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CONCEPT FOR A SATELLITE-BASED ADVANCED AIR TRAFFIC MANAGEMENT SYSTEM

Volume I. Summary

H.T. Freedman
C.S. Hoffman
B.N. Gaon
T. Felisky
W. Fried

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16. Abstract

This report contains the results of studies and analyses directed toward the definition of a Satellite-Based Advanced Air Traffic Management System (SAATMS). This system is an advanced, integrated air traffic control system which is based on the use of a satellite constellation for surveillance, navigation, and communications. The system is designed to service the anticipated air traffic density (commercial, military, and general aviation) predicted for the period from 1995 and beyond. The major items discussed in this report include the definition of user classes, the management concept, the system services and functions, the system description, system costs, the system performance, transition into full system operation, and the RDT&E plan. The report is presented in ten volumes. This volume summarizes the study findings.

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GLOSSARY

ACC	Airport Control Center
ADF	Automatic Direction Finder
AGL	Above Ground Level
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
ATCAC	Air Traffic Control Advisory Committee
ATCRBS	Air Traffic Control Radar Beacon System
ATM	Air Traffic Management
CARD	Civil Aviation Research and Development
CA	California
CAS	Collision Avoidance System
CCC	Continental Control Center
CNI	Communication Navigation Identification
CONUS	Continental United States
DABS	Discrete Address Beacon System
DOD	Department of Defense
DOT	Department of Transportation
DME	Distance Measuring Equipment
DNSDP	Defense Navigation Satellite Development Program
FAA	Federal Aviation Administration
F&E	Facilities and Equipment
FL	Florida
GA	General Aviation
GAATMS	Ground Based Advanced Air Traffic Management System
IAC	Instantaneous Airborne Count
ID	Identification
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IR	Infrared
LA	Los Angeles
MLS	Microwave Landing System
MSL	Mean Sea Level
NAD	North American Datum
NAFEC	National Aviation Facilities Experimental Center
NASA	National Aeronautics and Space Administration Administration
O&M	Operations and Maintenance
PPM	Pulse Position Modulation

GLOSSARY (continued)

RCAGT	Remote Communication Air-Ground Terminal
RCC	Regional Control Center
R&D	Research and Development
RDT&E	Research, Development, Test, and Evaluation
RNAV	Area Navigation
SAATMS	Satellite-based Advanced Air Traffic Management System
SAMUS	State Space Analysis of Multisensor System
STC	Satellite Tracking Center
TCA	Terminal Controlled Airspace
TOA	Time of Arrival
TRACON	Terminal Radar Approach Control
TSC	Transportation Systems Center
TX	Texas
UHF	Ultra High Frequency
VFR	Visual Flight Rules
VHF	Very High Frequency
VOR	Very High Frequency Omni-Directional Range
VORTAC	Very High Frequency Omni-Range TACAN
2D	Two Dimensional
3D	Three Dimensional
4D	Four Dimensional

1. INTRODUCTION

INTRODUCTION

The objective of the SAATMS Concept Definition study was to define in detail the functional and operational characteristics of an advanced technology, satellite based, air traffic management system which would handle demand levels forecast for the 1995 time period. The study included preparation of a detailed description and evaluation of the system requirements, functional mechanization, and operation; a system specification; a plan for transition from the in-being system to the advanced system, a detailed cost estimate; and a research, development, test, and evaluation plan for implementing the system. Each of these outputs is presented in the subsequent volumes of this report. This volume presents a summary of the study findings.

The summary is presented in the following eight parts:

1. Why an Advanced System
2. What Is the Satellite-Based Advanced Air Traffic Management System
3. How Does the Satellite-Based Advanced Air Traffic Management System Operate
4. What Is the Satellite-Based Advanced Air Traffic Management System Performance
5. How Does the Satellite-Based Advanced Air Traffic Management System Get Developed
6. How Do We Transition From the In-being System to the Satellite-Based Advanced Air Traffic Management System
7. What Does the Satellite-Based Advanced Air Traffic Management System Cost
8. What Are the Satellite-Based Advanced Air Traffic Management System Benefits

2. WHY AN ADVANCED SYSTEM

HISTORICAL BACKGROUND FOR THE ADVANCED AIR TRAFFIC MANAGEMENT SYSTEM

The Advanced Air Traffic Management System study was initiated as the result of the Civil Aviation Research and Development (CARD) Policy Study Report and the Department of Transportation Air Traffic Control Advisory Committee's (ATCAC) concern regarding the growth potential of the present system into the 1990 time frame. These concerns were particularly aimed at (1) the shortage of terminal capacity, (2) the need for improved separation assurance due to higher aircraft density, and (3) the increasing costs of air traffic control. The Department of Transportation initiated system studies designed to address these problems.

As a result of the ATCAC report, it was decided to go ahead with the development of what was termed the Upgraded Third Generation System as an initial solution of these problems. The Upgraded Third Generation System is expected to safely increase capacity without significantly increasing the staff. The implementation criteria included the installation of close parallel runways at major airports, the use of microwave landing systems, a discrete address beacon system with digital data link, and increased use of automation. While proceeding with the Upgraded Third Generation System, ATCAC recognized potential problem areas with it. These problem areas included saturation of communication channels and DME facilities, growth in controller staff proportional to the growth in demand, inadequate navigation facilities for VSTOL aircraft, inadequate navigation and surveillance services in remote areas, and a need for greater navigation accuracy to permit closer routing. Therefore, a series of studies was initiated into what was called the Fourth Generation Air Traffic Control System. These studies provided a long term look at the emerging air traffic control system for the purpose of achieving better balance in the development program, and making a systematic evaluation of the role of new technology on the future air traffic control system.

During 1971 and 1972, Autonetics participated in a three-phase study to define what was then termed the Fourth Generation Air Traffic Control System. The three phases were conducted with the following goals and results:

Phase I - Establish demand distribution for 1975-1990. Establish top level functional requirements and demand capacity. Perform system studies to formulate candidate systems. Through an iterative process, two system approaches, one ground-based and one satellite-based, were identified as best meeting the required goals.

Phase II - Extend the functional requirements analysis, define an operational concept, and compare the system approaches. As a result, performance measures for the system were identified and performance and cost measures for both approaches were derived.

Phase III - Combine the best features of the two defined concepts and define a Hybrid System Concept. Compare all three concepts to the Upgraded Third Generation System. Based on reduced cost and improved levels of performance, the Hybrid System Concept was recommended.

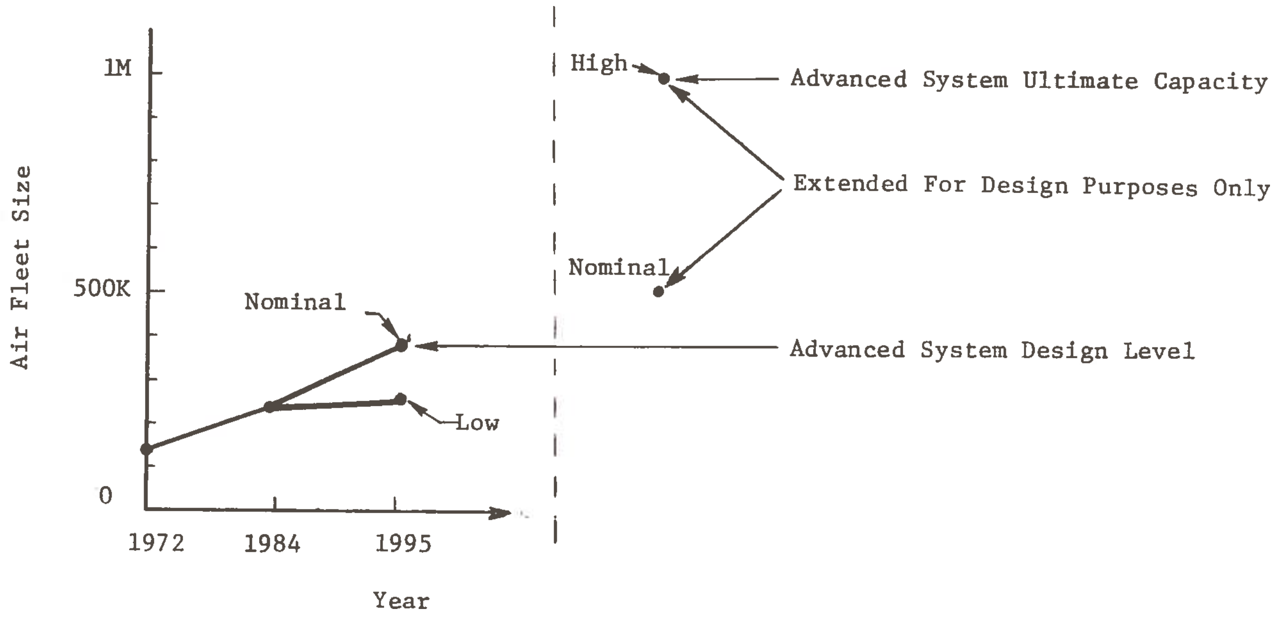
The present study is based on the previously defined Hybrid System Concept. The study is directed toward delineation of the SAATMS using the Hybrid System Concept as the point of departure.

IS AN ADVANCED SYSTEM REQUIRED?

Why consider an advanced system? The answer is dramatically evident if the projected demand levels are considered. As the airfleet size increases over the next several decades, the demands on the air traffic control system will correspondingly increase. A premise behind the ATCAC report is that the present system will be incapable of handling the increased traffic. If the services and safety of air travel are to be maintained for all users, a major improvement to the present air traffic control system must be implemented.

The form of the improvement to the present air traffic control system must be addressed on several levels. Clearly, the projected costs, services, and growth potentials are factors that must be considered. The intent of the initial Autonetics study was directed toward identifying candidate systems which could best answer the long-term air traffic management needs. The present study was directed toward delineating the specific system concept which has the highest potential for meeting the future goals. The system previously designated the Hybrid System was used as a point of departure for the satellite-based system concept described in this report.

GROWTH IN AVIATION



GROWTH RATE IMPACT

The primary growth rate occurs with the GA users. There are several significant items that occur as a result of this large number of general aviation users.

(1) The users comprising the greatest percentage of the airfleet can least afford significant avionics expenditures required to receive services from the system.

(2) To be responsive to the user needs, the system must supply services to the users in the airspace in which these users normally operate, i.e., the lower altitude regions.

(3) The regions of highest aircraft densities can be expected to be in those areas reserved for the GA user.

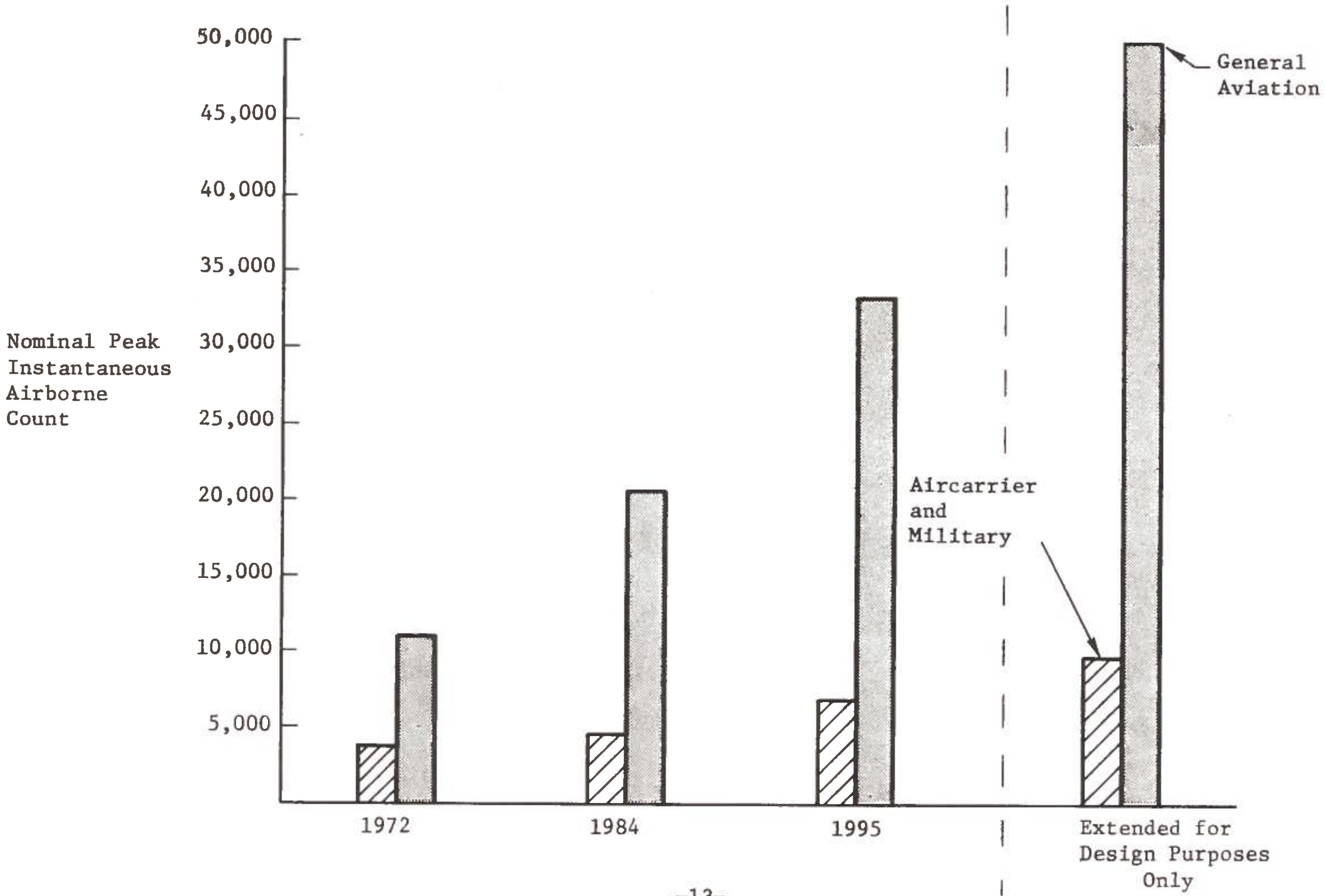
(4) To be fully accepted by the GA user, the advanced system must not impede his freedom of flight.

(5) The majority of the aircraft will not be using the high class aircarrier airports and, in fact, may be using airports remote from the large metropolitan centers.

(6) The present accident rate among general aviation users results primarily from a lack of surveillance information. In a future system, low cost surveillance and separation must be provided.

(7) Present FAA statistics indicate that in the enroute regions, i.e., greater than 30 nmi from an airport, 80 percent of general aviation users fly at 6,000 ft or less, 64 percent fly at 4,000 ft or less, and 22 percent fly at 2,000 ft or less. In other words, the great majority of users fly at low altitudes. Further, most mid-air collisons occur at low altitudes. Thus, in a future ATM system, surveillance, communications, and navigation services must be provided down-to-the-ground level if the great majority of users are to be provided with adequate separation assurance.

INSTANTANEOUS AIRBORNE COUNT GROWTH



3. WHAT IS THE SATELLITE-BASED ADVANCED AIR TRAFFIC MANAGEMENT SYSTEM

WHY CHANGE THE HYBRID?

The hybrid system previously defined by Autonetics was used as the point of departure for the Satellite-Based Advanced Air Traffic Management System Concept Definition Study. The hybrid system used an integrated satellite mechanization for surveillance, navigation, and communications, supplemented by towers for communications and navigation in terminal areas. The jurisdictional authority was divided between satellite control centers for all enroute aircraft and hub control centers for all terminal area aircraft. Aircraft at airports were under the jurisdiction of airport control centers. The function of the communications and navigation towers located in the terminal areas was to reduce the signal density loading within the satellite receivers and hence the multiple access noise. In the hybrid design, multiple access noise was the limiting factor in system performance. The hub control centers were used to provide a fail operational backup to the enroute centers.

During the course of the present concept definition study, several techniques evolved which obviated the need for communications and navigation towers in the terminal areas. First, the aircraft communications signaling scheme was altered to a more efficient one. An integrated waveform is still employed and aircraft identity is still self-contained within each transmission, but the capacity of the link has been increased, and the multiple access noise was substantially reduced. Second, the aircraft surveillance and communications were placed on different channels, again reducing the self-noise problem.

In addition to eliminating the communications and navigation towers in the terminal area, the present SAATMS concept has eliminated the hub control centers. Their function is now performed by the Regional Control Center. There are two regional centers. Each one has the capability of performing the ATM functions for all aircraft within its jurisdiction regardless of flight phase. These centers are 100 percent backed up by a third center which also performs the flow control and satellite tracking. The functions of the airport centers remain unchanged. This arrangement provides fail-operational performance and substantially reduces system costs.

WHAT IS THE SATELLITE-BASED AIR TRAFFIC MANAGEMENT SYSTEM

The Satellite-based Advanced Air Traffic Management System (SAATMS) is designed to provide the surveillance, navigation, communications, and control functions required to implement a comprehensive air traffic management system on a CONUS-wide level. In a geographic sense, the system is highly distributed but achieves cohesiveness through the use of a constellation of satellites. These satellites provide the necessary links that allow the most remotely located airport to be fully integrated into the total system. The versatility of the system is such that there is actually no such thing as a remote site except in a purely geographic sense.

Through the use of satellites, the SAATMS provides the surveillance, navigation, and communication functions from ground level upward over the entire CONUS region and far into the contiguous land and oceanic regions.

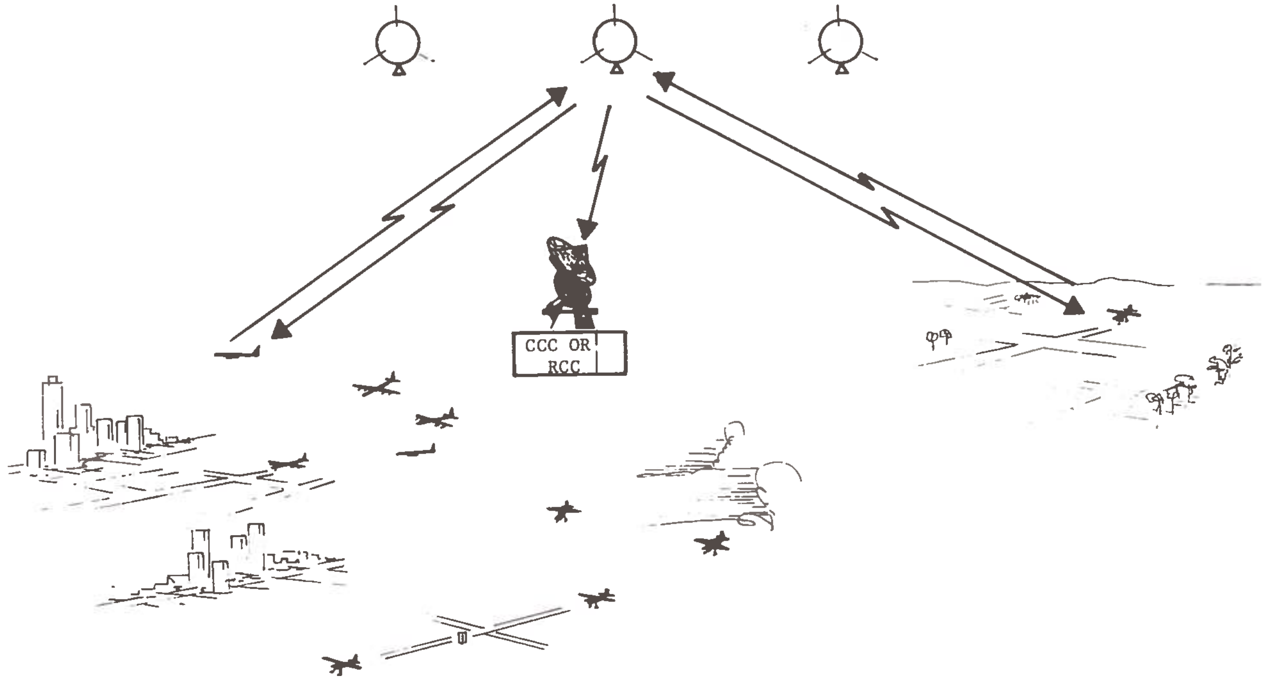
The surveillance function employs satellites to relay signals from active users. Each aircraft active in the system transmits a surveillance pulse encoded with the user's unique identification code. The satellites relay these signals to three control centers where the instantaneous aircraft position and velocity can be computed for every active aircraft in the system. This technique is employed for aircraft in both enroute and terminal airspace. The system accuracy is enhanced in high density airspace through the use of calibration stations.

The satellite system also provides one of the two basic navigation modes intrinsic in the SAATMS design. By transmission of navigation signals, the satellites provide basic data which allow equipped aircraft to compute their position and velocity. This navigation mode is completely independent of the surveillance system. This mode is available for aircraft in both enroute and terminal airspace and is usable from ground level upward. The other navigation mode is based on retransmitted surveillance data processed in a VOR format.

All the digital data required for ground-to-air communications are provided through satellites for enroute and terminal approach airspace. This is supplemented by direct aircraft-to-ground digital data and voice channels for use at airports. All the airports, control centers, and remote sites are interconnected through the satellite system. These channels are separate from the ground-to-air channels.

There are a total of 15 satellites in the selected constellation: 6 geostationary satellites with equatorial subsatellite points and 9 inclined, eccentric orbit, geosynchronous satellites whose subsatellite points share a common figure eight ground track.

THE SATELLITE-BASED ADVANCED AIR TRAFFIC MANAGEMENT SYSTEM



THE SAATMS JURISDICTIONAL ELEMENTS

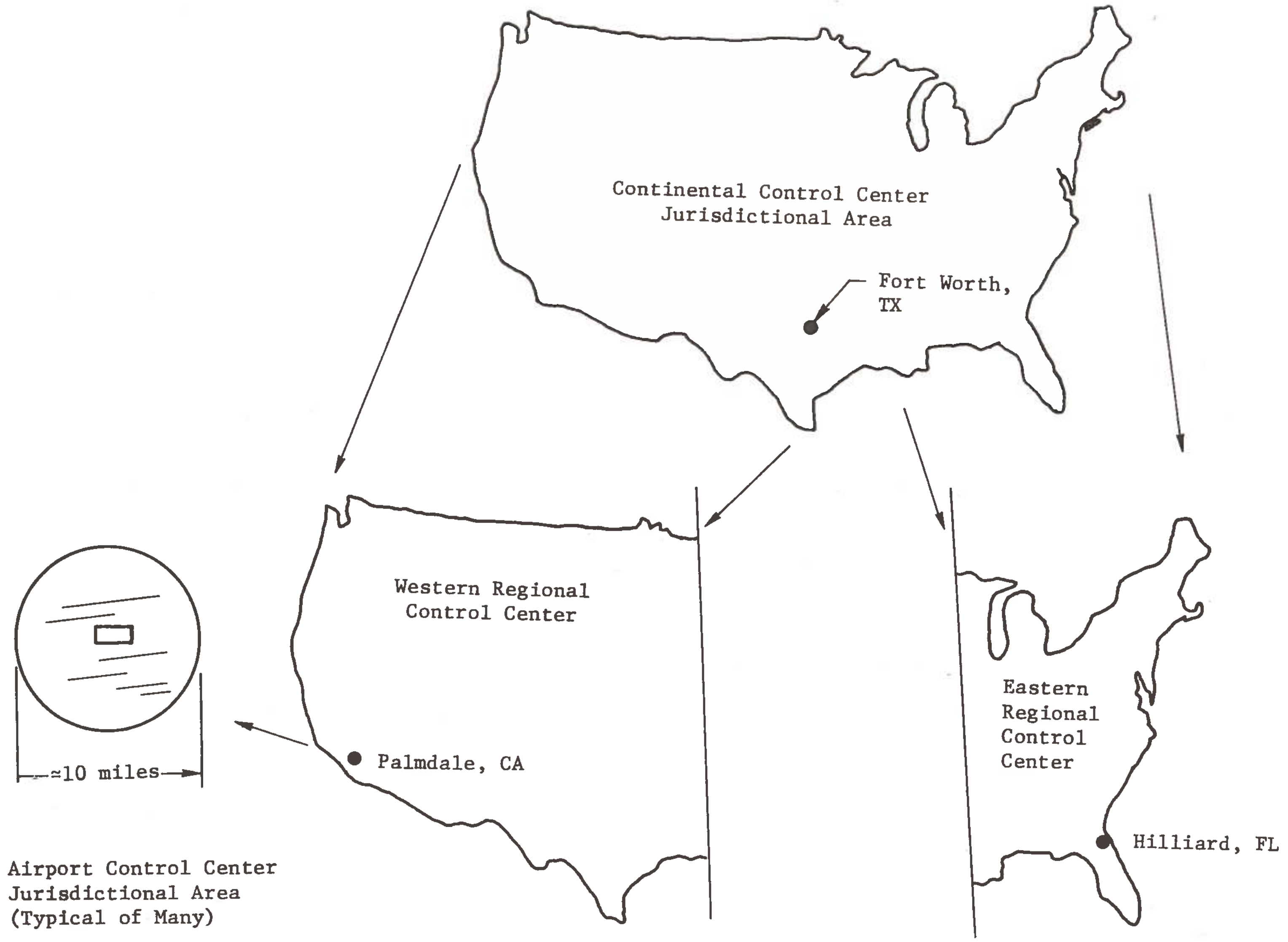
There are three major ground jurisdictional elements which provide the basic framework of the SAATMS design: the Continental Control Center (CCC), the Regional Control Center (RCC), and the Airport Control Center (ACC). There is one Continental Control Center, two Regional Control Centers, and numerous Airport Control Centers within the system.

The CCC is located in the south central portion of CONUS. A potential site is Fort Worth, TX. This center serves as a command and monitor center for the entire system. In the event of a catastrophic failure of either or both RCC's or in the event of a national emergency, the CCC can assume limited control of the entire system. Conversely, the RCC's are autonomous and can provide normal services and interchange data without reliance on the CCC.

The RCC's are located on the east and west coasts. Potential sites are Palmdale, CA, and Hilliard, FL. These control centers serve as primary command and control elements for their assigned regions. They have primary tracking responsiblity for all users within their respective regions and have control responsibility for all users in enroute, transition, and oceanic airspace but not for aircraft within the ACC jurisdictional regions. All communications to and from user aircraft in the control jurisdiction are disseminated from and received at these centers during normal system operation. The potential sites for the CCC and RCC's were chosen to provide good visibility with the geostationary satellites and to make use of existing ATC facilities.

Airport Control Centers are located at all primary aircarrier airports and those secondary and feeder airports that have manned control towers. These centers have command and control responsibility for all aircraft within the airport boundaries. All ground surveillance and control, airport arrival control, and runway management control are within the domain of the ACC's. Communications to all aircraft in this jurisdiction are handled by direct line of sight through the ACC.

SAATMS CONTROL CENTERS



THE SURVEILLANCE FUNCTION

All active aircraft participating in the system periodically transmit a surveillance pulse containing the aircraft identification (ID) code. While the transmission rate is periodic, it is not synchronized among users. The surveillance pulses are received by the satellites and retransmitted to the earth.

The satellite surveillance signals are received by antennas which track each satellite. The signals are decoded to identify the time of arrival (TOA) and the associated ID code as received from each satellite. These data are used by the RCC's and CCC for surveillance position computation.

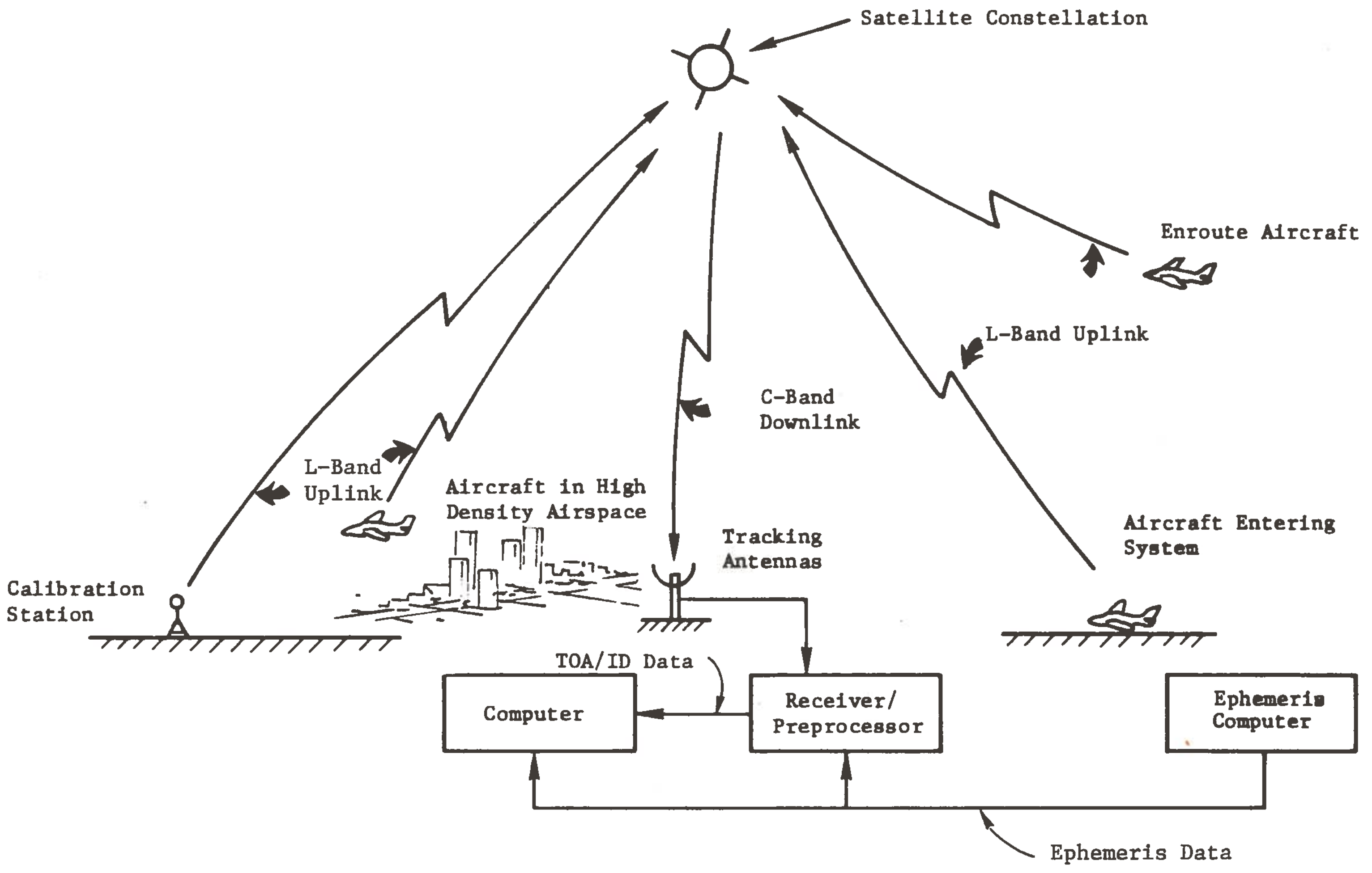
Acquisition computers scan all of the incoming TOA/ID data for purposes of identifying users entering the system. Aircraft entering the system transmit a surveillance pulse once each 2 sec. This rate is maintained until acquisition is achieved. Once the aircraft is acquired, the computer performs a position computation and assigns track responsibility to the RCC in whose jurisdiction the aircraft is located.

The tracking responsibility for an aircraft at an RCC begins when an acquisition computer assigns the responsibility or when an aircraft is handed off to the RCC by the adjacent center. This responsibility for tracking the aircraft continues (1) until the aircraft exits one RCC region and is handed off to the other RCC, (2) until the aircraft exits the system at an ACC or other airport, or (3) until unexpected termination of surveillance signals occurs and contingency measures are initiated.

The surveillance update rate is adaptive to the situation. In normal flight, an 8 sec update rate is used; but in conflict situations or high density regions, update rates of 2 sec are possible.

The accuracy of the surveillance system is independent of aircraft position within CONUS and altitude of flight. Relative accuracies of 35 ft (1 σ)(an aircraft in relation to another aircraft) and absolute accuracies of 150 ft (1 σ) (an aircraft in relation to a fixed earth point) are achieved.

SURVEILLANCE FUNCTIONAL ELEMENTS



THE COMMUNICATIONS FUNCTION

The SAATMS employs an integrated communication subsystem that interconnects all ground based system elements as well as the users and the controlling ground jurisdictions. The major features of the communications scheme include several unique items that enhance the integrated avionics capability.

The subsystem is based on the premise that integrated user avionics will minimize user costs and thus will be of primary importance in achieving a cost effective system design. For this reason, a single transmission-reception band (L-band) is employed for all information sent to or received from user aircraft. All user communications (as well as surveillance and navigation) system data interfaces are at L-band (1535 to 1660 MHz).

The interface between the users and the control elements is primarily via satellites, with supplementary direct digital and voice ground-to-air interfaces at airports. Satellite communications insures continuous coverage at all altitudes and locations within CONUS and adjacent regions. A user within the system is always assured that communications links are present. A greater number of channels is used to account for the higher 1995 demand and hence higher communications load.

By primarily using digital data communication with voice backup, the system is conducive to automation. Digital data links allow a degree of flexibility, speed, and backup to be implemented. The voice option enhances system flexibility and allows human intervention in the event of emergencies.

The system is designed to require relatively few user frequency changes for the primary digital links. The small number of voice and digital frequency changes assures that user induced errors will be minimized.

The ground-to-ground communications subsystem allows a large amount of data transfer between sites.

COMMUNICATIONS RF LINKS

Function	Path	Band	Bandwidth (MHz)	Number of Channels	Single Channel Bandwidth (MHz)	Comments
A-G Digital Data	A-S	L	15	1	15	Asynchronous, with Aircraft ID's as basic element in PPM code
	S-G	C	15	1	15	
G-A Digital Data	G-S	C	15	3	5	Discrete address, time ordered, shared with navigation function
	S-A	L	15	3	5	
	T-A	L	5	1	5	
Voice Links	G-S	C	3.75	150	0.025	Ground-air two-way voice links
	S-A	L	3.75	150	0.025	
	A-S	L	3.75	150	0.025	
	S-G	C	3.75	150	0.025	
	T-A	L	10	400	0.025	Line-of-sight two-way voice links
	A-T	L	10	400	0.025	
G-G Digital Data	G-S	C	3	600	0.005	Employs four Equatorial satellites for 2400 channel capacity
	S-G	C	3	600	0.005	

Notes: A = Aircraft
S = Satellite
G = Ground
T = ACC's
PPM = Pulse Position Modulation
Total Spectrum = 55 MHz at L-band and 46 MHz at C-band

THE NAVIGATION FUNCTION

There are two primary navigation modes provided in the SAATMS. For suitably equipped aircraft, a navigation scheme based on satellite signals is provided. This scheme is completely independent from the surveillance function. For aircraft which do not possess the navigation avionics, a simpler, less expensive navigation scheme is employed. This scheme is based on retransmitted surveillance data processed in a VOR format. The satellite navigation scheme is intended for military, aircarrier, and general aviation aircraft who require high accuracy navigation.

The aircraft receives signals from the satellites which include a precisely timed marker pulse plus ephemeris data. The navigation signals are transmitted by the satellites individually with each satellite transmitting every 3 sec.

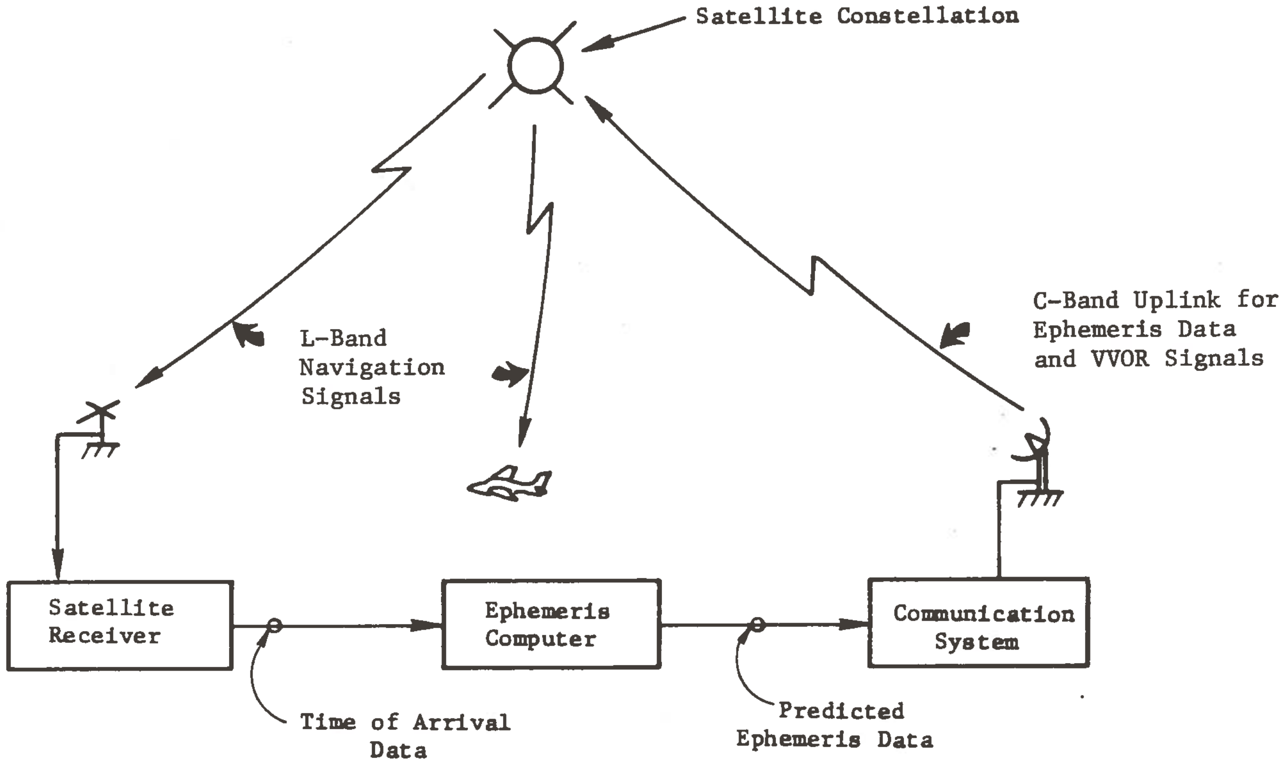
The ephemeris data transmitted by the satellite consist of the satellite position coordinates at its transmission time and its transmission time error with respect to master time. The aircraft measures the time of arrival of the pulses and using these data plus the satellite position data, estimates its position and velocity. The navigation accuracy is 90 ft ($1\ \sigma$).

The navigation scheme employed by the GA user is based on ground processing of surveillance data. The technique is called virtual VOR (VVOR) due to its operational similarity to the present VOR system.

The VVOR system uses a ground processor located at the RCC's, the normal ground/aircraft communication links, and an aircraft display. The user requests the system to provide navigation from any point to any other fixed grid point. Based on the surveillance data for the user, the ground system processor computes the course required to place the aircraft on the selected path and the distance to the selected destination point.

The communication link is used to transmit these data to the user, where the signals are encoded for display to the pilot. The service is similar to having a VOR/DME system on the aircraft, except that many more effective VOR stations are present. Essentially, then, a VOR/DME system with Area Navigation (RNAV) capability exists. This capability can be used for approach guidance to runways operating in reduced visibility.

SATELLITE NAVIGATION FUNCTIONAL ELEMENTS



ALL WEATHER SURFACE SURVEILLANCE AND GUIDANCE

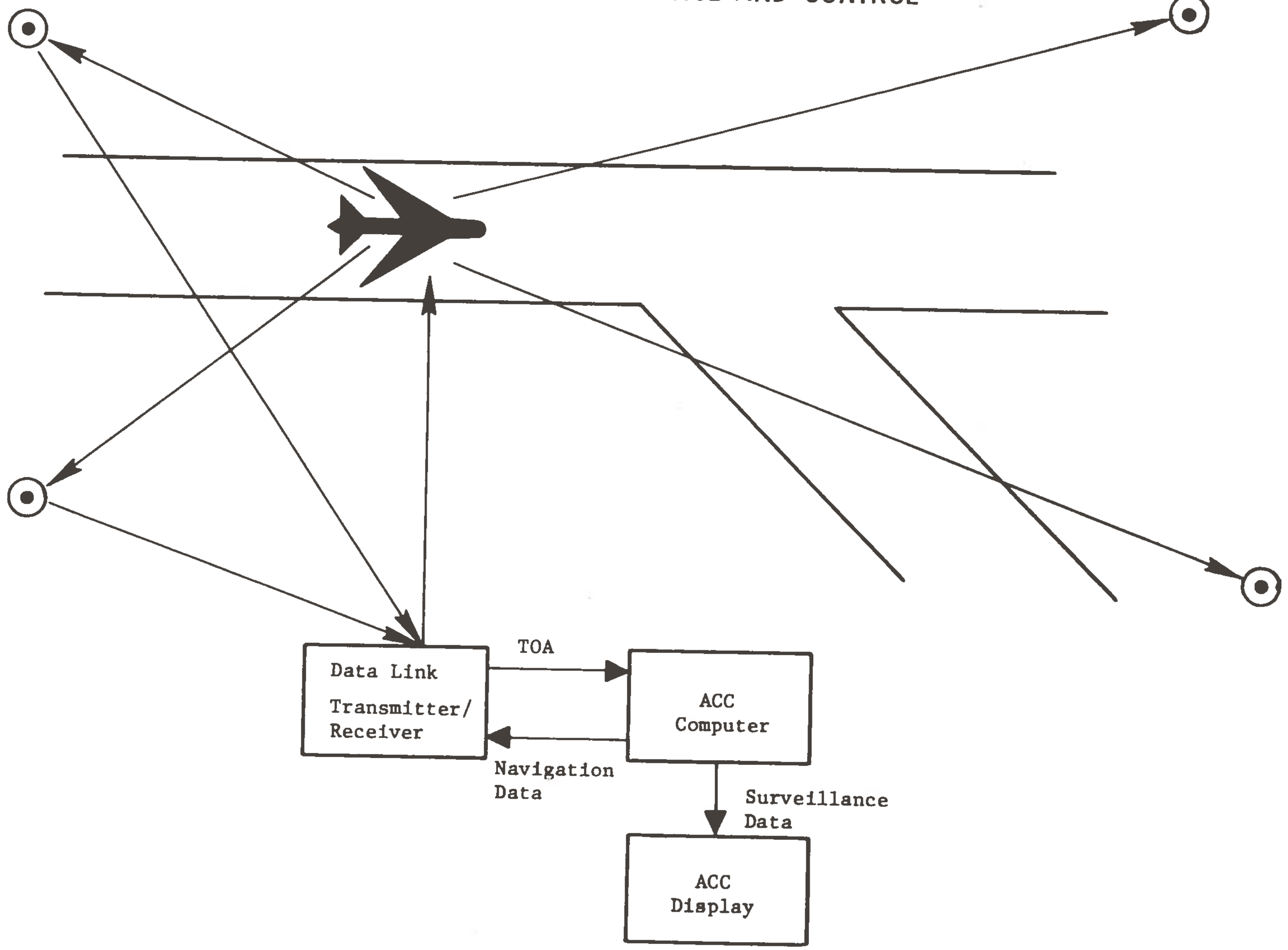
To minimize both aircraft and airport equipment costs, a trilateration TOA scheme, similar to the satellite surveillance, is recommended for the primary SAATMS airport ground control system. The advantages of this system, particularly at large airports, are high accuracy, self-contained aircraft identifications, simultaneous tracking of all aircraft, adaptive update rates, and minimal blind spots. In addition, the technique is fully compatible with SAATMS aircraft transceivers; i.e., no additional avionics are required.

Ground control is accomplished using the normal aircraft 3-pulse ID waveform, in this case, received by towers rather than satellites. The towers are local to the airport and uniquely configured to maximize accuracies and eliminate blind spots.

The towers receive the aircraft signal and transpond the signal to the ACC. Time-of-arrival differences are measured at the ACC and the aircraft position is determined. The position data are used for two purposes. First, they are used to perform aircraft surveillance and provide separation advisories. Second, the data are retransmitted to the aircraft for navigation.

The navigation position data are retransmitted to the aircraft on the normal digital link, and the navigation mode requires no additional avionics receivers. A special navigation display would be required but can be integrated with the existing situation display. Location accuracies of 24 ft ($1\ \sigma$) can be achieved.

AIRPORT SURFACE SURVEILLANCE AND CONTROL



DISCRETE SENSORS PROVIDE HIGH SURFACE NAVIGATION ACCURACY

While the trilateration scheme previously discussed is, in general, suitable for surveillance of surface traffic, it is felt that an auxiliary discrete sensor technique should also be used. These discrete sensors can be used at high density intersections, during poor visibility when increased accuracy is required, where airport configuration creates special blind spot trouble areas, or at airports serving primarily small GA users where a less costly surveillance scheme is desired. This technique makes use of discrete scanning infrared (IR) sensors located at critical points on the airport surface. The sensors detect the xenon beacon normally used on aircraft.

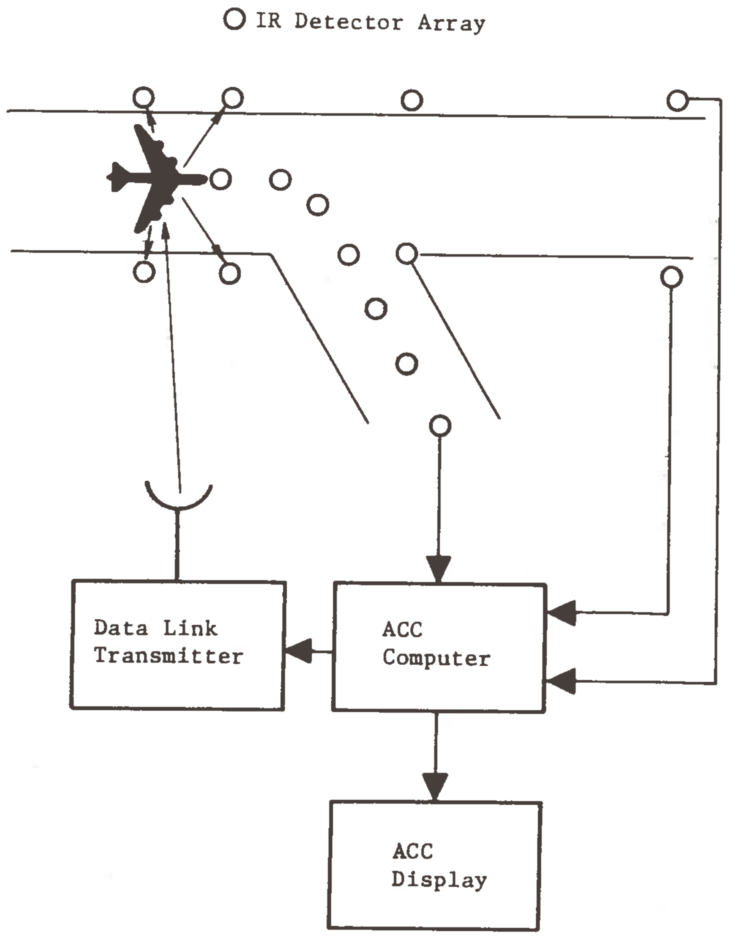
Infrared sensors, consisting of multi-element silicon detector arrays, are placed on each side of the runway for reception of the lamp emissions. The sensors measure the angles to the aircraft, thereby providing sufficient information to determine aircraft position. The sensor outputs are transmitted to the ACC computer. The ACC computer determines aircraft position, transmits guidance information via the digital data link to the aircraft, and simultaneously displays all aircraft positions.

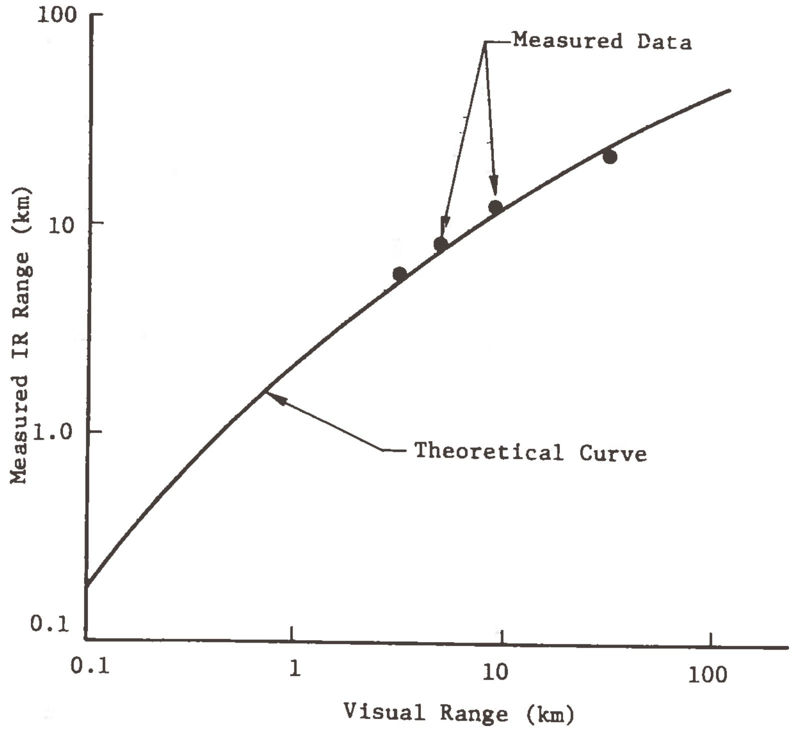
Autonetics has conducted some limited testing to investigate the range improvement factor of the IR over the visual. Although the data points are limited, good correlation with the theoretical curve is obtained.

It should be noted that the theoretical improvement is better at shorter ranges. Additionally, at short ranges, the location accuracy is very good. For example, at a 200-ft distance, a 2 deg sensor can locate the aircraft beacon within 6 ft. Thus, high accuracy navigation data can be retransmitted to the aircraft. These data are particularly important in Category III conditions for keeping aircraft on runways and for indicating and directing turns. The accuracies required for these functions are probably beyond the capabilities of the trilateration scheme but well within the performance of discrete IR sensors.

The IR system has the advantages of high accuracy, low cost, high reliability, and utilization of the normal aircraft beacon. Furthermore, with the lamps located under the aircraft, the system lends itself to operation with sensors located in the housing of the center lights installed on the airport taxiway and ramp areas. This technique can also be used on ground vehicles such as cars, trucks, etc., for complete control of all airport ground traffic.

DISCRETE IR SENSORS





4. HOW DOES THE SATELLITE-BASED ADVANCED AIR TRAFFIC MANAGEMENT SYSTEM OPERATE

SAATMS OPERATIONAL ASPECTS

The objective of any air traffic management system is to provide services to its users. These services must satisfy the needs of the user as well as facilitate the smooth functioning of the system itself. Not all users require all system services, nor are all users capable of receiving all system services. The degree to which services are provided is directly dependent upon such factors as user equipment, phase of flight, flight objectives, mode of operation, and most of all, the operational concept.

An air traffic management system provides services to its users by performing functions. Whereas services are the objectives of the system, functions are the means by which services are provided. The primary responsibility for fulfilling each service rests either with the ground or the pilot. The SAATMS is a highly air managed system in that the pilot is responsible for using the navigation function to conform to his established flight plan or routes. The ground uses the surveillance function to provide separation assurance and thus ensures a high degree of safety. In the SAATMS, conformance is the aircraft's job while safety is the system's job.

SYSTEM SERVICES

The primary services provided by the SAATMS are separation assurance, traffic control, and flight plan conformance.

A degree of safety not present in today's system is available to users of the SAATMS. The SAATMS is able to provide the service of separation assurance to all of its users, GA as well as air carrier, because of satellite surveillance. What makes the satellite surveillance system different from today's system is that aircraft are never too low or too far away from the sensor to be detected. Since satellites are used to relay the data from aircraft to the ground, there are no remote sites. All parts of CONUS are equally visible. This means that surveillance is available at remote airports where many of today's accidents occur.

The demand projections for 1995 indicate a substantial increase in the number of aircraft wishing to use primary airports. To enhance the efficiency of these airports and to reduce delays, the system will provide the traffic control service. The system provides algorithms, sensors, and data processing to solve metering, sequencing, and spacing equations that result in minimum delay with maximum safety. Commands are then sent via the digital and voice links to the aircraft to control their arrival to the airport according to the computed solution. Traffic at GA airports is controlled in much the same fashion as VFR traffic is controlled today. Communications are primarily by voice.

Both the aircarriers and GA users are responsible for conforming to flight plans, established traffic pattern routes, and commands received from the system. They perform the navigation function in order to implement the conformance service. The system assists them by providing navigation data.

The aircarrier is required to fly precise routes in order to expedite the flow of traffic in controlled airspace. To do this, he must have high quality navigation data which he receives from the satellite constellation. To make use of these data he must have on board a navigation processor and display.

The GA user is not required to fly precise routes nor can he afford to expend as much money in avionics as the aircarriers. The system therefore provides him with a navigation capability based upon his surveillance data. This capability is called virtual VOR (VVOR).

SYSTEM SERVICES

Function / Service	Surveillance	Navigation	Digital Communications	Voice Communications	Control
Flight and Flow Planning			X		
Flight Plan Conformance	X	X	X		
Traffic Control	X	X	X	X	X
Separation Assurance	X		X	X	X
Landing Nav and Guidance		X	X		
Ground Nav and Guidance		X	X	X	
Operational Regulations			X		
Flight Advisory Services			X		
Weather Services				X	
Record Services			X		
Facilities Operation and Maintenance			X		
Emergency Services	X			X	

VIRTUAL VOR (VVOR)

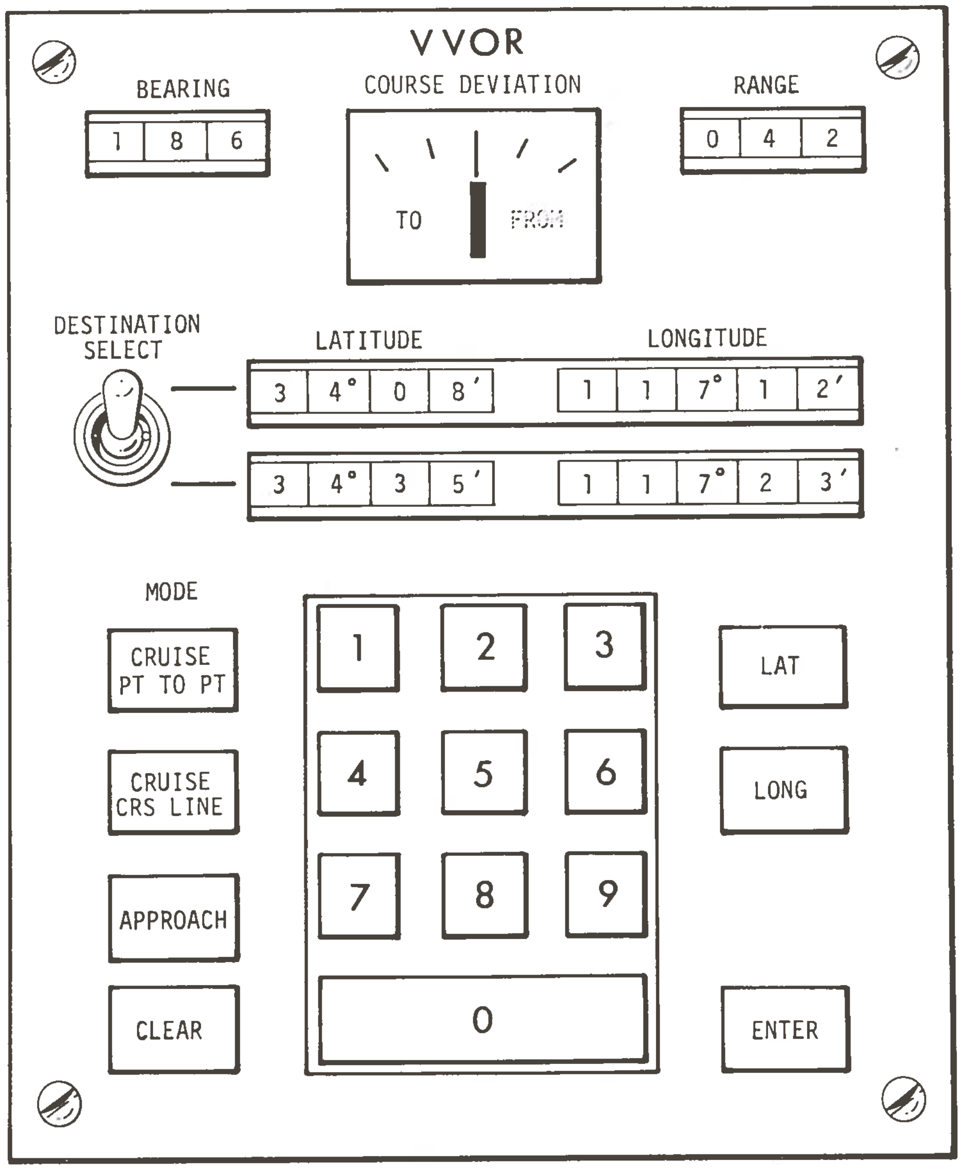
Virtual VOR (VVOR) provides the GA user with a navigation capability far superior to the present VOR navigation system. The added capability over present day VOR includes area navigation (RNAV), range-to-go information at no additional cost, and instrument approach.

The RNAV capability results from the fact that a much denser grid of VVOR stations is used than is available today. Whereas the present system places VOR stations several miles apart (in 1982 only 1000 stations are planned for the entire CONUS), VVOR uses a latitude/longitude grid with intersections spaced 1 min apart. This is equivalent to covering the entire CONUS with 5.5 million VOR stations and provides a dense grid of points approximately 1 mile apart.

The pilot will plot his desired course on an aeronautical chart in the same manner he does today. If necessary, the course will have dog legs to avoid high terrain or restricted airspace. The course is not restricted, however, by the location of the VVOR stations. The pilot merely decides on his route. He determines the latitude/longitude coordinates of the end points of each leg of his route. He then dials the first set of coordinates into his VVOR panel and observes his VVOR display to make his course good. The display is identical to today's VOR course deviation display. When he reaches the end of his first leg, he dials in the next set of coordinates and repeats the procedure. There is no need for him to either fly out of his way to stay on Victor airways or to take cross radial readings from two or three VOR stations to fly an off airway route.

The system provides an instrument navigation capability. This capability is most useful to the GA user in approaching airports in poor weather conditions. The pilot selects the runway threshold as his destination and goes to an approach as opposed to a navigation mode. The system then defines a straight line on the runway heading that terminates at the threshold. This line is the equivalent of today's ILS localizer. The pilot flies along this line and uses his range to go readout to determine range to touchdown and, hence, desired altitude. The desired altitude at different ranges is published for each runway in the national airspace system. By adhering to the published altitudes, the aircraft flies a form of a glide path to the runway. This technique is equivalent to today's VOR instrument landings but has the advantage of permitting straight-in rather than a circling approach.

The GA user can obtain this greater navigation capability for far less avionics cost than is required for today's VOR navigation. He must add a VVOR control and display panel to his basic avionics package and increase the size of his communications decoder. This represents a small increase in the cost of the SAATMS avionics package.


VVOR
BEARING
1 8 6
COURSE DEVIATION
TO
FROM
RANGE
0 4 2
DESTINATION SELECT
LATITUDE
LONGITUDE
3 4° 0 8′
1 1 7° 1 2′
3 4° 3 5′
1 1 7° 2 3′
MODE
CRUISE PT TO PT
CRUISE CRS LINE
APPROACH
CLEAR
1
2
3
4
5
6
7
8
9
0
LAT
LONG
ENTER

SAATMS USER CLASSES

From the previous discussion it becomes clear that the needs and capabilities of aircraft differ in ways that affect both the services they are capable of receiving from the system and their ability to be controlled by the system. The definition of user classes provides a basic structure in which rules and procedures for different aircraft categories can be stated. The reason for categorizing aircraft into user classes is to insure that the airspace structure and system management concept are compatible with the needs and capabilities of the aircraft using the system.

In the SAATMS, user classes are defined in terms of combinations of avionics, performance, and pilot proficiency. The airspace is structured in such a way that aircraft are grouped by avionics, performance capabilities, and pilot proficiency.

There are two basic users in the SAATMS, controlled and cooperative. Uncontrolled users have no avionics requirements and are not considered to be part of the system. They are confined to posted regions in low density areas at altitudes below 3,000 ft AGL.

The cooperative user is equivalent to today's GA aircraft. He is required to carry surveillance, two-way digital and voice communications, and a VVOR control and display panel. The cooperative user receives the service of separation assurance in addition to VVOR.

The controlled user is equivalent to today's IFR aircraft. He is required to carry two sets of surveillance, voice and digital communications plus a redundant satellite navigation processor and display. In addition, he must carry a VVOR display and control panel.

For this price in avionics, the controlled user receives the same separation assurance as the cooperative user plus a sophisticated 4D RNAV capability. In addition, he receives preferred routing, priority for the airspace he is using, the right to use primary aircarrier airports at all times, and a guaranteed arrival slot at his destination airport.

An optional equipment capability for controlled users is the Collision Avoidance Subsystem (CAS). This air-to-air mode capability is based upon the interchange of air derived navigation data and is primarily contained in the basic avionics package for all controlled users. An additional processor and display must be added to perform the aircraft tracking and avoidance calculations. This mode is provided in support of the high automation levels expected in SAATMS and will provide backup in the event of ground failures, provide the pilot confidence in the performance of the ground system, and allow more optimum air managed control during the enroute and arrival phases.

SAATMS USER CLASSES

Aircraft Performance Classes

Class	Cruise Altitude (ft)	Cruise Speed	Landing Speed (knots)	Weight (lb)
1	3,000 to 12,000	90 to 200 knots	<100	<12,500
2	10,000 to 29,000	200 to 400 knots	100 to 120	13,000 to 100,000
3	30,000 and up	0.7 Mach and up	>120	20,000 to 700,000+

Aircraft Avionics Classes

Controlled	Cooperative
Surveillance transmitter	Surveillance transmitter
Two-way digital L-band communication	Two-way digital L-band communications
Two-way L-band voice communications	Two-way L-band voice communications
Satellite navigation processor	VVOR display and control panel
Satellite navigation display	
All of the above must be backed up	
VVOR display and control panel	

Optional Upgrade

MLS

Air-to-Air CAS

SAATMS AIRSPACE STRUCTURE

The SAATMS contains four airspace categories: controlled, mixed, cooperative, and uncontrolled. Controlled enroute airspace is located above 12,000 ft MSL and is characterized by a highly flexible route structure. Users flying in this airspace must have an approved flight plan and equipment for surveillance, satellite navigation, and two-way digital data link plus two-way voice communications. It is anticipated that mostly aircarriers, military, and large General Aviation (GA) aircraft will fly in this airspace. Virtually an infinite number of routes is available in this region. Further, based upon the demand analysis, this airspace can be characterized as relatively low density.

Controlled terminal airspace is characterized by high altitude approaches and closely spaced routes. These features result in less noise under the approach path and more airspace for cooperative aircraft. This airspace is an application of the concept of Terminal Control Airspace (TCA) which has been modified to take advantage of the greater accuracy afforded by the SAATMS. Aircraft using this airspace receive metering, sequencing, and spacing traffic control services in addition to separation assurance.

Mixed airspace extends from 6,000 to 12,000 ft MSL. This airspace is shared by unpressurized controlled aircraft, short-haul aircarriers, and cooperative aircraft. The type of aircraft using this airspace will be mostly light GA aircraft although the short-haul aircarriers will include turbo prop and pure jets. Controlled traffic receives priority over cooperative aircraft when operating in this airspace.

Airspace reserved solely for cooperative users is located below 6,000 ft MSL. It is characterized by a high degree of freedom of flight. No flight plans are required for flight in this airspace and no established route structure exists. The aircraft are free to select the flight path they desire. The system will provide separation assurance to these users in the same manner as for controlled users.

Enroute oceanic airspace extends from the 12 nmi CONUS territorial limit out into the contiguous oceanic region. The air traffic control system has no jurisdiction over foreign aircraft who are using this airspace and are neither departing nor landing in CONUS. Therefore, SAATMS cannot require that users of this airspace be equipped with surveillance gear and hence cannot provide separation assurance to these aircraft. Aircraft who are suitably equipped to fly in SAATMS, however, need not use different equipment to fly in oceanic regions.

Certain areas in sparsely populated regions and low traffic density will be posted for uncontrolled aircraft. These areas will extend from the ground to 3,000 ft AGL. Aircraft flying in these areas have no equipment requirements nor do they receive any services from the system.

SAATMS AIRSPACE STRUCTURES

Airspace Category	Region		
	Enroute	High Density Terminals	Airports
Controlled	Above 12,000 ft MSL 3D RNAV Routes	Cone extending out 70 nmi from primary aircarrier airport. Bottom of cone extends up from runway at a 6 deg angle, top at an 8 deg angle. 4D routes consisting of paths spaced 1,600 ft horizontally and 1,000 ft vertically merging to a single path per runway at 3 nmi from touchdown.	Primary aircarrier airports containing segregated aircarrier and GA runways. Region boundary extends in 5 nmi radius around the runways up to 3,000 ft AGL and is contiguous with the terminal approach and departure zones.
Mixed	6,000 to 12,000 ft MSL 3D RNAV Routes for controlled aircraft; no route structure for cooperative aircraft.	Ground to 12,000 ft MSL except where primary aircarrier airport terminal zone is located. 3D routes consisting of standard arrival and departure routes.	Airports with control towers. Region boundary extends in a 5 nmi radius around the runways up to 3,000 ft AGL. Route structure consists of established traffic pattern for each runway.
Cooperative	Ground to 6,000 ft MSL except for airport control zones and uncontrolled airspace. No route structure.	Ground to 6,000 ft MSL except for airport control zones and primary aircarrier airport terminal zone.	
Uncontrolled	Ground to 3,000 ft AGL in posted low density regions. No route structure.	None	Airports without control towers. Region boundary extends in a 1 nmi radius around the runways up to 1,200 ft AGL. Route structure consists of established traffic pattern for each runway.

AGL means Above Ground Level

RNAV means Area Navigation

SAATMS MANAGEMENT CONCEPT

The management concept describes how aircraft fly in each airspace region. The SAATMS concept is characterized by considerable freedom of flight for all aircraft. Responsibility for adherence to a flight plan rests with the pilot. While the system provides data to the pilot to assist him in selecting routes, the pilot makes the decision about where and when he wants to fly. A high level of safety is maintained by having surveillance data on all aircraft. The system uses the surveillance data to provide conflict intervention commands whenever two aircraft come too close to each other.

For controlled aircraft flying solely within controlled airspace, long-term planning is accomplished during preflight. The result of long-term planning is an approved flight plan. From then on, all planning is short term. The forms of this planning are assignments to specific routes, clearances to embark on successive legs of the flight, approval to deviate or modify the long-term plan, and metering, sequencing, and spacing in the terminal regions.

In all cases, path conformance is the responsibility of the pilot. In the transition zones to and from the cruise phase of flight, however, the system will provide vectors for the aircraft. In a sense this is a form of ground managed path conformance. Conflict intervention is provided by the ground for all aircraft except those flying outside CONUS. (Conflict intervention is not applicable during the landing phase. It is provided during the approach where the land/waveoff decision is made.)

Controlled aircraft operating in mixed airspace are treated much like those aircraft operating solely in controlled airspace. The differences are minor. During the arrival transition and final approach phase, the aircraft relies on a standard approach path or traffic pattern rather than on a short-term path assignment or clearance issued from the ground. Since a standard path is used in transition, path conformance is the primary responsibility of the pilot. For aircraft under the jurisdiction of the ACC, only separation advisories are provided from the ground - the responsibility for avoiding collisions rests with the pilot.

Cooperative aircraft operate in an identical fashion to controlled aircraft operating in mixed airspace. The one minor exception is in the planning area. Since these aircraft are not required to file a flight plan, all activities outside the jurisdiction of the ACC result from distributed short-term planning. Inside the ACC, controlled and cooperative aircraft are treated alike.

CONTROLLED AIRSPACE

Flight Phase	Planning		Path Conformance		Conflict Intervention	
	Prime	Backup	Prime	Backup	Prime	Backup
Preflight	GS	GS	NA	NA	NA	NA
Departure Taxi	GT	GT	A	G	G	A
Takeoff	GT	GT	A	G	G	A
Departure	GT	GT	A	G	G	G
Departure Transition	GT	AT	G	A	G	A
Cruise CONUS	GT	GT	A	A	G	A
Cruise Oceanic	GT	AT	A	A	A	G Advisories
Arrival Transition	GT	GT	G	A	G	A
Arrival	GT	GT	A	G	G	A
Approach	GT	AT	A	A	G	A
Landing	GT	AT	A	A	NA	NA
Arrival Taxi	GT	GT	A	G	G	A
Postflight	GT Close Flight Plan	NA	NA	NA	NA	NA

A - Air Managed (Pilot Responsible)
G - Ground Managed (System Responsible)
S - Strategic (Long-term)
T - Tactical (Short-term)
NA - Not Applicable

5. WHAT IS THE SATELLITE-BASED ADVANCED AIR TRAFFIC MANAGEMENT SYSTEM PERFORMANCE

HOW WELL DOES SAATMS PERFORM

SAATMS performance was evaluated in terms of safety, capacity, and delay. These performance measures are related to each other such that specification of two fixes the third. The system performance goal is to serve the 1995 demand at today's safety level with a delay equal to or less than that specified by TSC.

Two measures of safety were used. One was concerned with the time between conflicts as a function of separation distance. The other was concerned with the spacing required between two aircraft to prevent a conflict resulting from a blunder consisting of a specified acceleration of one aircraft relative to another. Saturation capacity of a runway was the number of takeoff and landing operations per hour given an infinite queue of arriving and departing aircraft. Delay was determined from a scenario based upon demand data for the Los Angeles region generated by the Mitre Corporation. Capacity and delay were evaluated using several runway utilization models.

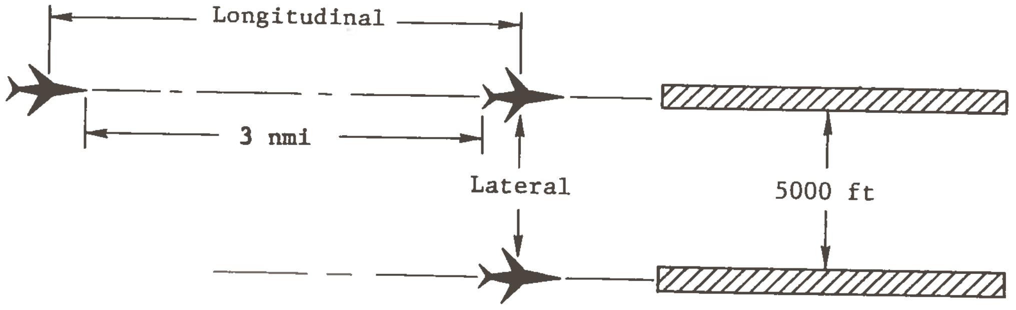
SAATMS AIRCRAFT SEPARATION REQUIREMENTS

One of the primary factors which affect the ability of a system to achieve a desired level of capacity and safety performance is the aircraft separation standard. One of the prime design goals of the SAATMS is to increase capacity over that of the present system while maintaining the same level of safety. The aircraft longitudinal separation for today's system, neglecting wake turbulence, is 3 nmi. If one of two aircraft in trail on a common path were to accelerate toward the other with a magnitude of 0.5 g, the present system will be able to prevent a collision. Under the same conditions of acceleration and probability of preventing a collision, the SAATMS could reduce the aircraft longitudinal separation standard to 0.8 nmi.

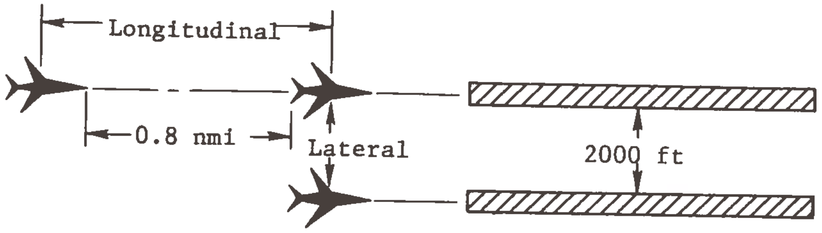
Under the present IFR, aircraft on parallel approaches to parallel independent runways can be separated by as little as 5,000 ft. This separation protects aircraft from blunder accelerations of up to 11.5 ft/sec^2 (0.36 g). This requires airport runways to be separated by at least 5,000 ft to support independent operations. Under the same operating conditions, SAATMS can provide the same level of safety with independent runway separations of 2,000 ft.

The longitudinal and lateral separation standards presented above do not consider the effects of wake turbulance. These separation standards could only be supported under atmospheric conditions in which wake vortex hazards did not exist.

AIRCRAFT SEPARATION



Present System



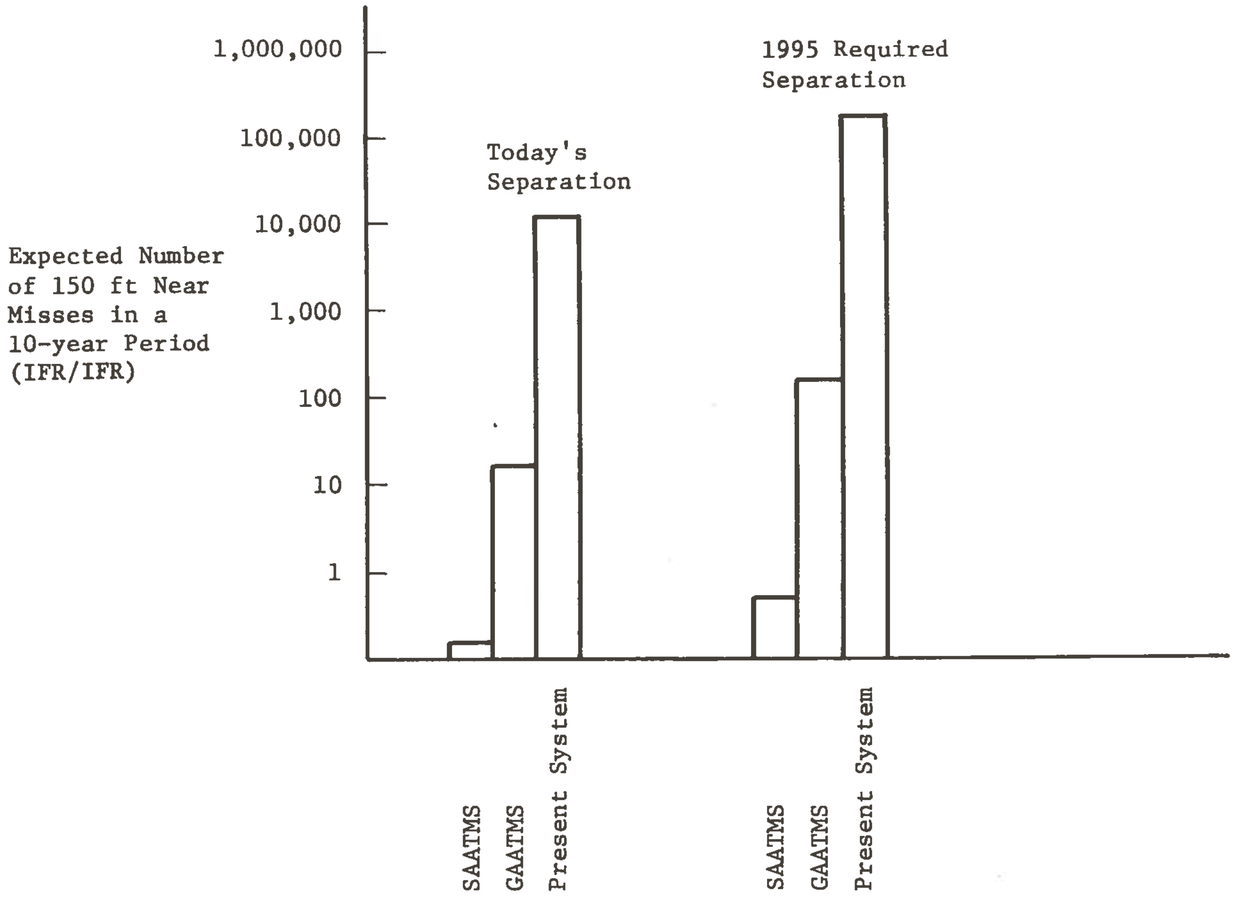
SAATMS with the Same Safety Level

Wake turbulence effects are not included in either system.

SAATMS ENROUTE SAFETY

A total system safety measure has been developed to permit comparison of different Air Traffic Management Systems. To facilitate these comparisons, a demand scenario has been projected for the 1995 time frame and imposed upon the SAATMS, the GAATMS, and the present system. The safety for the three systems was measured in terms of the expected number of conflicts per year using a model which has been normalized or calibrated to the 1968 near mid-air collision data. The separation standard used in the evaluation of all systems was chosen to be the same separation used in today's system.

The results of the analysis show that the enroute safety for the SAATMS is orders of magnitude higher than that of either the present system or the GAATMS. This is due to the higher surveillance and navigation accuracy of the SAATMS and its higher reliability. If the separation standard used by SAATMS is reduced by as much as five times to meet the greater demand, the resultant safety is still greater than that provided by the other systems using today's separation standard.

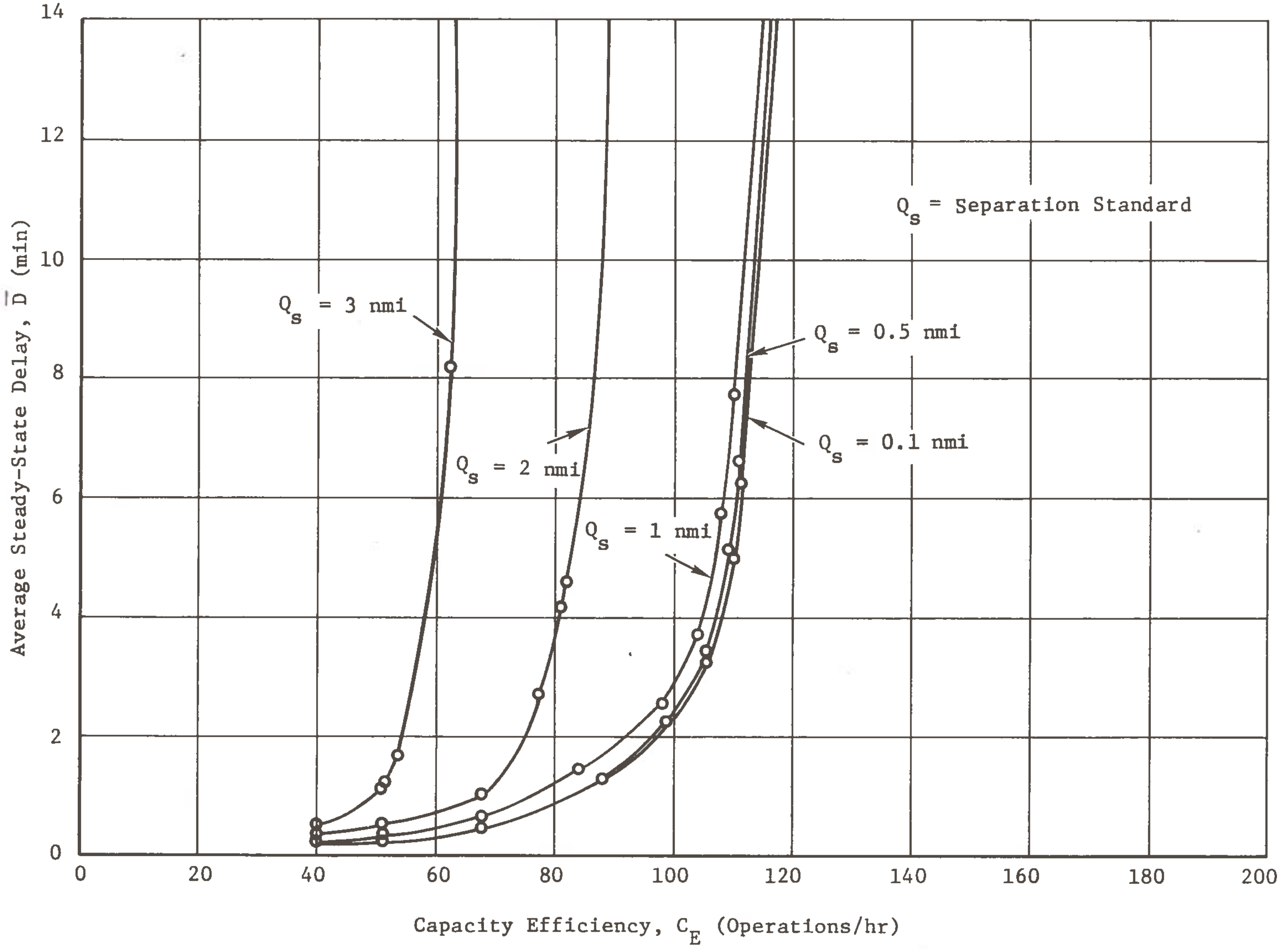

Expected Number of 150 ft Near Misses in a 10-year Period (IFR/IFR)
1,000,000
100,000
10,000
1,000
100
10
1
Today's Separation
1995 Required Separation
SAATMS
GAATMS
Present System
SAATMS
GAATMS
Present System

SAATMS SYSTEM PERFORMANCE

The three system performance parameters used to evaluate the SAATMS are capacity, safety, and delay. These three performance measures are inter-related; two of these measures must be specified to obtain a unique specification of the third. Delay and safety have been specified as system requirements; the capacity of the system was evaluated subject to the delay and safety requirements. A capacity equal to the demand was used as a design goal.

A bottleneck analysis was performed to determine that aspect of the air traffic systems that limits capacity. This was found to be the runways including the final approach. The capacity of airports in the Los Angeles region was determined since these airports are typical of those serviced by the SAATMS.

IFR runway capacity as a function of average aircraft delay is shown in the accompanying chart. The curves represent different longitudinal separation standards. If wake turbulence effects are neglected, the longitudinal separation standard for the SAATMS is 0.8 nmi. Examination of the curves shows that the separation standard lies in a region where it does not limit capacity. Capacity is affected by the system rules and procedures governing runway operations. The reduction of the longitudinal separation standard through improved surveillance or navigation subsystem accuracies would not appreciably increase the runway capacity.

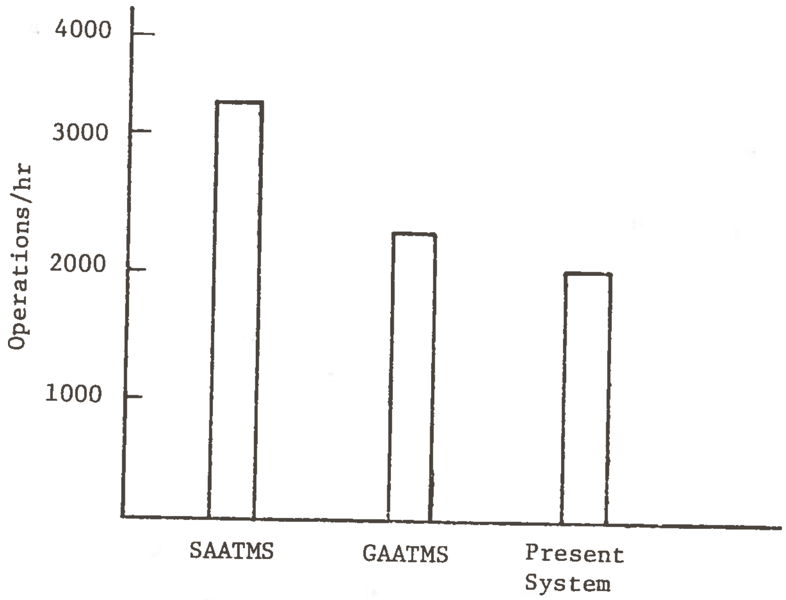

14
12
10
8
6
4
2
0
Average Steady-State Delay, $\overline{D}$ (min)
0
20
40
60
80
100
120
140
160
180
200
Capacity Efficiency, C_E (Operations/hr)
Q_s = Separation Standard
Q_s = 3 nmi
Q_s = 2 nmi
Q_s = 1 nmi
Q_s = 0.5 nmi
Q_s = 0.1 nmi

DEMAND-CAPACITY COMPARISON BY AIRPORT CLASS

A capacity vs demand analysis was made for primary aircarrier, secondary, and feeder airports in the LA Basin. The secondary and feeder airports operate under VFR in the same manner they do today. Under these conditions, the capacity of the airport at today's safety level is determined by non-system factors such as wake turbulence and spacing of aircraft on the runway. The limiting factor is the number of runways in relation to the demand. When visual flight rules apply, all systems, the present one as well as SAATMS, perform equally well. The analysis shows that the 1995 demand can be met under VFR operations. More runways will have to be added at the secondary and feeder airports to meet the post 1995 demand.

The situation at primary aircarrier airports is different. These airports operate under IFR conditions. That is, the established separation standards to meet today's safety levels are applied at all times. Under these conditions, surveillance accuracy becomes the significant parameter. The higher accuracy of SAATMS results in greater capacity than is available in either the present or GAATMS systems. These data are shown in the accompanying chart. SAATMS is capable of meeting and exceeding the post 1995 demand at these airports, while the other systems are not. Since the bulk of the traffic at these airports is aircarrier, the increased capacity and hence the decreased delays is of particular economic importance.

LOS ANGELES TERMINAL AREA PRIMARY AIRPORT CAPACITY



6. HOW DOES THE SATELLITE-BASED ADVANCED AIR TRAFFIC MANAGEMENT SYSTEM GET DEVELOPED

SAATMS RDT&E

The SAATMS RDT&E program has three primary objectives:

(1) Provide an orderly program of research and development aimed at realizing the full potential of the SAATMS with minimum technological risk.

(2) Schedule the RDT&E activities to make maximum use of scheduled DOD/NASA satellite programs.

(3) Develop a system management plan which will result in adequate control of the RDT&E activities and which will insure orderly and economical development of the SAATMS.

The evolutionary development of a SAATMS requires an orderly program of research, technical development, test, and evaluation. The goal of the RDT&E program is to gather the knowledge required to initiate a low-risk implementation program for the SAATMS which will satisfy the air transportation demands in the 1990 time period. This program must span all activities from initial concept formulation, through concept definition and system development, to the beginning of the system implementation program to ensure continuity of efforts and a minimization of costs.

SAATMS TECHNOLOGY

The technology required to implement the functions of the SAATMS concept is presently available. No significant advancement of the state of the art appears necessary. Rather, the R&D activities are directed toward establishing the details of the equipments, the optimization of techniques, and the realiziation of the full cost savings benefits from the functional integration.

Thus, the risk within the SAATMS lies not with the technological areas but instead with the ability to obtain the full potential from the designs. For example, the high peak power amplifier required for the surveillance function is available off-the-shelf as a tube (ceramic triode). Additionally, a solid state version is presently laboratory demonstrable. The solid state transmitter offers lower cost and long life. Hence, R&D activities are directed toward developing the solid state version and obtaining the cost and maintainability benefits. However, prototype development and feasibility testing can proceed using the ceramic triodes.

By and large, the benefits and features obtainable from the SAATMS accrue as a result of the use of satellites and a common functional waveform. Both of these are established technologies and need only be optimized for application to the SAATMS. The status of the technology for SAATMS components and techniques is shown in the accompanying chart.

IMPACT OF CURRENT TECHNOLOGY STATUS ON THE SAATMS CONCEPT

SAATMS Item	Technology Status 1973					Effect on System		
	Here Today	In Development	Feasibility Demonstrated	Presently Under Investigation	Conceptual	Vital No Backup Technology	Alternate Technology	Minor Impact
Components								
Aircraft Antennas	X							
Aircraft Receiver			X					
Aircraft Transmitter	X		X					
Aircraft Processor			X					
Satellite Transmitter				X			X	
Satellite Receiver			X					
Ground Signal Processor			X					
Signal Waveform			X					
Surveillance Software			X					
Navigation Software			X					
Automation Software		X		X	X	X		
Surface Guidance Sensor				X			X	X
Techniques								
Satellite Surveillance				X			X	
Satellite Navigation			X					
Satellite Communications	X							
Surface Guidance				X				X
Operational Concepts					X			X

SAATMS SATELLITE TESTING

The SAATMS RDT&E is closely aligned with planned DOD/NASA satellite experimental programs. The SAATMS satellite R&D activities will be fully coordinated with other government agencies to both minimize direct DOT costs and to maximize availability of test data.

There are three satellite test programs applicable to the SAATMS development, i.e., ATS-F, Aerosat, and the Defense Navigation Satellite Development Program (DNSDP). The earliest of these is the ATS-F, which is scheduled for launch in 1974. If the SAATMS program is to profit by ATS-F, planning and specific hardware fabrication must begin in 1973. Hence, the plan recommends the initiation of these activities now. Although the applicability of the ATS-F is limited, multipath and multi-access experiments, among others, can be accomplished, and SAATMS candidate techniques developed.

The most promising candidate from these preliminary satellite tests will be included in the Aerosat experiments. The Aerosat is planned to have a wide-band channel; therefore more realistic evaluations can be accomplished. Using the data gathered from the ATS-F experiments, simulations and analyses, signal waveforms, and avionics hardware mechanization can be selected which will be compatible with the SAATMS satellite objectives.

Perhaps the most promising area for satellite preoperational testing is the DNSDP. Several satellites will be launched in 1977, and wide-band L- and C-band channels are planned. In addition to multipath and link experiments, SAATMS surveillance, communication, and navigation techniques can be evaluated using these satellites. Coordination with DOD must begin early to insure inclusion of DOT SAATMS objectives in the test and associated equipment design. Using these satellites, a more detailed and complete evaluation of the SAATMS waveforms and techniques can be performed. The use of DNSDP is preferred.

The SAATMS R&D activities are directed toward meeting these dates with the necessary requirements defined, techniques analyzed, and equipment fabricated to insure a useful test and evaluation program. In addition, the RDT&E plan recommends outfitting a test aircraft specific to the SAATMS needs. With a dedicated test aircraft and the availability of the equipments, the support necessary to accomplish the satellite tests will be assured.

SATELLITE EXPERIMENT PROGRAM

ATS-F Tests and Experiments	Aerosat* Tests and Experiments	DNSDP Test and Experiments
Initial Multipath Experiments	Detailed Multipath	Multipath Experiments
TOA Measurement Techniques	TOA Measurement Techniques Evaluation	Link Characterization
Link Characterization (Partial)	Link Characterization	TOA Measurement Techniques
Aircraft Antenna Pattern Experiments	Aircraft Antenna Patterns	Aircraft Antenna Patterns
Preliminary Multi-access Noise	Navigation Waveform Noise	Navigation Waveform
Satellite Tracking	Surveillance Waveform	Surveillance Waveform
	Communication Waveform	Communications Waveform
	Multi-access Noise	Multi-access Noise
	Preliminary Surveillance Mechanization	Asychronous Acquisition and Tracking
	Preliminary Operational Concept Evaluations	Surveillance Mechanization
	Satellite Tracking	Navigation Mechanization
		Communication Mechanization
		Operational Concept Evaluation
		Control Software Evaluation
		VVOR
		Satellite Tracking
		Limited SAATMS Operational Tests
		Integrated Avionics Evaluation

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*The short evaluation time planned for the Aerosat satellites prior to its operational phase will impose limits on these tests.

SYSTEMS DEVELOPMENT REQUIRES A SYSTEM MANAGER

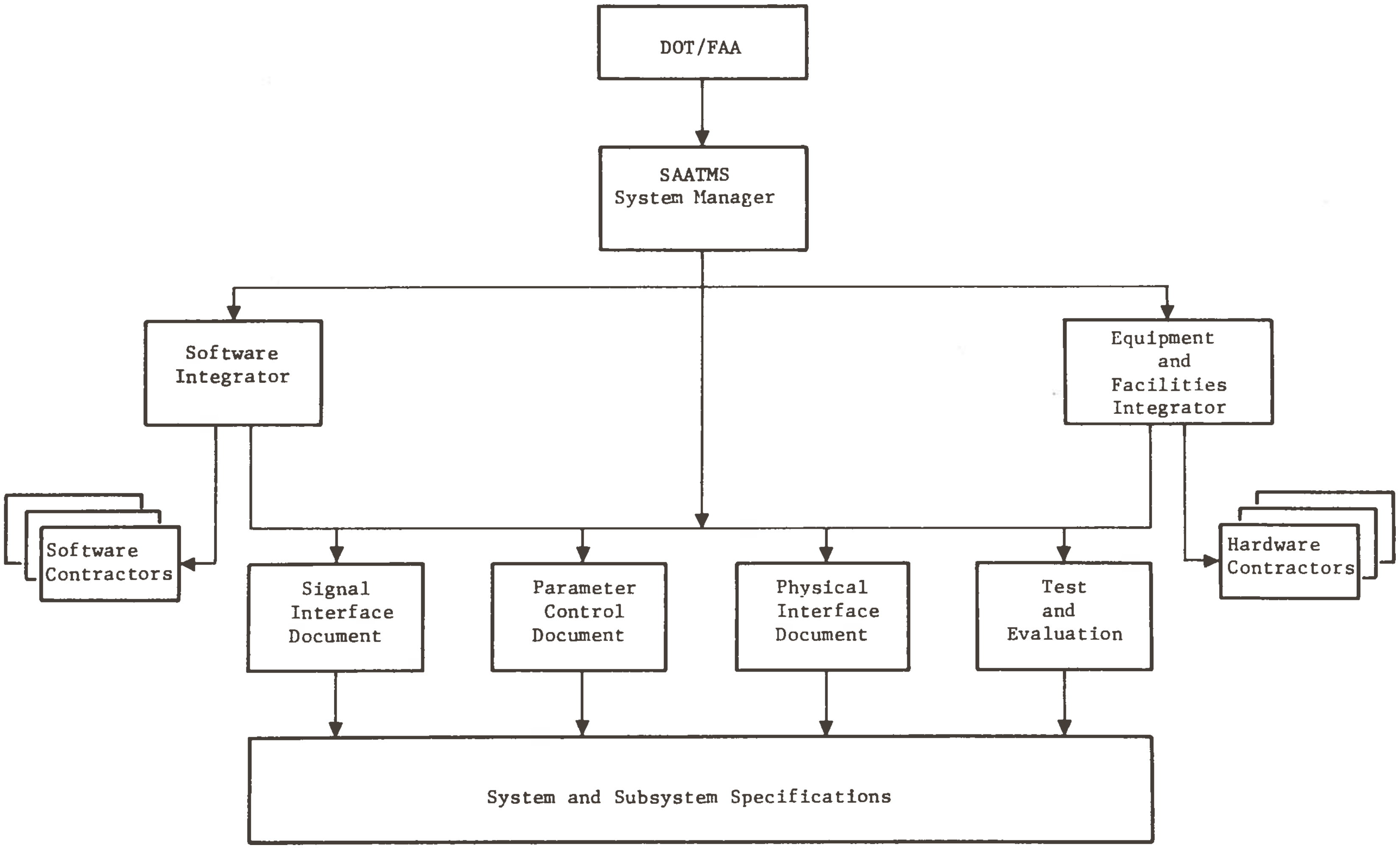
The number and complexity of the interfaces involved in a SAATMS require a formalized systems management approach to control its orderly and economical development. A system manager should be chosen to manage and control the design and development, to integrate the numerous end items into subsystems and ultimately into a complete system, and to develop the performance of the subsystem and system through tests and evaluations.

A system of this complexity warrants a minimum of two associate system integrators, one for software and one for equipment and facilities. Each of these associates should operate under the direction of a central government agency whose responsibility would be to monitor the integration, performance, operation, and cost of the RDT&E activities. Each of the associate integrators would be responsible for the selection of the hardware or software contractors, with concurrence from the responsible government agency. The system manager would also be responsible for the development of the control documentation required to assure that the specifications are met.

Operational testing will be performed to verify that the specification requirements are met. The system manager will be responsible for developing test plans and procedures and for scheduling the tests to phase in with the R&D activities. If this job is performed properly, a major cost savings can be realized. This savings results from the use of operational software, equipment, and facilities for operational testing. When the test program is complete, the software, equipment, and facilities are available for use in full system operation. This means that a substantial portion of the RDT&E and F&E costs can be shared. This savings can only be achieved if a strong systems manager is available to supervise and control the design and integration of the SAATMS equipment, software, and facilities.

A strong system manager, a comprehensive RDT&E plan, and a complete set of control documents are mandatory requirements for a successful, minimum-cost system development cycle.

THE SYSTEMS MANAGER



SAATMS RDT&E COSTS

As a result of integrating the SAATMS test objectives with those satellite tests planned by DOD/NASA and employing an overall systems management approach to the subsystem and system developments, a substantial cost savings will be effected. First, coordinating the SAATMS satellite tests with those planned by ATS-F, Aerosat, and DNSDP will obviate the need for special SAATMS satellite research launches. All SAATMS techniques and operational concepts can be evaluated using these programs. After these initial evaluations are performed and the SAATMS subsystems optimized, a SAATMS specific satellite constellation will be launched, and pre-operational tests will be accomplished.

During these pre-operational tests, the function of the System Manager becomes paramount. With care, the equipment, subsystems, and systems used during the pre-operational testing will be suitable for use during the initial SAATMS implementation/transition phase. Thus, the satellites, CCC, RCC, and ACC used during the RDT&E phase will be employed during transition. This permits a sharing of costs between RDT&E and F&E.

Utilzing this approach, the DOT costs directly related to RDT&E, which are not later recoverable, amount to $178 million. The total RDT&E program will cost over $570 million.

SAATMS RDT&E COSTS

SAATMS RDT&E	$178 Million	
DOD/NASA Planned Satellite Test Program ATS-F Aerosat DNSDP	$224 Million	(If included in SAATMS RDT&E)
F&E Cost Satellites Facilities	$170 Million	(If included in SAATMS RDT&E)
Total	$572 Million	

7. HOW DO WE TRANSITION FROM THE IN-BEING SYSTEM TO THE SATELLITE-BASED ADVANCED AIR TRAFFIC MANAGEMENT SYSTEM

TRANSITIONING TO THE SAATMS

The SAATMS transition planning permits an evolutionary changeover from the in-being system. The transition will occur over a 13-year period, with user benefits as the driving force. The transition approach was based, on one hand, on a number of significant transition criteria, and, on the other hand, on the characteristics and configuration of the SAATMS and the system from which the transition must be made:

The primary transition criteria include:

(1) Gradual and evolutionary introduction of operational and functional concepts
(2) No requirement for users to carry dual avionics
(3) Modular avionics to minimize cost
(4) Avoidance of government budget peaks
(5) Exploitation of the full useful life of avionics equipments; approximately 10 years
(6) Single control jurisdiction over all aircraft within a given airspace region

THE TRANSITION SCHEDULE

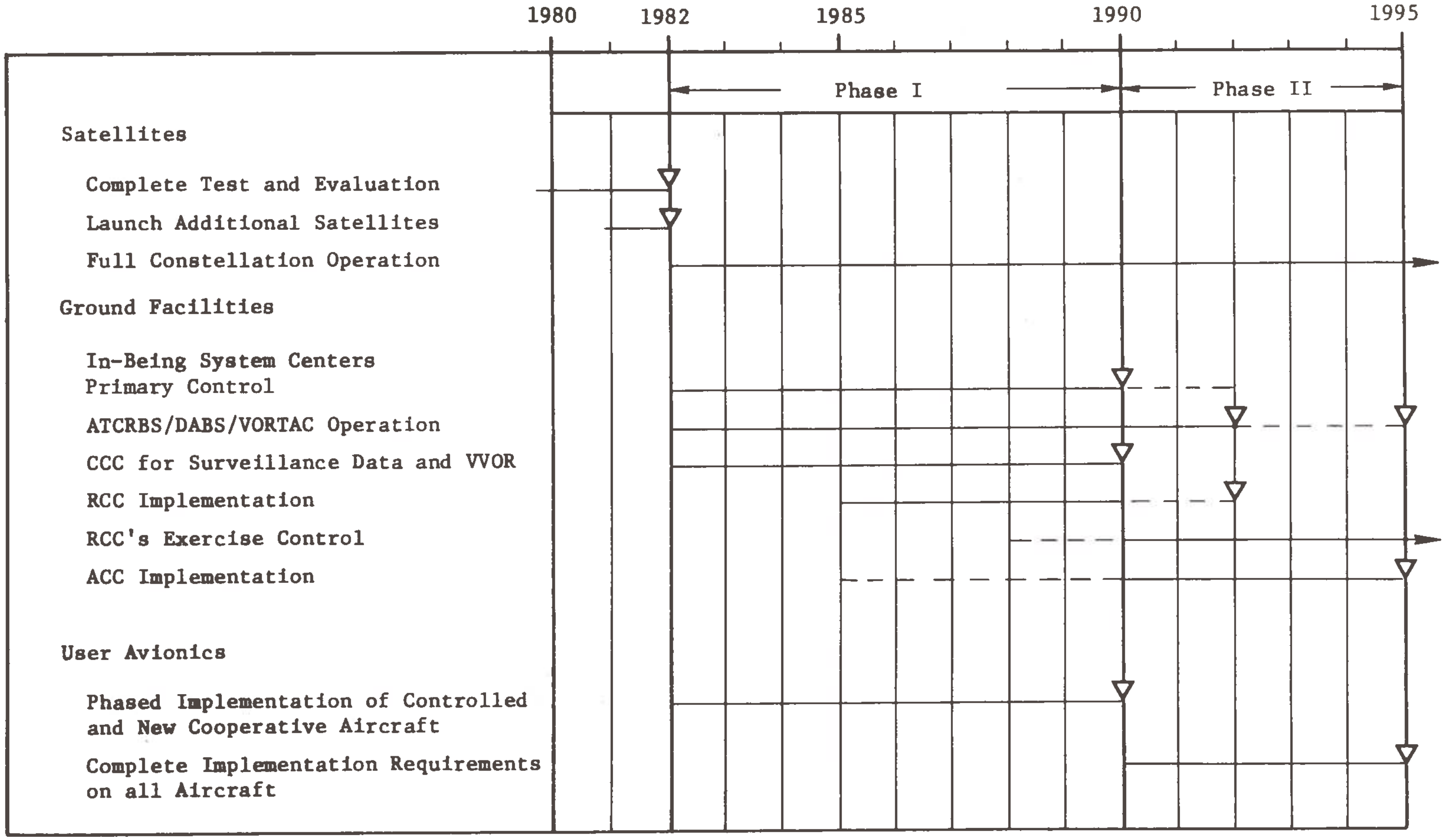
The SAATMS Transition Plan permits an evolutionary transition over a 13-year period. User benefits are the driving force behind the plan. The plan has no excessive federal budget peaks nor does it require users to carry two different sets of avionics equipment for the same function.

Smooth transition to the SAATMS is achieved by early satellite implementation, parallel operation of ground elements without a requirement for dual avionics, and time phasing procedures oriented to increasing user benefits and services. The transition period consists of two phases, i.e., Phase I from 1982 to 1990 and Phase II from 1990 to 1995. The overall transition schedule is presented in the accompanying chart.

During Phase I, the in-being system and the SAATMS will operate completely in parallel. All communications with SAATMS-equipped aircraft will be performed by the existing ATC facilities, ARTCC's, and TRACONS's, although the surveillance data used for control will be obtained from the satellites. The SAATMS CCC and some ACC's will be operational during this phase. During Phase II, the remaining ground elements of the system will be implemented. Control jurisdiction will be transferred to the RCC and ACC, and the ground facilities of the in-being system will be gradually decommissioned. At the end of Phase II, the SAATMS will be fully operational and the in-being system will be fully decommissioned.

The transition plan is based on the assumption that a combined ATCRBS/DABS surveillance system will exist by 1982, with limited implementation of DABS. It is evident from the timing of the recommended SAATMS implementation schedule that it may not be cost effective to carry out the complete ground facility implementation of DABS, or, indeed, any DABS implementation. This is particularly true if the SAATMS RDT&E program demonstrates the cost/benefits and performance characteristics of the SAATMS.

OVERALL SAATMS TRANSITION SCHEDULE



TRANSITION PHASE I

At the beginning of Phase I in 1982, the full SAATMS satellite constellation will be in orbit and a limited CCC will be operational. The satellites will carry all of the electronics equipment required for the SAATMS surveillance, communication, and navigation functions. The CCC will be implemented for its normal functions as well as some of those functions which will later be performed by the RCC's, e.g., VVOR processing. All users will be under the primary control jurisdiction of the ARTCC's and TRACON's. These centers will receive the surveillance position data on all Third-Generation-equipped users within their jurisdiction from ATCRBS or DABS sites. In addition, they will receive the surveillance position data on SAATMS-equipped users from the CCC via satellite communication links or, in some cases, via land lines.

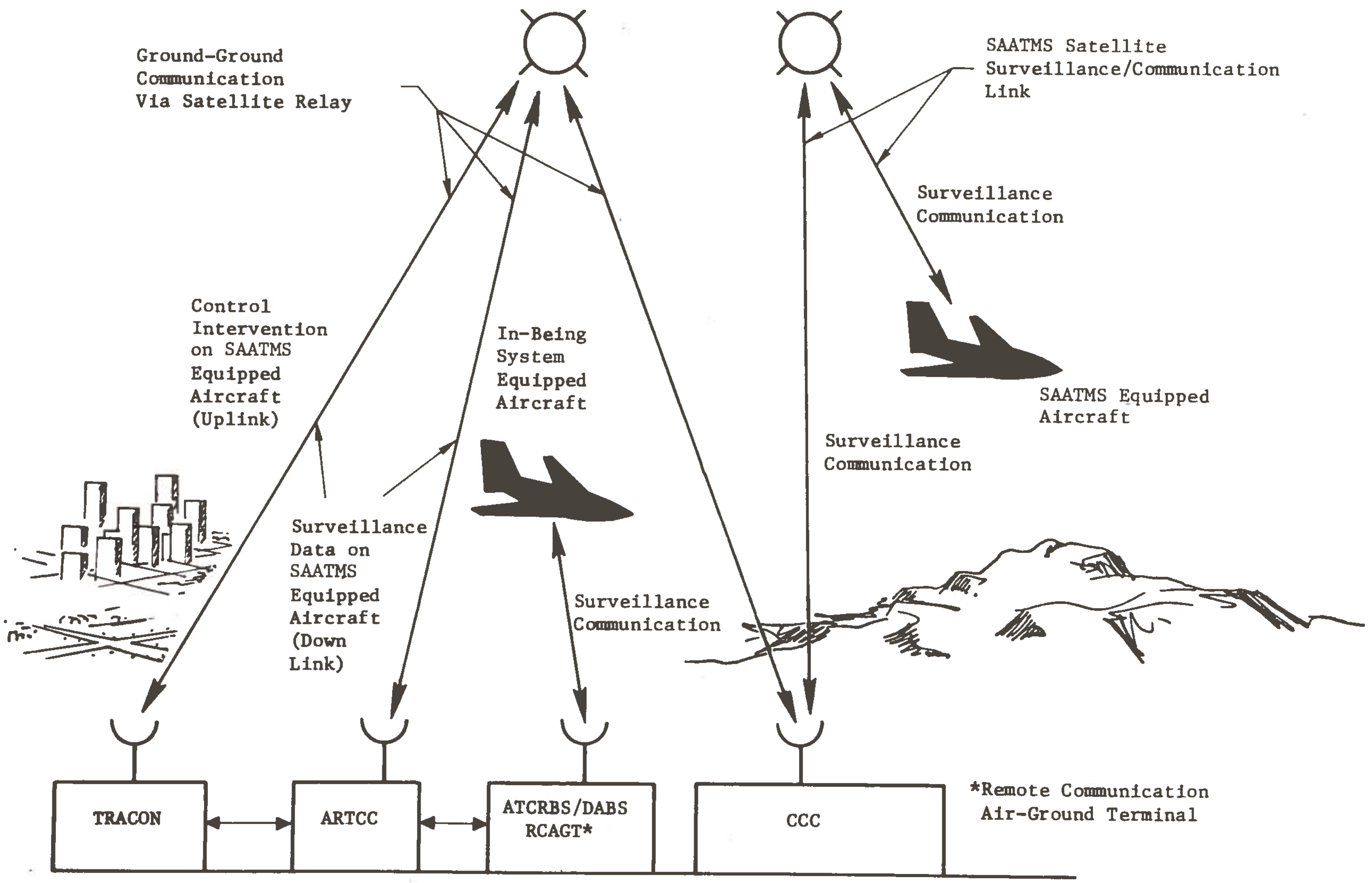
The processing required for conflict detection and resolution will be implemented at the ARTCC's and TRACON's. For Third Generation users, any conflict resolution safety commands (or boundary intrusion commands) will be transmitted to the aircraft either via voice (ATCRBS-equipped users) or via DABS data link (DABS-equipped users). Safety commands for SAATMS-equipped users will be transmitted from the ARTCC or TRACON to the aircraft via a link to the CCC and thence to the user via the SAATMS satellite digital data link. This approach assures the establishment of a single control jurisdiction over all aircraft operating within a region.

During Phase I, selected ACC's will be implemented at a few high density terminal area TRACON's, initially operated off-line for evaluation purposes and later operated on-line in conjunction with the cognizant TRACON. Ultimately, these ACC's will be tied in directly to the cognizant RCC.

Between 1982 and 1988, aircraft may be equipped with SAATMS avionics to receive SAATMS services. By 1988, all new aircraft will be required, by regulatory procedures, to carry the surveillance transmitter and all used aircraft will be required to carry this equipment by 1991.

During the last few years of Phase I, the two RCC's and additional ACC's will be installed and checked out. By that time, the bulk of the fleet will have transitioned to SAATMS. Therefore, at the end of Phase I, the primary surveillance and control functions will be transferred from the ARTCC's, TRACON's, and the CCC to the western and eastern RCC's; and the CCC will assume its normal SAATMS functions.

PHASE I - TRANSITION SURVEILLANCE-CONTROL-COMMUNICATION LINKS

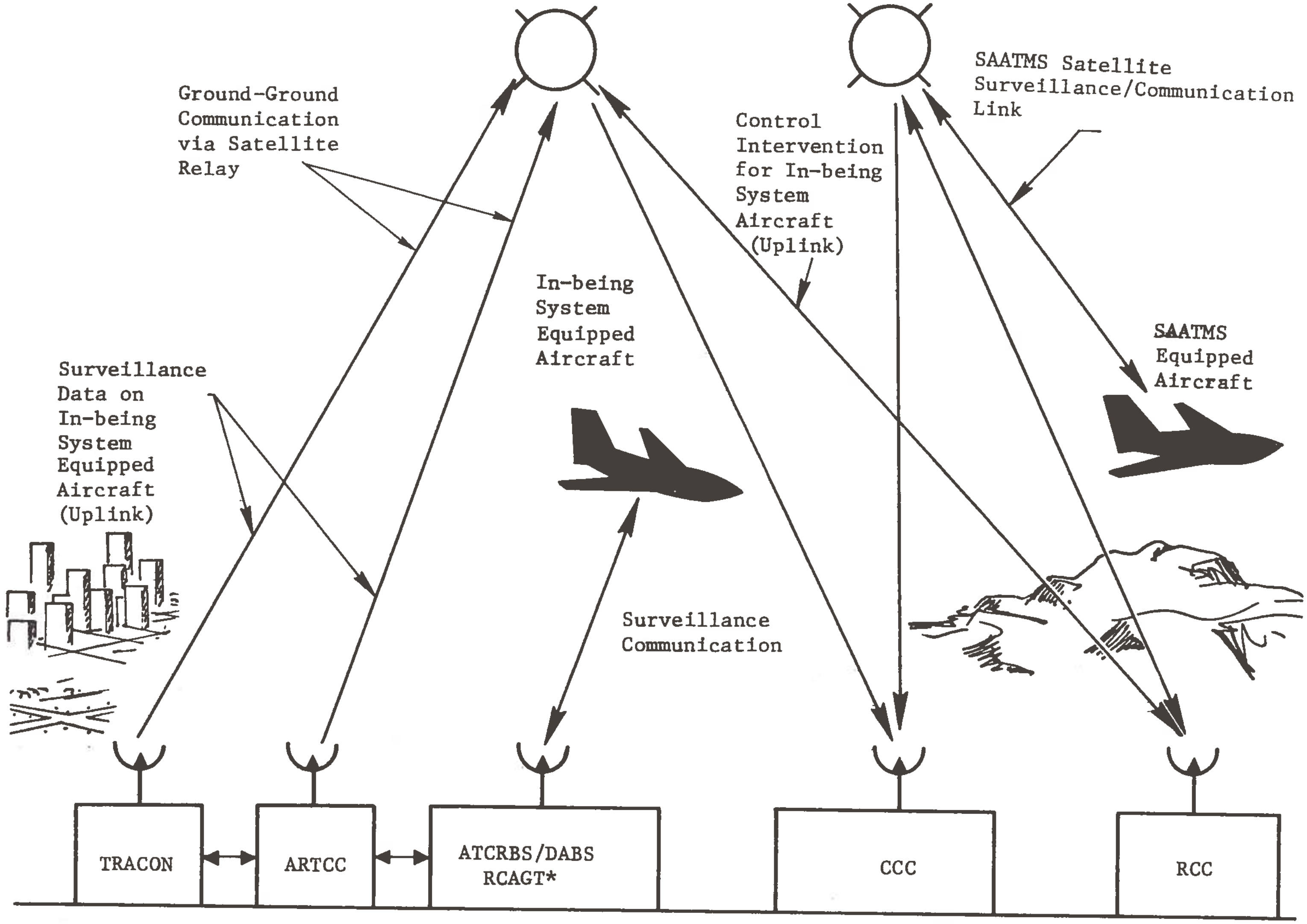


TRANSITION PHASE II

At the beginning of Phase II, primary control jurisdiction over all aircraft will be transferred at an accelerated rate to the RCC's. Third Generation System facilities will be gradually decommissioned during the 5-year period from 1990 to 1995. By the start of Phase II, only a small percent of users in the system will not be SAATMS-avionics equippped. Regulatory procedures will require that all new aircraft be equipped with SAATMS surveillance/communications functions by 1990, and used aircraft by 1992.

During the early part of Phase II, surveillance position data on non-SAATMS-avionics equipped users will be obtained at ATCRBS or DABS sites and transmitted via the TRACON's and ARTCC's to the RCC via satellite. The RCC will perform the conflict detection and resolution processing on all aircraft regardless of the source of surveillance position data. Conflict resolution commands to SAATMS-equipped users will be over the normal SAATMS digital data link. Conflict resolution commands to the non-SAATMS-equipped users will be via the ARTCC or TRACON over the DABS data link or VHF voice. By 1992, all users will have transitioned to the SAATMS surveillance/communications function and Third Generation ATC facilities; i.e., ATCRBS, DABS, TRACON's, and ARTCC's will be decommissioned. At approximately the same time, decommissioning of the VORTAC sites will begin. By that time, the bulk of the controlled users will be equipped with SAATMS navigation avionics as a consequence of benefit incentives and federal regulations. GA aircraft may still use VOR on a limited basis during this period. However, by the end of Phase II, the entire VORTAC net will be decomissioned. GA users will receive navigation service either by means of VVOR or with low cost versions of the SAATMS satellite navigation function. Thus, by 1995, SAATMS will be in full operation, and the in-being system facilities will be fully decommissioned to reduce system O&M costs.

PHASE II TRANSITION SURVEILLANCE-CONTROL-COMMUNICATION LINKS



*Remote Communication Air-Ground Terminal

8. WHAT DOES THE SATELLITE-BASED ADVANCED AIR TRAFFIC MANAGEMENT SYSTEM COST

SAATMS COST

An estimate of the total federal government and user costs for SAATMS was made, based upon the proposed SAATMS configuration. The objective of this effort was to arrive at a consistent set of data which reasonably reflects the cost of implementing and operating the system.

The primary sources used for generating the cost data were the RAND Corporation cost analysis and the DOD Pricing Guide. Since the SAATMS is an advanced air traffic system, many of the components of the system have no direct, identifiable, commercial or military counterpart. Thus, the cost of such items can only be estimated by

(1) Consulations with experienced designers and engineers, both in-house and associated with other companies or research organizations

(2) Comparison of the proposed SAATMS components with known available, similar components

SAATMS FEDERAL GOVERNMENT R&D AND F&E COSTS

The early SAATMS expenditures are in the area of R&D and F&E costs. The R&D costs are concerned with developing and testing SAATMS techniques, equipment, and subsystems. The F&E costs are concerned with implementing the SAATMS. The estimated cost of the SAATMS R&D effort is $178 million. This amount would be expended from 1974 to 1983, peaking at a level of approximately $25 million per year. The output of the R&D effort would be the specifications and operating requirements for the operational equipment. Several of the later RDT&E tasks require use of prototype SAATMS subsystems. The operational use of these subsystems extends beyond the R&D phase and into the transitional and implementation phases. Since their use extends far beyond the testing phase, their cost has been included in F&E rather than R&D.

The F&E costs are those required to acquire and install the facilities and equipment necessary to bring the system to its initial full operating capability in 1995. The costs of the initial spares are included but not the costs of the replacement of equipment at the end of its operating life. The F&E cost estimates assume current or slightly advanced technology for the required hardware. Existing government land is assumed to be available for all facilities. The satellite costs were estimated using the Mitre Corporation estimating relationships. The use of standard launch vehicles with one or more spacecraft per launch was assumed. Use of the space shuttle would substantially lower these costs.

All costs are in 1973 dollars with no allowances for inflation.

SAATMS FEDERAL GOVERNMENT R&D AND F&E COSTS

R&D Cost:						$178 Million
F&E Costs ($ Million)						
Site (No.)	Land	Buildings	Equipment	Software	Installation and Checkout	Total
CCC (1)	*	15	103	33	22	173
RCC (2)	*	30	179	19	39	267
STC (7)	*	*	1	*	*	1
ACC (729)	*	43	234	17	51	345
Calibration Stations (50)	*	1	1	*	*	2
Totals	*	89	518	69	112	788

	Satellites	Launch Vehicles	Total
Geostationary (6)	32	56	88
Geosynchronous (9)	22	28	50
Totals	54	84	138
F&E Grand Total			$926

*Less than One Million Dollars

SAATMS FEDERAL GOVERNMENT OPERATIONS AND MAINTENANCE (O&M) COSTS

The O&M costs are those required to operate the system and to maintain it in a state of operational readiness. The latter requirements include the costs incurred in replacing worn out equipment with new equipment of exactly the same capability. The O&M costs are, therefore, recurring costs and are estimated on an annual basis. Actually, O&M costs will be incurred on completed and operating portions of the system, while F&E costs are still incurred on those portions yet under construction.

The number of controllers required, and thus the controller costs, is based upon the 1995 demand level of 40,000 IAC and an assumed automation level which permits 40 aircraft per controller. This controller productivity number was used to provide a common basis for comparing alternate mechanization costs. However, the control and automation philosophy of the SAATMS is such that higher automation levels can be achieved. This is due to the high surveillance and navigation accuracies available, the complete use of RNAV by all users, the 100 percent backup available, and the use of air derived separation assurance as a backup in high density airspace. Since approximately two-thirds of the O&M costs are controller costs, the total O&M costs are very sensitive to the degree of automation assumed and, thus, the number of controllers required.

The O&M cost elements used are those specified by the TSC Data Formats Specification. All costs are in 1973 dollars, with no allowances for inflation nor increases in personnel salary costs.

SAATMS FEDERAL GOVERNMENT O&M COSTS

O&M Costs ($ Million)						
Site (No.)	Control Personnel	Maintenance	Equipment Replacement	Flight Inspection	Other	Total
CCC (1)	72	2	14	*	1	89
RCC (2)	144	5	23	*	3	175
STC (7)	0	1	*	0	1	2
ACC (729)	181	59	32	0	42	314
Calibration Stations (50)	0	*	*	0	*	*
Totals	397	67	69	*	47	580

	Satellites	Launch Vehicles	Total
Geostationary (6)	5	8	13
Geosynchronous (9)	3	4	7
Totals	8	12	20
O&M Grand Total			600

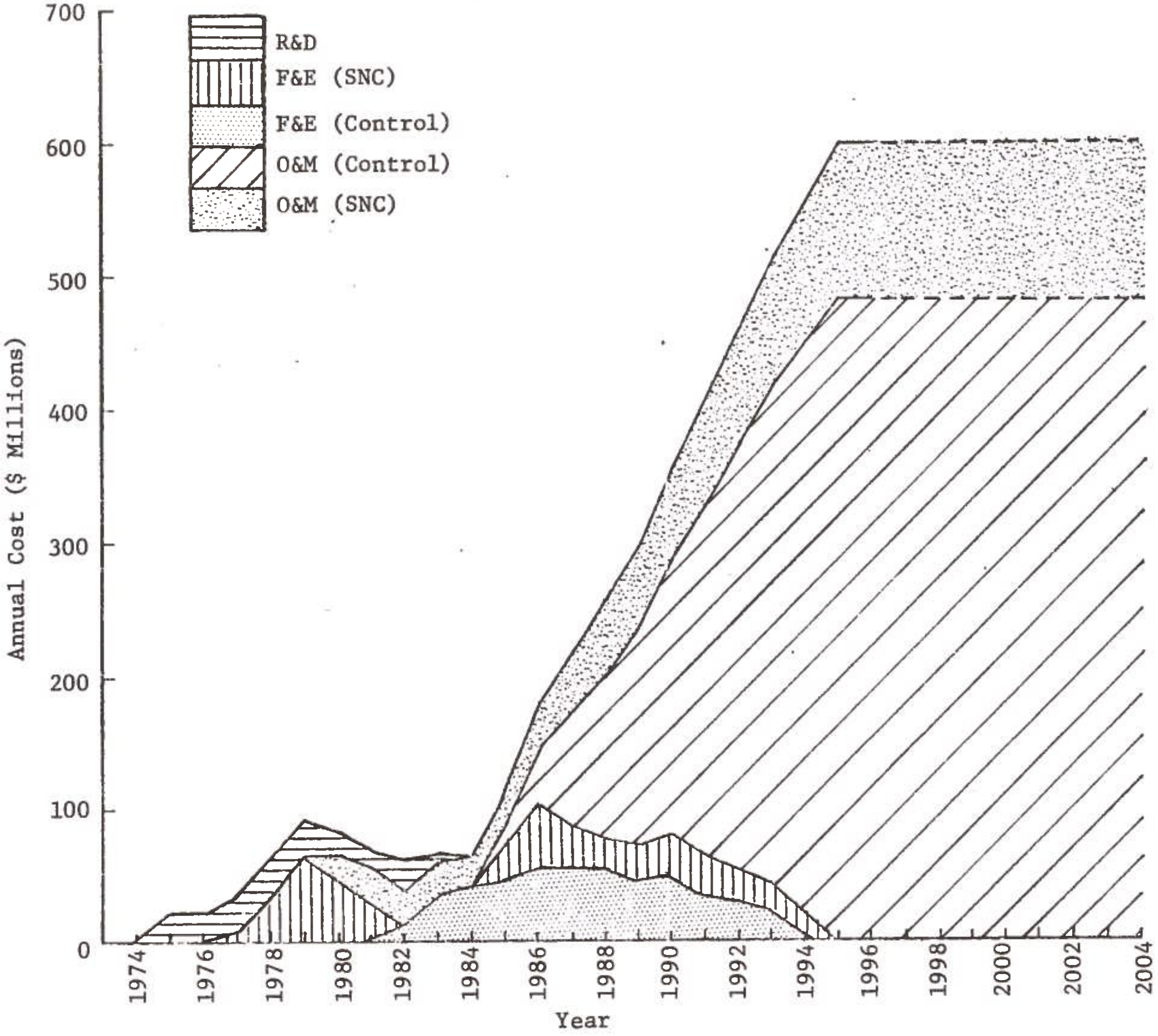
SAATMS ANNUAL EXPENDITURES

The annual expenditures required to implement and operate the system were determined from the R&D, F&E, and O&M cost estimates, the proposed time phasing, and the transition plan. The operational satellite constellation is assumed to be installed in the 1978 to 1982 time period, along with the initial increment of the ground facilities (i.e., portions of the CCC). As additional facilities are completed, they become operational and begin to incur O&M costs. The major portion of the system is constructed and brought on-line during the 1990 to 1995 time period. The system is assumed to be fully operational in 1995.

The F&E and O&M costs are divided into those associated with the Surveillance, Navigation, and Communication (SNC) functions and those associated with only the control function. The F&E costs are those annual expenditures required to acquire and install the initial complement of facilities and equipment.

The O&M costs consist of the annual costs of the controllers, the computer operators, their supervision, the maintenance personnel, maintenance materials and supplies, equipment replacement costs, and other operating costs.

INCREMENTAL SAATMS ANNUAL EXPENDITURES



SAATMS USER COSTS

The costs of the user avionics were obtained by either estimating parts counts for the airborne equipment and applying factors to account for manufacturing, selling, and profit costs or by comparing the parts count with the costs of currently available avionics equipment of similar complexity and capability. The costs assume large volume production by several competitive manufacturers, using existing or slightly advanced technology. Only the costs of the minimum equipment required for each class were determined. Additional equipment for redundancy, increased capability, or operating convenience were assumed to be purchased at the user's option.

The typical GA user carries only the minimum equipment required to interface with the system. This equipment will be the lowest priced of all the available avionics equipment.

The improved GA user has a larger, more expensive, better equipped, and probably multi-engine aircraft. This user carries the same minimum avionics equipment as the typical GA user but also has additional equipment with added capability for flight in controlled airspace.

The aircarriers will be equipped with the highest capability, top-of-the-line avionics. The equipment complement will be similar to that carried by the improved GA user, but the equipment will be fully ruggedized ARINC quality equipment.

TYPICAL SAATMS USER COSTS

User Class	Functions Provided	Costs (Dollars)		
		Purchase	Installation	Maintenance
Typical GA	Surveillance (Satellite) Digital and Voice Communication RNAV (VVOR) (VVOR) Approach Ground Surveillance	3,025	600	600*
Improved GA	Surveillance (Satellite) Digital and Voice Communication RNAV (Satellite and VVOR) VVOR Approach Ground Surveillance Ground Navigation MLS (Optional) Air-Air CAS (Optional)	13,250 (1,600) (1,400)	2,650 (320) (280)	2,650* (160*) (140*)
Aircarrier	Surveillance (Satellite) Digital and Voice Communication RNAV (Satellite and VVOR) Ground Surveillance Ground Navigation MLS Air-Air CAS	32,200	6,440	6,440*

*Maintenance cost per year, including allowance for equipment replacement.

9. WHAT ARE THE SATELLITE-BASED ADVANCED AIR TRAFFIC MANAGEMENT SYSTEM BENEFITS

SYSTEM BENEFITS - LOWER COSTS, IMPROVED SERVICES

The operational benefits of the SAATMS can be largely traced to the use of satellites. The SAATMS design and operating concepts strike a happy balance between aircarrier and GA requirements and Government resources and responsibilities.

This section describes the SAATMS features and their relationship to user benefits. The ability of other systems to supply these benefits is also discussed. Basically, the SAATMS benefits fall into three categories:

(1) Cost
(2) Safety
(3) Services

Feature: Integrated Avionics

Benefit:
Lower user cost
Functional backup
More services for less money

How Provided: The systems approach to the design of the SAATMS, coupled with the use of common links and frequency bands, allows a total integration of the SAATMS user avionics. The integration is brought about specifically by the use of common waveforms and links for the surveillance, communications, and navigation functions. Thus, similar design techniques are used with a common integrated Communication Navigation Identification (CNI) package resulting. This integrated CNI package in turn results in a lowering of avionics costs. This approach particularly benefits the GA user, who receives a maximum of service for a minimum of investment.

Comparison with Other System: By comparison, the present and planned ATC systems have evolved as the deficiencies in service have been uncovered. As a result, a patchwork ATC system exists. There is no commonality among the various functions in their technique, design, or equipment mechanization. An individual user requires a separate equipment for each service and his total avionics complement includes VHF (communications), VHF/UHF (navigation), and L-band (surveillance). The comparative costs of the non-integrated present system and the integrated SAATMS avionics is shown in the accompanying chart.

Present System

Equipment	Service	Approximate Cost*
Navigation/ Communication	Navigation/ Communication/ Localizer	2000
ADF	Approach Guidance	1250
DME	Navigation	2700
Transponder	Surveillance	600
Area Navigation	Navigation	2000

Percent Fleet	Equipment	
98%	Navigation/ Communication	⇒ Average GA User Costs - Present System: $5600
55%	Backup/ Navigation/ Communication	
60%	ADF	⇒ 1972 New GA Aircraft Avionics Cost (AOPA Data): $9000
30%	DME	
40%	Transponder	

SAATMS

Equipment	Service	Approximate Cost	
Integrated Transceiver	Digital Communications Surveillance	2500	⇒ Average SAATMS GA User Avionics Cost: $3600 (includes installation)
Integrated Controls and Displays	Voice Communication VVOR Approach Guidance ILS Area Navigation	525	

*Average of King Radio and NARCO Equipment Costs

Feature: Down-to-Ground Coverage

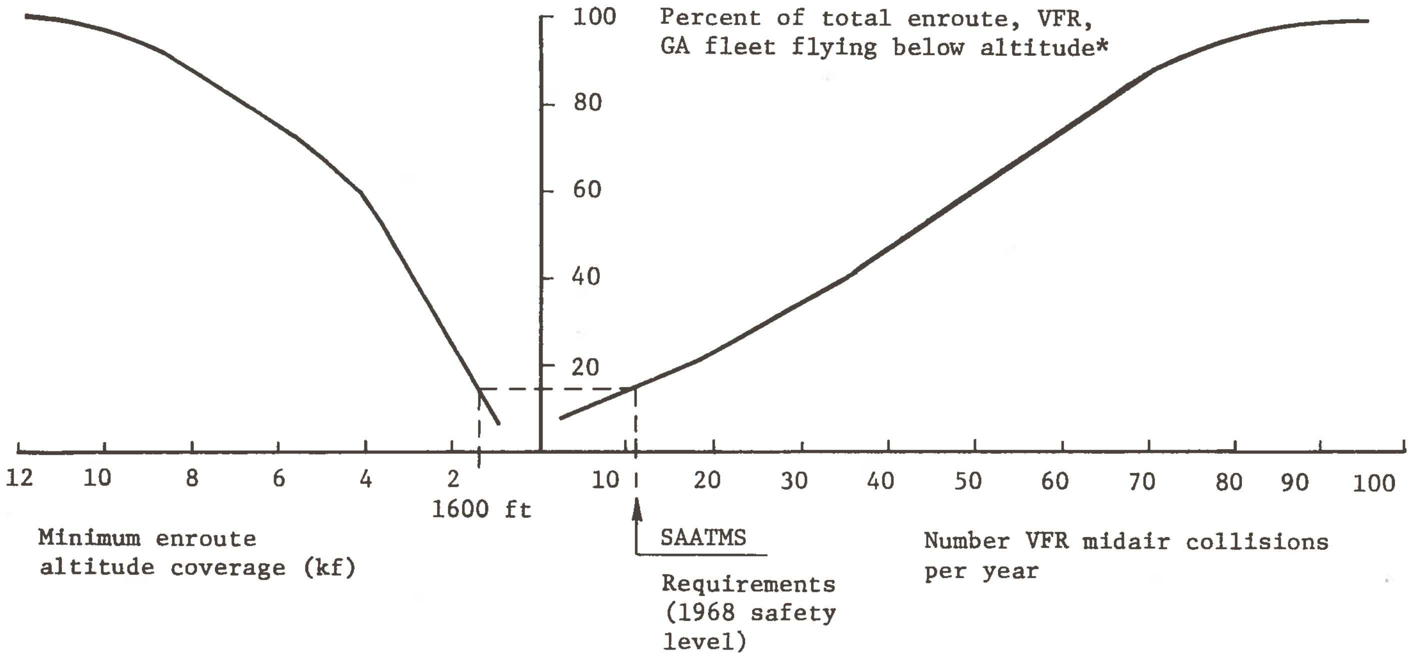
Benefits: Increased safety at lower costs
Lower F&E costs

How Provided: Regardless of an aircraft's location, satellite surveillance is always available. The primary cause of GA accidents, according to a recent FAA/Mitre Corporation study, is the lack of surveillance data at remote sites. When over 10 percent of the enroute (more than 30 miles removed from an airport) GA fleet is flying lower than 3000 ft, down-to-ground surveillance becomes important. Satellites provide these data.

Comparison with Other Systems: A ground based system can only lower coverage by increasing the number of sensors. Increasing the number of sensors raises the system F&E and O&M costs. Satellites provide this coverage at no additional cost. The enroute coverage required to meet the SAATMS safety standard is shown in the accompanying chart. This chart was obtained by estimating the number of VFR/VFR and VFR/IFR midair collisions from an enroute demand model. The number was normalized to the 1968 near midair collision data presented in a study by the FAA.

The enroute safety data indicate that to reduce the accident rate for GA aircraft, a significant reduction in the amount of airspace not under surveillance must be achieved.

ENROUTE SAFETY



*FAA-DOT-Systems Management Division - Traffic and Economic Analysis, "Altitude Distribution of Airborne Aircraft - Peak Hour Friday August 1963, CONUS" Working Paper (Project 150-25)

Feature: Surveillance at Remote Airports

Benefits:
- Increased safety
- Improved services
- Lower F&E and O&M costs

How Provided: A satellite system inherently provides coverage at remote sites. This coverage provides increased safety by keeping all aircraft under surveillance, provides separation assurance, and improves services by providing VVOR and VVOR landing guidance. These services are provided at virtually no additional systems F&E or O&M costs.

Comparison with Other Systems: A ground based ATC system can only extend coverage by increasing the number of ground based sensors or by installing control towers at these low-density airports. Thus, providing services at remote airports requires additional equipment and operations and maintenance expenditures. Based upon the FAA/Mitre safety data, however, not providing these services results in increased costs due to the large number of accidents that occur at these airports. These data show that from 1964 through 1971, 147 out of 179 airport collisions occurred at airports with no surveillance equipment. The cost of providing these services at feeder airports for SAATMS and the GAATMS is shown in the accompanying chart.

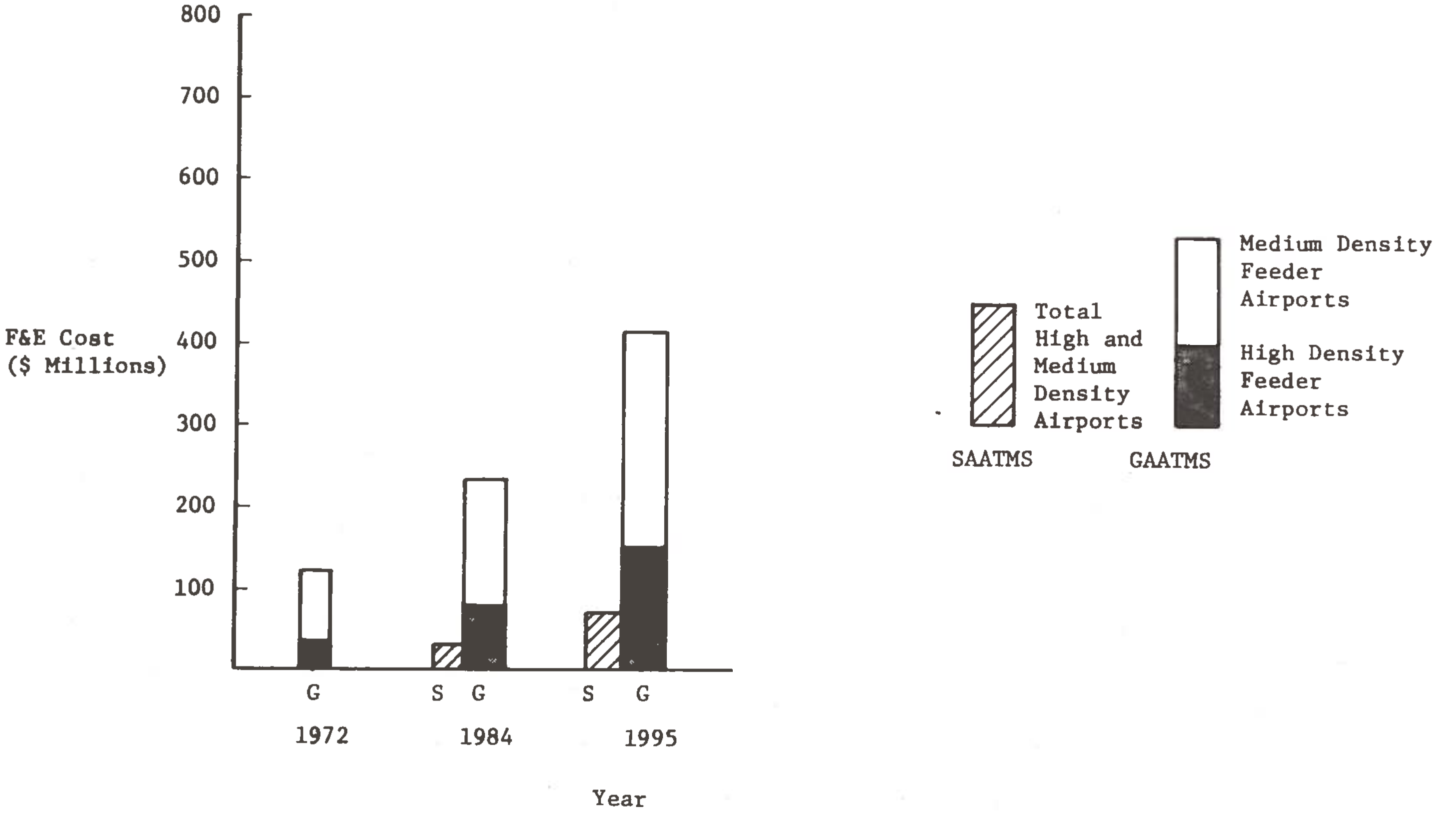
Future ATC systems will require surveillance on a high percentage of system users. If surveillance is provided by ground radars, a considerably larger number of ground radars must be used than is currently planned. If satellites are added to the system to supply the necessary low altitude coverage, the question must be asked: Why not use satellites in the terminals also? Dual equipment means dual costs for both the user and the government.

F&E COST FOR PROVIDING SERVICES AT FEEDER AIRPORTS

High Density Feeder Airports - Surveillance, Communications, Instrument Landing

Medium Density Feeder Airports - Surveillance, Communication

All Feeder Airports (SAATMS) - Surveillance, Communications, ILS - All Airports



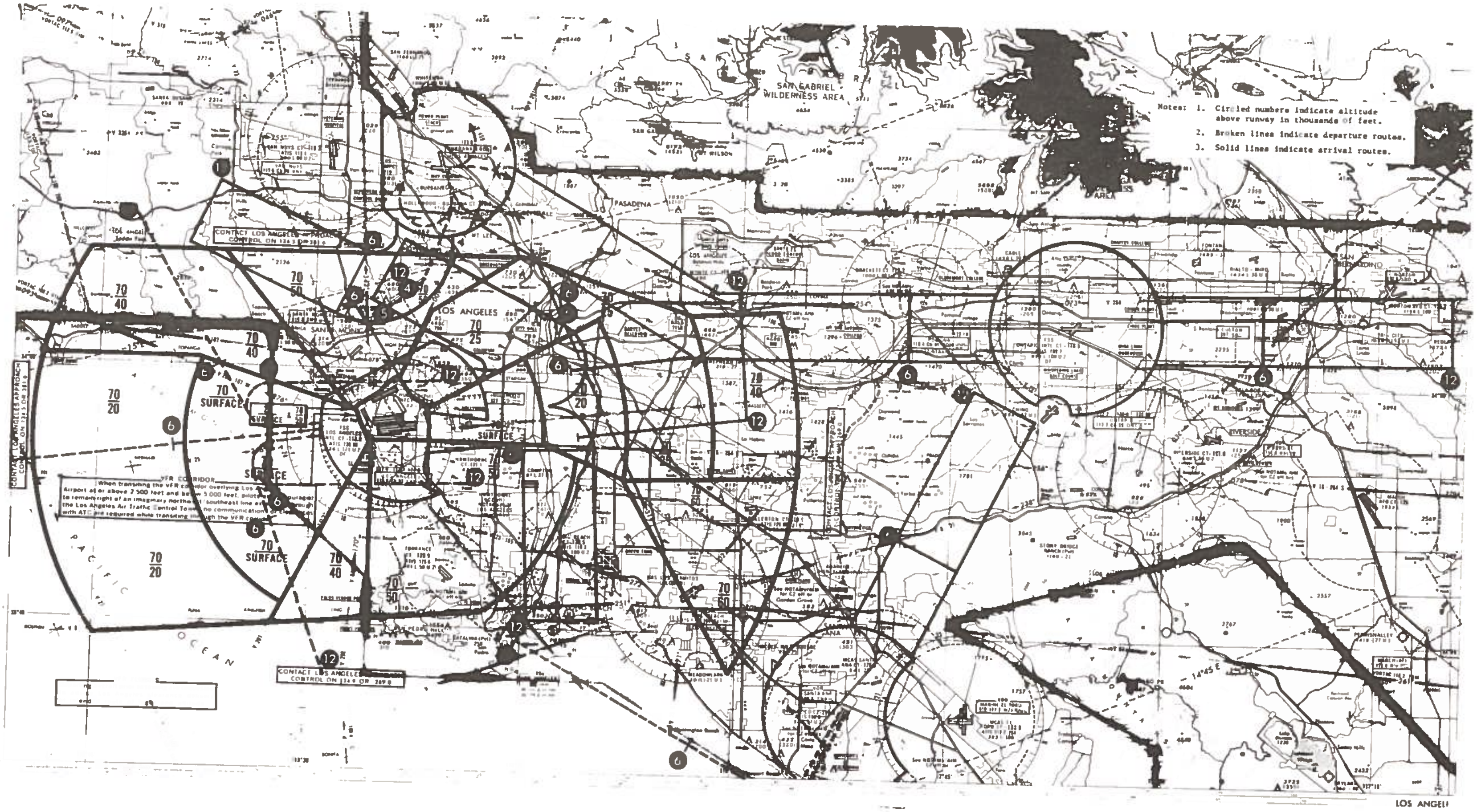
Feature: Range Independent Accuracy

Benefit: More efficient use of airspace
Improved safety

How Provided: In a satellite system, accuracy is not dependent upon range from the sensor. A satellite system can be developed that exhibits an almost constant accuracy regardless of aircraft location. Thus, spacing between routes can be uniform throughout CONUS. This provides more airspace for use by the GA users. In addition, since the high surveillance and navigation accuracy is range independent, the safety level is improved for a given separation standard. Accurate surveillance data are available for all aircraft, regardless of location.

Comparison with Other Systems: In the ground based ATC systems, the accuracy of the data degrades directly with range away from the sensor. Thus, while a 0.1 deg azimuthal accuracy means a 20 ft accuracy at 2 mi, it results in a 500 ft accuracy at 50 mi. The route structure must correspondingly grow; more volume is consumed and more restrictions are placed on the GA users. As the accuracy degrades, the conflict potential increases, and the expected safety level decreases.

TERMINAL CONTROL AIRSPACE FOR LOS ANGELES BASIN



Notes: 1. Circled numbers indicate altitude above runway in thousands of feet.
2. Broken lines indicate departure routes.
3. Solid lines indicate arrival routes.

Feature: High Accuracy Surveillance and Navigation Data

Benefit: High safety level, reduced number of conflicts

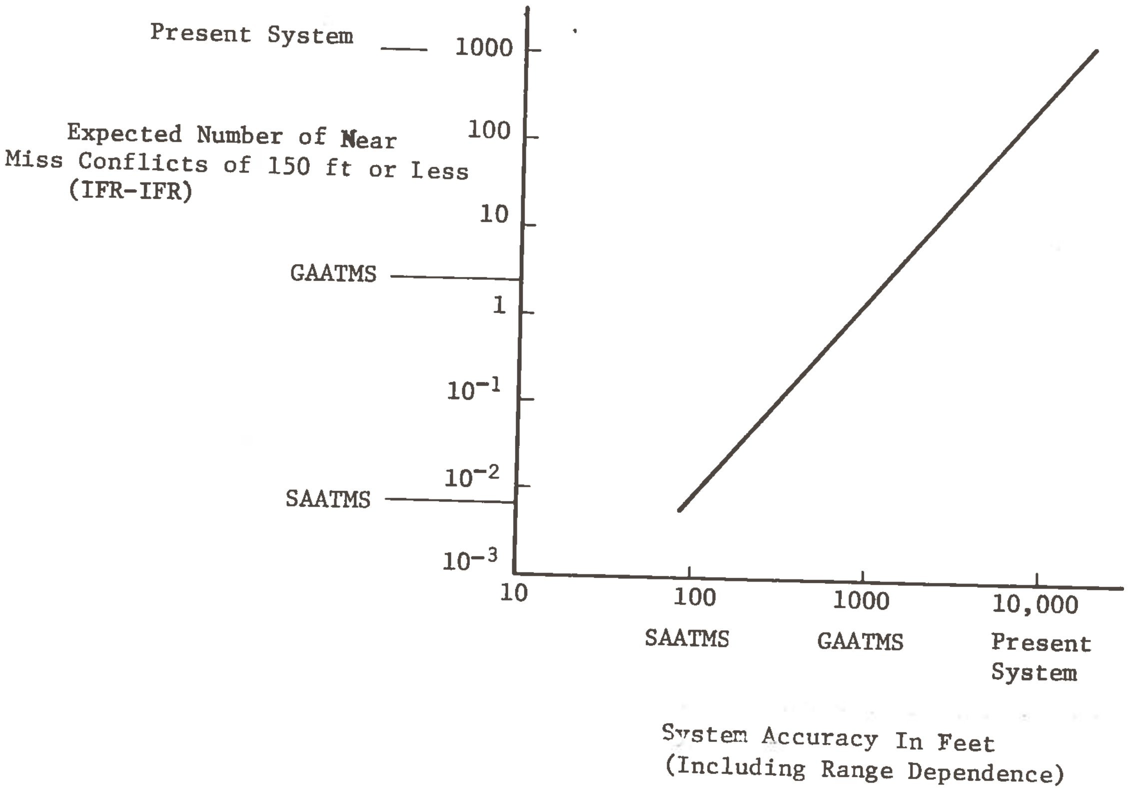
Increased automation potential

Lower O&M costs

How Provided: The automation potential of any SAATMS is ultimately limited by the controller workload. Assuming the controller must monitor each system intervention, the lower the number of interventions, the lower the controller workload and the larger the number of aircraft that can be monitored, i.e., the higher the automation potential.

Comparison with Other Systems: Present automation aids are aimed at increasing controller productivity by decreasing dependence on voice and increasing the amount of displayed information. The SAATMS further increases controller productivity by increasing the use of high precision navigation, area navigation, and surveillance and reduces convergence of aircraft over VOR sites. With these techniques, the number of expected system interventions will be less, and the controller workload is lowered.

LOWER CONFLICTS → LESS WORK LOAD → GREATER PRODUCTIVITY



Feature: Virtual VOR (VVOR)

Benefit:
Low cost navigation
RNAV for general aviation
Lower O&M costs

How Provided: The use of satellites allows down-to-ground surveillance and communication with all aircraft regardless of their remoteness from a large metropolitan area. Using the surveillance data and a grid consisting of virtual navigation sites, a highly flexible and very low cost area navigation service is offered the SAATMS GA user. The key to providing this service and obtaining the O&M benefits is derived from having surveillance on all users regardless of altitude or location. This total coverage is available only from satellites.

Comparison with Other Systems: The present and the planned Upgraded Third Generation systems use VOR/DME stations to provide navigation information. This is a point source system with position accuracy decreasing as the distance from the station increases. One thousand such stations are planned for CONUS by 1982 at a yearly O&M cost of more than $30 million. To use this navigation system, the pilot must buy a VHF omnidirectional receiver. To obtain range data he must add DME. To enjoy the convenience of area navigation, he must add an RNAV computer. The SAATMS user receives all of this for the basic price of the VVOR, and no VOR sites need be maintained.

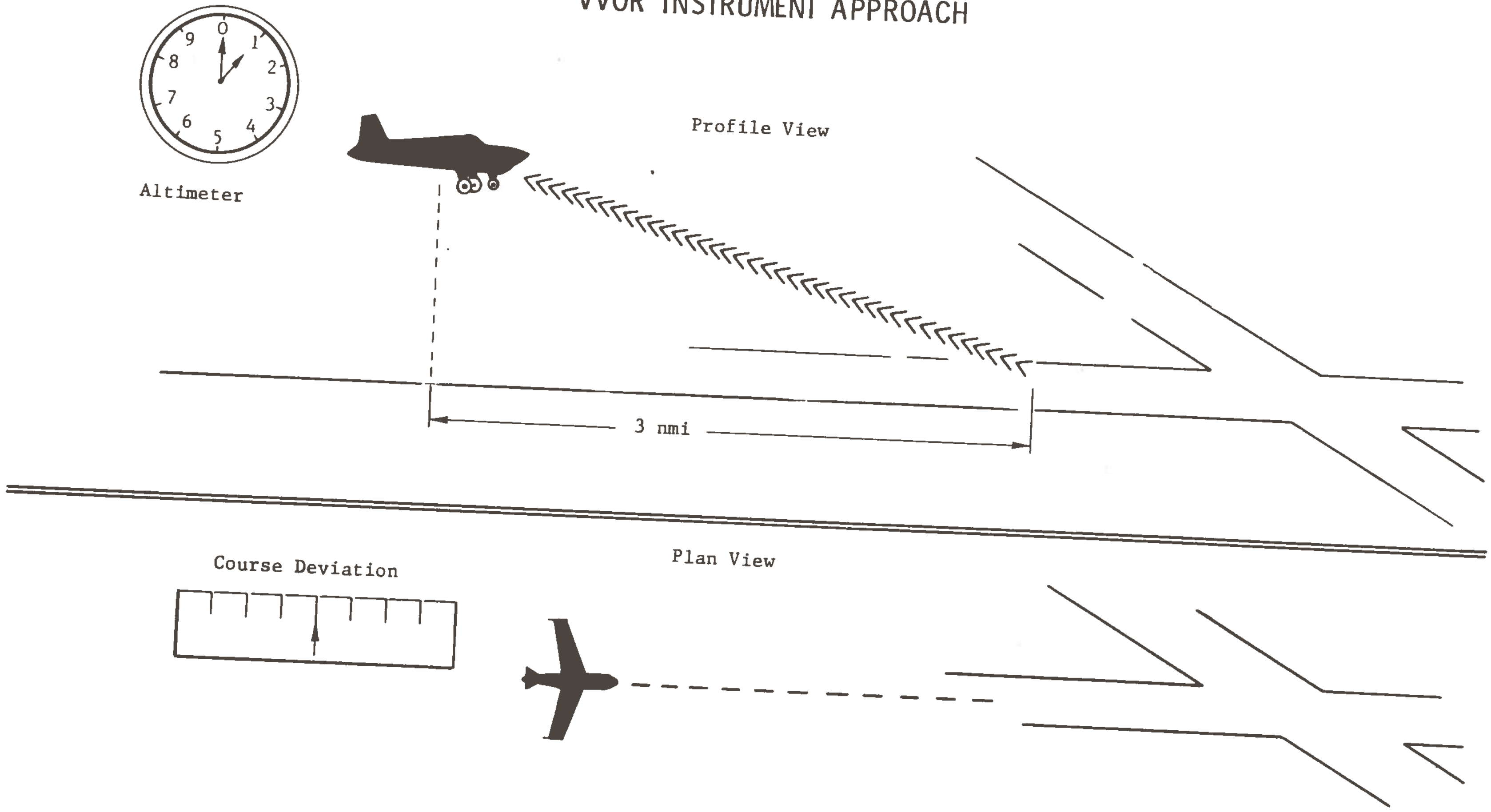
VIRTUAL VOR

Feature:	Instrument Approaches for the GA User	Benefits:	Increased user services at no additional costs Lower O&M costs

How Provided: The flexibility of the VVOR concept allows its use as an instrument approach system. A virtual site is located at the runway threshold. Range from touchdown and angle off centerline can be derived and transmitted for display to the pilot. Glide path is obtained procedurally by publishing altitudes at various ranges from touchdown for all runways. No additional avionics is required, and no added airport equipment is necessary. Further, the VVOR concept allows the use of straight-in approach and arrival patterns at airports minimizing environment and safety problems and easing pilot workload.

Comparison with Other Systems: This feature is analogous to VOR instrument approaches that are made in the present system. The present procedure requires a circling approach and continual altitude checks against cross radials from offset VOR stations. The localizer accuracy is diminished because the VOR station at the airport is offset from the runway. The VVOR procedure makes use of the DME feature to allow straight-in approaches. No cross radial checks are required. High localizer accuracy is assured by placing the virtual station at the center of the runway threshold.

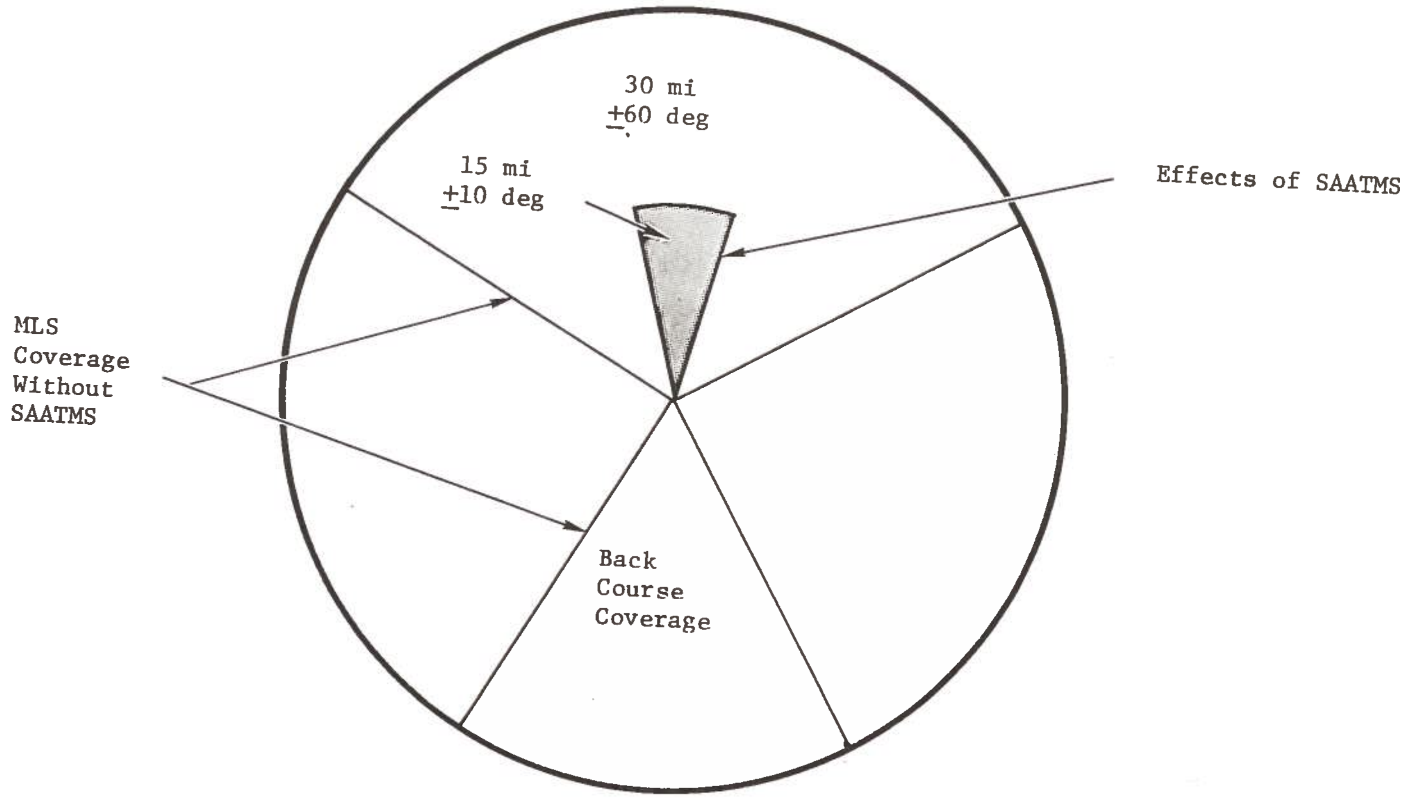
VVOR INSTRUMENT APPROACH



Feature: Low Cost Microwave Landing System (MLS)   Benefits: Lower F&E costs
Lower O&M costs

How Provided: The universal coverage and range independent accuracies of the satellite surveillance and navigation subsystems allow a considerable reduction in the MLS requirements. The requirements for the backcourse coverage to provide guidance during "go-around" can be deleted since high accuracy navigation is available regardless of aircraft location. These data can also be used to develop the area navigation routes required to implement curved approaches, thus reducing the MLS angular coverage requirements. Lastly, the accuracy of the SAATMS satellite navigation, in all three dimensions, is such that the MLS range can be reduced to less than 15 nmi. These benefits are a direct result of the total down-to-ground coverage and the range independent accuracy afforded in a satellite system.

Comparison with Other Systems: Current MLS (Category III) is expected to provide wide-angle coverage, ±60 deg, backcourse guidance, and range coverage out to 30 nmi. This extensive angle and range coverage is necessary since the current system navigation and surveillance accuracy is poor. In SAATMS, the higher navigation accuracy permits aircraft to approach the airport with greater precision and to engage the MLS at shorter ranges. Therefore, less MLS coverage is required along with lower power. The results are lower costs for development, installation, and operation of the SAATMS MLS.


30 mi
±60 deg
15 mi
±10 deg
Effects of SAATMS
MLS Coverage Without SAATMS
Back Course Coverage

Feature: Data Mobility

Benefits:
Flexibility
Backup
Fail operational and fail safe
Reduced cost

How Provided: This feature results from the fact that all elements of the system, both air and ground, are in communication with the satellite constellation. Further, all surveillance, navigation, and communication data are transmitted over a common satellite frequency band. Therefore, there is a direct tie between all system elements and all system data. With this type of system, it is no more difficult to transmit data from coast to coast than across town. The result is complete data mobility with widely separated remote centers having the capability to back up each other.

Comparison with Other Systems: This feature requires a satellite system and as such is not available in the present or planned air traffic control system. To provide this capability with a nonsatellite system would require a costly cable net or microwave system. Therefore, the present system and the GAATMS must achieve backup and fail-operational design through redundant systems at each center, thus essentially doubling the cost of the system.

Data Mobility Provides

- Dispersed Automation Backup
- Centralized Control Facilities
- Complete Element Backup
- Efficient Flow Control
- Minimum Jurisdictional Handoffs

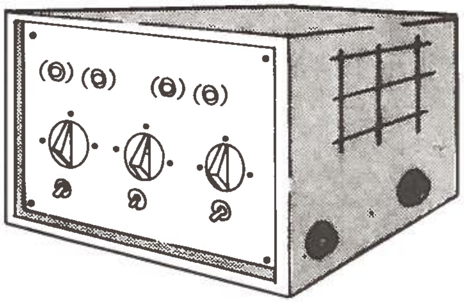
Feature: Modular Avionics   Benefit: Upgrade in steps from basic package

How Provided: The SAATMS has a basic avionics requirement for an integrated communications, navigation, and identification package. Pilots wishing to add to this basic package may do so by purchasing only those modules that meet their special needs. No redesign of the basic package is necessary to accommodate these modules. Some common additions to the avionics package are MLS, an air-to-air display, traffic situation display, automatic frequency tuning, and random digital message display.

Comparison with Other Systems: Present and planned systems are not integrated nor are they modular. Each function is represented by a different black box or subsystem. While it is true that an upgrade to the basic package can be achieved by adding a new black box, the new subsystem cannot be integrated into the basic package in a modular fashion. For example, the addition of a traffic situation display into the cockpit of a 1973 airliner would require either special signal conditioning or a special purpose interface to drive the display even if the situation data were available.

MODULAR AVIONICS

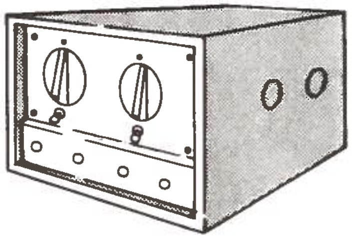
Transmitter/Receiver



Surveillance
Digital Communication
Voice
RNAV
Landing Guidance
Ground Surveillance

+

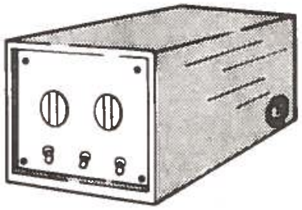
Computer



Satellite RNAV
Air Derived Separation
Assurance

+

MLS



Category I, II, III
Landing

Feature: Difficult to Jam Benefit: Reduced Vulnerability

How Provided: The use of satellites coupled with the integration of the avionics reduces the overall vulnerability of the SAATMS. The SAATMS design imposes severe power requirements on an intentional jammer. To degrade the surveillance function, five satellite jammers, each with more than 1,000,000 watts effective radiated power, must be used.

Comparison with Other Systems: Due to the dispersed nature of the ground based ATC systems, a greater number of jammers is required to cause degradation, but the ease of accessibility of these sites drastically reduces the required jammer power. For example, eight jammers will be required to degrade the Los Angeles ARTCC to the point where the data become unreliable, but each jammer need have only 20 watts effective radiated power.

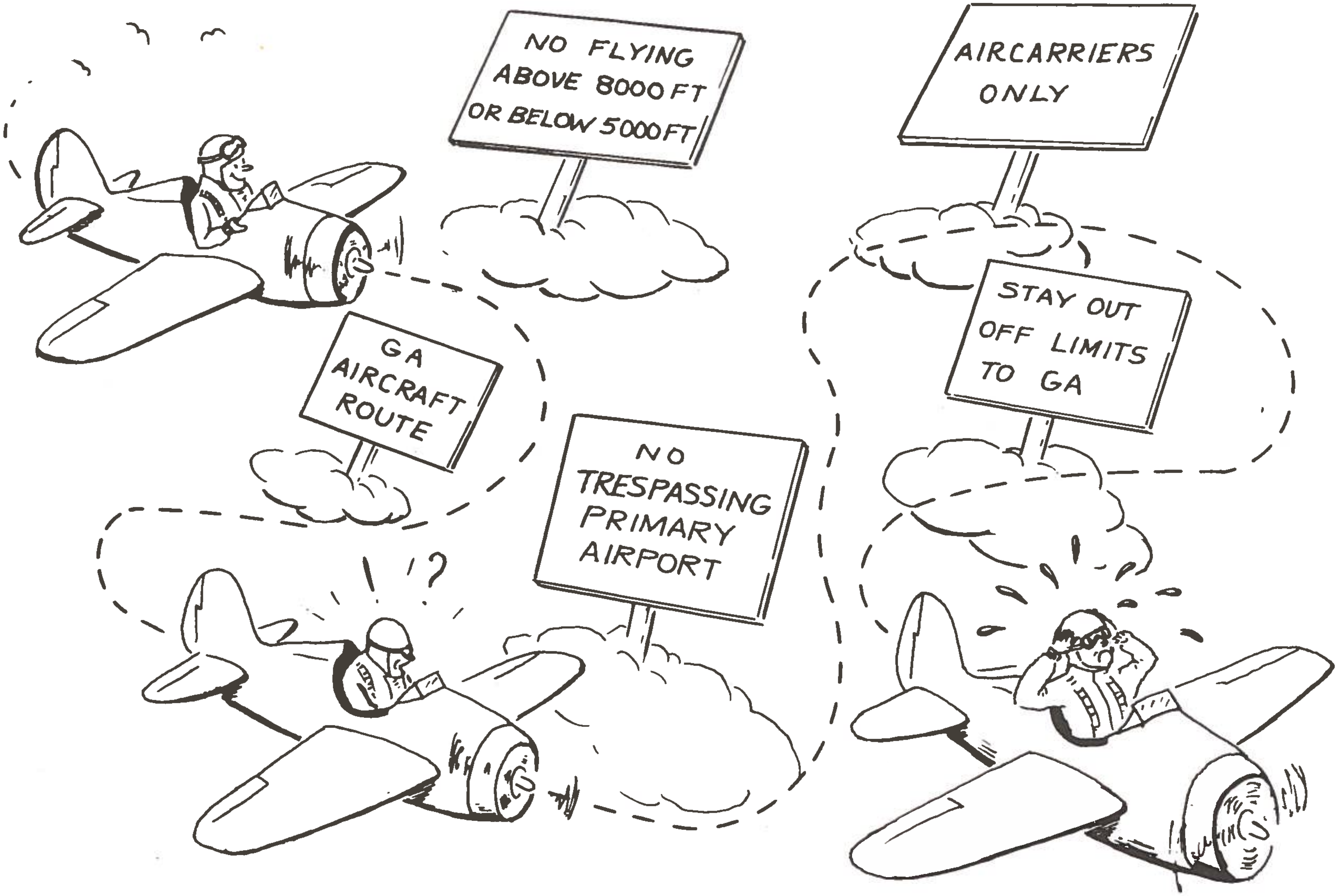
SAATMS Function	Jammers Needed	Antenna Size (ft)	Jammer Power (kw)
Communications	10	3	13.5
		5	5
Surveillance	5	10	1.8

Feature: Freedom of Flight

Benefits: User acceptance
Easy Planning and scheduling

How Provided: This feature is a direct result of the high surveillance and navigation accuracies inherent in SAATMS. These accuracies, when coupled with the down-to-the-ground CONUS-wide coverage afforded by use of satellites, results in a minimum of operational restrictions being required to maintain a high degree of safety. The system provides information to pilots for use in planning their flights. The final decision concerning route, altitude, and time of flight is left to the pilot. In this way, pilots may usually fly where and when it is most convenient for them, with the system guaranteeing them safety at all times.

Comparison with Other Systems: Universal surveillance is not available in 1973 nor is it expected to be for low altitude in 1982. Therefore, little protection is provided by the system for GA aircraft. The surveillance system used for IFR flights in 1973 and 1982 suffers the disadvantage of range dependent accuracies. The result is a larger separation standard to maintain safety. Even with the use of area navigation, these systems must employ a more rigid route structure as well as a greater reliance on flow control to maintain safety and capacity. As a second-order effect, the lower accuracy of the 1973 and 1982 systems require that routes be spaced farther apart with a corresponding less efficient use of the airspace.


NO FLYING ABOVE 8000 FT OR BELOW 5000 FT
AIRCARRIERS ONLY
GA AIRCRAFT ROUTE
STAY OUT OFF LIMITS TO GA
NO TRESPASSING PRIMARY AIRPORT
! ?

Feature: A Satellite-Based SAATMS   Benefits: Lower O&M Costs

A Fully Integrated SAATMS

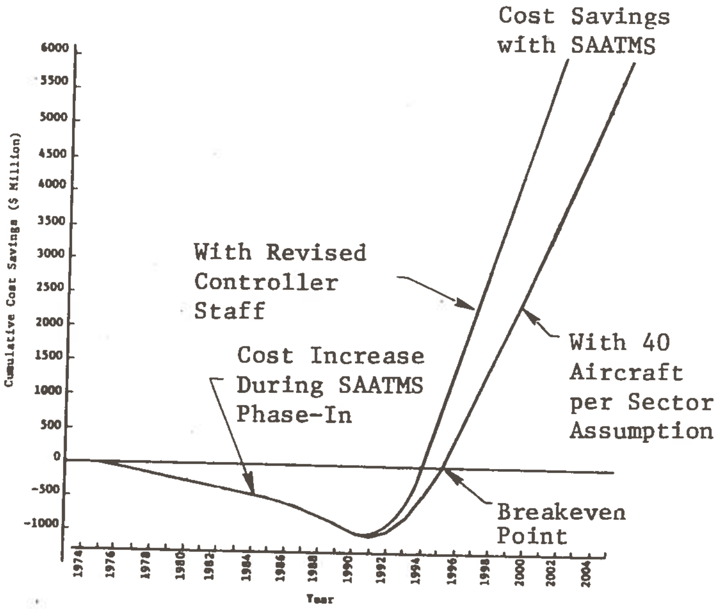
How Provided: The use of satellites coupled with a fully integrated SAATMS design allows substantial O&M savings to be realized. To provide a basis for comparison of the SAATMS and the GAATMS, the 1973 version of the FAA 10-year plan was used as a point of departure. The GAATMS used in the comparison was the configuration described in the 10-year plan. The controller requirements from the plan were projected to 1995 and the controller costs obtained assuming a constant ($20,000) controller salary. The effects of inflation were thereby eliminated. The FAA plan assumes a controller productivity increase of 5 percent per year, as a direct result of the increased automation of the present system and the GAATMS. The maintenance personnel and costs were similarly projected to 1995. An additional $50 million per year was added to the GAATMS to account for other unspecified O&M costs. The GAATMS costs do not include the equipment replacement costs, which are included in the 10-year plan under F&E. Based upon these estimates, the SAATMS O&M costs are $500 million less per year than the GAATMS. This savings results from the lower number of controllers and maintenance personnel required and the centralization of facilities.

Comparison with Other Systems: Using these projections of the GAATMS and SAATMS annual costs and adding the SAATMS RDT&E and transition costs, the cumulative cost improvement of the SAATMS over the GAATMS can be obtained. The implementation of the SAATMS requires additional expenditures above and beyond that for operating the GAATMS. These amount to a total investment of approximately $1 billion by 1991. As the SAATMS facilities become operational and the GAATMS is decommissioned, the effect of the reduced O&M costs becomes evident. By 1995, nearly all of the initial investment is recovered; i.e., the break-even point is reached. From that point on, the savings mount rapidly, reaching nearly $6 billion by 2005.

COMPARISON OF SAATMS AND GAATMS O&M COSTS

	GAATMS		SAATMS 1995	
	1973	1995	With 40 Aircraft per Sector	With Revised Controller Staff
Number of Enroute and Terminal Controllers	21,600	33,300	18,500	9,650
Annual Cost of Enroute and Terminal Controllers	$375 M	$665 M	$397 M	$211 M
Number of Maintenance Personnel	11,200	19,200	5,200	5,200
Annual Cost of Maintenance Personnel	$234 M	$383 M	$67 M	$67 M
Equipment Replacement	-	-	$89 M	$89 M
Other O&M	$50 M	$50 M	$47 M	$47 M
Total O&M	$659 M	$1098 M	$600 M	$420 M

CUMULATIVE COST SAVINGS SAATMS OVER GAATMS



ADDITIONAL SAATMS FEATURES AND BENEFITS

Feature	Benefits
A. Operational	
1. Flexible routing	More economical flight Parallel offset RNAV
2. Performance class segregation	Safety due to reduced wake turbulence effects Higher capacity and less delay
3. Demand adaptive rules and procedures	GA user can use controlled airspace in off-peak hours Growth
4. Maximum use of pilot for control (air managed conformance)	Less communications Less work for controller More freedom and responsibility for pilots
5. High altitude approaches to primary airports	More economical approach Faster approach Less noise under approach path
B. Automation	
1. Automated metering and spacing in terminals	High capacity Improved safety since aircraft fly different paths Less work for approach controller
2. Automated surveillance and tracking of all aircraft	Improved safety Higher capacity Lower controller workload
3. Automated conflict detection and resolution	Improved safety
4. Automated boundry protection	Improved safety More efficient flow control

ADDITIONAL SAATMS FEATURES AND BENEFITS (continued)

Feature	Benefits
5. Automated communications and data transfer	Fewer voice messages Less work for the pilot Less chance for error
6. Automated surface guidance at ACC's	All weather taxi and takeoff
7. Automated flight service stations	Lower O&M costs Better data exchange between pilot and FSS
C. Avionics	
1. Identical equipment for oceanic and CONUS	Lower user cost Easier pilot training
2. Broad beam, low-gain antennas	Lower antenna cost Relatively insensitive to normal aircraft maneuvers
3. No additional equipment required for missed approaches	Lower user cost Safer procedure since no mode change is required
D. Navigation	
1. Entire CONUS on a common grid	Eliminates registration errors Fail operational backup
2. Independent channels for navigation and surevillance	Backup Increased pilot confidence Fail operational
3. All aircraft have an RNAV capability	More economical flight Improved safety

ADDITIONAL SAATMS FEATURES AND BENEFITS (continued)

	Feature	Benefits
4.	Navigation data provided in three dimensions	Improved safety Reduced flight technical errors
5.	Satellite navigation system is nonsaturable	Higher capacity Growth
6.	Instrument approach capability at all airports	Weather independence Improved safety
7.	Air-to-air collision avoidance mode	Increased pilot confidence Independent CAS backup
E.	Surveillance	
1.	Low cost surveillance for ground traffic at ACC's	All weather surface operations Higher capacity Improved safety
2.	Unique aircraft signatures	Easier data processing Better control
3.	Adaptive update rates	Reduced communications load More rapid acquisition
4.	Terminal area calibration sites	Higher accuracy in high density airspace
5.	All aircraft covered by surveillance	Higher capacity Improved safety Better flow control
6.	Rapid startup	Rapid reaction to failures Fail safe operation More flexibility

ADDITIONAL SAATMS FEATURES AND BENEFITS (continued)

Feature	Benefits
F. Communications	
1. Narrow effective pulses	High accuracy Multipath rejection
2. Long transmitted pulses	Low transmitter power Lower cost
3. Independent voice and digital communications	More flexibility Backup
4. Common frequencies for surveillance, navigation, and communications	Lower cost Facilitates backup surveillance with navigation Lower pilot workload
5. Digital link for primary messages	Less use of voice Higher automation potential Less chance for error
6. High signal-to-noise ratio	High accuracy Fewer false signatures
7. Line of sight for air-to-air and air-to-ACC communications	Less crowding of satellite channels Lower power required
8. Satellites used as relays	Lower O&M costs Universal coverage No near/far problem Totally integrated system
G. Facilities	
1. Hardened control facility possible	Military requirements met Resistance to natural disasters

ADDITIONAL SAATMS FEATURES AND BENEFITS (continued)

Features	Benefits
2. Maximum functional integration	Lower cost High reliability Backup Greater flexibility
3. Excess capacity	Growth to post 1995
4. Functional backup and redundancy	Fail-operational Fail-safe Fail-soft
5. Independent facilities	High reliability Greater flexibility Backup

REPORT OF INVENTIONS APPENDIX

Title: Virtual VOR (VVOR)

Pages wherein VVOR is described:

Volume I, pp 26, 36 through 40, and 106
Volume II, p 25
Volume III, pp 64 through 70 and 146
Volume IV, pp 25 and 26
Volume X, (15 pages)

Comment: The concept of VVOR developed in this program combines the features of universal CONUS-wide surveillance, digital communications, and centralized data processing to provide low cost area navigation capability to all system users. As described in this report, VVOR is applied to aerial navigation. The concept also has application to ship navigation in harbors, ports, rivers, and ocean waters within the United States territorial limits. Autonetics is applying this concept to marine navigation in these areas.