" backup strategies. They should include determination or coast time, failure recognition time, and backup activation procedures on overall facility operation and quality of service delivered during the transition period. System-wide tests of the facility configuration in failure modes should address, at a higher level, the same questions. If necessary, the preliminary facility configuration design should be modified to overcome design shortcomings. Resource estimates for this effort are $350,000 and two years, FY 1979 and 1980, in this plan.

(g) Develop Prototype Facility Specification - The normal and degraded state tests conducted above, and any revisions and iterations which may be required, should result in a preliminary facility configuration design as well as data on operational requirements of the system. These findings should be used to completely describe the requirements for each type of facility and for the facility network. This description should become the design specification for the prototype AATMS facilities. The specification should include hardware and software elements, internal organization of facilities, hierarchical arrangement of elements within the total system, lines of interaction within and among facilities for management and administrative purposes, and the tentative set of procedures which would govern system operations. An important by-product of this effort should be support to the generation of control/display specifications and computer architecture specifications. This work should cost $450,000 and be performed in FY 1980.

Design of an Advanced Data Acquisition Network

The principal hardware and software requirements for a fail-safe system operating at the recommended level of automation need to be specified. These requirements should include both computer hardware and sensor and communications subsystem interface hardware. The AATMS data processing system should be specified to the level of detail necessary for the purchase or design of hardware. The work should include an optimum machine configuration recommendation and an estimate of associated costs.

(a) Preliminary Design and Specification of Computer Architectures - The requirements for future computer systems and software at each future facility need to be assessed, and a computer system design reflecting the fail-safe design requirements determined above should be produced. Logical task groupings should be assessed and assigned to machines consistent with the goal of the automation effort. The effort should encompass the tentative design of the system, including intersite and intrasite communications capabilities and requirements, the sensor network, and a total system design recommendation. Factors to be considered include interfaces, reliability, task optimization, system and software debugging and checkout, information flows, future expandability, and cost. The computer system consists of all computer functions, interfaces between sensors and computers, and operating parameters such as operation times, memory and word sizes and types of computers. The preliminary design resulting from this effort is used by other elements of this task. This effort should cost $300,000 and be done in FY 1978 and 1979.

(b) Network Design Study – Alternative data communications networks should be evaluated and a functional approach to the design of this information network formulated. The normal and failure mode information flows in the system and support hardware and software should be analyzed, as should computer networks in order to assess their potential utility in future system designs. Future network characteristics should be evaluated in terms of network topology, information flows, redundancies, and computer implications. Resource estimates for this task are the same as for the preceding effort.

(c) Network Design Specifications – Hardware design specifications for the data acquisition network need to be produced on such matters as the number of registers for each CPU, data transfer rates of cabling, characteristic times for different devices, skew rates for modems, critical instruction times, transmission systems, and switching times. These specifications should be related to system operational times, such as coast time, failure recognition time and backup activation time. This work should cost about $200,000 and take two years to complete: FY 1978 and 1979.

(d) Design Modifications for Backup Modes – The details of the computer and network designs generated in item (a) above should be iteratively modified based on an analysis of system criticalities, their functional hardware equivalents, system sensitivities, failure probabilities, types of backups available and desirable, and total impact on system resources. The backup contingency design analysis is expected to materially affect the normal mode system design derived above. This effort is estimated to cost $200,000 and should be accomplished in FY 1979.

(e) Design of Computer Algorithms – Specifications for all required computer algorithms for normal and failure modes of system operation need to be produced. The purpose of each algorithm, estimates of maximum permissible time (or, equivalently, computer cycles) to execute the algorithm, devices sequenced or addressed by the algorithm, recommended languages for software algorithms, and estimated instruction counts should be covered in the related specifications. Algorithms related to system reliability should be identified. Appropriate coding techniques should also be specified. This effort should cost $1.5 million, and be accomplished during FY 1978, 1979, and 1980.

(f) Failure Response Specification - The response to failures of each system functional component, and measures to protect against any types of failures, need to be developed and described. The impact of these recommendations should be assessed in terms of software flexibility; hardware, including communications equipment; required algorithms; and personnel and procedures. Contingencies in the event of failure, and the software to support these contingencies, should be specified. Resource estimates for this and the following task are $250,000. The work should be done in FY 1980.

(g) Cost Estimates - The implementation (F&E) cost of the sensor-computer systems, including redundancies, for all facilities and their connections, should be estimated under this effort. Anticipated software costs (coding and debugging) should also be estimated. Cost benefits should be identified. Operations and maintenance (O&M) costs for subsystems should be estimated and cost-based tradeoffs should be identified. The costs of differently configured systems should be estimated for the variety of backup modes identified as suitable for the future system design.

6.4.4 Task 4 - Development, Fabrication and Test

The major components of the automation concept developed in Task 3 need to be tested and evaluated in operational environments as close as possible to those projected for AATMS. Such environments should be obtained through simulation and live tests. The initial activities in this Task should be to develop, fabricate, and test an experimental facility capable of simulating the operational environment of the future system. Specific parameters should be measured and identified in test planning activities, in order to obtain data to support concept implementation decisions.

Prototype equipment to be tested and evaluated should be developed concurrently with the development of the test facility. This equipment should be fabricated according to specifications resulting from Task 3, concept development, of this recommended Research and Development Program and should include both hardware and test program software. Elements should include modular pieces of the computer system, data acquisition network equipment, sensor interface equipment, work stations and man-machine interface equipment, and fail-operational network equipment. These elements should enable assembly and test, as well as operational evaluation of the systems and subsystems in the Continental, Regional, Terminal-Hub, and Airport Control Centers; of the interconnections among these facilities and various sensor systems; and of the functioning of the operator, management, and maintenance systems.

Software may be developed specifically for this Task, or it may be adapted from other on-going system automation efforts, especially those concerned with the metering and spacing, flow control, and the conflict prediction and resolution functions. The unique nature of the hardware anticipated in the effort may necessitate a unique fabrication program. The work station consoles should be units that are flexible in representing operations, management, and maintenance work stations in the various control centers. A number of work stations or consoles should be used so that interconnections and interrelationships between stations can be studied as part of this effort.

There will be two major experimental efforts connected with the test portion of this task: simulations and flight tests. The simulations need to be system-and controller-oriented so that both system and controller operations can be evaluated. These tests should include evaluation of the automated system in failure conditions, machine control modes, induced tasks, hardware and software functioning, workload, human factors, and interfaces at both system and subsystem levels. Measurements and assessments should be made during these experiments for use in altering the final design of the system to meet system requirements.

The experimental flight tests should consist of tests using fully instrumented aircraft (ideally those used in conjunction with the satellite experiment program), and simulations to explore user-system interface problems. These tests should be user-oriented, and should explore how user performance impacts on system operation. Requirements placed on the user by highly automated system designs should be factored into the development of avionics employing the multiple satellite test program. Specific experiments should be conducted including evaluation of aircrew workload changes brough about by system automation and considering the levels of user acceptance and confidence in the system; evaluation of pilot and aircraft performance on system operation, including considerations of pilot experience and competence, reliability of performance, and failure effects; pilot qualification and training requirements as a function of airspace or control mode; and the impact of the system on freedom of flight, required avionics, performance flexibility, demand sensitivity; and procedures. This large effort is estimated to require the following resources in the indicated schedule year: FY 1979-$5.7 million; FY 1980-$11.3 million; FY 1981-$11.3 million; and FY 1982-$5.7 million.

After completion of the tests, evaluations and assessments indicated above appropriate system design revisions should be made. Detailed specifications for the hardware and software should be generated (see Task 5 below). These specifications should support the development of the operational system, together with its deployment, checkout and operation.

6.4.5 Task 5 - Software Reconfiguration, Design, Development, and Operational Test

This Task is designed to modify, develop, and operationally test the software necessary to subsequently undertake a combined satellite-automation-control mode experiment over the conterminous United States. This software should be the basis for the software in the operational system. The tests run in connection with this effort and the operational multiple satellite tests (see Section 6.2) should represent a complete checkout of the AATMS Concept in an operational air traffic environment. The simulation vehicles developed in connection with Task 4 should be used to exercise the system test equipment (computer systems and avionics) so that the flight test aircraft and control facilities function in their projected normal operating modes. System failures and airborne failures should be induced and the system response evaluated. The results of these tests should support any final modification of the system specifications prior to procuring system hardware and software. The resources estimated for this effort are, by year: FY 1981 - $2 million; FY 1982 - $2 million; FY 1983 - $6 million; and FY 1984 - $6 million. Additional operational test resources are also included in the multiple satellite program.

6.4.6 Resource Summary

Development of the automation concept to the implementation-ready stage is estimated to cost $66.9 million. The program itself, and its cost, depend on the present, on-going Engineering and Development Program of the Federal Aviation Administration in related areas. A schedule of the Tasks to be performed in this recommended Research and Development Program is shown in Table 6-5.

TABLE 6-5. AUTOMATION TASK RESOURCES BY YEAR BY TASK
(Costs in Thousands of 1973 Dollars)

Task/Element	Fiscal Year									Task Cost Totals
	1976	1977	1978	1979	1980	1981	1982	1983	1984	
I. Extension of Definition Studies and Development of Evaluation Techniques	925	1,575								2,500
II. Demonstration of the Effects of Automation and the Feasibility of Automated Air Traffic Operations	700	2,200	1,300							4,200
III. Concept Development			2,075	4,525	3,600					10,200
IV. Development, Fabrication and Test				5,700	11,300	11,300	5,700			34,000
V. Software Reconfiguration, Design, Development, and Operational Test						2,000	2,000	6,000	6,000	16,000
Cost Totals by Year	1,625	3,775	3,375	10,225	14,900	13,300	7,700	6,000	6,000	66,900

APPENDIX A

ABBREVIATIONS AND GLOSSARY

ABBREVIATIONS

AATMS - Advanced Air Traffic Management System
ACC - Airport Control Center
AEROSAT - Aeronautical Oceanic Satellites
ARTCC - Air Route Traffic Control Center
ARSR - Air Route Surveillance Radar
ARTS - Automated Radar Terminal System
ASR - Airport Surveillance Radar
ASTC - Airport Surface Traffic Control
ATC - Air Traffic Control
ATCAC - Air Traffic Control Advisory Committee
ATCRBS - Air Traffic Control Radar Beacon System
ATS - Applications Technology Satellite
CAS - Collision Avoidance System
CCC - Continental Control Center
CFCF - Central Flow Control Facility
CONUS - Continental United States (48 states here)
DABS - Discrete Address Beacon System
DME - Distance Measuring Equipment
FAA - Federal Aviation Administration
F&E - Facilities and Equipment Costs
FSC - Flight Service Center
FSS - Flight Service Station
FY - Fiscal Year
IFR - Instrument Flight Rules
ILS - Instrument Landing System
IPC - Intermittent Positive Control
MLS - Microwave Landing System
NAS - National Aviation System; also National Airspace System
O&M - Operation and Maintenance Costs
PIAC - Peak Instantaneous Airborne Count
PIREP - Pilot Report
PWI - Proximity Warning Indicator; also Pilot Warning Instrument
RNAV - Area Navigation
RCC - Regional Control Center

RPE	-	Revenue Passenger Enplanements
RPM	-	Revenue Passenger Miles
THC	-	Terminal-Hub Center
TRACAB	-	Terminal Radar Approach Control in the Tower Cab
TRACON	-	Terminal Radar Approach Control
VOR	-	Very High Frequency Omnirange
VFR	-	Visual Flight Rules
V/STOL	-	Vertical and Short Takeoff and Landing Aircraft
WVAS	-	Wake Vortex Avoidance System

GLOSSARY

Advanced Air Traffic Management System (AATMS) - All components, human and otherwise, of a system providing air traffic management and control services for the 1995 time period. These services include Airport and Airspace Use Planning; Flight Plan Conformance Monitoring; Separation Assurance; Spacing Control; Airborne, Landing, and Ground Navigation; and Flight Advisory Notification.

Air Carrier - An aircraft certified by the FAA for the purpose of carrying persons or goods for hire on an established airway. The term also applies to an organization operating an air carrier.

Air Derived - Information generated on an aircraft.

Air Route Traffic Control Center (ARTCC) - A facility established to provide air traffic control services primarily to aircraft operating on IFR flight plans within controlled airspace, and principally during the en route phase of flight.

Air Taxi - An aircraft used by the holder of an Air Taxi Operating Certificate.

Air Traffic Control (ATC) - A service that promotes the safe, orderly, and expeditious flow of air traffic, including airport, approach, and en route air traffic control.

Air Traffic Control System - All components, human and otherwise, of a system providing ATC services.

Air Traffic Controller - A duly authorized individual involved in providing ATC.

Air Traffic Control Radar Beacon System (ATCRBS) - Commonly referred to as a secondary surveillance system, ATCRBS was adopted from the basic Mark X System developed by the military in World War II for identifying aircraft as friend or foe. ATCRBS works by interrogating airborne transponders which transmit an assigned code and, with an altimeter encoder, barometrically-derived altitude information.

Airport Control Center (ACC) - The facility in AATMS which manages traffic in the final approach, landing, taxi, takeoff, and departure phases of flight.

Altimeter Encoder - An airborne device used to digitally cipher an aircraft's barometrically derived height or altitude.

Approach - The flight segment in which runway alignment and descent for landing are accomplished.

Automated Radar Terminal System (ARTS) - A system which provides for the automatic tracking of primary and secondary radar targets and displays this information on radar scopes with an alphanumeric identification tag for each aircraft being tracked.

Busy Hour Demand - The number of aircraft expected to request permission to take-off or land during the busiest hour of operation at each airport.

Collision Avoidance System (CAS) - A device installed on aircraft for the purpose of detecting the presence of other aircraft, assessing the potential collision hazard, warning the pilot if necessary, and providing appropriate command signals indicating the proper evasive manner.

Constellation - A group of three or more satellites placed in specific orbits, in this context, to provide surveillance, navigation, and communication in AATMS.

Continental Control Center (CCC) - A facility in the AATMS Concept performing national flow control, acting as backup for the Regional Control Centers, and coordinating with the national FSS.

Controlled Aircraft - Aircraft that are participating and receiving traffic separation service from the ATC system.

Controlled Airspace - Airspace in which traffic separation service is being provided by the air traffic management system.

Course - The intended direction of flight in the horizontal plane.

Data Link - Any communication channel or circuit used to transmit information from a sensor to a computer, a readout device, or a storage device.

Demand - Air traffic activity, commonly referenced in terms of aircraft fleet sizes, revenue passenger miles, revenue passenger enplanements, etc.

Discrete Address Beacon System (DABS) - A surveillance system which directs all interrogations to a given aircraft by utilizing that aircraft's unique address. Each aircraft is interrogated in turn, and responds only to interrogations containing its address.

Distributed ATC Management - A system control concept based on having some separation and traffic management functions controlled by pilots and some controlled by a ground agency.

Distance Measuring Equipment (DME) - An airborne-interrogate and ground-respond system used to measure the distance of an aircraft from a radio navigation aid.

Downlink - Aircraft-to-Ground, satellite-to-ground, or satellite-to-aircraft communications link.

En Route ATC Service - Air traffic control provided for aircraft on IFR flight plans while these aircraft are operating between departure and destination terminal areas.

Fail-Operational - A system capability of operating under contingency or failure conditions that maintains the level of safety and capacity that existed at the time of failure.

Fail-Safe - The protective design philosophy for AATMS which provides the system with backup capability to effect fail-operational and fail-soft modes of operation.

Fail-Soft - A system capability of operating under contingency or failure conditions that, although compromising other nominal system attributes, retains the safety of normal modes of operation.

Fix - A geographical position determined by visual reference to the surface, use of one or more radio navigation aids, celestial plotting, or other navigational devices.

Flight Plan - Specified information relating to the intended flight of an aircraft, such as intended route, departure time, speed, etc. When approved by the control authority, a flight plan becomes a clearance.

Flight Path - The altitude profile and horizontal track of an aircraft's flight.

Flight Service Station (FSS) - A facility which provides flight information and assistance services.

Flow Control - A method used to regulate or restrict the number and flow of aircraft to levels which are consistent with the capacity of the ATC system.

Functional Integration - The incorporation of several functionally independent subsystems into a single, unified system.

General Aviation - All aviation and aircraft that are neither military nor commercial aviation.

Geostationary Satellite - A satellite orbiting in the earth's equatorial plane (zero inclination angle) which appears stationary with respect to a point on the surface of the earth.

Geosynchronous Satellite - A satellite in 24 hour orbit with an inclination angle (to the equatorial plane) other than zero.

High Density - An airspace environment wherein the air traffic activity level (relative to the airspace and system capacity) is sufficiently high that aircraft must move with the minimum achievable spacing consistent with safety.

Hub - A hub encompasses the airports, terminals, and transition airspace associated with a metropolitan area.

Instrument Flight Rules - Rules of flight for aircraft in controlled airspace. Implied is a requirement for prior ATM system approval and clearance.

Intermittent Positive Control (IPC) - A control concept in which aircraft are advised of threats due to other aircraft, weather, airspace boundaries, and surface obstacles, and given commands for appropriate evasive maneuvers. This service could be provided to both controlled and uncontrolled aircraft, but requires a knowledge of aircraft position and threat position.

Itenerant - All aircraft arrivals and departures other than local operations.

Local Operations - Flights performed by aircraft which operate in the local traffic pattern or within sight of the tower, or are known to be departing for, or arriving from, flight in nearby practice or operating areas.

Metering - The process of adjusting the arrival flow to the acceptance rate.

Mixed Airspace - Airspace containing aircraft flying under visual (VFR) and instrument (IFR) flight rules.

National Airspace System (NAS) - The common system of air navigation and air traffic control encompassing communication facilities, air navigation facilities, airways, controlled airspace, special use airspace, and flight procedures authorized by Federal Aviation Regulations.

Operation - A takeoff or landing by an aircraft.

Peak Instantaneous Airborne Count (PIAC) - The number of aircraft that are airborne over CONUS during the busiest instant of time in any particular year.

Positive Control Airspace - That airspace in which conformance monitoring by the air traffic management system of actual versus planned flight trajectories is performed to ensure separation of aircraft.

Primary Radar - That form of radar that depends upon reception of reflected electromagnetic energy for the detection of objects in the area under surveillance.

Proximity (Pilot) Warning Indicator (PWI) - An airborne device whose function is to warn a pilot of the proximity of other aircraft. It may also provide other information to assist the pilot in evaluating the situation, such as relative bearing and bearing rate of other aircraft, relative altitude, range, or combinations of these parameters. After visually locating the intruding aircraft, the pilot must evaluate the threat and select and execute an appropriate evasive action.

Regional Control Center (RCC) - The facility in AATMS which performs en route traffic management, serves as backup for the THC's and selected ACC's and coordinates with the regional flight service station to obtain weather data as required for regional level air traffic management.

Revenue Passenger Enplanements - The total number of paying (revenue) passengers boarding commercial aircraft, including originating, stopover, and transfer passengers.

Revenue Passenger-Mile - One revenue passenger transported one mile in commercial service.

Roll Call - A sequential surveillance interrogation of suitably equipped aircraft using the DABS technique.

Route-Time Profile - A flight path equivalent to a moving volume of airspace for which the altitude, cross-track, and along-track dimension limits are continuously (but flexibly) specified as a function of time for the entire route.

Sequencing - The process of ordering aircraft in a schedule.

Saturation Capacity - That number or flow of aircraft which will exceed airport or system capacity and lead to increased delays and possibly reduced safety.

Separation Standards - The nominal separations prescribed by the air traffic management system to ensure that the probability of violation of separation minima, and hence collision probability, is acceptably low.

Strategic Control - Strategic control of an aircraft by ATC implies long-term permission to fly a pre-determined conflict-free time-scheduled, three-dimensional flight path. ATC retains responsibility for authorizing, modifying, and monitoring compliance by the aircraft in executing the agreed flight path. Responsibility for executing the agreed flight path would remain with the pilot of the aircraft.

Synchro-DABS - A DABS-based concept using time synchronization of interrogation responses that allows use of time-of-arrival techniques to provide one-way DME and air-derived collision avoidance.

Tactical Control - A control concept in which an aircraft's flight path is modified through a series of ATC instructions, each guiding the aircraft through a short, collision-free segment of its intended flight.

Terminal Area - The bounded airspace and surface area in the vicinity of one or more (nearby) airports.

Track - The flight path of an aircraft over the surface of the earth.

Terminal-Hub Center (THC) - The facility in AATMS which performs transition control for ACC-to-RCC and RCC-to-ACC handoffs, traffic management within the larger hubs, and coordination with collocated flight service stations.

Transponder - An automated airborne receiver-transmitter from which a coded response is triggered by interrogation from a ground transmitter. Response normally contains information on aircraft identification, altitude and airspeed, and occassionally, heading, altitude rate, and position.

Uncontrolled Airspace - Airspace in which aircraft are not provided separation assurance or other ATC services.

Upgraded Third Generation (ATC) System - All components of the system for providing air traffic control service in the 1980's.

Very High Frequency Radio Omnirange (VOR) - A ground-based radio station whose signals can be received and decoded to give bearing-to-the-station information.

Visual Flight Rules - Rules of flight for aircraft under visual meterological conditions in which the pilot utilizes visual observations, and possibly IPC, to avoid collisions with other aircraft or obstructions.

Wake Turbulence - Tornado-like vortices generated at the wing tips of aircraft in flight and lasting up to several minutes which can cause aircraft encountering these vortices to lose control.

APPENDIX B

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