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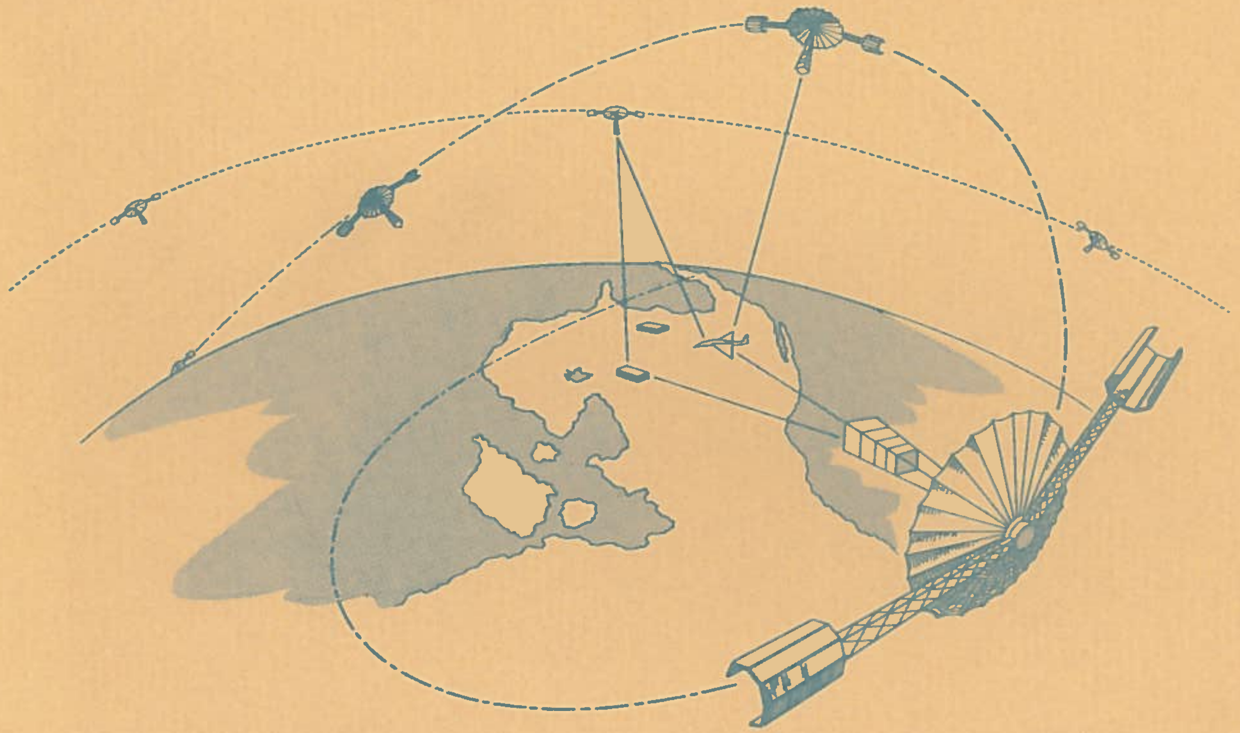
ADVANCED AIR TRAFFIC MANAGEMENT SYSTEM STUDY OVERVIEW



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16. Abstract

This report summarizes the U.S. Department of Transportation study and development plans for the air traffic management system of the late 1980's and beyond. The plans are presented in the framework of an evolutionary system concept of traffic management, building upon the Upgraded Third Generation Air Traffic Control System, and defined to meet the projected demands for service, safety, and flexibility in a cost effective manner. In order to provide the information needed for planning future system developments, a program of research and development is described for the system concept presented in the report.

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INTRODUCTION

PURPOSE AND SCOPE

This report gives an overview of the preferred concept for an Advanced Air Traffic Management System (AATMS), a design to accommodate air traffic growth during the post 1980 time frame.(1) Decision-supporting research and development activities related to attaining AATMS also are summarized.

AATMS was formulated and evaluated as a part of the Advanced Air Traffic Management System Study conducted by the Transportation Systems Center of the U.S. Department of Transportation under the sponsorship of the Office of the Assistant Secretary for Systems Development and Technology. This study was undertaken as a result of a growing concern by various agencies, including the Department of Transportation's Air Traffic Control Advisory Committee (ATCAC), that the Upgraded Third Generation Air Traffic Control System presently being developed for use in the 1980s might be unable to accommodate projected demands of the 1990s and beyond.(2)

Initial formulation studies supporting the selection of the AATMS Concept provided information on future air traffic activity, system and user operational modes, and subsystem performance requirements. A further definition and evaluation of the AATMS Concept included cost effectiveness evaluation, engineering research and development requirements, and the total impact of implementation of a Fourth Generation System on the existing or Baseline System.

HISTORICAL BASIS FOR THE AATMS SYNTHESIS

The AATMS Study is the product of a systematic evaluation and synthesis of the most attractive elements of several parallel studies. These studies were undertaken to provide a timely, orderly, long-range plan for an Air Traffic Management System designed to accommodate air traffic growth projected for the 1990 time frame. The AATMS Study seeks to address those areas of concern expressed in the Air Traffic Control Advisory Committee's (ATCAC) report, namely — limited terminal capacity, safe aircraft separation in high density airspace, and continuing escalating cost of air traffic control. AATMS is a hybrid system incorporating features of the Upgraded Third Generation System (as projected for the 1982 Baseline, a ground-based system), an Extended Upgraded Third Generation System, a Satellite-Based System, Strategic Control, and the application of extensive control automation.

The 1982 Baseline is a projection of the level and state of the Upgraded Third Generation ATC System in 1982.(3)

The Extended Upgraded Third Generation System Study is an examination of techniques and cost to effect alternatives in building upon the Upgraded Third Generation (1982 Baseline ATC System).(3) This study proposes the extension of the ground-based Discrete Address Beacon System (DABS) to that of Synchro-DABS, an advanced system which will integrate communication, navigation and surveillance functions. It also provides an optional air-to-air Collision Avoidance System (CAS) capability, and extends collision avoidance capability beyond the limits of surveillance capability design.

The Satellite-Based System provides surveillance, navigation, and communication functions from the ground level upward over the entire Continental United States (CONUS) region and far into the contiguous oceanic regions.(4,5) The system accuracy is enhanced in the high density airspace through the use of ground-located calibration stations. This system provides several possible navigation modes which allow equipped aircraft to compute position and ground speed. All required ground-to-air communications is provided through satellites for both en route and terminal airspace. All airports, control centers, and remote sites are interconnected through this satellite system. A selected constellation of 15 satellites is one proposal; 6 geostationary satellites with equatorial subsatellite points, and 9 satellites with inclined, eccentric, geosynchronous orbits (these subsatellite points share a common figure eight ground track).

Strategic Control is an advanced air traffic management concept based upon a central control authority assigning to each participating aircraft, a conflict-free, four-dimensional, route-time profile.(6) Those profile assignments are long term, as compared to present day short-term tactical control instructions. The route time profiles are determined in a manner that provides predictable and efficient use of air space and available runway operation time. This concept increases terminal area capacity, reduces air carrier delays, improves safety, and reduces controller work loads.

The automation study(7,8) defines the man-machine interface architecture projected for air traffic management in the 1990s. It also examines the prospective employment of men and machines as air traffic management is converted from labor-intensive to a machine-intensive activity.

AIR TRAFFIC DEMAND FOR THE 1990s AND BEYOND

In support of long-range planning, a projection of the air traffic environment in 1995 was made to estimate the demands that could be placed upon an air traffic management system operating in that time frame. The estimate of future air transportation demand used to estimate the 1995 air traffic environment was based on certain socio-economic trends forecast by the Federal Aviation Administration (FAA) and other Governmental agencies. These trends, i.e., population growth, shifts in population densities, consumer spending habits, and gross national product (GNP) levels determine the rate of expansion of specific factors and their impact upon future air traffic growth.(9) The principal factors considered are presented in the following paragraphs.

Public Demand for Commercial Air Transportation. The public demand for commercial air transportation is measured by two related parameters; revenue passenger miles (RPM) and revenue passenger enplanements (RPE). RPM represents the number of miles flown per year by airline passengers; RPE represents the number of paying passengers carried by commercial flights per year. Forecasts for both domestic and international flights are made periodically by the FAA using various parameters to estimate future passenger demands. These parameters include GNP, revenue yield per passenger mile, aircraft fleet availability, fare and route structures, passenger trip lengths, and a number of socio-economic factors such as income levels and population distribution. It is estimated that between 1972 and 1995 the number of revenue passenger miles and revenue passenger enplanements will increase by a factor of eight and six, respectively.(1,9)

Demand Characteristics. The impact of projected RPM and RPE demand upon the air traffic management system is only realized when the forecasts for the fleet size of air carrier, general aviation, and military aircraft are included in the analysis and total fleet activity is estimated. The FAA ten year forecast of air carrier aircraft is based on the number of each type of aircraft in the inventory and on order, projected passenger demand, and operating and performance data for each type of aircraft. By considering the rate of air carrier fleet growth, the trend to an all jet fleet, and accommodation of RPM and RPE, projections for air traffic growth can be extrapolated to 1995.

The 1995 estimated air carrier operations (takeoffs and landings) is based on estimates of average aircraft utilization and trip length figures and on trends determined by the Civil Aeronautics Board (CAB).(1,9) The forecast number of operations for general aviation aircraft is based on trends in annual utilization, average flight duration, and the distribution of flight time between itinerant and local use. The military activity within CONUS is expected to remain nearly constant over the next two decades.(2)

The peak instantaneous airborne count (PIAC) for the 1995 time period represents a demand measure which should be considered in the design of future air traffic management systems. This count (Figure 1) represents the number of aircraft estimated to be airborne over CONUS during the busiest instant of time during the year.(1,2,3,4,8,9)

Demand will have an impact on the design of the various subsystems that comprise the air traffic management system. The surveillance system capacity must be sufficient to handle all the cooperative aircraft within its coverage for the expected peak demand. Communications subsystems must be adequate to handle messages without unacceptable delays. Navigation subsystems must not deny or impair service to anyone in their zone of coverage. Various costly labor-intensive aspects of the control system have been traditionally dependent upon demand for service. Thus, future system cost can be constrained by breaking this interdependence.

Air Traffic Demand Summary. This study has estimated that growth in the demand for air transportation between 1972 and 1995 will result in the following:(10,11)

- An eight-fold increase in the number of revenue passenger miles
- A doubling of the air carrier fleet
- A 150 percent increase in the size of the general aviation fleet
- A tripling of the number of general aviation operations
- 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 one third of these will be under Instrument Flight Rules (IFR) in 1995).

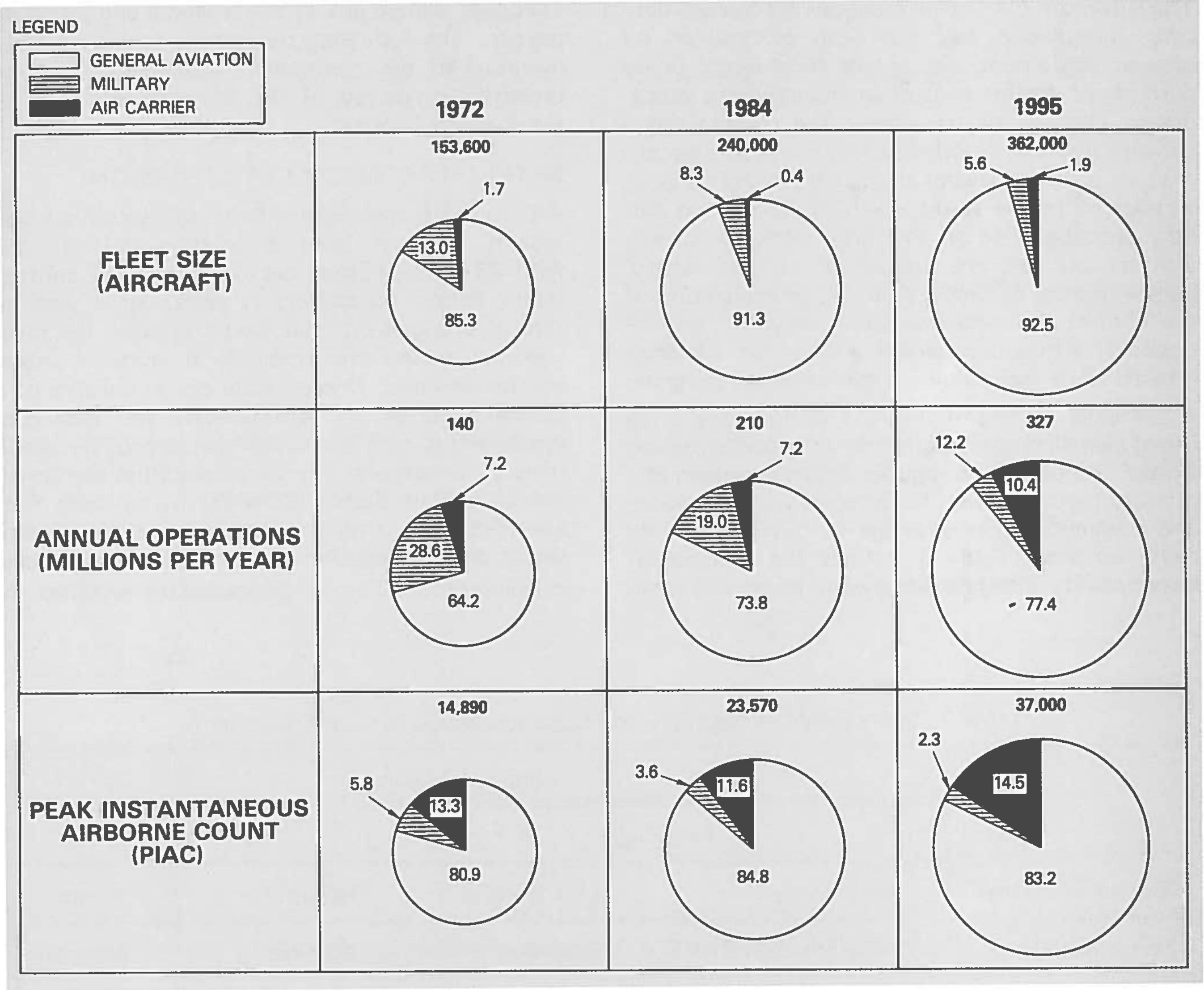


Figure 1. Projected Air Traffic Parameters

THE AATMS CONCEPT

The Advanced Air Traffic Management System concept formulation has not been constrained by present equipment, equipment technology or by current air traffic control or management procedures. The ability to achieve the recommended concept from the installed system in an evolutionary manner is one of several important tradeoff criteria considered in the study. AATMS retains the current philosophy of an air traffic management system by utilizing the following: tactical control augmented by Strategic Control, centralization of the control and data processing network, and increasing automation which allows for adequate growth while maintaining a cost-effective program.

A principal feature of the AATMS Concept is the use of a satellite constellation over the conterminous United States and contiguous oceanic regions as a primary mechanization for surveillance, navigation, and communication coverage in terminal and en route airspace. Table 1 defines the component responsibility interface for ground-based and satellite-based equipment in the terminal and en route regions. The following paragraphs provide a brief narrative of the component subsystems that are presently conceived as the principal elements of the AATMS Concept.

SATELLITE CONSTELLATION DESIGN

Although the engineering design of a satellite-based system has not been completely defined, the AATMS Concept Study has evaluated some constellation design parameters in search of a satellite sensor arrangement that would provide the most adequate surveillance umbrella at practical implementation costs. One possible design consists of a constellation of six geostationary and nine geosynchronous satellites which would provide simultaneous coverage at any location within the Continental United States (CONUS) by at least four satellites. This arrangement assures three dimensional aircraft location by the use of hyperbolic multilateration. The six geostationary satellites are

Table 1. Surveillance, Navigation, and Communication System Equipment

	Airspace Region			
	Terminal		En Route	
System Elements	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(4)	GC-RNAV(4)	

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.
(4) Ground Computed Area Navigation – An alternative navigation system where aircraft position information is obtained via satellite sensors, ground control stations, and certain aircraft location data.

in a circular, equatorial orbit, 22,000 miles above the earth. Their antenna viewing axes are centered about the 40°N parallel (Figure 2). Electronic packages aboard the satellites relay data and some voice communication between control centers and aircraft navigating in both en route and oceanic airspace. Four of the geostationary satellites, more centrally located with respect to CONUS, have additional equipment for relaying digital data transmissions between control centers.

The nine geosynchronous satellites are in inclined, eccentric, elliptical orbits that maximize the time of satellite visibility from CONUS. The orbits have an inclination with respect to the equatorial plane of approximately 80 degrees. The orbit inclination and eccentricity parameters define an elliptical orbit that places the point of apogee at approximately 29,000 miles above the earth at the 80°N parallel and the point of perigee at the 80°S parallel at a distance of approximately 15,000 miles above the earth. The type of orbit shown in Figure 2 provides good CONUS coverage. The nine geosynchronous satellites traverse a common ground track. Each arrives at the same point over the earth's surface at intervals of one sidereal day. In this example, the nine satellites equally spaced in a common orbit would arrive over the same ground point at a rate of one every 2 hours and 40 minutes.

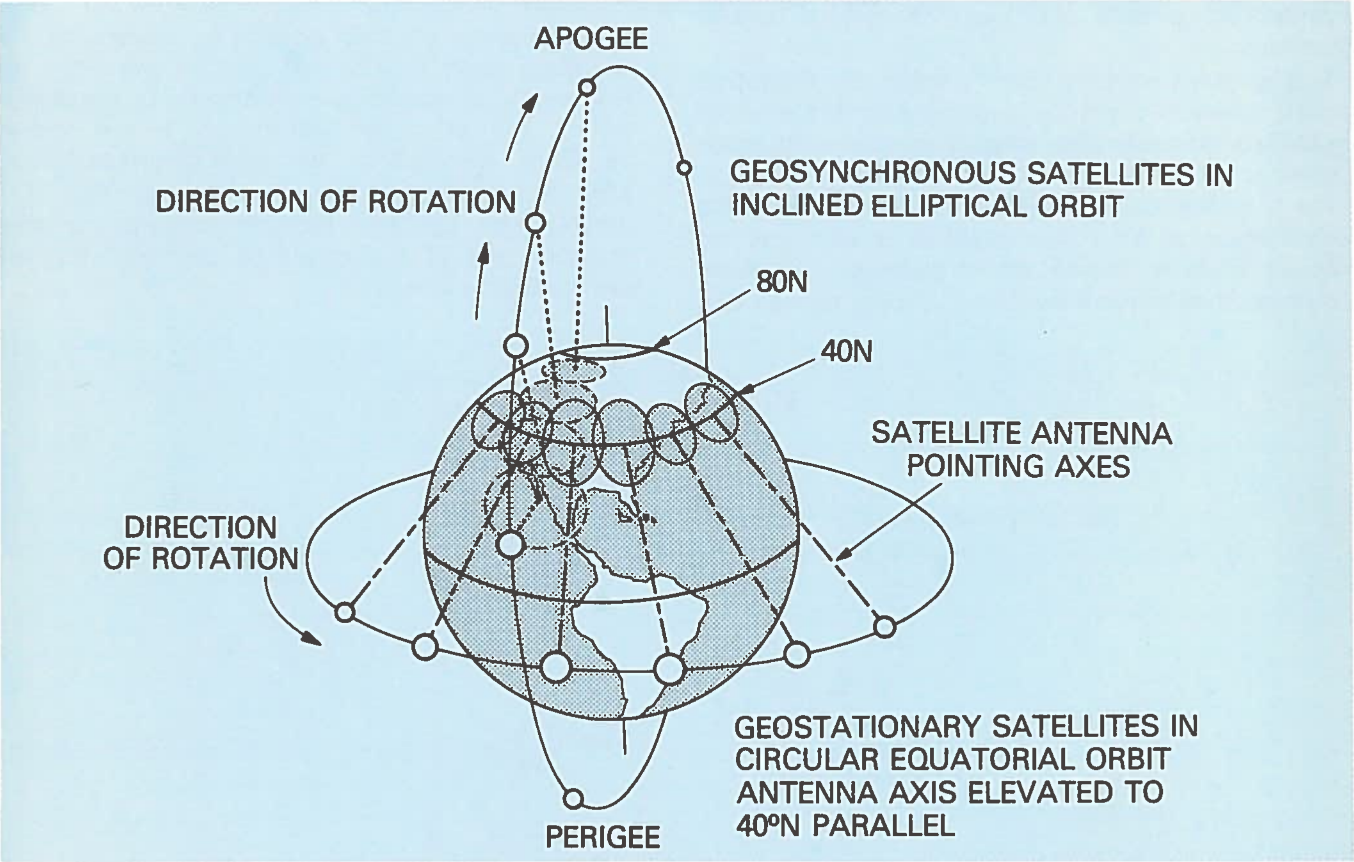


Figure 2. Geosynchronous and Geostationary Satellite Configuration

The succession of sub-satellite points of an inclined circular orbit produces a "figure eight" ground track (Figure 3). As the orbit becomes slightly eccentric, the upper loop of the "figure eight" becomes smaller and the lower loop becomes larger. The cross-point intersection moves into the Northern Hemisphere. The five "position" sketches in Figure 3 illustrate the satellite and earth kinetics required to achieve the figure eight ground track.

Three-dimensional hyperbolic multilateration techniques may be used to locate an aircraft position. These techniques depend on range difference measurements between several signal sources (satellites) and an aircraft. Each range difference localizes the aircraft to a hyperboloid-of-revolution having corresponding pairs of satellites as foci (Figure 4).(12,13) The aircraft position is determined as the intersection of a number of hyperboloids. At least three independent surfaces are required to locate a point in space. Thus, hyperbolic multilateration requires a minimum of three independent pairs of satellites, or a total of at least four satellites. To reduce measurement errors and assure the availability of signals on which to base position measurements, it is advantageous to use more than the minimum number of satellites. Weighting and filtering statistical methods can be used to determine a "best" position approximation from the collection of position estimates.

Figure 5 shows a collection of geostationary and geosynchronous satellite sensors functioning to receive and relay aircraft signals to ground-based data centers within CONUS. All of the satellites are tracked by ground tracking centers and since their (satellite) positions are known, they can act as signal sources (or receivers) for accurate surveillance and navigation measurements. The geostationary and geosynchronous satellites are equipped to relay surveillance signals, transmit navigation signals, and relay digital data transmissions from control centers to aircraft and from aircraft to control centers.

The selected satellite constellation configuration must provide down-to-the-ground coverage of all CONUS airspace and airspace in the contiguous oceanic areas. The number of satellites required in the constellation should be sufficient to insure the visibility of at least four satellites at all points and at all times in the region of coverage. The total number of satellites should be sufficient to maintain an adequate level of performance in case of individual satellite equipment failure, or aircraft signal degradation due to aircraft maneuvers resulting in fluctuations of satellite-received signal energy.

The basic surveillance principle is illustrated in Figure 5. The aircraft transmits a timing signal which is received by the constellation of satellites. The signal time-of-arrival (TOA) at each satellite depends upon the distance between the aircraft and the satellite. Upon receipt of the signal, each satellite retransmits the signal to a ground station. The ground station then utilizes differences in TOA and the known position of the satellites to calculate the position of the aircraft. Navigation functions much in the same way except the aircraft typically computes its position.

The accuracy of this system is limited by the accuracy with which the satellite positions are known, by propagation disturbances in the atmosphere, and by noise disturbances in the system receivers. Atmospheric and noise disturbances and satellite position errors are translated into TOA errors. The position location calculations thus translate the TOA errors into corresponding aircraft position errors.

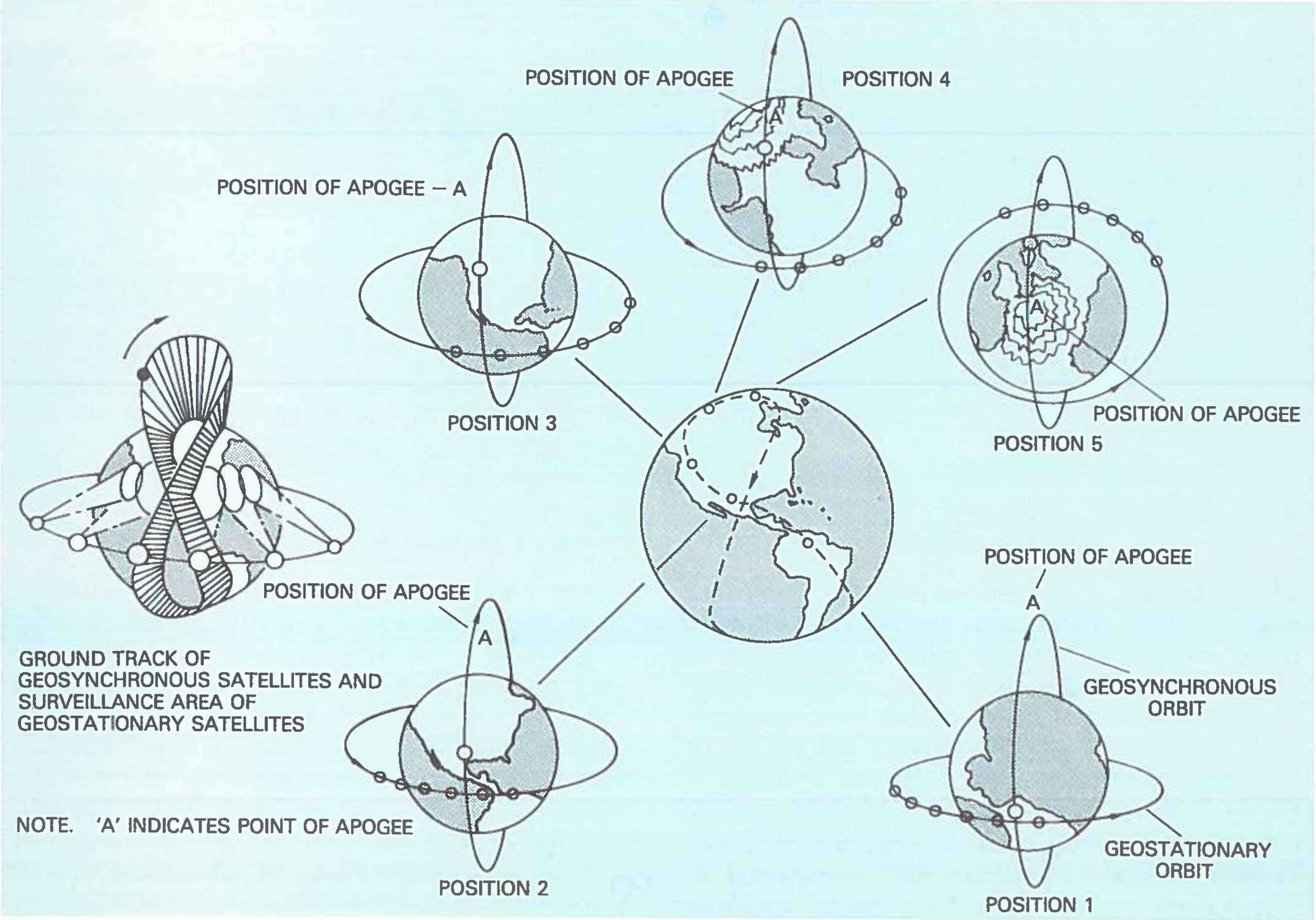


Figure 3. Satellite and Earth Kinetics Required to Achieve Figure Eight Ground Track

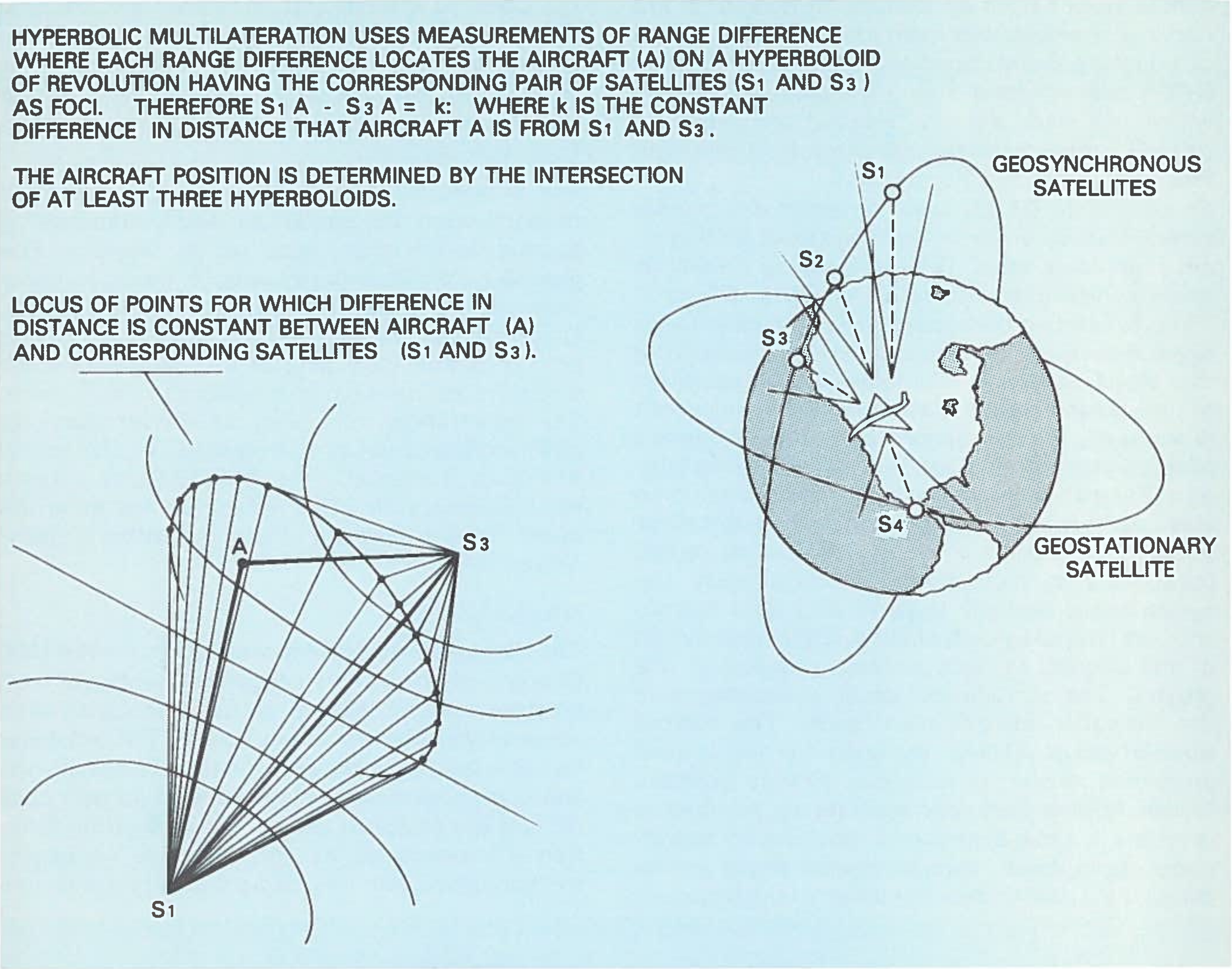


Figure 4. Satellite-Based Concept of Hyperbolic Multilateration

SURVEILLANCE AND DATA LINK COMMUNICATION EQUIPMENT

Surveillance and data link capability in AATMS will be provided by the Discrete Address Beacon System (DABS) in high density en route and terminal airspace regions and by satellite sensors in high density areas and the remote en route areas. The DABS sites will have Synchro-DABS capability to provide one-way ranging and Collision Avoidance System/Proximity Warning Indicator (CAS/PWI) functions to suitably equipped users within range of these sites. DABS is being developed by the FAA for the Upgraded Third Generation System(14).

In the 1982 Baseline System, DABS is assumed to have replaced the Air Traffic Control Radar Beacon System (ATCRBS) as the primary surveillance sensor. Under the AATMS Concept, 106 DABS sites will be retained. Each DABS site is expected to be capable of maintaining surveillance and digital data link communication with at least 2000 aircraft and have the potential of a theoretical maximum capacity of 6000. At each DABS sensor site, a list is maintained of aircraft for which that site must provide surveillance data and a communication channel. Addition of an aircraft to a DABS site's list (roll call) is accomplished using an acquisition mode, wherein an "all call" interrogation from the site causes an airborne transponder to reply with its pre-assigned address code. Alternately, a control facility can directly add an aircraft to a sensor's list by transmitting the address code and approximate position to the sensor. The DABS site maintains an approximate track of each acquired aircraft in order to know where to direct the next interrogation. Interrogations are time-ordered so that aircraft replies arriving at the site do not overlap. The timing of individual interrogations from the DABS site is set so that each aircraft responds at a precise reference time (T_R, as shown in Figure 6). One frequency (1030 MHz) will serve ground-to-air transmissions for interrogations and data link messages, and another frequency (1090 MHz) will handle replies from all aircraft transponders. The nominal time between interrogations, for purposes of updating aircraft position, is four seconds. Each DABS site will have a mini-computer installation which will track aircraft, maintain and order the roll call, format messages, and generate Intermittent Positive Control (IPC) commands.

In addition to DABS, satellite sensors will provide surveillance coverage in high density areas and remote en route areas. One mode using a satellite-based surveillance method is shown in Figure 7. Aircraft entering the system transmit a surveillance signal once every two seconds. The transmission of this signal pattern is maintained until acquisition by the ground station is achieved. When an aircraft is acquired, the surveillance computer performs a position computation and initiates a tracking function. Surveillance signals are now transmitted once every eight seconds, although more frequent transmissions may be initiated by the control center, particularly in high density terminal areas. Unsynchronized periodic transmissions from the aircraft are relayed by each satellite, within line-of-sight of the aircraft, to data processing centers on the ground. The surveillance signal is encoded with the aircraft's identification code. The relative times-of-arrival (TOA) are used by the ground processing center to compute aircraft position. Signals from at least four satellites are required to calculate a three-dimensional position of aircraft under surveillance. Aircraft transmissions are received by L-Band satellite receivers which convert the signal to C-Band and retransmit the information to satellite tracking antennas associated with ground processing centers. The processing center decodes the downlink signal to determine TOA and the aircraft identification (ID) code as received from each satellite.

The aircraft surveillance technique just described depends upon the aircraft randomly transmitting specific information, such as its identity. The ground-system determines what it needs to know from the asynchronously generated aircraft signals. Other surveillance techniques include time-ordered polling of individual aircraft so that each aircraft transmits its message in a relatively interference-free environment, or having the aircraft report its position based upon its own navigation calculations. The reader is referred to the AATMS Study — Technical Summary or other references for more detailed information on these surveillance techniques.(3,4,5,15,16)

NAVIGATION

The navigation equipment provided in the AATMS Concept offers various navigation techniques and provides suitable options to users equipped with various levels of airborne equipment. The constellation of satellite sensors used for aircraft surveillance and communication also provides navigation data for suitably equipped aircraft. The navigation function is implemented by either satellite navigation mechanization, requiring data processing equipment

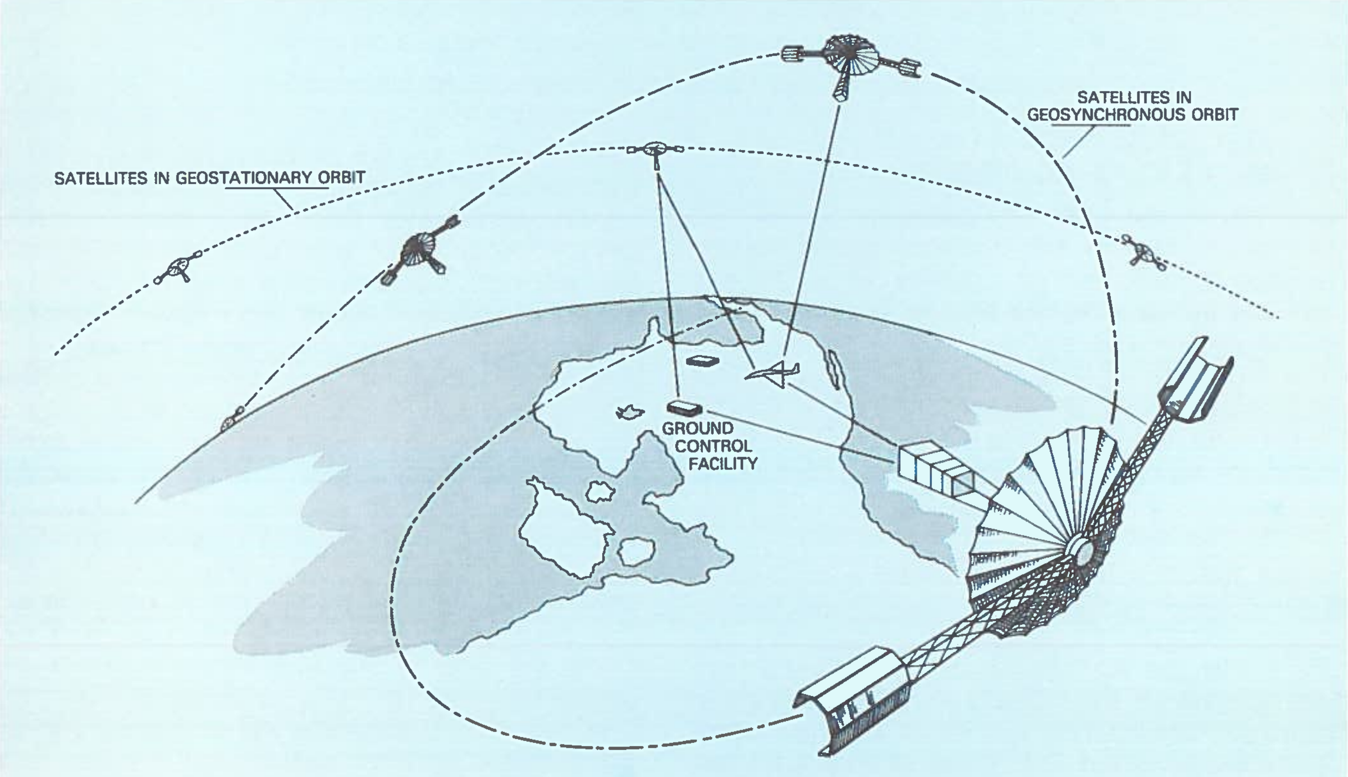


Figure 5. Using Satellites for CONUS Aircraft Surveillance

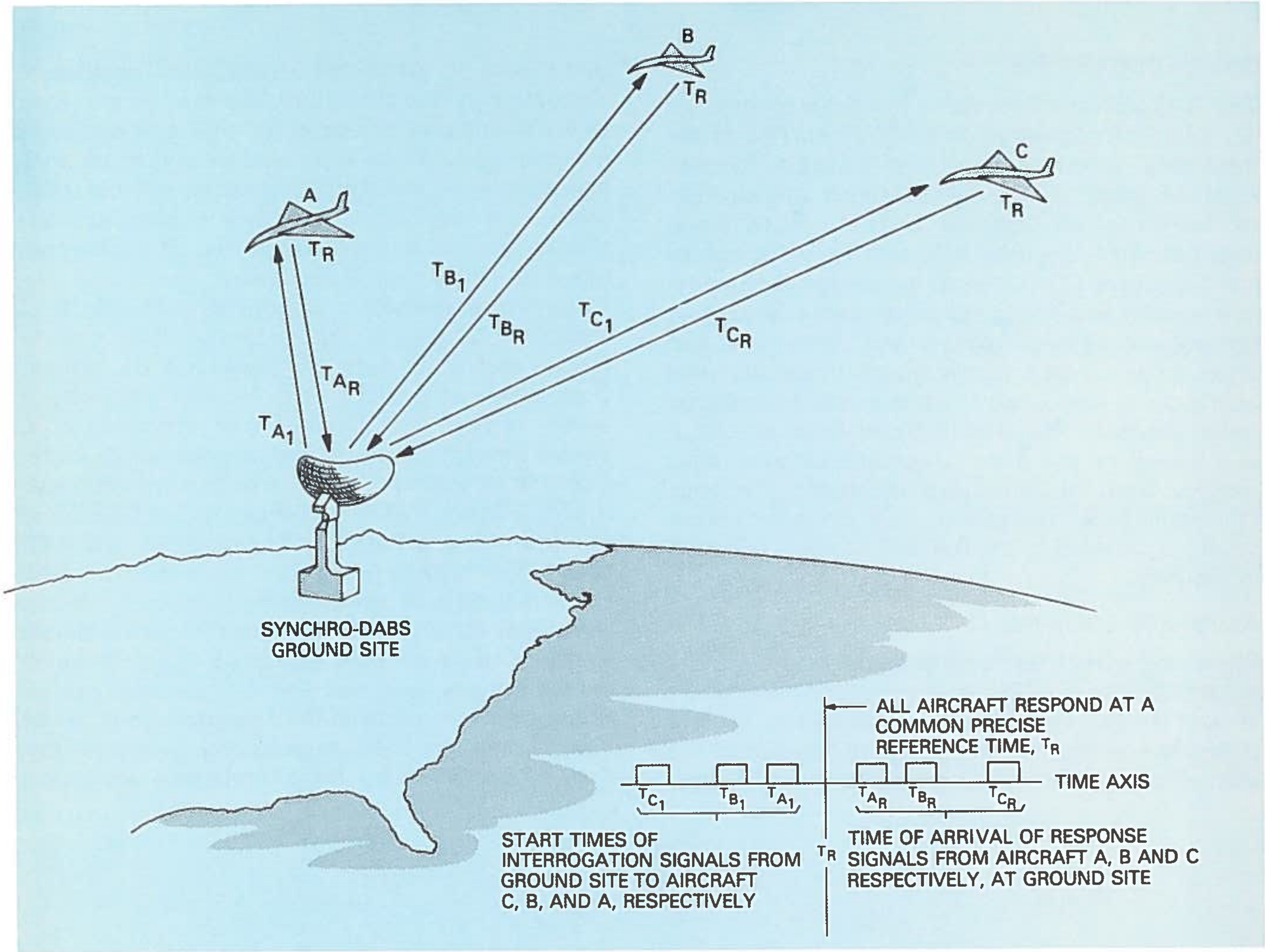


Figure 6. Synchro-DABS Interrogation Timing

on-board the aircraft, or by employing surveillance data with ground-based data processing to provide navigation and course guidance information to participating aircraft.

The first technique is independent of the surveillance function. The satellite sensor transmits time-ordered signals which include a precisely timed marker pulse. By measuring the TOA signals from at least four satellites, suitable data processing equipment onboard aircraft could compute three-dimensional aircraft position (Figure 8). The satellite transmits its ephemeris data with the time-ordered marker pulses. This navigation data is also used by the ground stations to confirm the satellite location and compute predicted satellite ephemeris data. The ephemeris data is transmitted from the ground station to the satellite for retransmission by the satellite to the aircraft as an integral part of the downlink navigation information.

The alternative navigation technique provided by satellite sensors is designated Ground-Computed Area Navigation (GC-RNAV). This technique uses aircraft position data derived from surveillance and aircraft waypoint or destination data provided to the control center, and ground-based data processing equipment to compute course guidance commands which are sent to the aircraft. This technique is useful in local flights where frequent selection of the next waypoint data is required and relatively short ranges yield acceptable cross-track errors. Another option in the second technique is based on the principle of distance-off-track where the ground track is defined as a great circle path between waypoints. This option is useful for long distance flights with a preselected route since the cross-track is independent of distance from destination.

Navigation service to minimally equipped users also can be provided by a network of 300 VOR sites which will be retained from the network of 900 sites currently undergoing modernization. Another navigation technique involving one-way ranging by suitably equipped aircraft to DABS sites also can be provided; however, multiple sites are needed to use this technique, or co-use with VOR equipment is necessary. These techniques are discussed in more detail in other AATMS Study material.(2,16)

COMMUNICATIONS

The AATMS Concept retains the direct air-ground-air voice links operating in the VHF portion of the frequency spectrum from the Baseline System. Approximately 1,100 ground-based transmitter-receiver sites in terminal and en route areas, together with the data link, will be sufficient to handle future CONUS communication system requirements. Satellite-based voice links will be used for oceanic airspace regions and these may also prove to be a cost effective means of serving users operating in low density terminal and domestic en route airspace. The satellite-based links also serve as a backup to the direct air-ground-air voice links retained from the 1982 Baseline System. The range of surveillance, navigation, and communication coverage provided in the AATMS Concept is shown in Figure 9.

AVIONICS EQUIPMENT

Six avionic user classes were chosen to represent the expected range of 1995 requirements for user needs as well as for flight service conformance. Table 2 shows the general equipment types for each of the user classes. These classes represent levels of capability and, in total, the diversity of equipment complements that the future fleet may be expected to install and use. It is expected that different users will carry avionics of different quality redundancy and degree of sophistication based on the cost, safety and level of service they choose, and the airspace in which they wish to fly. The minimum required equipment complement for mixed airspace is a surveillance transponder, data link (IPC) logic and displays, a voice communications transceiver, and some type of navigation equipment. Duplication of equipment to increase reliability is a user option. The flexibility of obtaining ATC service through a range of system-compatible equipments is an essential characteristic of the proposed AATMS Concept. The continued use of DABS and the Intermittent Positive Control (IPC) and ATC data links assures transition compatibility with many elements of the Baseline System, while the additional features that satellites offer are available to those users suitably equipped. Aircraft which are extensively equipped use satellite-based navigation techniques, deriving their position from signals sent via satellites. Satellite position information can then be processed by the aircraft area navigation

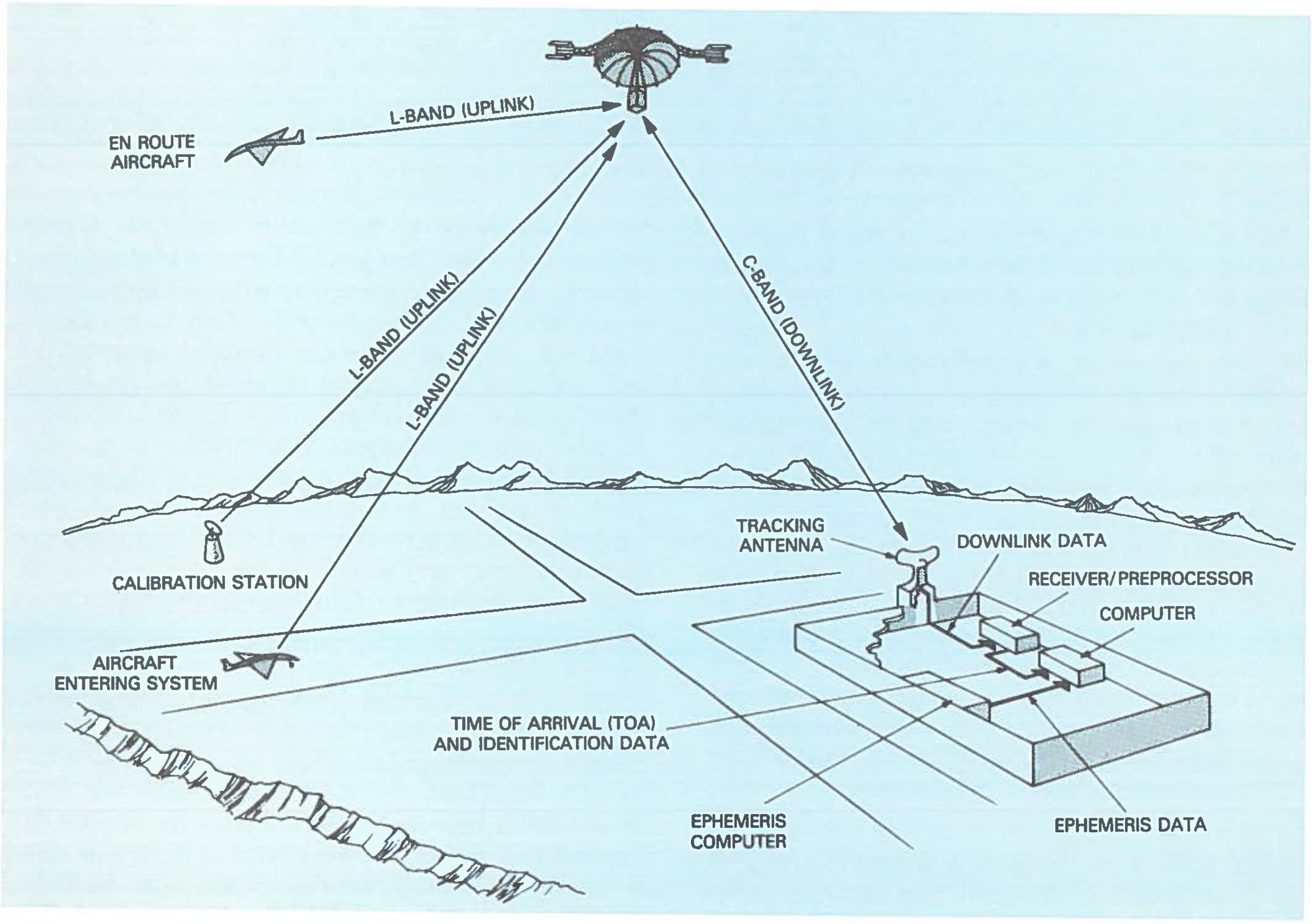


Figure 7. Satellite Surveillance Subsystem Functional Elements

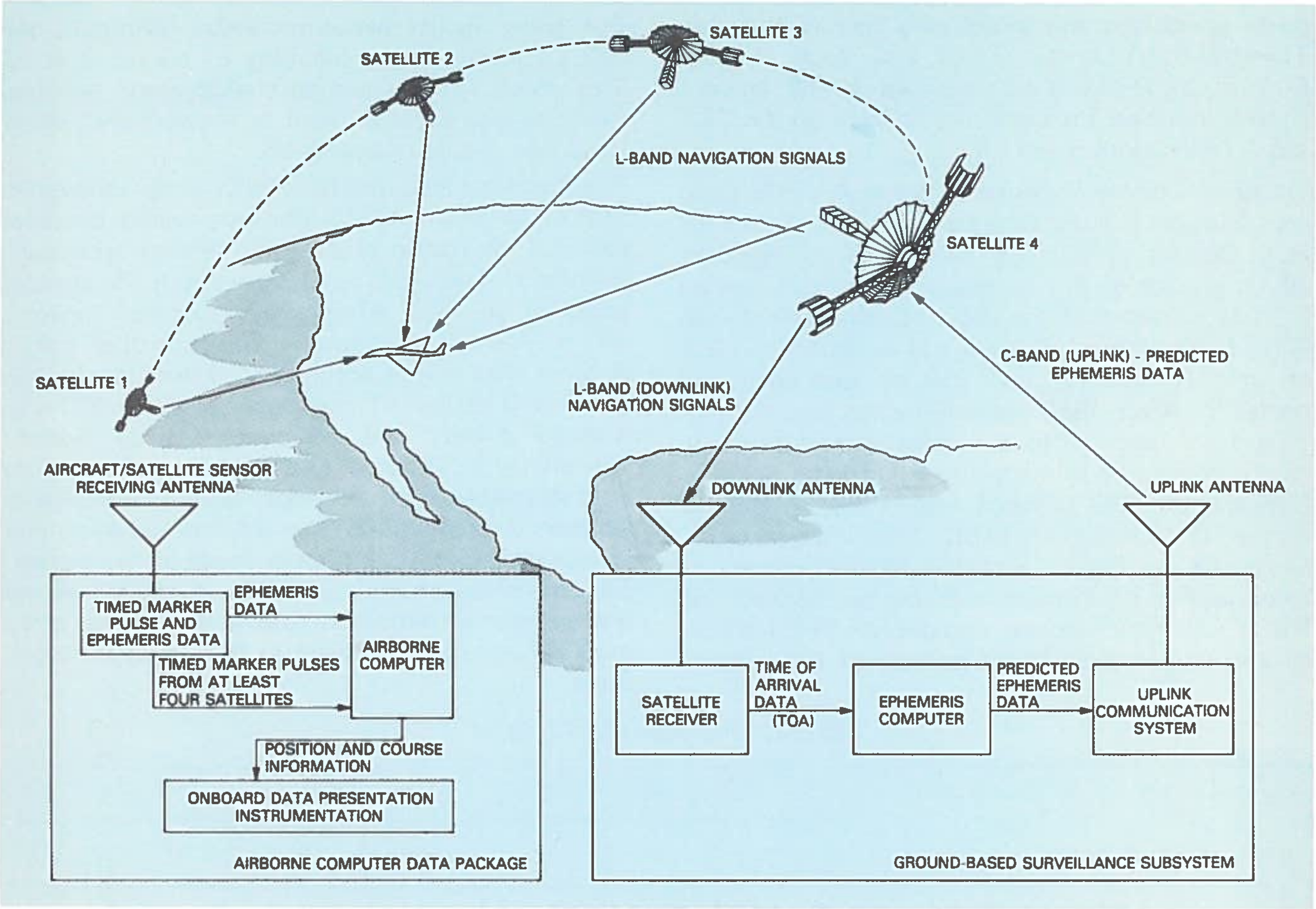


Figure 8. Navigation Technique Using Satellite Sensor Data and On-Board Computer

equipment. Users expecting to fly in strategically controlled airspace must be equipped with four-dimensional area navigation (4D-RNAV) equipment so that accurate conformance to route-time profile clearances is assured. Various area navigation equipment complexes are projected as useful to segments of the fleet. The satellite-based navigation system using Ground-Computed Area Navigation (GC-RNAV) technique offers less complex and less expensive navigation service to suitably equipped users, while the minimally equipped users could continue to obtain an inexpensive, but limited, navigation capability by using VOR navigation equipment.

CONTROL FACILITIES

The AATMS control and data processing facilities include three national en route control centers, twenty terminal-hub control centers, and terminal facilities at primary and secondary airports. A flight service center is associated with each level of facility control. Thus, control and flight service functions are integrated, enhancing the prospects of centralization of physical plants and the automation of tasks.

En Route Facilities. A single Continental Control Center (CCC) (Figure 10) performs national flow control functions and serves as the central conduit for management of system resources. The CCC coordinates with the National Flight Service Center (NFSC) to acquire weather data, system capability, and the information vital to national flow planning. In addition, the CCC serves as a backup to either Regional Control Center (RCC) in the event of computer failure or periods of abnormal operation.

The two Regional Control Centers in the AATMS Concept are assigned responsibility for the Eastern and Western Continental and oceanic regions. In its area of jurisdiction an RCC provides air traffic services for domestic en route traffic. These two regional facilities have consolidated the services provided by the twenty Air Route Traffic Control Centers (ARTCCs) presently in operation throughout CONUS. Each RCC will provide traffic advisories and perform handoff coordination for aircraft in adjacent oceanic control regions. The RCC coordinates with the co-located Regional Flight Service Center (RFSC) to obtain environmental data, system capability, and status information as required for regional-level air traffic management. Each RCC provides backup for the other in en route operations and serves as a backup for each Terminal-Hub Center (THC) and each Airport Control Center (ACC) within its region. The regional centers also have the capability to back up the CCC should conditions require it.

Terminal Control Facilities. In the AATMS Concept, Airport Control Centers (ACC) and Terminal-Hub Centers (THC) are two types of facilities which provide air traffic services in terminal areas. It is estimated that by 1982, approximately 492 Air Traffic Control Towers will be installed (133 at primary airports and 359 at secondary airports)[3]. After 1982, essentially no new control towers are expected to be needed except at new or newly designated primary airports. In the AATMS Concept the 492 manned towers are designated Airport Control Centers (ACC). Each ACC provides air traffic services for aircraft within its respective 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 the adjacent terminal facilities also permits them to support each other in backup modes of operation.

The Terminal-Hub Center (THC) is an innovative feature in the AATMS Concept which provides terminal air traffic services for remote secondary airports in major hub areas, but outside the control zones of an ACC. After 1982 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 approximately 227 unmanned towers will be controlled by twenty Terminal-Hub Centers. Centralization of terminal air traffic services for secondary airports is desirable because their relatively low volume operation can be maintained with minimum levels of manpower. The level of automation proposed in AATMS makes the concept of remote air traffic control not only practical but more efficient in the use of the work force.

Table 2. User Avionics By Class

Avionic Equipment	Avionics Classes					
	A	B	C	D	E	F
GENERAL FEATURES						
Interface Compatibility						
Ground-only					●	●
Ground and Satellite	●	●	●	●		
Redundant Equipment						
Dual Equipment Units	●	●				
Single Equipment Units			●	●	●	●
AVIONICS ELEMENTS						
Surveillance/Data Link						
DABS Beacon (Ground-only)					●	
DABS Beacon (Ground-Satellite)	●	●	●	●		
IPC Data Link/Display	●	●	●	●	●	
ATC Data Link/Display	●	●				
Altimeter 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	●	●	●			

Flight Service Centers. The National Flight Service Center (NFSC), co-located with the CCC, contains the central data processing facility and data base for the entire system. This data base includes not only the necessary data to conduct flight service station activities throughout CONUS and adjacent oceanic regions, but also all environmental information, 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 back up any HFSC which has sustained extensive failure of data processors.

There are twenty-three Flight Service Centers, one co-located with the CCC, one each with the two RCCs, and twenty co-located with the twenty Hub Flight Service Centers. The two RFSCs, co-located with the Eastern and Western RCCs, have three major functions. As operational facilities, they provide flight services for oceanic traffic. They also act as support facilities 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 HFSC to support any individual HFSC within its region.

The AATMS Concept incorporates twenty Hub Flight Service Centers (HFSC), which are co-located with Terminal-Hub Centers in sites formerly occupied by ARTCCs. Each HFSC supports approximately 175 remote, unmanned Flight Service Station (FSS) terminals. These 3500 self-service terminals are situated at airports or other con-

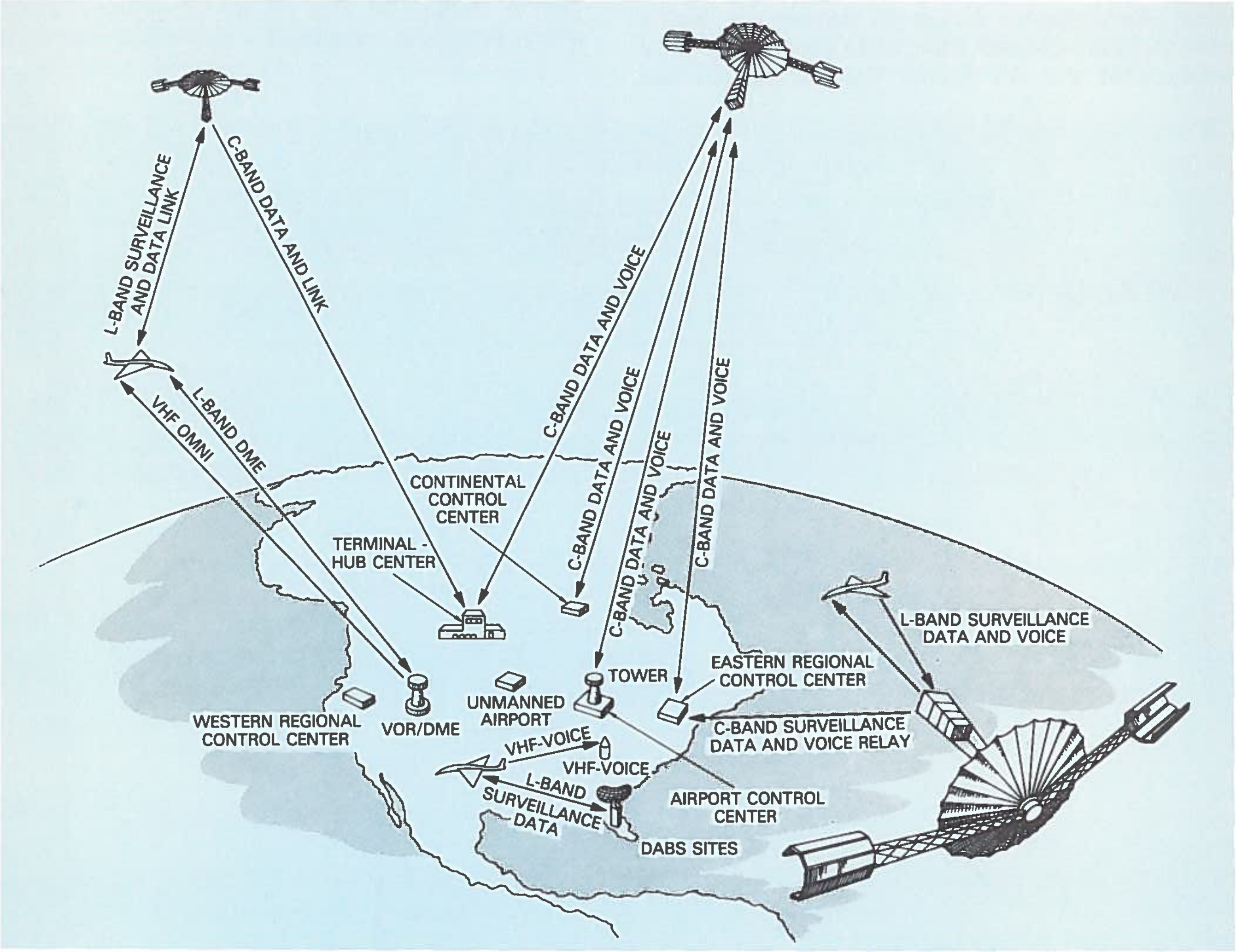


Figure 9. AATMS Surveillance, Navigation, and Communication Elements

venient locations. 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.

SYSTEM AUTOMATION AND STAFFING REQUIREMENTS

In a complex surveillance and control system, the greatest benefits of automation are achieved 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. Therefore, a detailed analysis of air traffic control operations was made to develop a complete list of functions, subfunctions, and tasks necessary to meet service demands of airspace users.

Task Assignments. A list of generic air traffic control tasks derived from an in depth functional analysis of the Air Traffic Control System was examined in light of the performance capabilities required to carry them out. An evaluation was made of each task to assess its suitability for assignment to man or machine resources. Each task was then ranked as to its suitability for automation. Five groups of tasks, which ranged from the most suitable to the least suitable candidates for automation, were then chosen. Man and machine resource requirements for each candidate grouping were calculated, and that which provided a complementary balance of human and automated constituents and satisfied the goals of safety and capacity was selected as an initial level of automation.

Major air traffic system functions that appear as candidates for automation are actually made up of many individual tasks, interrelated in complex ways. Because of those complexities, assignment of man and machine responsibilities was not made at the global level of functions but at the task leve where specific performance requirements could be more accurately assessed. Consideration of a number of variables indicates that automation of a system should be approached in discrete steps, where each step represents a viable and internally

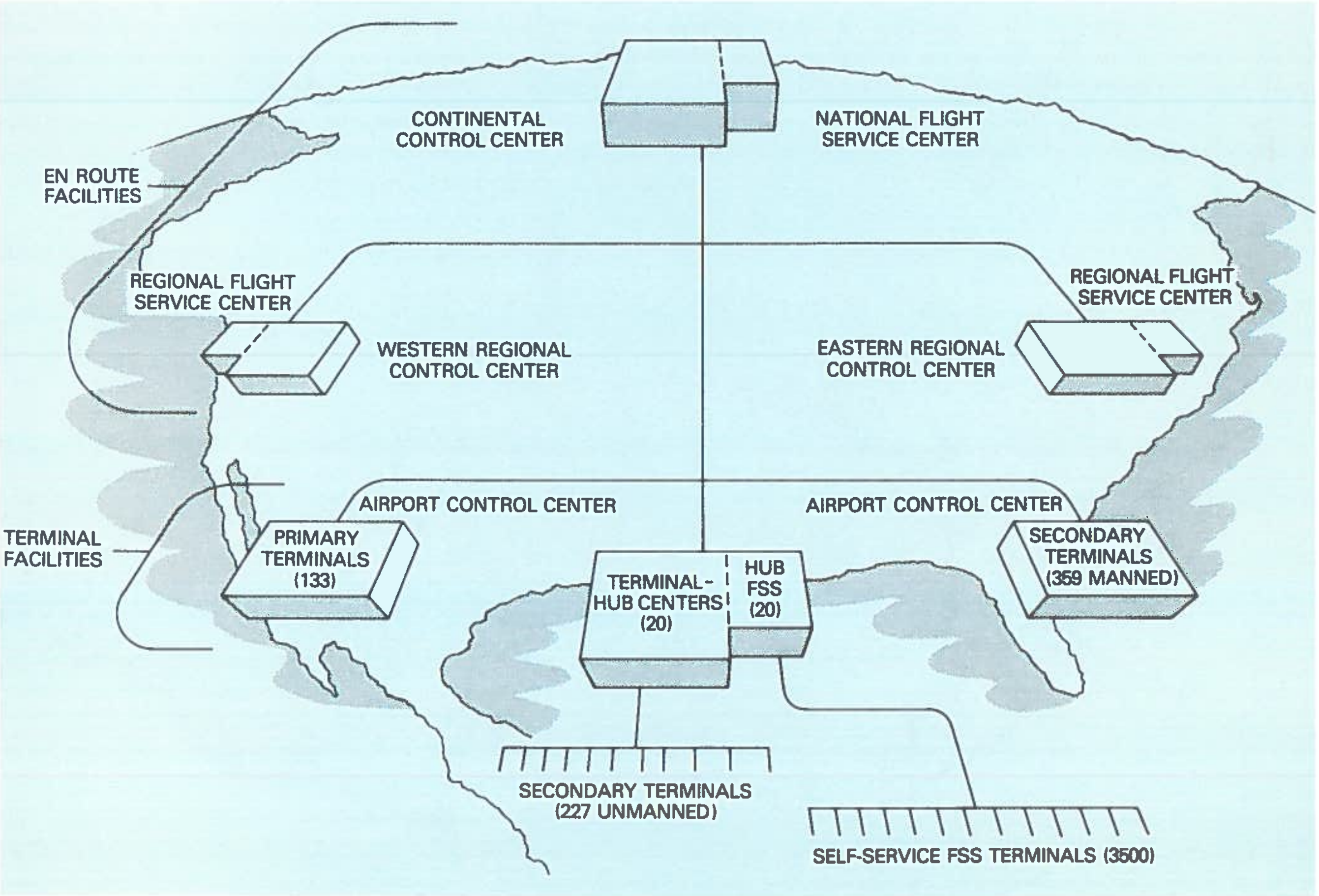


Figure 10. AATMS En Route and Terminal Control Facilities

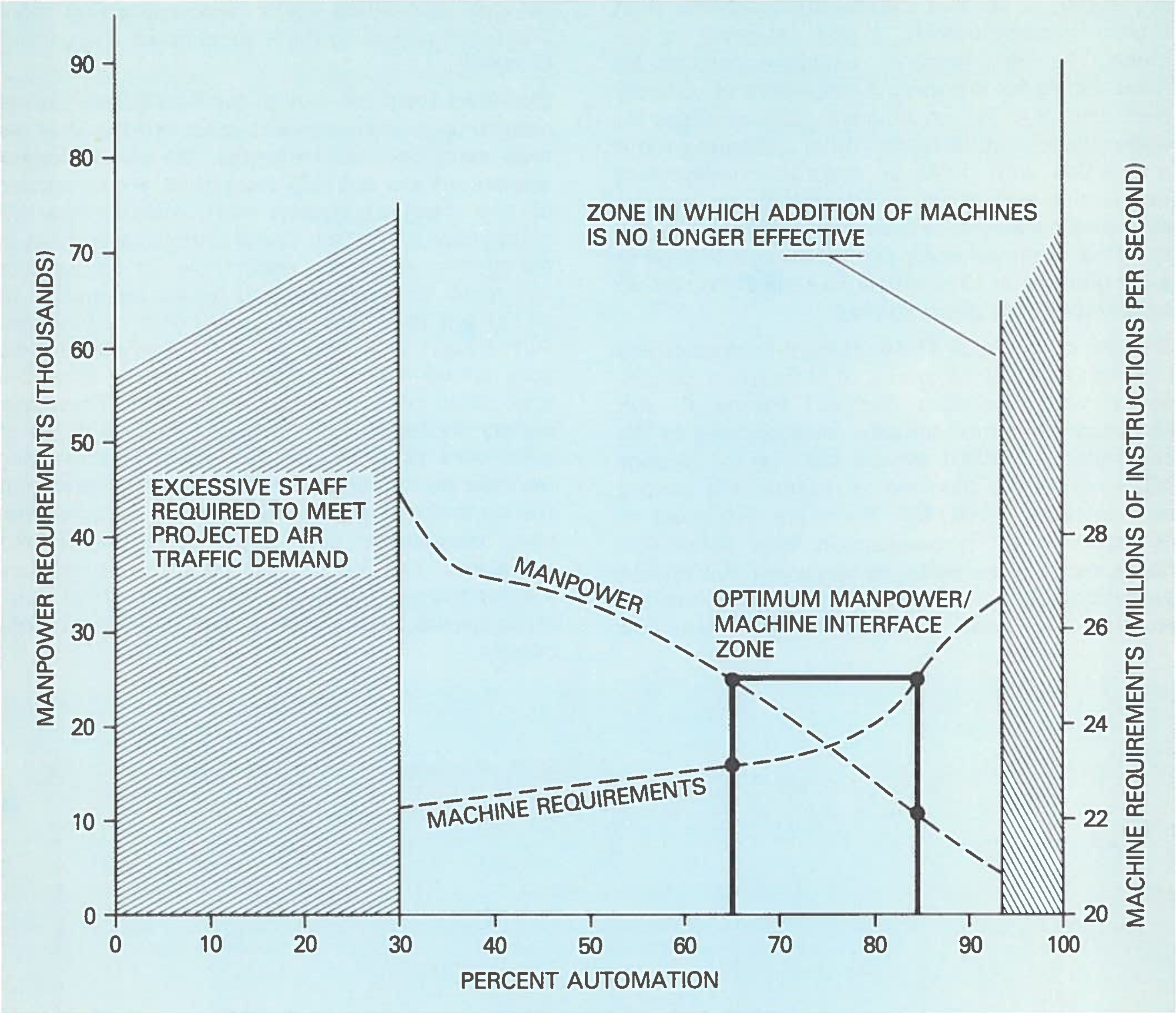


Figure 11. Man and Machine Resource Requirements At Successive Levels of Automation

consistent combination of man and machine resources. Calculation of the man and machine resource requirements for each of the candidate groupings indicated that the zone of maximum automation benefit occurred where machines were responsible for between 64% and 86% of the tasks, Figure 11. This is represented by the shaded portion in the figure. The machine resources curve begins to increase sharply beyond the region, though the manpower requirements decrease steadily throughout. A subsequent study was directed towards two ends. The first was to refine and adjust the allocation of task within the range of 64% to 86% of automation to find a set of functionally coherent man-machine task assignments which made best use of man's capabilities. The second was to test automation groupings which lay outside the 64-86% range to ascertain that this was indeed the zone of greatest automation benefit. It was found that a lower percentage of automation produced manpower requirements that were not significantly different from those projected for the Baseline System; i.e., about 30,000 controllers.(7,8,17)

The automation level recommended by the study is one in which approximately 70% of the air traffic control tasks are assigned to machines. This level of automation is not, however, uniform across all the major functions of the system. Some functions are fully automated, and others are wholly reserved for performance by human operators. Figure 12 shows the recommended degree of automation by individual function and by five major classes of functions. At the higher reaches of automation, substantial reductions in the work force could be achieved, at least theoretically, but the ability of man to control and manage the system was questionable. Generally, the tasks which are automated are those requiring computation, data processing, or routine and repetitive actions. Most routine decision-making is also delegated to machine. The tasks assigned to human operators are those calling for interpretive judgement of complex decisions. Man is also assigned responsibilities for tasks which require non-routine, communications interaction with pilots or negotiators concerning intent and authorization. Emergency services are exclusively a human responsibility. The role of the machine in these largely manual areas is to serve as a decision aid or to supply automatic alerts and act as prompters for the controller.

Staffing of AATMS. The workforce to operate and maintain AATMS is made up of three major personnel classes: Operators, Support Personnel, and Managers. Operators broadly corresponding to the controller and flight service staff in the present ATC system are required to perform the various manual tasks in AATMS. There are five types of operators who, in cooperation 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 (Table 3).

Operators form the core of the AATMS manpower requirements and represent almost two-thirds of the total staff. Support Personnel, the second largest element of the AATMS workforce, are comprised of two 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 a malfunction. Automation specialists are a new manpower category whose need is occasioned by the extensive application of automation in AATMS. These specialists are responsible for overseeing the status of automated resources and for aiding or correcting machine performance where necessary. The role of the automation specialist is to ensure the completeness, consistency, and adequacy of automated operations. The skill requirements for this category are not those of air traffic operations but of computer science, programming, and automation technology.

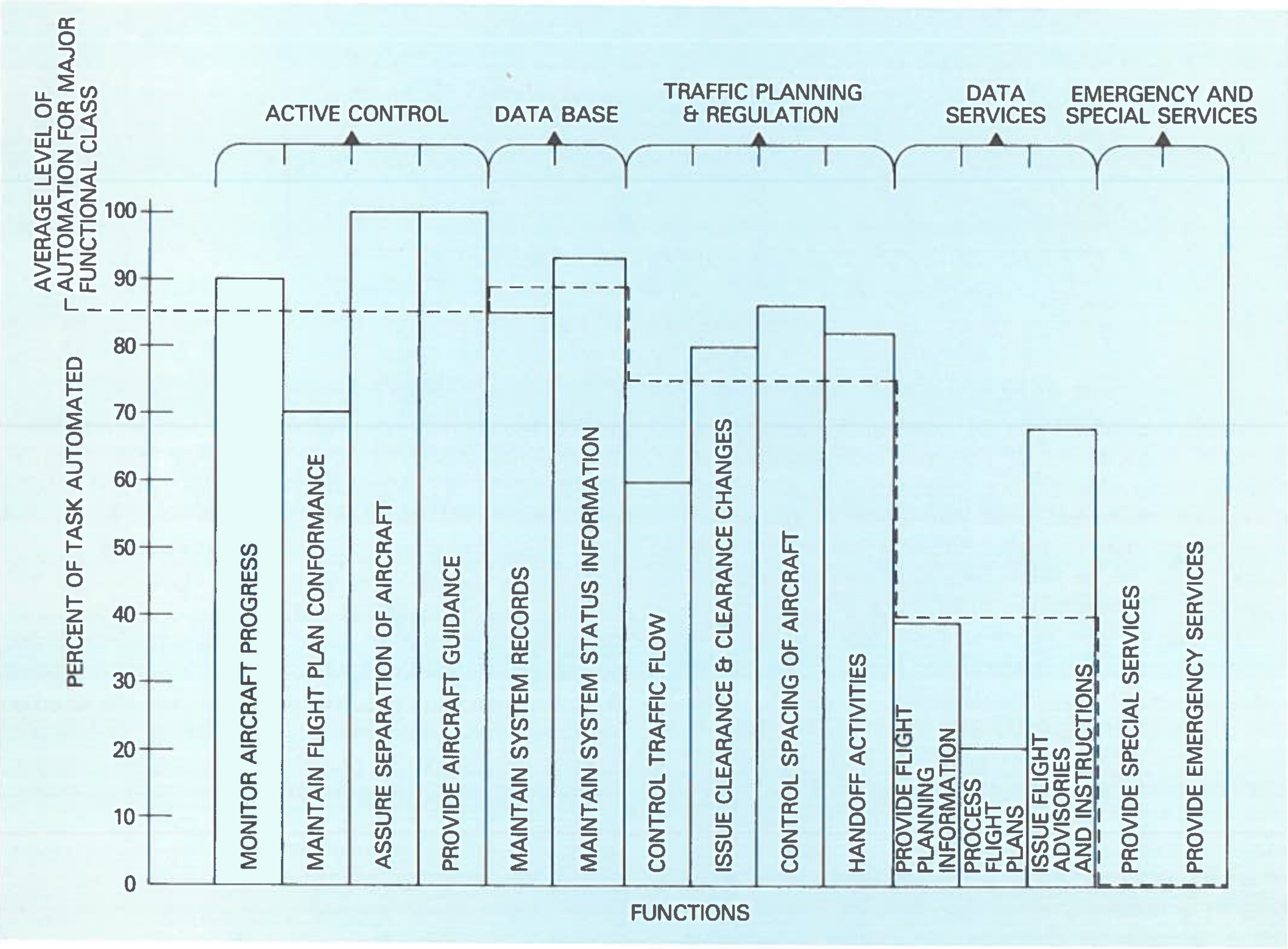


Figure 12. Recommended Level of Automation by Function

Table 3. Responsibilities and Assignments of AATMS Operators

Operator 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)

The third element of the AATMS workforce is the Manager. This personnel category is a direct outgrowth of increased automation in air traffic operations. It is at this level that the need arises for man to exercise control over the man/machine process and to coordinate the application of resources to meet demand for services. It is foreseen that three evels of management will be necessary in AATMS. First, there is direct overseeing of the human and automated resources carrying out operational tasks. This level is called supervisory and is roughly equivaent to the watch supervisor of today's ATC system, although with somewhat expanded concerns. AATMS supervisors will have three main areas of responsibility — load control (matching resource capacity to demand on a dynamic basis), resource assignment (distributing demand equitably across available resources), 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 coordination and management of all resources within a given facility, both in normal modes of operation and in degraded states, not with the direct supervision of individual resources. The types of responsibility are the same as at the supervisory level but the scope of concern is facility-wide.

At the topmost level of management are the System Directors, the highest echelon of managers. Their 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. It is envisioned that director-level personnel will 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. Table 4 lists the AATMS facility staffing requirements that are estimated for 1995.

Table 4. AATMS Facility Staffing for 1995

Facility	No. of Sites	Per Site Per Shift			All Sites All Shifts(c)		
		Operator	Support(a)	Manager(b)	Operator	Support	Manager(d)
CCC	1	115	35	60	403	130	130
RCC	2	200	60	68	1,400	420	350
THC	20	9	3	2	630	210	120
THC (HFSC)	20	119	36	31	8,320	2,520	1,900
Primary Airport	133	—(e)	—(e)	—(e)	1,850	560	700
Secondary Airport	359	2	—(f)	—(f)	2,500	760	600
TOTAL					15,100	4,600	3,700
					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

References: 7,14

SYSTEM OPERATING MODES, AIRSPACE STRUCTURE AND BACKUP MODES FOR 1995

The primary operating mode within which the control system normally obtains position information on each aircraft depends upon the equipment aboard each aircraft and the airspace region in which the aircraft is maneuvering. Satellite surveillance techniques would be used to obtain aircraft position information in en route, oceanic and low density terminal airspace. DABS would be used in the high density terminal airspace. Aircraft flying in mixed airspace capable of replying to interrogations from ground-based DABS sites would do so. Although they could not interface with satellite subsystems, they could operate in mixed en route and low density terminal airspace, providing DABS or Intermittent Positive Control (IPC) service is available. Depending on the estimated surveillance position errors, increased separation standards may be applied between aircraft operating with different surveillance techniques.

Figure 13 correlates operating modes and airspace structure with the control techniques proposed for the 1995 time frame. Within each airspace category, the primary operating mode and, in descending order, the next immediate backup mode of operation, are listed. Tactical Control modes back up Strategic Control modes. The lower the operating mode echelon, the greater the dependence on ground-based equipment for navigation data and for the maintenance of a conflict-free airspace. The avionic equipment shown under each airspace category provides the user with the capability of performing within the defined control modes.

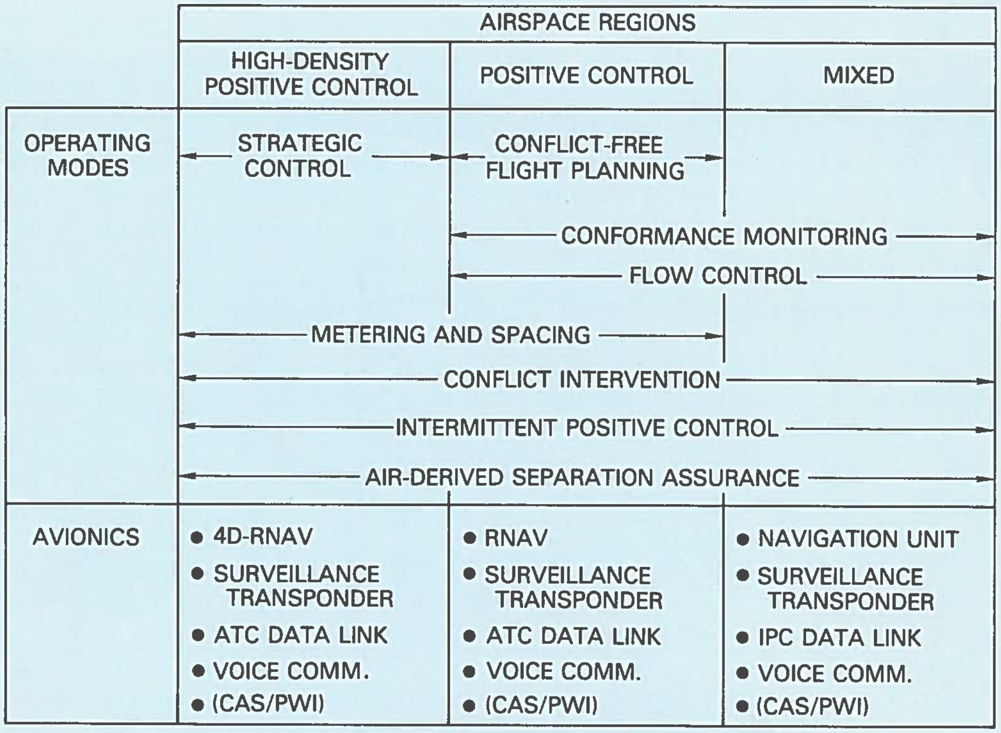


Figure 13. Operating Modes and Airspace Structure for 1995

The en route and terminal airspace structure proposed for use in 1995 is shown in Figure 14. The geometry of the structure is designed to be integrated with the various operating avionic levels and the operating modes proposed in the AATMS Concept. The 1995 Airspace Structure (Figure 14) has structural similarities to the 1982 Baseline System (Figure 15) but it is a product of design rather than necessity. The high density airspace region depicted in Figure 14 essentially serves the same function as the Terminal Control Airspace (TCA) and Extended Control Service (ECS) regions depicted in the 1982 Baseline System. The region designated as "Positive Controlled Airspace" in the 1995 structure would provide a positive control umbrella over the entire CONUS. This airspace would be under surveillance and aircraft maneuvering within it would be under control of the management system. In the high density positive controlled airspace, Strategic Control would be the primary control mechanization during periods of peak loading.

An objective of the Advanced Air Traffic Mana ment System is to maintain normal operation (degradation in either system capacity or safety) the case of ground equipment or user avion failure. Achieving fail operational status necessita an adequate matrix of backup modes for the s tem and the users. For the ground system, t would first be achieved through the use of redu dant subsystem equipment. Where mixed grou based and satellite-based system exists to se users that have a variety of capabilities, the back modes available are conditioned by two import factors: first, the service coverage of ground s tems employed in this concept is limited by line- sight restrictions, and their use as backup un requires the tacit assumption that aircraft will main within the coverage of the backup facili and second, users must be equipped compati with the backup subsystem.

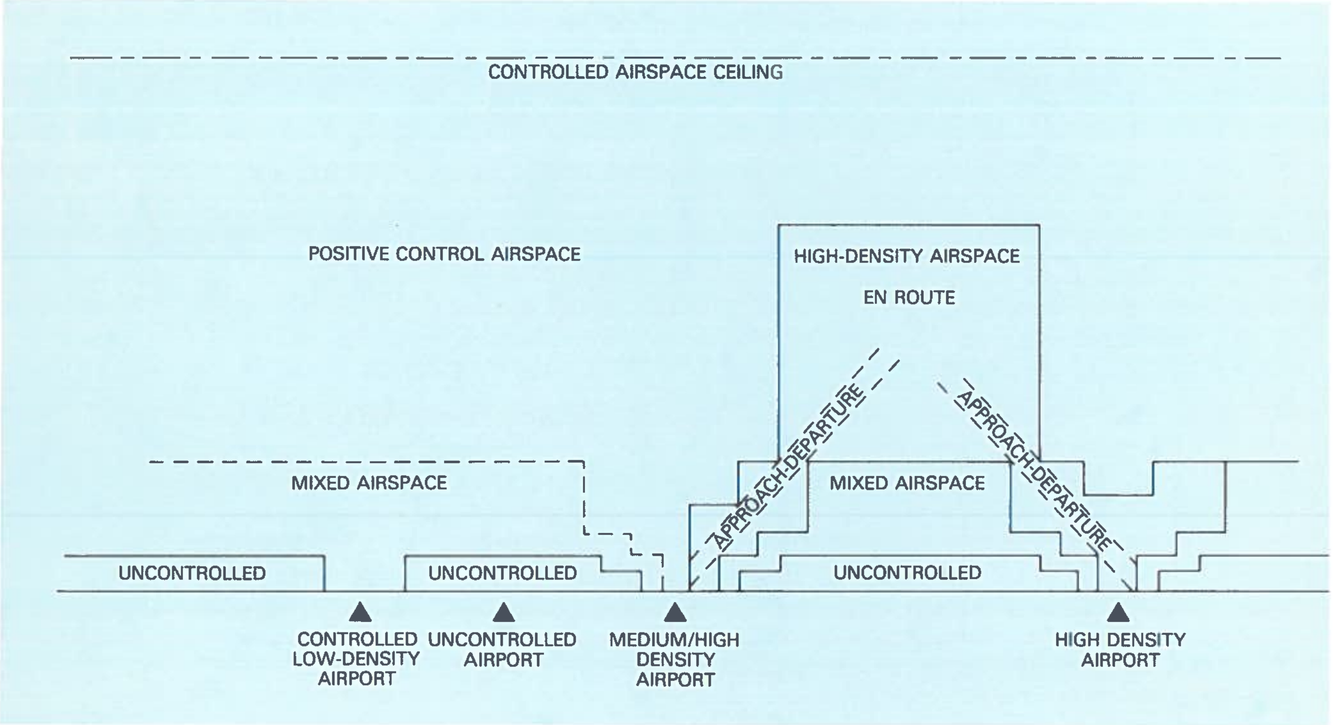


Figure 14. En Route and Terminal Structure-Elevation View

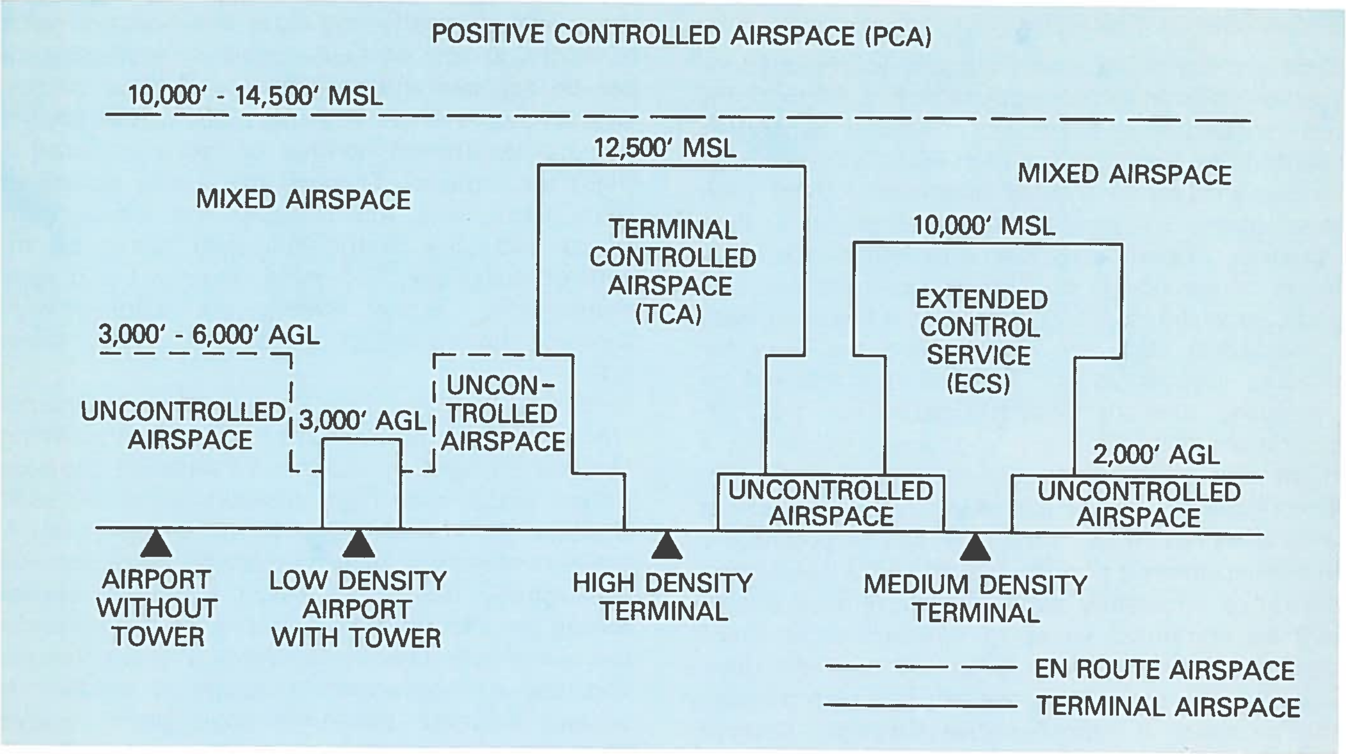


Figure 15. 1982 Baseline System Airspace Structure

Allowing for the line-of-sight limitations, ground subsystems functionally back up 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. Failure of some system elements may not be catastrophic; for example, degradation of one or more satellites in the constellation may only result n 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. 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 these equipments fail. However, they will be operating under visual flight rules (VFR) and the loss is not critical.

STRATEGIC CONTROL

Strategic Control is a centralized management control concept in which nonconflicting flight paths are pre-determined for all positively controlled flights. The clearance for each flight is transmitted to the airplane as a three-dimensional flight path description, to be flown according to a time schedule. Usually this clearance will consist of a series of waypoints defined in longitude and latitude, or with respect to the range and bearing from a navigation aid; the altitude and the time for making each waypoint. Separation is ensured 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 parameters such as fuel consumed or flight time, in addition to providing a conflict-free path through the airspace. A representative Strategic Control terminal arrival path is presented in Figure 16. It is assumed that a sequence of coordinate 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 milestone at the required time of arrival.

Strategic Control, characterized by dynamic, advance planning of nonconflicting flight paths and associated clearances by a central control authority, is an extension of the traffic control system presently used in the North Atlantic organized track system.(6) It may be envisioned as a concept in which the entire flight is scheduled from assigned takeoff time to threshold time and to time-of-arrival gate. Strategic Control will be most effectively applied in high density airspace to increase capacity, minimize delay, and improve 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.

Potential conflicts between controlled aircraft can be readily identified and resolved; encroachment upon 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 are reduced. Through the use of optimized route flight time, fuel consumption can be minimized and, due to the long-term nature of the control technique, controller workload and communications channel loading are reduced from those of the more tactically directed control methods.

Both equipped and unequipped traffic can operate from the same runway with proper flight planning If conflicts, system changes, or schedule slippages do not occur, each flight proceeds according to its Strategic Control clearance (route-time-profile). As a practical matter, these perturbing influences wil occasionally occur and hence require resolution during the flight and at a time when the nature o the perturbation becomes known. This preplanning and use of appropriately equipped aircraft to achieve accurate path-time compliance removes variables that otherwise introduce considerable randomness into system operation. The necessity for revising a flight plan will depend on an aircraft's ability to meet its next fix (fixes) on schedule, or its ability to proceed to its intended landing without conflicting with other strategically controlled aircraft. If the craft cannot reach a fix on schedule, or if conflicts arise, a new route-time profile that can accommodate the aircraft can be generated. This may require the resequencing o adjacent aircraft scheduled for specific times ove nearby fixes or runways.

Strategic Control would be used in particular portions of positive controlled airspace (High Density Positive Controlled Airspace) when flow, traffi density, or other conditions dictate. The capability of using Strategic Control procedures outside o high density positive controlled airspace exists, by the use of tactical control to reroute aircraft tha may encroach on the flight profile of a strategically controlled aircraft. This technique could be applied in Positive Control and Mixed Airspace where al aircraft must have a surveillance transponder, and a data link modem (capable at a minimum o receiving IPC instructions).

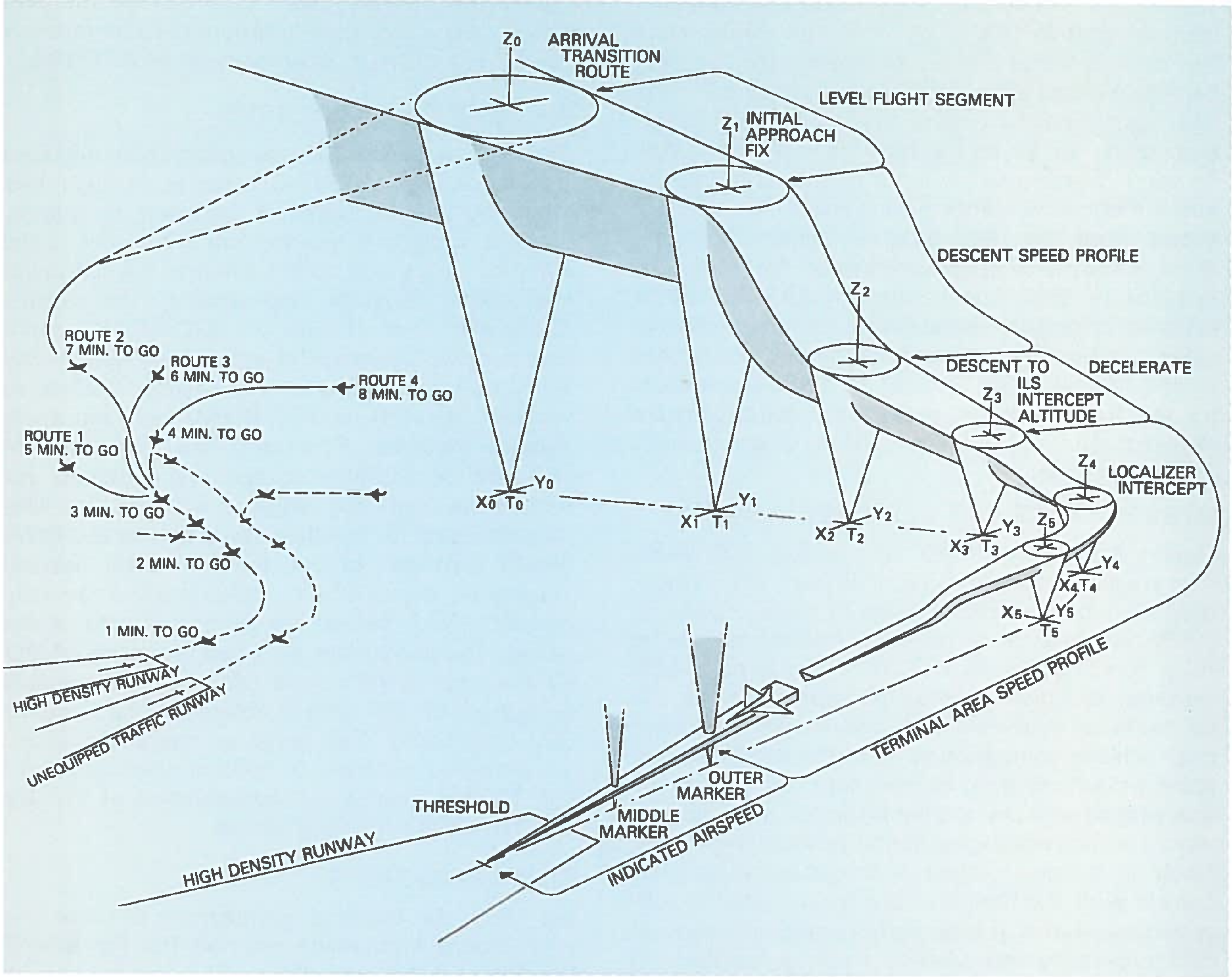


Figure 16. Strategic Control Terminal Arrival Path

IMPLEMENTATION APPROACH

The hybrid ground and satellite-based system concept selected in this study offers an implementation approach that will assure maximum conversion benefit in a cost effective manner. Transition to the new system will not cause any degradation in system safety or in its capacity to meet air traffic demand. System users will not be forced to operate with functionally identical equipment. AATMS will evolve from the 1982 Baseline System; however, those elements of the ground system forecast to be in place by 1982, but not part of AATMS, will be retained in parallel operation for ten years to allow sufficient time for implementation and conversion to the new avionics. Figure 17, a milestone chart for the AATMS Study, records the major program elements and the projected fiscal year for their implementation.

SURVEILLANCE DATA LINK SUBSYSTEMS

During the 1977 to 1982 time period, 106 DABS sites are planned for installation in high and medium density hub areas and in busy en route regions.(3) DABS will operate at the same frequencies and be fully compatible with ATCRBS. The initial DABS avionics, designed so that modular additions can be made, produce flexible options so that users may achieve compatibility with the satellite-based system mechanization at minimum cost as the new space-based services are incorporated into the system. The satellite experimental program will likely result in the deployment of several satellites compatible with the design of the future satellite subsystems and with at least partial implementation of data processing and satellite tracking facilities. If, during the 1978 to 1982 time period, a decision is made to implement the satellite-based subsystem, and additional satellites are launched, operational capability of the subsystem would be achieved between 1985 and 1989. When the subsystems are operational, users equipped with the basic DABS avionics can add satellite-compatible add-ons to receive satellite-based services at any altitude throughout CONUS. The DABS avionics would continue to operate at 1030 MHz 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. Services previously provided by the primary radar and the ATCRBS network would be phased out ten years after initial subsystem deployment. DABS or DABS/Satellite-compatible avionics, therefore, would be required in controlled airspace after the time period (1984-1988). Beyond 1982 no additions are recommended for these subsystems. The 106 DABS sites installed at high and medium density terminal and en route regions would be retained as a part of the AATMS program. The study assumed that weather and military requirements for primary radar data can be met wit
other means and that international commitmen
can be met without retaining radar or ATCRBS.

NAVIGATION SUBSYSTEMS

The current civil aviation navigation plan will cont
nue to use the VORTAC network through 198
Once the satellite system is deployed, by adding
satellite navigation receiver and processors to the
avionics, users can obtain satellite navigation se
vice. After satellite deployment, the Groun
Computer Area Navigation (GC-RNAV) servi
will provide down-to-the ground navigation cap
bility to users equipped with DABS/Satellite su
veillance, data link, and GC-RNAV logic and displa
avionic modules. Synchro-DABS one-way DM
will also be available to suitably equipped use
within the operating range of a DABS site. Use
not equipped for satellite navigation or GC-RNA
would continue to use the VORTAC networ
During the period 1994 to 1998, satellite navigatio
and GC-RNAV will be the primary means of nav
gation. The study plans a gradual reduction of VO
sites during this transitional period until the planne
base level of 300 sites is obtained. The remainir
300 sites could then serve as navigation aids i
uncontrolled airspace if residual user demand i
the 1990s indicates that continuation of this lev
of VOR service is cost-effective.

COMMUNICATIONS

By 1982, the Baseline complement of voice con
munications equipment planned for the Baselin
System will be completed. This equipment wi
continue in use throughout CONUS as part of th
AATMS program. Users expecting to fly in ocean
regions will need satellite-compatible voice con
munications equipment. If voice communicatior
through satellite facilities prove to be a cost effe
tive and reliable communications technique, as no
anticipated, users eventually may be expected t
convert from the present VHF equipment t
satellite-compatible equipment. Data link commun
cation is expected to be implemented in conjun
tion with the surveillance subsystems.

FACILITIES

The AATMS Concept requires a shift in the e
route and hub control authority from a distribute
approach to a centralized concept employing
Continental Control Center (CCC), two Region
Control Centers (RCC) and 20 Terminal-Hu
Centers (THC). The terminal control faciliti
would remain at 492 as presently proposed for th
1982 time frame. To assure safety during the tra
sition period, all aircraft operating within the sam
region would have to be under a single contr

authority although the surveillance data used for control might be obtained from different sources. 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 retained and transferred to operate the Regional Control facilities and Terminal-Hub Centers, respectively. Transfer of control authority from the Air Route Traffic Control Centers to the Terminal-Hub Centers should be complete by 1990. 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.

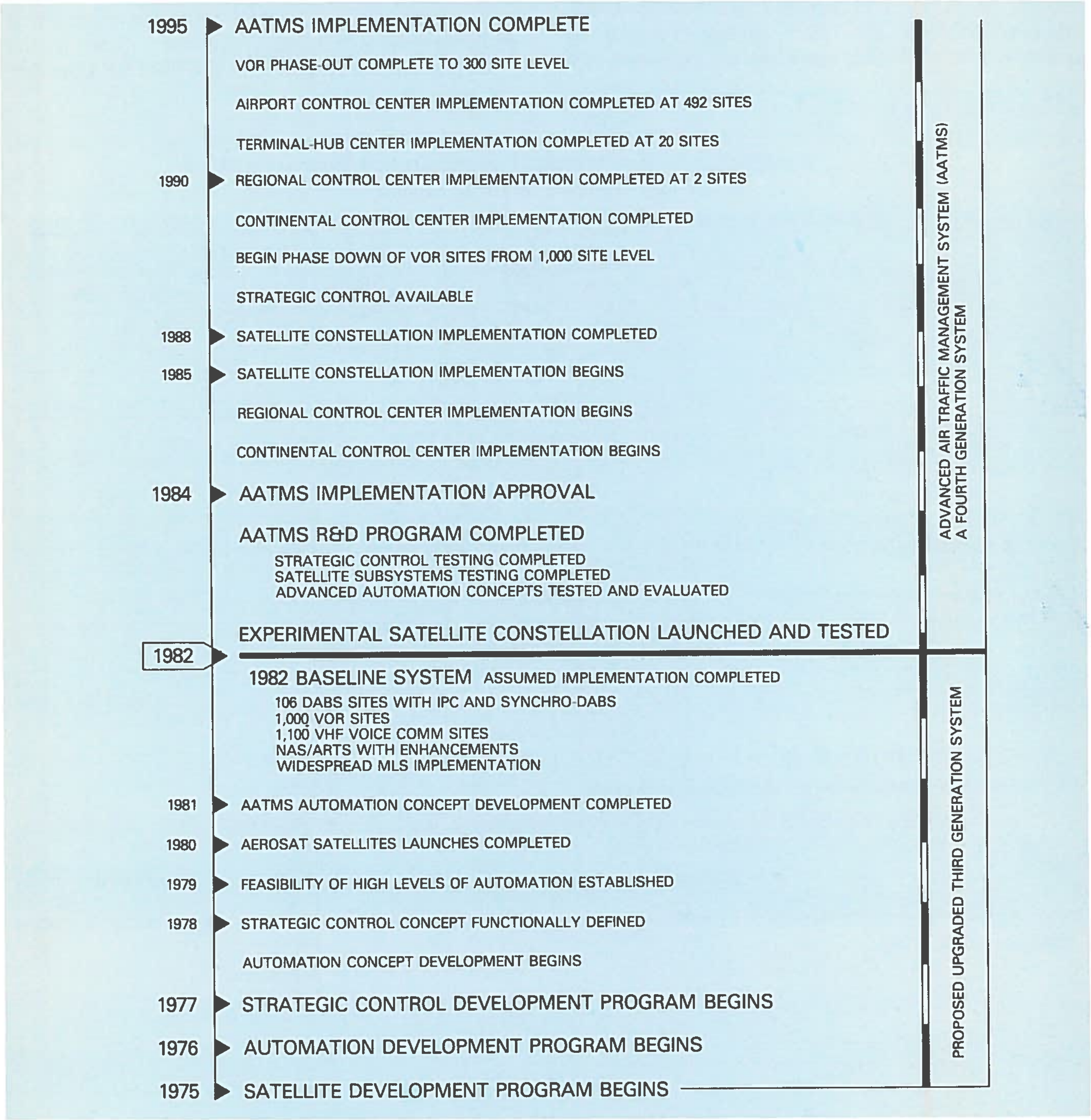


Figure 17. Implementation and Milestone Chart

COST ANALYSIS

FACILITIES AND EQUIPMENT COSTS

Surveillance, Navigation, and Communication Systems. The AATMS Concept calls for 10 to 15 synchronous orbit satellites to provide surveillance, navigation, and communication capabilities in all conterminous United States and nearby oceanic airspace. Based on two independent studies, satellite deployment costs were estimated.(3,4,16) In one study, the deployment of 13 satellites cost an estimated $97.5 million. Three Space Shuttle and Tug launches would be required, at $12 million per launch, for a total of $36 million. The total on-station F&E cost is $133.5 million, Table 5. In another study, fifteen satellites are required: six geostationary units costing $32.44 million and nine geosynchronous units costing $21.62 million. In addition, three Space Shuttle and Tug launches at a cost of $36 million would be required. The total F&E cost is $90.6 million. This cost is thought to be conservative based on the capabilities of the particular system design.

AATMS assumes the implementation of a 1982 Baseline System concept that includes 106 DABS sites to service high density terminal and en route airspace regions, and the retention of three hundred VOR sites from the Baseline System. No appreciable change in Baseline VHF voice communication equipment is projected. Therefore, there are no F&E expenditures required in the AATMS Concept.

Table 5. 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
DABS/Synchro-DABS	106	$.827(1)	—
SATELLITES			
Geostationary(2)	6-7	$5.4-$11.8	$55-$100
Geosynchronous(2)	6-9	$2.4-$5.5	
Launch of Satellites(3)	3	$12.0	$35
Satellite Tracking Centers	7	—	$ 2
Calibration Stations(4)	50	—	$ 2
Ground-Based Communications(4)	1,100	—	—
VOR	300	$.280	—
COST TOTALS			$90-$135

(1) Unit cost for DABS installation at existing radar/ATCRBS sites is estimated to be $233,000.

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

(3) 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.

(4) Retention of the baseline ground-based voice communication subsystem is assumed as a backup to the satellite-based communications function.

References: (3, 5, 16)

Control Facilities. The Continental Control Center and Regional Control Centers are assumed to be completely new facilities. The Terminal-Hub Centers (THCs) are assumed to be located in the buildings of the present ARTCCs, and the Airport Control Centers (ACCs) are assumed to be located at already existing tower facilities, Therefore, building costs for the THCs and ACCs are minimal and only reflect modernization. It was also assumed that the building and modernization costs were proportional to the size of the staff at each site since building size and accoutrements are dependent on the number of occupants. A total cost estimate of the software requirements for future air traffic management system have been made in several studies and in each, software costs have been approximately $100 million. The costs were allocated in this effort to each facility in the following proportions: CCC – 15%; RCC – 30%; THC – 35%; and ACC – 20%. This allocation is based on the assumed relative complexity of the functions to be performed at each control facility and the assumption that a commonality of programs would exist between similar sites. Table 6 lists the F&E cost by facility for the AATMS Concept.

Table 6. AATMS Facility Costs – Facilities and Equipment Costs
(All Costs in Millions of 1973 Dollars)

Facility Type	No. of Sites	Unit F&E	Total F&E
CCC-Continental Control Center	1	$33	$ 33
RCC-Regional Control Center	2	49	97
THC/FSC-Terminal-Hub Center and Flight Service Center[1]	20	16	315
ACC-Airport Control Center (primary or secondary airport)	492	–[2]	635
Totals			$1,080

[1] Includes co-located flight service facilities.

[2] Unit site F&E highly variable among different sites.

OPERATIONAL AND MAINTENANCE COSTS

Surveillance, Navigation, and Communication Systems. The same studies used to determine the F&E costs also were used to estimate the annual O&M costs.(3,5) These costs were determined using the estimated seven-year lifetime for the satellite equipment and dividing the F&E cost by seven. Thus, O&M costs for the first satellite concept are one-seventh of the total F&E of $133.5 or $19 million annually. If the F&E cost of the other system concept is used, annual costs are about $12 million. Additional system-level costs of about $34 million annually for the voice communications system O&M, $5 million for the VOR System, and $4 million for DABS sites also were estimated in this study. The annual surveillance, navigation, and communication operation and maintenance costs projected for the 1995 time frame are listed in Table 7.

Table 7. Surveillance, Navigation, and Communication Subsystem Costs
(Costs in Millions of 1973 Dollars)

Subsystem	Annual O&M Cost in 1995(1)
DABS/Synchro-DABS	$4
Satellites	
Geostationary	$5-$10(2)
Geosynchronous	
Launch of Satellites	$5
Satellite Tracking Centers	$2
Calibration Stations	—
Ground-Based Communications	$34
VOR	$5
Cost Totals	$55-$60

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

(2)Satellite lifetimes of seven years were assumed.

References: (3,5,17).

Table 8. AATMS Facility Costs — Operation and Maintenance Costs
(All Costs in Millions of 1973 Dollars)

Facility Type	Annual O&M (1995 for Facilities)	No. of Personnel(1)	Annual O&M (1995) for Personnel(2)	Total Annual (1995) O&M
CCC-Continental Control Center	$ 3	654	$ 13	$ 16
RCC-Regional Control Center	11	2,176	45	56
THC/FSC-Terminal-Hub Center and Flight Service Center	47	13,750	284	331
ACC-Airport Control Center (primary or secondary airport)	112	6,924	144	256
Totals	$173	23,504	$486	$659

(1)Includes controllers, support, and managerial personnel.

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

Control Facilities. Operation and maintenance costs of the control facilities do not include the control work force or the staff whose costs are discussed below. The facilities O&M costs are dominated by the costs associated with the control/display computer, data processing, and memory O&M. These cost estimates were based on the initial F&E expense for these items assuming seven-year and ten-year lifetimes, respectively.(5) Interfacility communication equipment O&M costs also were estimated. In the AATMS Concept, the O&M cost reflects retention of the existing 1982 ATC network.(3) Considerable savings could be achieved by implementing interfacility communication through the system satellites. These critical functions by a satellite-based system should be studied further, especially in relation to backup mode operation. Communication subsystem costs were apportioned according to the number of control personnel at each type of facility. The annual operating costs for these facilities would be $174 million dollars and approximately $486 million dollars would be required to pay the staffing salaries.

Salaries for controllers, support personnel, and managers account for about 75 percent of the annual operating and maintenance cost. Table 8 lists the operational and maintenance cost for maintaining the AATMS facility complement in 1995.

A summary of the annual 1995 manpower cost estimates are provided in Table 9. These estimates are derived from estimated staffing levels for AATMS and are stated in 1973 dollars based on assumed nominal salary levels for each personnel category.(7)

Table 9. Annual Manpower Cost Summary
(*1973 Dollars)

Staffing Category	No. Personnel	% of Workforce	Annual Salary (thousand $)*	Annual Manpower Cost (million $)*
Operator	15,138	64.4	20	302.76
Support Maintenance	3,056	13.0	18	55.01
Automation	1,530	6.5	16	24.48
Manager Supervisor	2,122	9.0	25	53.05
Executive	1,592	6.8	30	47.76
Director	66	0.3	40	2.64
Totals	23,504	100.0	—	485.70

AVIONICS EQUIPMENT COSTS

The costs of avionics subsystems required to interface with elements of the recommended sensor and control system have been estimated based upon the results of several independent studies.(3,5,18,19) These studies assessed preliminary equipment designs, and then assessed the fabrication and installation costs based on current equipment practices. The avionics cost data from two studies were used to indicate a range of costs for each of the six user classes presented earlier. This was done to reflect the uncertainty associated with projecting future avionics costs. Representative avionics costs for the six user classes for both a DABS-compatible satellite system (Table 10) and a system based on asynchronous aircraft surveillance transmission (Table 11) are presented in this report even though it is anticipated that a wide variety of avionic subsystems will be available.

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 various equipment complements presented in Tables 10 and 11 was determined to be between $5,300 and $6,100 million dollars. Some of these costs represent the retention of compatible equipment from the 1982 Baseline System. A phase-in period will allow users to interface with new system features in consonance with equipment life-times and amortization periods.

Table 10. AATMS Avionics Costs by User Class Based on Those 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

References: 3 and 16.

Table 11. AATMS Avionics Costs by User Class Based on Those for an Asynchronous Satellite-Based System

Class	Avionics	Unit Cost	Package Cost
A	Dual Surveillance, Digital Communications, Voice Communications, and Navigation Receiver and Processor	$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, and 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	$ 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	$ 8,500
	VOR Receiver	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

References: 5 and 16.

BENEFITS OF AATMS

The AATMS surveillance, navigation, and communication mechanization concept has advantages and disadvantages which affect both system personnel and system users. However, of those concepts that have been examined, the AATMS Concept is the most cost effective program or mechanization alternative. This is due to the use of satellites to meet future air traffic management operational requirements as projected for the 1990s and beyond.(16) More definitive information and test results are needed to support detailed mechanization considerations in determining system design. To acquire this data, additional research and development (R&D) is required. Table 12 lists the major advantages of the AATMS Concept as well as the principal disadvantages that provide somewhat offsetting obstacles to an immediate acceptance of this proposal.

ASSESSMENT OF SATELLITE-BASED SURVEILLANCE, NAVIGATION, AND COMMUNICATION

The AATMS Concept, embracing a hybrid DABS/Satellite system mechanization, provides an effective and balanced system approach. The DABS sensors provide coverage for large numbers of aircraft maneuvering in relatively small but dense traffic regions in which system reliability is critical. The proposed satellite constellation provides extensive, supplementary coverage of larger, but lower traffic density, airspace regions, thus minimizing the number of ground-based sites required for maintaining coverage of en route airspace and remote, low density terminals. Additional benefits derived from AATMS include improved surveillance and navigation position determination capability which enables an increase in capacity while continuing high safety standards. A satellite constellation also provides a common grid for surveillance and navigation, minimizing coordinate conversion and sensor registration problems. Also, satellites using hyperbolic multilateration are capable of determining aircraft altitude without reliance on airborne barometric altimeters or altimeter encoders.

The system backup modes rely on the strength of two compatible, independent systems, each capable of providing backup to the other in critical failure mode operations. The implementation of AATMS will reduce the pilot's workload by providing new system-oriented avionics which require minimum frequency changing. The AATMS Concept also reduces navigation complexity by the introduction of a new navigation technique, Ground-Computed Area Navigation, which can provide direct routing data to any suitably equipped aircraft.

ASSESSMENT OF CONTROL FACILITY CONFIGURATION

Centralizing the control facilities, a primary consideration in the AATMS Study, is expected to provide improved efficiency and lower system operating and maintenance costs by requiring a smaller workforce. Greater flexibility is possible when a centralized pool of controllers, computers, and resource data can be allocated as the requirement for air traffic management tasks arise throughout the en route CONUS region. The peak instantaneous load requirements for the two Regional Control Centers are lower than the sum of those requirements of the present twenty Air Route Traffic Control Centers (ARTCCs). Reserve capacity to handle peak loads can be time-shared by the two Regional Control Centers, whereas the ARTCC must have its own reserve capability to handle peak busy-hour traffic for its individual region. Aircraft handoffs and data exchange will be greatly simplified in the Regional Control Centers compared to the existing intercenter coordination in the ARTCC where exchange capability is influenced by the Centers' proximity to each other.

High operating efficiency and reliability is achieved in this concept through the interlocking backup modes of flight service facilities afforded by the hierarchical structure of AATMS. The benefits of centralizing the control facilities were difficult to estimate since no decentralized system concept is available for comparison. Rockwell International, using an assumed automation level and a centralized control facility configuration, estimated the annual savings of just the facility configuration to be over $100 million dollars.(5) An independent analysis by the Rand Corporation arrived at similar cost figures.(19) 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 centralization.(19) This additional facility would require a staff complement of about 1,700 people at an annual cost, in 1995, of about $37 million dollars. The additional facility cost would exceed $8 million annually to operate and maintain in that same time frame. To provide comparable capability in the hub areas, an additional $12 million dollars would be required for facilities and $70 million dollars per year to staff them. Thus a noncentralized facility concept would entail annual costs of approximately $127 million over the proposed costs of the centralized facility concept of AATMS.

ASSESSMENT OF PROPOSED CONTROL AUTOMATION

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 multipurpose resource sharing computer network and a fail-operational design philosophy. Cost savings are possible because workload, information, program, and specialized hardware sharing is possible with a linked computer system. Also the large data base, existing at one location, is accessible and capable of being shared by other facility elements in the network. 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 function.

Table 12. Major Advantages and Disadvantages of the AATMS Program

Advantages	Disadvantages
Surveillance, navigation, and communication coverage provided down to the ground throughout CONUS. Air Traffic management services available at all air fields including all remote locations. Provision of more economical air traffic management services than the Baseline System. $600 to $800 annual operations and maintenance cost savings due to advanced automation techniques . . . with respect to present labor intensive air traffic control to meet projected 1995 demand. $100M annual operations and maintenance cost savings due to facility centralization . . . with respect to the Extended Upgraded Third Generation System. $50M annual operations and maintenance cost savings due to satellite/DABS sensor configuration . . . with respect to the Extended Upgraded Third Generation System. Reduced subsystem facility and equipment costs due to universal coverage provided by satellites . . . with respect to the Extended Upgraded Third Generation System. Increased airport capacity and more efficient use of high density positive control airspace by use of Strategic Control in place of tactical control modes.	Limited test data related to the performance of satellite-based surveillance, navigation, communication, and associated avionics. Inability to modify the impact of satellite F&E cost over a number of years, since the full constellation is needed coincident with initiation of satellite-based services.

RESEARCH AND DEVELOPMENT

The Research and Development program, in consonance with the study objectives, is directed to a definition, development, and validation of key features of the AATMS Concept to that level at which implementation decisions can be made. A further objective is to obtain information necessary to support the most cost-effective air traffic management design while maintaining a practical risk factor in achieving system deployment success. This research and development plan supplements the current, ongoing FAA Engineering and Development program. Estimates of needed resources to accomplish the presented program are somewhat tentative and will require continual refinement and updating. The estimated cost of the Research and Development program from FY 1976 through FY 1984 is about $260 million. The cost breakdown for the major program elements is as follows:

CONUS Multiple Satellite Tests and Experiments	$175 million
Automation	$ 65 million
Strategic Control	$ 20 million
	$260 million

These costs are based on 1973 dollars and reflect the implementation and development of equipment and facilities beyond those either currently available or those a part of the present FAA R&D developments. Figure 18 shows the major program elements and the costs by fiscal year as well as a cumulative cost by year for the entire program.

MULTIPLE SATELLITES

The AATMS Study considered three possible satellite surveillance system approaches.[15] It concluded that a system incorporating one of these approaches could reduce the number of surveillance, communication, and navigation and air traffic management facilities currently installed to serve CONUS and oceanic areas. This would result in reduced operation and maintenance costs in the future system. An extensive experimentation and evaluation program is necessary, however, to provide the information for specifying and eventually procuring the satellite-based subsystem of the AATMS Study. The Applications Technology Satellite (ATS-6) and the Aeronautical Oceanic Satellite System (AEROSAT) experimental satellites are important test resources, but are inherently limited in their ability to validate satellite air traffic control in CONUS. ATS-6 is a single satellite with limited capabilities and the two experimental AEROSAT satellites are primarily for North Atlantic coverage and cannot be used to validate three-dimensional position location experiments. While the ATS-6 and AEROSAT programs will provide important information supporting a future implementation decision, the most important technical information will be obtained from CONUS multiple satellite tests and experiments. These experiments will require four or more satellites over CONUS for surveillance and navigation position determination experiments in operational air traffic environments. One of the major results of this research and development program will be the determination of a satellite system design which is best suited to future air traffic control. Both independent and dependent navigation modes are included within the AATMS Concept and the test program will explore the capabilities and limitations of each technique in this regard. These satellite tests will also provide information for evaluating selected subsystem mechanizations, including both avionics and ground facilities, and for making a preliminary evaluation of the control concept. The following paragraphs describe the essential milestone tasks and their respective required cost to research and develop the CONUS multiple satellite constellation.

TASK 1 — CONUS Multiple Satellite Program and Test Planning. Program and test plans will be prepared between FY 1976 and FY 1978 to provide management documentation to conduct the CONUS multiple satellite tests and experiments. These plans will be updated as additional data becomes available.

TASK 2 — Design Requirements and Specifications. Design studies and analyses will be performed to derive specification requirements for the ground, space and airborne elements. This task is scheduled over a two-year period beginning in FY 1977 to take advantage of the ATS-6 test results. A detailed model will be developed for analyzing satellite orbit and constellation geometry to support and accommodate surveillance, navigation and communication requirements. The model will consider aircraft/satellite factors, i.e., antenna patterns received, signal energy levels, platform stabilization, look angles, multiple body gravity, nonspherical earth, and solar pressure. The major gains sought by the study will include accuracy relationship between satellite constellation geometry and surveillance and navigation functions, satellite visibilities as relative position to aircraft and ground stations change, system performance effects of different aircraft antenna patterns and maneuvers and user effects degradation. The space shuttle will be investigated to determine the most cost-effective means of launching and inserting the satellites into orbit. Satellite attitude control, link characterization, multipath analyses, time-of-arrival (TOA)

TASK KEY	MAJOR PROGRAM ELEMENTS	FISCAL YEAR 1976	1977	1978	1979	1980	1981	1982	1983	1984	PROGRAM ELEMENT COST - $
▧	I DEVELOPMENT PLANS ★	400	400	400							1,200,000
☐	II CONUS MULTIPLE SATELLITE DESIGN DEVELOPMENT, FABRICATION AND PRELIMINARY - TEST		2,000	9,800	14,500	17,000	7,000				54,000,000
▒	III CONUS MULTIPLE SATELLITE EXPERIMENTS AND DEMONSTRATION					26,000	27,000	42,000	5,000	5,000	105,000,000
▥	IV PRELIMINARY AATMS AUTOMATION DEMONSTRATION EXPERIMENTS	1,625	3,775	1,300							6,700,000
■	V AUTOMATION CONCEPT DESIGN, DEVELOPMENT, FABRICATION AND TEST			2,075	10,225	14,900	11,300	5,700			44,000,000
▨	VI STRATEGIC CONTROL DEVELOPMENT AND TEST		700	1,200	2,860	4,270	3,540	2,820	2,200	900	17,000,000
▤	VII SYSTEM INTEGRATION, EXPERIMENTATION AND EVALUATION						2,000	2,000	13,000	13,000	30,000,000
	PROGRAM COST BY FISCAL YEAR	2,025	6,875	14,475	27,575	62,170	50,840	52,520	20,200	18,950	255,580,000

★ $300,000.00 SPENT IN FY75 FOR TASK I

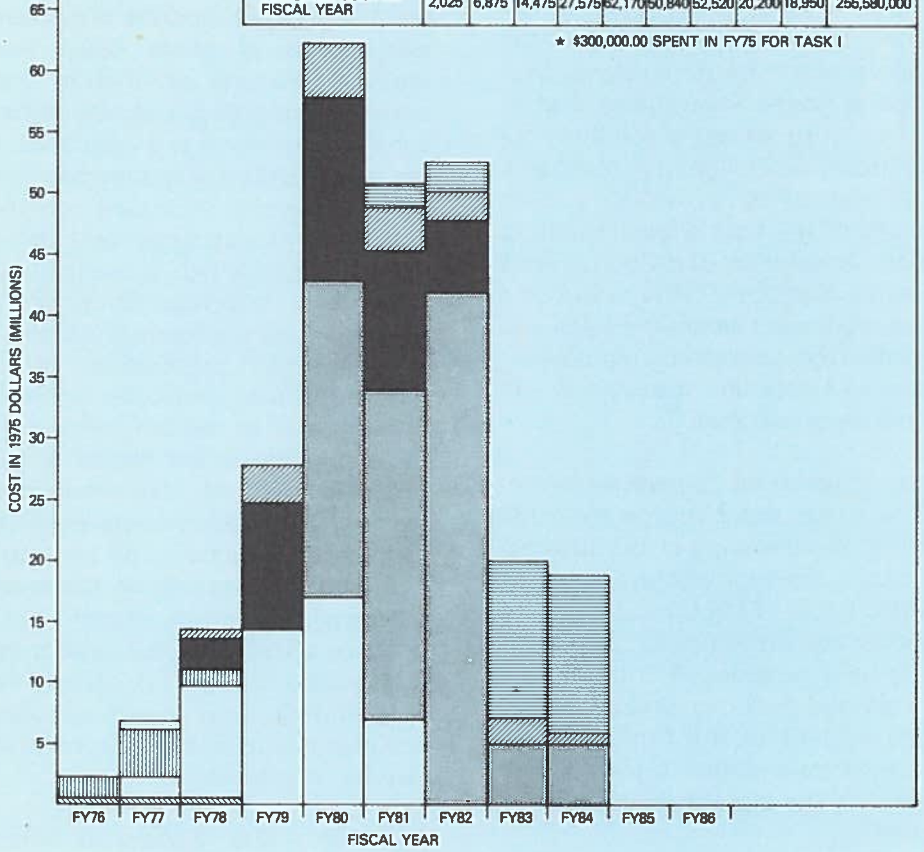


Figure 18. Advanced Air Traffic Management System Development Program

measurement techniques analysis, and tracking algorithms development will be analyzed and studied. A model will be developed to determine the characteristics of errors introduced into the satellite link by propagation anomalies, time, and geographic factors. A satellite navigation algorithm will be developed to test the sensitivity of navigation accuracy to equipment and to system errors. Requirements analysis will be performed on the functional elements of the ground-support and avionic elements.

TASK 3 — Design Development, Fabrication, and Test. This effort, performed between FY 1978 and 1980, will design, develop, fabricate and test the initial hardware and software associated with the CONUS multiple satellite test program. Ground support equipment which includes satellite control and tracking centers and associated calibration stations will be constructed and tested. Existing sites may be modified to reduce the cost of land acquisition and complete construction. Laboratory tests will be conducted on satellite antennas, transmitters, transponders and power sources equipment. A satellite ready for laboratory testing is produced as part of this effort.

TASK 4 — Field Test Using Available Resources. The purpose of this task, to be accomplished during FY 1981 and 1982, will be to test ground support hardware and software and avionics in an operational environment approximating that of the final mechanization using available satellite resources in connection with the CONUS ATC-Applications Satellite program.

TASK 5 — Multiple Satellite Fabrication and Test. Four satellites, in addition to the one fabricated under Task 3, will be fabricated and launched into selected orbits for full scale testing with a satellite constellation over CONUS. This effort spans six years beginning in FY 1980. Four satellites are required to resolve the technical uncertainties associated with the various three-dimensional position location concepts to be investigated and to demonstrate the feasibility of using satellites for CONUS ATC applications. Reliability considerations dictate the availability of using a fifth satellite to replace any 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 will be demonstrated and evaluated. The control of aircraft by employing satellite surveillance and data link subsystems will also be evaluated and demonstrated.

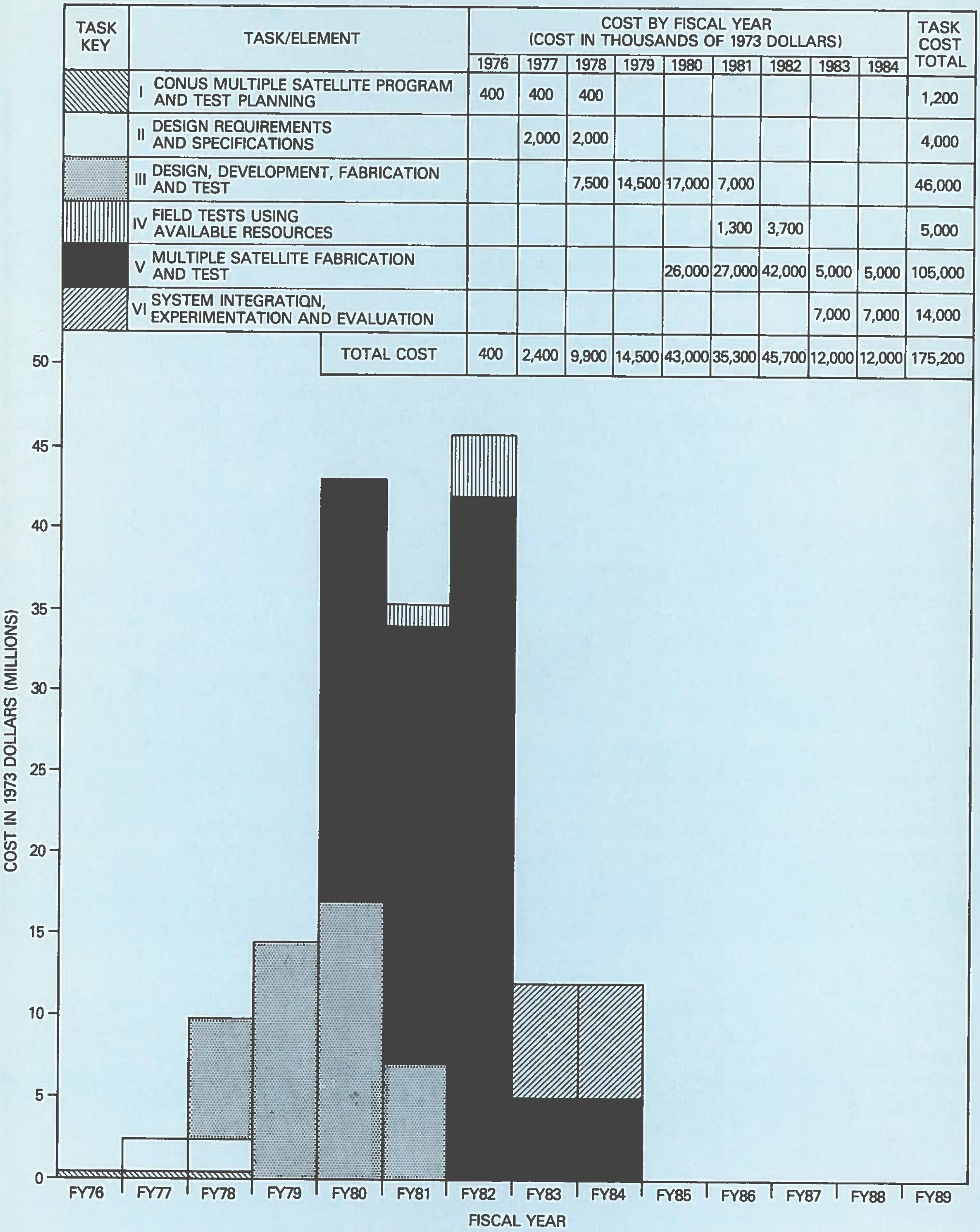
TASK 6 — System Integration, Experimentation, and Evaluation. The space and airborne elements will be integrated with the elements of the automation and control mode development programs to fully test and evaluate the AATMS Concept. Figure 19 defines the funding and estimates for the multiple satellite development program. A total budget of $176 million is required over the 10 year period. Approximately $90 million of the funding is required for the five satellites and their launches. The dollar figure for each of the tasks also includes the avionics development.

AUTOMATION

The development of a highly automated ATC system will require extensive research to establish detailed operational requirements and to delineate system hardware and software operational requirements and specifications. A summary of the R&D program is shown in Figure 20. Five major task areas are scheduled over a nine-year period. These tasks include 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 reconfiguration, design development, and operational test.

TASK 1 — Extension of Definition Studies and Development of Evaluation Techniques. This task incorporates three major efforts; 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 extensions of automation application studies done under the AATMS Study.(7,8,16) The effort of role definition should also define and detail the management and maintenance tasks in an advanced air traffic management system with respect to internal or control processes, and establish assignments of these tasks between man and machine. Future automation concepts presently under development include metering and spacing, conflict prediction and avoidance, flow control and the use of data link communications. However, the extent to which increased controller productivity can actually be attained by these improvements has not been quantified. A consideration of this task is to develop a technique for quantifying the relationship among control team workload, system capacity, and controller productivity. Productivity evaluation procedures developed under the effort should be sensitive to system hardware and the operational functions performed at control positions. Determination of the productivity potential of certain ATC improvements requires that the components of productivity be isolated and quantified. These efforts depend on the availability of a productivity evaluation model, such as the Delta resource attrition model developed for the AATMS Automation Study.(7) A Delta (Determine Levels of Task Automation) model was developed to generate resource utilization data and select appropriate degrees of automation.

TASK 2 — The Effects of Automation and the Feasibility of Automated Air Traffic Operations. This task encompasses the preparation of two demonstrations, each the basis of subsystem designs of an automated air traffic management system. The first effort is to demonstrate the effects of automating the air traffic system to a level where most tasks are assigned to machines. The second is to determine the technical feasibility of actually attaining a system with such a level of automation. These demonstrations will be crucial, since their 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.



TASK KEY		TASK/ELEMENT	COST BY FISCAL YEAR (COST IN THOUSANDS OF 1973 DOLLARS)									TASK COST TOTAL
			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

Figure 19. CONUS Multiple Satellite Test and Experiment Costs

TASK KEY	TASK/ELEMENT	COST BY FISCAL YEAR (COST IN THOUSANDS OF 1973 DOLLARS)									TASK COST TOTAL
		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

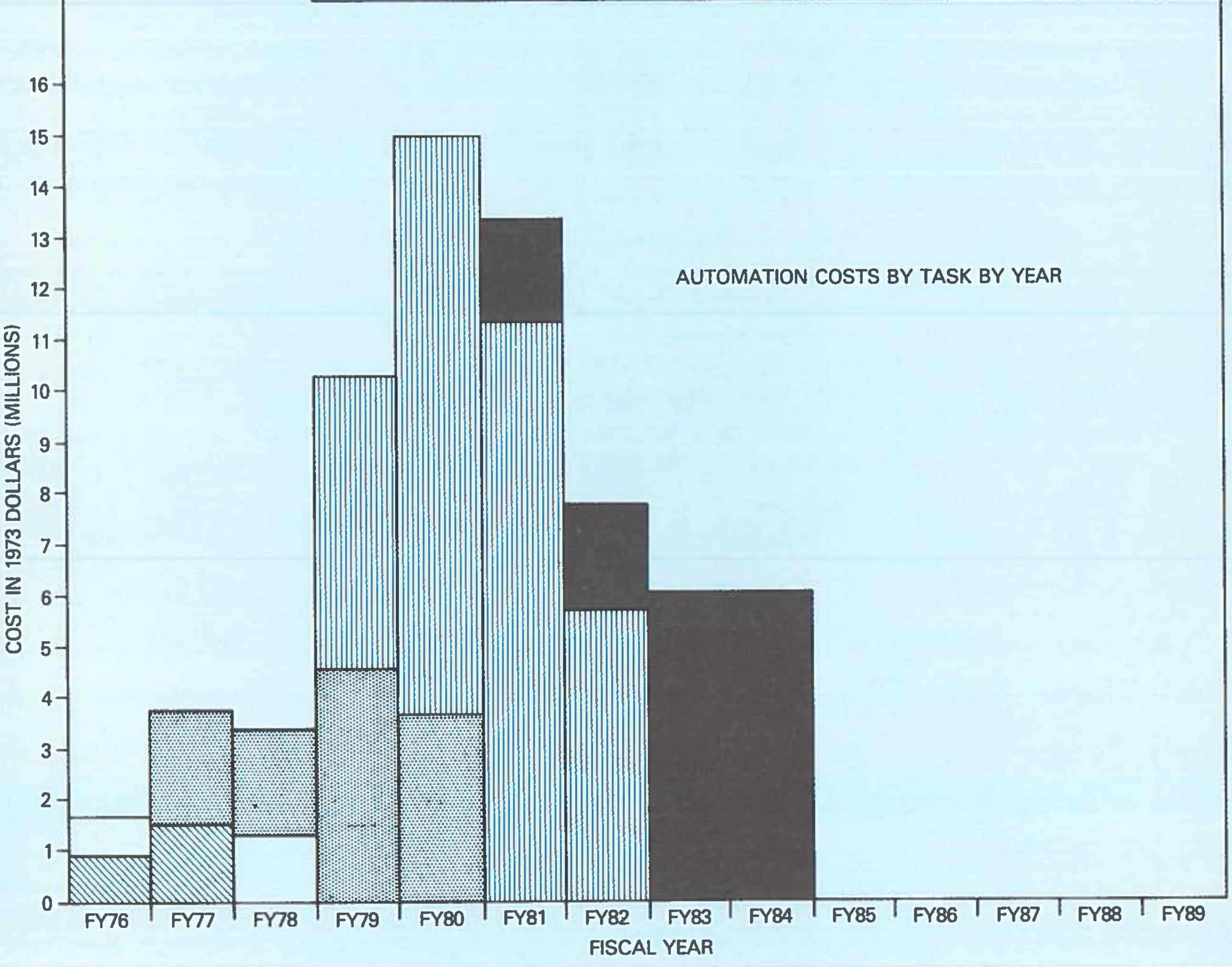


Figure 20. Automation Task Costs

TASK 3 – Concept Development. This task comprises four subsidiary efforts that translate the system from a conceptual state to a specific set of plans for controls and displays, facilities, and computer architecture in which all parts are integrated so that the system functions effectively in normal and in degraded states.

- A specific and systematic *fail-operational design* based on the concepts 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. Hardware and software equipment, mechanization techniques, resource configuration flexibility, system deployment and data on how to measure safety and capacity levels should be defined in this task effort.
- A basic assumption of this effort is that efficient, automated air traffic management is based on an effective partnership between men and machines determined by an appropriate, effective and efficient *interface between man and machine.* The interaction effects across control position types should be examined as part of each of the five elements making up the effort.
- Detailed design requirements and specifications for air traffic control, flight service, and data base facilities in an advanced ATC system should be developed. An examination of the *facilities configuration* proposed by this study should be examined. This effort should establish detailed requirements for the internal configuration of individual facilities and for the conduits of data flow 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 data processing 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 communication subsystem interface hardware. The AATMS *data processing system* should be specified to the level of detail necessary for the purchase or design of hardware.

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 operational environments. Prototype equipment to be tested and evaluated should be developed concurrently with the development of the test facility, and be fabricated according to specification detailed in Task 3. These elements should enable assembly and test, as well as an 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 to the functioning of the operational management, and maintenance systems. Software may be developed specifically for this task, or it may be adopted from other on-going system automation efforts, especially those concerned with metering and spacing, flow control, and the conflict prediction and resolution functions. 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. They 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.

The experimental flight tests should consist of tests using fully instrumented aircraft and simulations to explore user-system interface problems. The tests should be user-oriented. They should explore user-system interface problems. The tests should be user-oriented. They should explore how user performance impacts on system operation. Specific experiments should be conducted including evaluation of aircrew workload; evaluation of pilot and aircraft performance on system operation; pilot qualification and training requirements as a function of airspace or control mode; and the impact of the system on freedom of flight.

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. Tests conducted in connection with this effort and with the operational multiple satellite 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.

STRATEGIC CONTROL

The proposed research and development program in this area consists of four major tasks directed toward developing Strategic Control in successive levels of capability. An overall plan is shown in Figure 21, which includes a task cost breakdown by fiscal year and a cumulative cost curve, integrating all task costs by fiscal year of funding.

TASK 1 – Development of Basic Arrival Control Capability. The task includes analysis, simulation, and flight tests to demonstrate and evaluate the basic arrival control capability. Basic strategic arrival control capability needs to be developed. The program should be in a form suitable for implementation and testing on the basic arrival control simulation. Input for this effort should be a mathematical description of the geometry, scheduling strategy, route-time profile generation technique, demand requirements, aero-performance definition, and simulation objectives derived from the basic arrival control analysis. The real-time simulation should be capable of working with flight test airplanes as a part of a real-time test mechanization.

Specifications must be developed for four-dimensional navigation/guidance test avionics which can be used to determine flight test, and then can be further modified to incorporate the required strategic arrival and departure capabilities defined by subsequent analyses. Measurements must be obtained to determine the capability of an airplane using a four-dimensional navigation/guidance system to fly a predefined four dimensional track. These results should be used as inputs to strategically controlled simulator airplanes.

TASK 2 – Development of a Complete Arrival Control Capability. A complete strategic arrival control capability should be developed to include operation onto crossing runways, go-arounds, runway changes, "pop-up" demand, dynamic revolving and optimal scheduling. A detailed computer program for mechanizing the complete strategic arrival control capability must be developed by this effort. This evaluation should include only simulated airplanes; flight tests are deferred to the integrated system simulation and flight test efforts.

TASK 3 – Development of Departure Control Capability. The objectives of this task element are to develop the logic for Strategic Control of departures integrated with the complete control of arrivals, mathematically define the algorithm for the software to accomplish integrated departure and arrival control, and define the simulation test and experiments required to evaluate the integrated departure and arrival control software. 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 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.

TASK 4 – Analysis of Extended Capabilities. This task should determine strategic control system 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.

TASK 5 – Subsystem Specification. This task should generate the Strategic Control subsystem specification necessary to enable system acquisition. This work should include performance requirements specifications for the data processing hardware, software, communications, and avionics subsystems.

TASK KEY	TASK/ELEMENT	COST BY FISCAL YEAR (COST IN THOUSANDS OF 1973 DOLLARS) 1977	1978	1979	1980	1981	1982	1983	1984	TASK COST TOTAL
▨	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			2,744
░	III DEVELOPMENT OF DEPARTURE CONTROL CAPABILITY				600	520	1,770	1,600	750	5,240
▥	IV ANALYSIS OF EXTENDED CAPABILITY						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

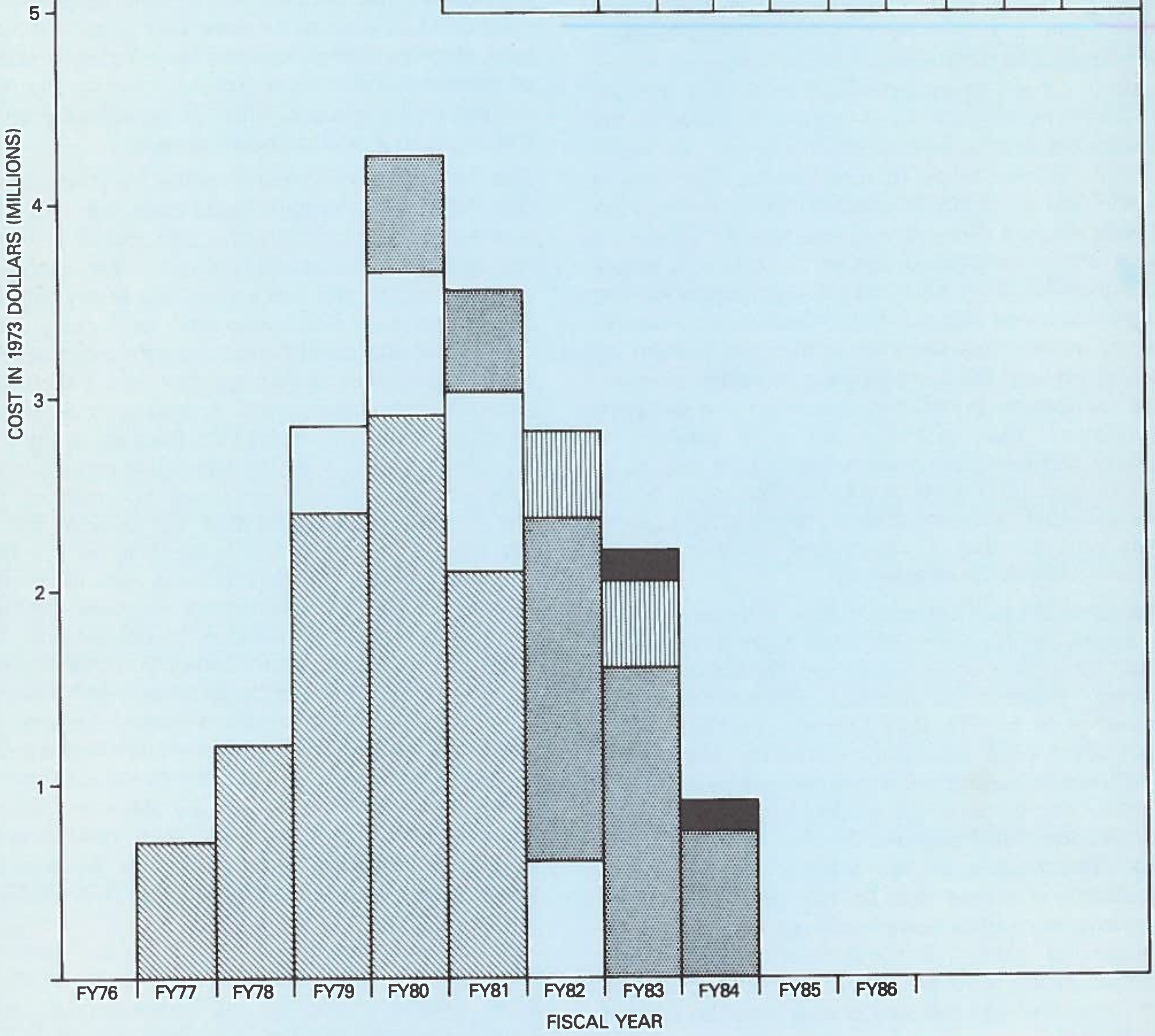


Figure 21. Strategic Control Development Program Resources By Year By Task

SUMMARY

The mechanization concept for the Advanced Air Traffic Management System was essentially determined based on an analysis of the comparable elements of the satellite-based and ground-based system studies. Air traffic control technique studies and future control automation architecture also were evaluated in obtaining the proposed fourth generation air traffic management system. Factors such as facilities, equipment, operations, and maintenance costs became important determinants in selecting the final AATMS mechanization.

Facility and equipment costs and their impact on life cycle equipment costs favor a satellite-based system. Avionics costs did not favor any particular system approach, whereas Government research and development costs, risk, and transition factors appear more favorable to a ground-based system. Operation and maintenance costs, sensor coverage, backup capability and demand sensitivity factors, all favor the satellite-based system. There was little discernible difference between the system concepts in their susceptibility to interference. The factors relating to operational characteristics and system susceptibility to intentional interference appear to favor the ground-based system in that it is better able to resist intentional system disruptions leading to performance degradation; however, no requirements in this area exist for either the present or future system, thus, no impact could be assessed. The evaluation concludes, based on a qualitative assessment, that satellites act as a catalyst to facility centralization, and hence induce savings in system operating costs. A distributed ground-based sensor system does not seem to promise the equivalent benefits that a centralized (satellite-based) sensor network could achieve.

The satellite-based system concept is determined to be operationally more desirable than the ground-based extension of the Upgraded Third Generation System. However, it is more difficult to obtain. Government facility and equipment cost considerations are a time dependent evaluation element. If satellite-based sensor implementation is delayed and further deployment of ground-based extensions beyond the 1982 Baseline System take place, the cost effectiveness of the satellite system would necessarily decrease due to the addition of new investments or sunk costs in coverage extensions to the ground system. Determination of the recommended sensor network was made by considering the impact of the selected concept on the user of the system.

This study has concluded that the greatest benefit can be achieved by using the most advantageous and cost effective element from each of the two candidate system concepts. The recommended mechanization concept, therefore, is satellite-based, but retains key sensor elements of the Baseline System, namely DABS, VHF voice communications, and limited VOR equipment. The DABS equipment of the Baseline System is retained because it offers compatibility between present and future system surveillance additions, handles traffic in dense traffic areas effectively, and provides critical safety and communications services where they are needed most and where reliability is critical. The VHF voice communications system is retained because it offers extremely good voice communications compatibility throughout the conterminous United States. The 300 VOR sites were retained because their limited quantity and selected location can provide limited coverage navigation service in uncontrolled airspace at minimal user cost. The retention of these elements also allows for continuation of present commitments to the International Civil Aviation Organization (ICAO) agreements during transition to a satellite-based system.

The AATMS sensor concept offers less development risk than does a system based solely on a satellite approach to air traffic control and assures a shorter, less complex transitional period. This concept is more suited to the users than is a solely satellite-based system. It also has greater backup capability than either the satellite-based or ground-based system, since it relies on two separate and independent sensor elements to provide aircraft services in most air space regions. The AATMS Concept is the most cost effective means of implementing and providing optimum CONUS functional system coverage. Figure 22 shows the cumulative cost by year for the two mechanization concepts building on the 1982 Baseline System. Since the voice communication subsystems for the two approaches were identical, the costs were not included in the comparison. The Extended Upgraded Third Generation System costs reflect no R&D expenditures since these costs are sunk costs insofar as this study was concerned. The Extended Upgraded Third Generation System continues the proliferation of ground-based subsystems. The curve shown in Figure 22 starts in 1982 at about the $125 million dollar level, reflecting the initial implementation costs for the System elements. The curve increases from 1982 to 1995, reflecting accumulating implementation, operation, and maintenance expense 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 to be completed prior to 1982). No further ground-based sensors are added after 1982; operational satellites

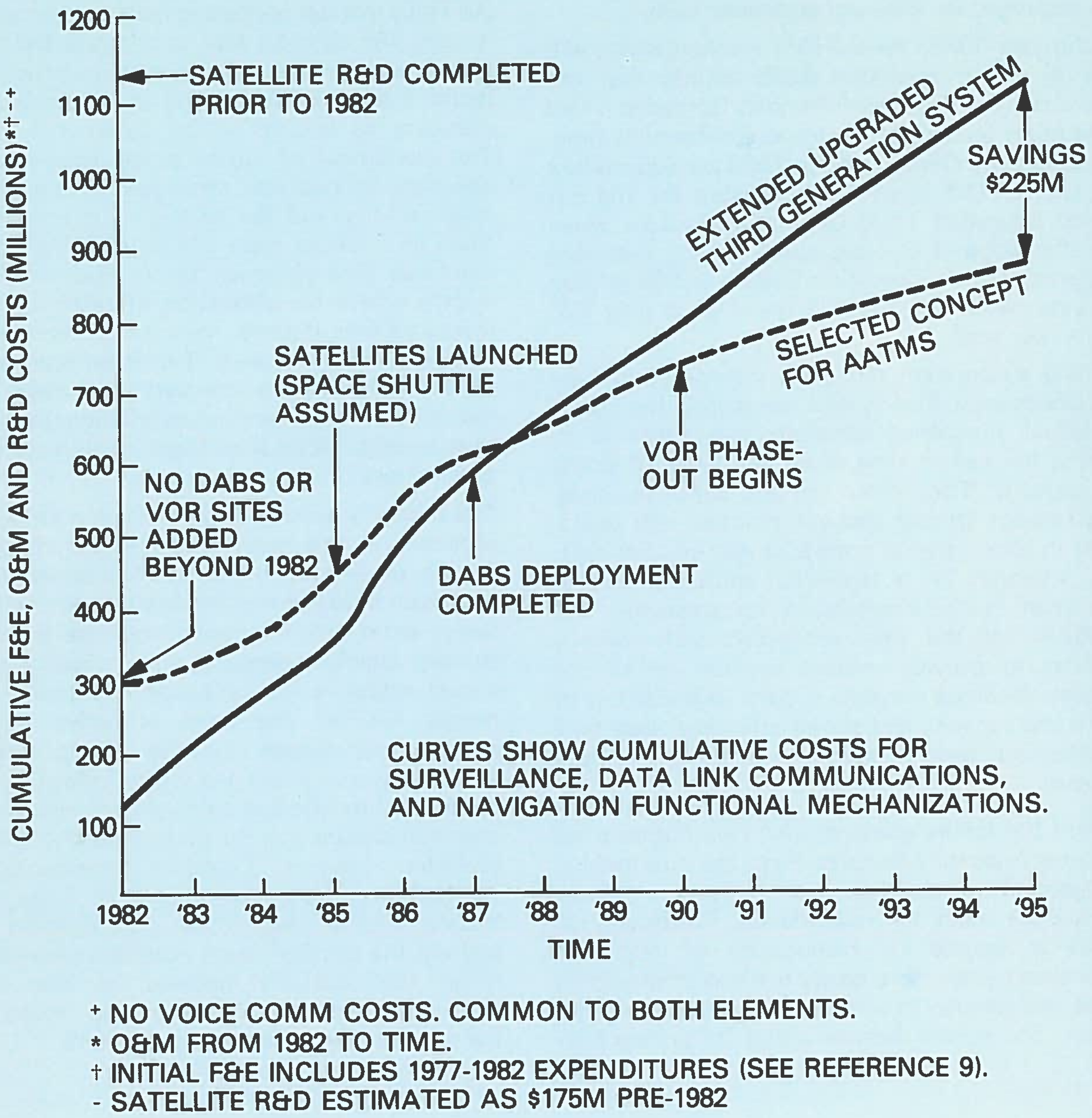


Figure 22. Satellite/DABS Mechanization Cost Savings Over Extended Upgraded Third Generation System

are implemented in 1985 and 1986, and the number of VOR sites is reduced from about 1000 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 operative at that time. Mechanization O&M costs for 1995 are $35 million less for AATMS than that estimated for the Extended Upgraded Third Generation System. However, the slope of the cost curve for the Extended Upgraded Third Generation System is $63 million per year, while for AATMS the slope is only $28 million per year.

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 degradations of safety and capacity and allows sufficient coast time to redeploy system resources or to redistribute demand.

Beyond the failure mode, the AATMS Concept 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 throughout the system. The second feature is that the system does not rely on manual modes of operation in degraded states. In a highly automative system such as AATMS, manual backup is neither practical nor is it safe. The operator has no effective and sure way to reinsert himself in critical automative control loops. Failure mode operations require automated elements be backed up by automated elements. The assessment of failure mode requirements and selection of response strategies remains a human responsibility and the backup to automated functions in a failure state continues to be a task for machines. One objective was to study an air traffic system where the allocation of tasks to men and machines was derived from consideration of the basic capabilities of each. The result is an air traffic system concept characterized by a high level of automation, with assignments determined by the relative capabilities of man and machine to perform specific tasks.

The mixed ground and space-based system concept proposed in this study offers a cost effective approach to air traffic control. The system's 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 makes AATMS the most attractive air traffic management system for the 1990s. Additional savings beyond those previously indicated may be possible if intersite and air-to-ground voice and data communications can be undertaken by the use of satellites. However, if satellite implementation for CONUS surveillance is delayed in favor of continuing deployment of the ground-based system beyond the baseline, such potential savings will no longer be available because of the counterproductive nature of the increased investment in the ground-based system beyond 1982.

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
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
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
IPC	— Intermittent Positive Control
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
VOR	— Very High Frequency Omnirange
VFR	— Visual Flight Rules

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 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.

Itinerant — 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 THCs and selected ACCs 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 predetermined 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 meteorological conditions in which the pilot utilizes visual observations, and possibly IPC, to avoid collisions with other aircraft or obstructions.

APPENDIX B
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