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CONCEPT FOR A SATELLITE-BASED ADVANCED AIR TRAFFIC MANAGEMENT SYSTEM

Volume IV. Operational Description and Qualitative Assessment

C. S. Hoffman
H. T. Freedman
C. V. Hamilton
W. R. Fried

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16. Abstract

This volume presents a description of how the Satellite-Based Advanced Air Traffic Management System operates and a qualitative assessment of the system. The operational description includes the services, functions, and tasks performed by the system, a description of user classes, the airspace structure, and rules and procedures. The concept for managing air traffic is then presented. It is characterized by pilot responsibility for conforming to a flight path while the ground concentrates on assuring flight safety, maximizing capacity, and minimizing delay. A discussion of the SAATMS automation philosophy and a description of how an aircarrier and a GA aircraft fly through the system complete the operational description. The qualitative assessment is concerned with three main issues: can the SAATMS readily be built as defined, what happens to the system after it is built and conditions change from what was assumed during the development stage, and the extent to which the system is vulnerable to intentional and unintentional interference.

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GLOSSARY

AATMS	Advanced Air Traffic Management System
ACC	Airport Control Center
ADF	Automatic Direction Finder
ADIZ	Air Defense Identification Zone
AGL	Above Ground Level
AMF	Analog Matched Filter
AOPA	Aircraft Owners and Pilots Association
ARINC	Aeronautical Radio, Inc.
ARTCC	Air Route Traffic Control Center
ARTS	Automated Radar Terminal System
ATC	Air Traffic Control
ATCAC	Air Traffic Control Advisory Committee
ATCRBS	Air Traffic Control Radar Beacon System
ATCS	Air Traffic Control System
ATM	Air Traffic Management
CA	California
CARD	Civil Aviation Research and Development
CAS	Collision Avoidance System
CCC	Continental Control Center
CNI	Communication Navigation Identification
CNMAC	Critical Near Midair Collisions
COMM	Communications
CONUS	Continental United States
CP	Central Processor
CST	Central Standard Time
CW	Continuous Wave

GLOSSARY (continued)

DABS	Discrete Address Beacon System
DOD	Department of Defense
DOT	Department of Transportation
DME	Distance Measuring Equipment
DNSDP	Defense Navigation Satellite Development Program
DNSS	Defense Navigation Satellite System
ERP	Effective Radiated Power
ESRO	European Satellite Reserach Organization
EST	Eastern Standard Time
ETA	Estimated Time of Arrival
FAA	Federal Aviation Administration
F&E	Facilities and Equipment
FL	Florida
FM	Frequency Modulation
FSS	Flight Service Station
GA	General Aviation
GAATMS	Ground-Based Advanced Air Traffic Management System
GDOP	Geometric Dilution of Precision
GFE	Government Furnished Equipment
IAC	Instantaneous Airborne Count
ICAO	International Civil Aviation Organization
ID	Identification
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions

GLOSSARY (continued)

I/O	Input/Output
IOP	Input Output Processor
IPC	Intermittent Positive Control
IPS	Instructions Per Second
IR	Infrared
JFK	Kennedy International Airport
LA	Los Angeles
LAT	Latitude
LAX	Los Angeles International Airport
LORAN	Long Range Navigation
LOS	Line-of-sight
LRR	Long Range Radar
MIPS	Million Instructions Per Second
MLS	Microwave Landing System
MODEM	Modulator-Demodulator
MSL	Mean Sea Level
MTBF	Mean Time Between Failures
NAFEC	National Aviation Facilities Experimental Center
NAD	North American Datum
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NAV	Navigation
NDB	Non-Directional Radio Beacon
NEF	Noise Exposure Factor
NFCC	National Flow Control Center

GLOSSARY (continued)

NMAC	Near Midair Collisions
NOTAM	Notice to Airmen
NOZ	Normal Operating Zone
NWS	National Weather Service
O&M	Operations and Maintenance
PCA	Positively Controlled Airspace
PIREPS	Pilot Reports
PN	Pseudo-Noise
PPM	Pulse Position Modulation
PWI	Pilot Warning Indicator
RAM	Random Access Memory
RCAG	Remote Control Air-to-Ground Facility (Present System)
RCAGT	Remote Communication Air-Ground Terminal
RCC	Regional Control Center
R&D	Research and Development
RDT&E	Research, Development, Test, and Evaluation
RF	Radio Frequency
RNAV	Area Navigation
ROM	Read-Only Memory
SAATMS	Satellite-Based Advanced Air Traffic Management System
SAMUS	State Space Analysis of Multisensor System
SID	Standard Instrument Departure
S/N	Signal-to-Noise
SNC	Surveillance, Navigation, Communication
STAR	Standard Arrival Routes
STC	Satellite Tracking Center
STOL	Short Takeoff and Landing

GLOSSARY (continued)

TACAN	Tactical Air Navigation
T&E	Test and Evaluation
TCA	Terminal Controlled Airspace
TOA	Time of Arrival
TRACAB	Terminal Radar Approach/Tower Cab
TRACON	Terminal Radar Approach Control
TRSA	Terminal Radar Service Areas
TRW	Thompson Ramo Wooldridge
TSC	Transportation Systems Center
TX	Texas
VFR	Visual Flight Rules
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
VOR	Very High Frequency Omni-Directional Range
VORTAC	Very High Frequency Omni-Range TACAN
VVOR	Virtual VOR
2D	Two Dimensional
3D	Three Dimensional
4D	Four Dimensional

1. OPERATIONAL DESCRIPTION

1.1 Introduction

The goal of a Satellite-Based Advanced Air Traffic Management System (SAATMS) is to promote the growth of air commerce by providing servies to all classes of users in all phases of flight. Services are provided to users to safely and efficiently satisfy their diverse needs for air transportation and recreational flying under a wide range of operational conditions. The manner in which the Autonetics version of the SAATMS operates to meet this goal is described in this section.

The discussion is organized into three parts: presentation of the SAATMS operational concept, discussion of an automation philosophy resulting from this operational concept, and two scenarios which describe how an aircarrier and a General Aviation (GA) aircraft fly through the system. The operational concept is presented in five parts as follows:

(1) System services, functions, and phases of flight are defined. These definitions are correlated with lists of services and flight phases provided by the Transportation Systems Center (TSC). This section shows the functions performed by the SAATMS to provide each service in each phase of flight.

(2) User classes are presented in terms of aircraft performance, pilot proficiency, and avionics requirements. This section describes the airspace reserved for each user class as well as the services each will receive.

(3) The SAATMS airspace structure is then presented. The boundaries for controlled, mixed, cooperative, and uncontrolled airspace in the enroute, terminal, and airport regions are defined. Particular emphasis is placed on describing Terminal Controlled Airspace (TCA) for primary aircarrier airports. This description includes a layout of the Los Angeles, CA, terminal area.

(4) The next section presents the rules and procedures for entry and exit from the system, flight in each airspace category, transition between jurisdictional areas, and emergency operations.

(5) The final portion of the operational concept is the management concept. This defines how aircraft fly in each airspace region. Included is a description of how SAATMS provides the five management concept services of planning, conformance, separation assurance, traffic advisories, and emergency assistance. The control concept summarizes the management concept by defining who, the pilot or the system, is responsible for providing each service in each phase of flight.

1.2 Operational Concept

The operational concept is concerned with four factors: the airspace structure, management concept, rules and procedures, and user classes. The airspace structure defines where aircraft fly while the management concept describes how they fly. The rules and procedures are the bridge between airspace structure and management concept and relate how aircraft fly to where aircraft fly. The user class definition describes the services each type of aircraft obtains from the system. To provide services, the system must determine the aircraft's identity and location, apply the rules and procedures for aircraft control within the constraints of the airspace, communicate information to the aircraft, and determine the response of the aircraft to this information.

Since the operational concept is highly dependent upon the services and functions performed by the system, these are presented first. Included is a definition of the flight phases underlying the system operation. This is followed by presentation of the four factors comprising the operational concept. The major characteristics of the SAATMS concept are that conformance is provided by the pilot while safety is provided by the system. This results in a highly air managed system with the ground primarily responsible for separation assurance.

1.2.1 System Services and Functions

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, as stated in the description of user classes, 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 means of functional operations. Whereas the services are objectives of the system, functional operations are actions taken by the system to provide the service. Services are essentially generic in that many different system configurations are capable of providing the same set of services; but the efficiency with which each configuration provides its services is a measure of system performance.

The responsibility for providing the service, i.e., air or ground, is defined by the management concept. For example, the ground is responsible for providing the separation assurance service in certain airspace while the pilot is responsible for assuring separation from other traffic in other types of airspace. The relationship between system services and the management concept is discussed in Section 1.2.5.

This section describes the services provided by the SAATMS and the functions performed by the system to provide each service. Since not all services are provided in every phase of flight and the way the service is provided differs from phase to phase, this section begins with a definition of the flight phases. The definitions are concerned mainly with establishing the boundaries for each flight phase, i.e., whey they begin and end.

Since there is a large industry team working to define concepts for an advanced air traffic management system, each study contractor has organized its effort and defined terms in a way that best meets its study objectives. The result is a nomenclature problem where many different terms are used to mean the same thing. To alleviate this problem, TSC issued a list of services and functions prepared jointly by them and TRW and urged that each study contractor use these definitions. The presentation format in this section is an attempt to comply with TSC's request. The Autonetics list of SAATMS services as presented in Ref. 1 has been reorganized and is presented as subsets to the TRW service categories.

1.2.1.1 Flight Phases

A normal flight consists of twelve phases as shown in Fig. 1.2-1. In addition, in the event of a missed approach, contingency flight phases are required. These are also shown in Fig. 1.2-1. Each flight phase is defined as follows:

(1) Preflight - Planning and Scheduling

This flight phase is concerned with all activities required to plan a flight. These include data gathering activities from the Flight Service Station (FSS), National Weather Service (NWS), and National Flow Control Center (NFCC). For controlled aircraft, this phase ends with the filing of an approved flight plan.

(2) Departure Taxi - System Entry

This phase of flight begins when the aircraft starts its engines, thereby activating its surveillance transmitter. The system acquires the surveillance signal and sends a message to the aircraft indicating that it has been acquired and is therefore in the system. The aircraft may not proceed with its flight until this message is received.

At airports with control towers, the aircraft must receive a clearance to taxi and a taxi route. The aircraft navigates along its taxi route until it arrives at a holding area short of the active runway, at which point this phase ends.

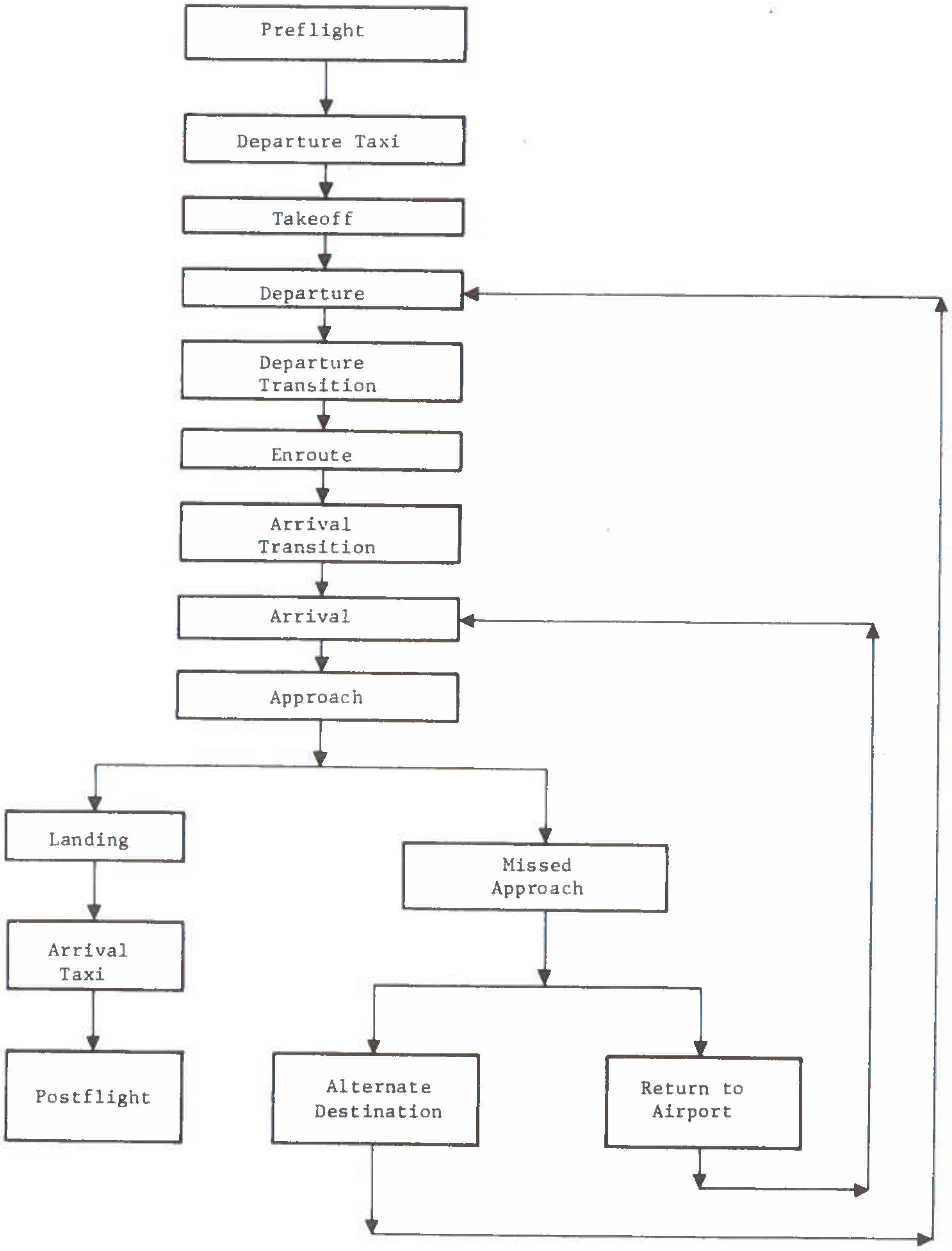


Figure 1.2-1. Flight Phases

(3) Takeoff - Start of Flight

This phase starts when the aircraft is cleared onto the active runway. It ends when the aircraft crosses the airport boundary and is handed off to the RCC.

(4) Departure - RCC Assumes Control

This phase starts when the RCC assumes control of the aircraft. It consists of a standard departure route which takes the aircraft from the airport through its climb to the point where it will pick up its planned enroute path.

(5) Departure Transition - Level Off

This phase of flight accounts for the time between completing the departure climb phase and starting the enroute cruise. Spatially, this phase cannot be well defined because aircraft climb at different rates, depending upon their gross weight and winds. Functionally, however, SAATMS operates the same in this phase as it does in the departure and enroute phases.

(6) Enroute - Cruise

For controlled aircraft, this phase of flight represents the time the aircraft spends on its approved flight plan. It starts at the completion of departure transition and ends when the aircraft requests a clearance into the arrival route. For cooperative aircraft, this phase consists of all flight time between departure and arrival.

(7) Arrival Transition - Metering, Sequencing, and Spacing

This phase of flight is for controlled aircraft approaching primary airports only. It starts 100 nmi from touchdown when the aircraft requests a clearance into the Terminal Control Airspace (TCA). The system performs metering and sequencing computations to determine the aircraft's arrival slot. It then computes an arrival route and times over waypoints along that route. If an arrival slot is not available, the aircraft will be placed in a holding pattern, which is a part of this flight phase. This phase ends when the aircraft enters the TCA arrival cone.

(8) Arrival - Descent

For controlled aircraft flying into primary airports, this phase starts when they enter the TCA arrival cone. The aircraft flies a precise 4D route with minor speed control and path stretching to make good the metering and spacing plan computed in the transition phase. For aircraft approaching other than primary airports with control towers, this phase starts when the aircraft requests a clearance into the airport control zone. For all aircraft, this phase ends when the aircraft crosses the airport boundary and is handed off to the ACC.

(9) Approach - Land/Waveoff Decision

This phase starts with handoff to the ACC. At the primary airports, the aircraft will shallow its descent angle of 6 to 8 deg to 3 deg. At the decision height, a decision is made to commit to the landing or to waveoff. The decision completes this phase. At other than primary airports, this phase includes all activities in the traffic pattern from entry into the pattern to the final landing/waveoff decision.

(10) Landing - Touchdown and Rollout

Once the decision is made to land in the approach phase, the landing must be completed. No conflict intervention commands can be responded to at this time. Activities include flare, touchdown, and rollout. A runway exit is assigned during this phase which ends when the aircraft clears the active runway.

(11) Missed Approach - Return to Airport or Alternate Destination

The missed approach is initiated at the decision height. It involves an aircraft configuration change and navigation to a missed approach fix. This segment is terminated at the missed approach fix where either a return to the airport is authorized or a clearance to an alternate destination is provided. In the former case, the aircraft reenters the arrival phase. In the latter case, it enters the departure phase.

(12) Arrival Taxi - Return to the Gate

This phase starts when the aircraft clears the active runway. A taxi route is assigned. The aircraft navigates to make that route good. This phase ends when the aircraft reaches its gate.

(13) Postflight - System Exit

When the aircraft shuts off its engines, its surveillance transmitter will stop transmitting. To avoid ambiguity about malfunctions, the pilot should inform the system of his intent to exit prior to shutting down his engines. If the aircraft was on a flight plan, the plan should be closed at this time.

1.2.1.2 System Services

The definition of the services provided by the SAATMS is presented in this section. The SAATMS services are grouped into categories consistent with the TSC list.

(1) Airport/Airspace Use Planning

Planning - The system will assist the user by constructing and keeping current a master flow plan. The flow plan will make use of data concerning user intent and will result in a master schedule designed to facilitate the flow of traffic along various routes and in and out of airports. In addition, the system will assist the user in selecting the shortest time and most economical routes. The system will also assist the user in preparing his flight plan, providing computational facilities for checking, revising, approving, and disseminating the flight plan, and modifying the plan upon receipt of in-flight data.

Airspace Structure - The system will develop and operate an airspace structure designed to separate aircraft of differing performance capabilities and needs. The system will be capable of providing planning, control, and separation services to the degree required by the users of each airspace category. The airspace structure includes standard arrival and departure routes; enroute regions of positive controlled, mixed, cooperative, and uncontrolled airspace; navigation routes; and special areas set aside for holding patterns, training and practice, and military operations; and special restricted areas. The system will set the boundaries of these areas, including buffer zones, and will guard the boundaries to protect them from intruders.

(2) Flight Plan Conformance

Traffic Control - The system will control the flow of traffic to enhance efficiency. That is, the system will provide algorithms, sensors, and data processing services to control the movement of traffic with minimum delay and maximum safety, while servicing all aircraft who wish to use the system. However, the responsibility for conforming to a plan rests with the pilot. He accomplishes this by making use of navigation and surveillance data sent to him by the system.

(3) Separation Assurance

The system will provide a guarantee to the user that he will receive intervention commands to prevent his coming into conflict with any other aircraft. This service will be provided to both cooperative and controlled aircraft over the entire CONUS except for the area inside certain airport boundaries where only separation advisories are provided and in posted uncontrolled airspace.

(4) Spacing Control

The control of spacing between aircraft is one of the methods by which SAATMS performs the separation assurance service. Therefore, this category of service is a subset of separation assurance. Another means of controlling spacing is through the establishment of rules and procedures, which are defined as follows.

Operational Regulations - The system will develop a set of rules and procedures which defines the minimum requirements for operating in the system, the price of admission to various airspace categories, traffic regulations and rules, legal responsibilities, jurisdictional boundaries, and operating procedures for the normal and backup modes.

(5) Airborne, Landing, and Ground Navigation

Ground Control and Guidance - In addition to providing control and separation assurance in the air, SAATMS will provide these services on the primary airport runways, taxiways, and ramps. Thus aircraft operating in poor visibility will not only receive all weather landing services but will be provided with guidance and control services while they are on the ground.

All Weather Landing - The system will provide equipment and facilities to enable all users to safely approach and land in Instrument Meteorlogical Conditions (IMC).

(6) Flight Advisory Services

General Information - In addition to providing weather advisory services to the user, the system will assemble and keep current traffic information and notices to airmen and make them available to users on an "as needed" basis. Included in this service will be pilot briefings designed to familiarize pilots with traffic patterns, obstructions, and peculiarities at destination airports, as well as enoute weather, waypoints, and procedures.

(7) Information Services

Weather Services - The system will gather, process, and disseminate weather data. Weather advisories will be prepared and made available to pilots to assist them in preparing and revising their flight plans. The system will gather weather data at frequent intervals and will update weather advisories.

(8) Record Services

Statistical Services - The system will collect, store, and analyze data required to evaluate system performance, plan for system growth and improvements, and assist the user in planning future flights or equipment acquisition.

(9) Ancillary Services

Facilities Operation and Maintenance - The system will operate and maintain all facilities comprising the SAATMS. Functions involved in providing this service include, but are not limited to, monitoring system performance, equipment maintenance, calibration, and general housekeeping.

(10) Emergency Services

Emergency Assistance - The system will assist users during all emergencies. Included will be search and rescue functions, routing and navigation, assistance to lost pilots, and the development of special emergency procedures. To provide this service, the system will perform surveillance, communications, and control functions to detect emergencies and will initiate and coordinate rescue operations. The down-to-ground surveillance capabilities of the SAATMS are particularly suited for the task of locating downed aircraft.

1.2.1.3 System Functions

To provide the services listed above, the system must perform a series of functions which are dependent upon a number of factors. These include the system mechanization, operational concept, and problem scenario (type of airport, traffic density, control concept, etc.). Additionally, performance of each function is logically associated with a flight phase. Filing of a flight plan basically occurs during preflight, while handoff/accept handoff is conducted during several phases of the flight profile. The functions that are performed to provide each service in each flight phase are shown in Table 1.2-1. All system functions are illustrated in Volume VIII.

The following paragraphs describe those functions performed by the SAATMS to provide the conformance and separation assurance services. These, along with planning, are the primary functions that make up the management concept.

1.2.1.3.1 Monitor Progress

The function of monitoring progress of aircraft in SAATMS pertains to maintaining surveillance on the aircraft during the entire time the aircraft is in the system and comparing the aircraft's position against a flight plan. In SAATMS, surveillance is performed by the ground based system for the purpose of maintaining safety. Comparison of aircraft position against a flight plan is an air managed function, performed by the pilot using navigation data. The monitor progress function is illustrated in Fig. 1.2-2.

1.2.1.3.2 Flight Plan Conformance

The function of conforming to the flight plan for controlled aircraft will be the responsibility of the aircrew during all portions of the flight. The satellite navigation system and aircraft processor will be used to determine the aircraft position and compare this position against the desired flight plan. Any discrepancies will be displayed to the pilot as a steering error. The pilot is responsible for nulling this error. During all flight phases, the ground system will be monitoring the aircraft to assure that separation standards are maintained.

Cooperative aircraft do not have a flight plan to conform to; however, they must conform to established traffic patterns inside the airport boundary. The pilot is responsible for this conformance. He will use direct vision and/or VVOR in performing this function. The flight plan conformance function is illustrated in Fig. 1.2-3.

TABLE 1.2-1 SAATMS SERVICES AND FUNCTIONS

SAATMS Services	FLIGHT PHASES					
	Preflight	Departure Taxi	Takeoff	Departure	Departure Transition	Enroute
Airport/ Airspace Use Planning	Flight Plan Development Flight Plan Processing	System/Aircraft Initialization				
Flight Plan Conformance		Taxiway Path Conformance	Departure Path Conformance	Flight Path Conformance	Flight Plan Processing Flight Plan Conformance Monitor Progress	Flight Plan Processing Flight Plan Conformance Monitor Progress
Separation Assurance		Spacing Monitor Progress	Spacing Monitor Progress	Spacing Monitor Progress	Spacing Monitor Progress	Spacing Monitor Progress
Spacing Control		System/Aircraft Initialization Sequencing Spacing Merging Monitor Progress	Interleaving Surface Guidance Spacing Monitor Progress Handoff	Accept Handoff Sequencing Merging Spacing Monitor Progress	Sequencing Merging Spacing Monitor Progress	Sequencing Merging Spacing Monitor Progress
Airborne, Landing, and Ground Navigation		Taxiway Path Conformance Surface Guidance	Surface Guidance Departure Path Conformance	Flight Path Conformance	Flight Plan Conformance	Flight Plan Conformance
Flight Advisory Services		System Status Reporting Aircraft Airport SAATMS Weather	System Status Reporting Aircraft Airport SAATMS Weather	System Status Reporting Aircraft Airport SAATMS Weather	System Status Reporting Aircraft Airport SAATMS Weather	System Status Reporting Aircraft Airport SAATMS Weather
Information Services	System Status/ Change Weather Traffic Facilities	System Status/ Change Weather Traffic Facilities	System Status/ Change Weather Traffic Facilities	System Status/ Change Weather Traffic Facilities	System Status/ Change Weather Traffic Facilities	System Status/ Change Weather Traffic Facilities
Record Services	Record Keeping Published Flight Routes Regulations and Directives Preferred Flight Plans Flight Plan Inventory	Record Keeping Flight Plan Inventory Flight Event Storage System Status Storage Standard Taxi Routes	Record Keeping Flight Plan Inventory Flight Event Storage System Status Storage Standard Takeoff Procedures	Record Keeping Flight Plan Inventory Flight Event Storage System Status Storage Standard Departure Routes	Record Keeping Flight Plan Inventory Flight Event Storage System Status Storage	Record Keeping Flight Plan Inventory Flight Event Storage System Status Storage Standard Flight Routes
Ancillary Services	System Servicing Facilities Operation and Maintenance Communications Navigation Surveillance Structures	System Servicing Facilities Operation and Maintenance Communications Navigation Surveillance Structures	System Servicing Facilities Operation and Maintenance Communications Navigation Surveillance Structures	System Servicing Facilities Operation and Maintenance Communications Navigation Surveillance Structures	System Servicing Facilities Operation and Maintenance Communications Navigation Surveillance Structures	System Servicing Facilities Operation and Maintenance Communications Navigation Surveillance Structures
Emergency Services		Emergency Resolution	Emergency Resolution	Emergency Resolution Search and Rescue	Emergency Resolution Search and Rescue	Emergency Resolution Search and Rescue

TABLE 1.2-1 (CONTINUED)

FLIGHT PHASES					
Arrival Transition	Arrival	Approach	Landing	Arrival Taxi	Postflight
					Exit Aircraft from System Flight Data Processing
Flight Plan Processing Flight Plan Conformance Monitor Progress	Flight Path Conformance	Flight Path Conformance	Flight Path Conformance	Taxiway Path Conformance	
Spacing Monitor Progress	Spacing Monitor Progress	Spacing Monitor Progress	Monitor Progress	Spacing Monitor Progress	
Sequencing Merging Spacing Monitor Progress	Sequencing Merging Spacing Monitor Progress Handoff	Accept Handoff Sequencing Merging Spacing Monitor Progress	Confirm Landing Surface Guidance Monitor Progress	Sequencing Merging Spacing Monitor Progress Release Aircraft Control	
Flight Plan Conformance	Flight Path Conformance	Flight Path Conformance	Flight Path Conformance Surface Guidance	Taxiway Path Conformance Surface Guidance	
System Status Reporting Aircraft Airport SAATMS Weather	System Status Reporting Aircraft Airport SAATMS Weather	System Status Reporting Aircraft Airport SAATMS Weather	System Status Reporting Aircraft Airport SAATMS Weather	System Status Reporting Aircraft Airport	
System Status/ Change Weather Traffic Facilities	System Status/ Change Weather Traffic Facilities	System Status/ Change Weather Traffic Facilities	System Status/ Change Weather Traffic Facilities	System Status/ Change Weather Traffic Facilities	
Record Keeping Flight Plan Inventory Flight Event Storage System Status Storage	Record Keeping Flight Plan Inventory Flight Event Storage System Status Storage Standard Arrival Routes	Record Keeping Flight Plan Inventory Flight Event Storage System Status Storage Standard Approach Procedures	Record Keeping Flight Plan Inventory Flight Event Storage System Status Storage	Record Keeping Flight Plan Inventory Flight Event Storage System Status Storage Standard Taxi Routes	Record Keeping Statistical Data Preferred Flight Plan Storage Continuing Leg Flight Plan Storage Flight Data Processing
System Servicing Facilities Operation and Maintenance Communications Navigation Surveillance Structures	System Servicing Facilities Operation and Maintenance Communications Navigation Surveillance Structures	System Servicing Facilities Operation and Maintenance Communications Navigation Surveillance Structures	System Servicing Facilities Operation and Maintenance Communications Navigation Surveillance Structures	System Servicing Facilities Operation and Maintenance Communications Navigation Surveillance Structures	System Servicing Facilities Operation and Maintenance Communications Navigation Surveillance Structures
Emergency Resolution Search and Rescue	Emergency Resolution	Emergency Resolution	Emergency Resolution	Emergency Resolution	

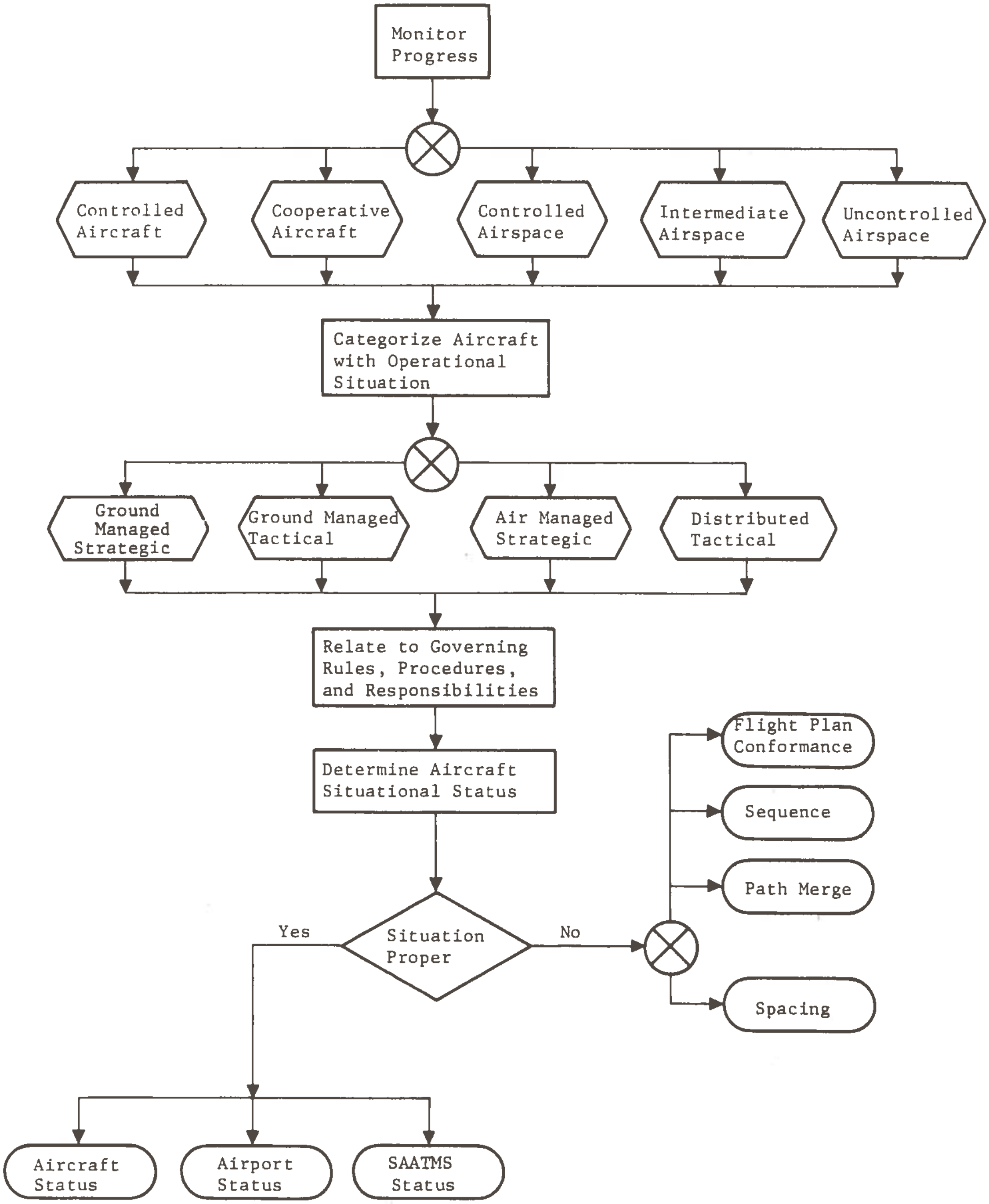


Figure 1.2-2. Monitor Progress

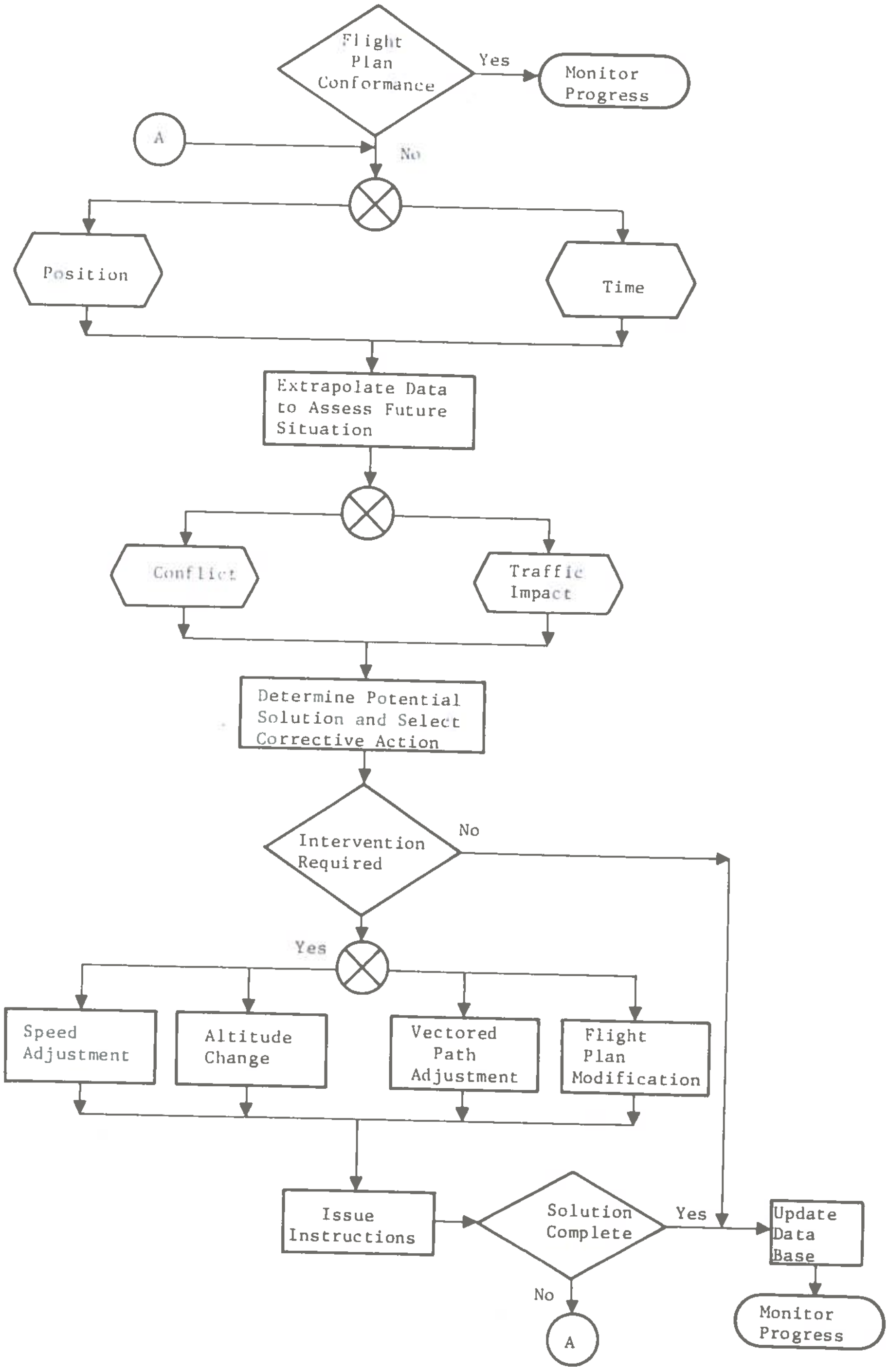


Figure 1.2-3. Flight Plan Conformance

1.2.1.3.3 Sequence

The function of sequencing pertains to insuring that the air traffic is established in the proper order. This function is primarily performed during the arrival phase of flight when many aircraft are converging upon a terminal area. During this phase, the ground system performs sequencing computations leading to assignment of an arrival slot for each aircraft.

This function is performed for all aircraft landing at airports that have control towers. Aircraft landing at non-control tower airports will have to perform this function themselves and will have to obey visual flight rules.

Figure 1.2-4 presents the logic followed in sequencing aircraft. All air traffic is automatically examined to determine (1) if the present sequence may result in a conflict, (2) if traffic flow could be improved by reordering the aircraft, and (3) if aircraft are sequenced according to their priorities when applicable. The computer system then processes through a logic sequence to determine the most appropriate solution.

1.2.1.3.4 Handoff Function

The function of handoff pertains to the transfer of control responsibility as aircraft move from one jurisdictional area to another. This function requires that positive communications be established between the receiving jurisdiction and the aircraft before the handoff is completed. The system will perform the handoff function in a highly automated manner that will require no voice communication for either pilots or controllers unless positive communications cannot be established. The handoff sequence is illustrated in Fig. 1.2-5.

1.2.1.3.5 Spacing

The spacing function insures that aircraft separation is maintained at all times in compliance with safety requirements. This function assures that airspace surrounding all airborne aircraft is protected against collisions and/or conflicts. Concurrently, the spacing function will operate in a manner to insure that airspace is not "wasted," causing undue delays in the flow of the traffic. The system will expedite traffic flow within safety requirements.

While aircraft are on the ground, the same basic functional concepts will apply. Spacing for both safety and expeditious flow reasons will be the driving forces behind this function.

The function of spacing will be primarily automated in the SAATMS. All aircraft will be equipped with surveillance transmitting equipment to allow total surveillance. The commands for providing collision avoidance or flow spacing will be transmitted to the pilot by data link. Voice communication will be used as backup

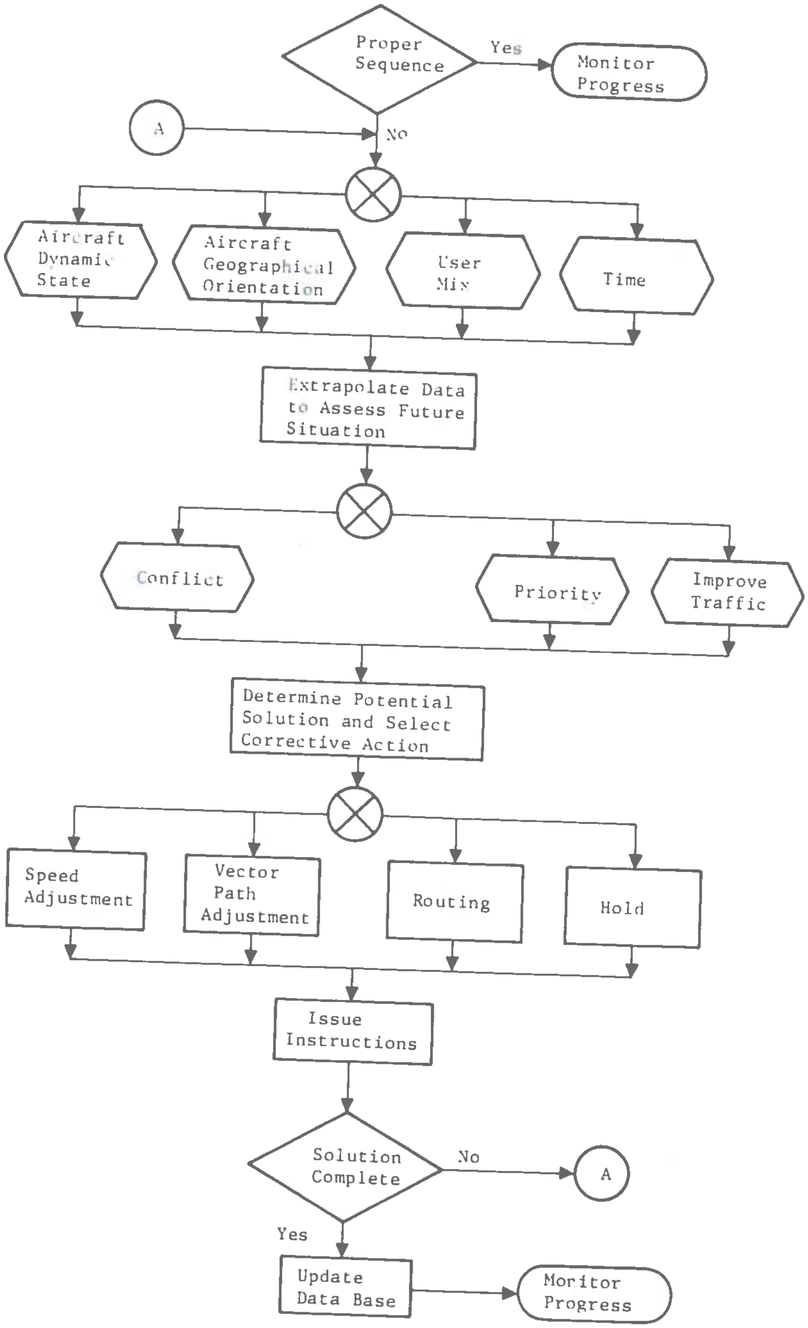


Figure 1.2-4. Proper Sequence Function

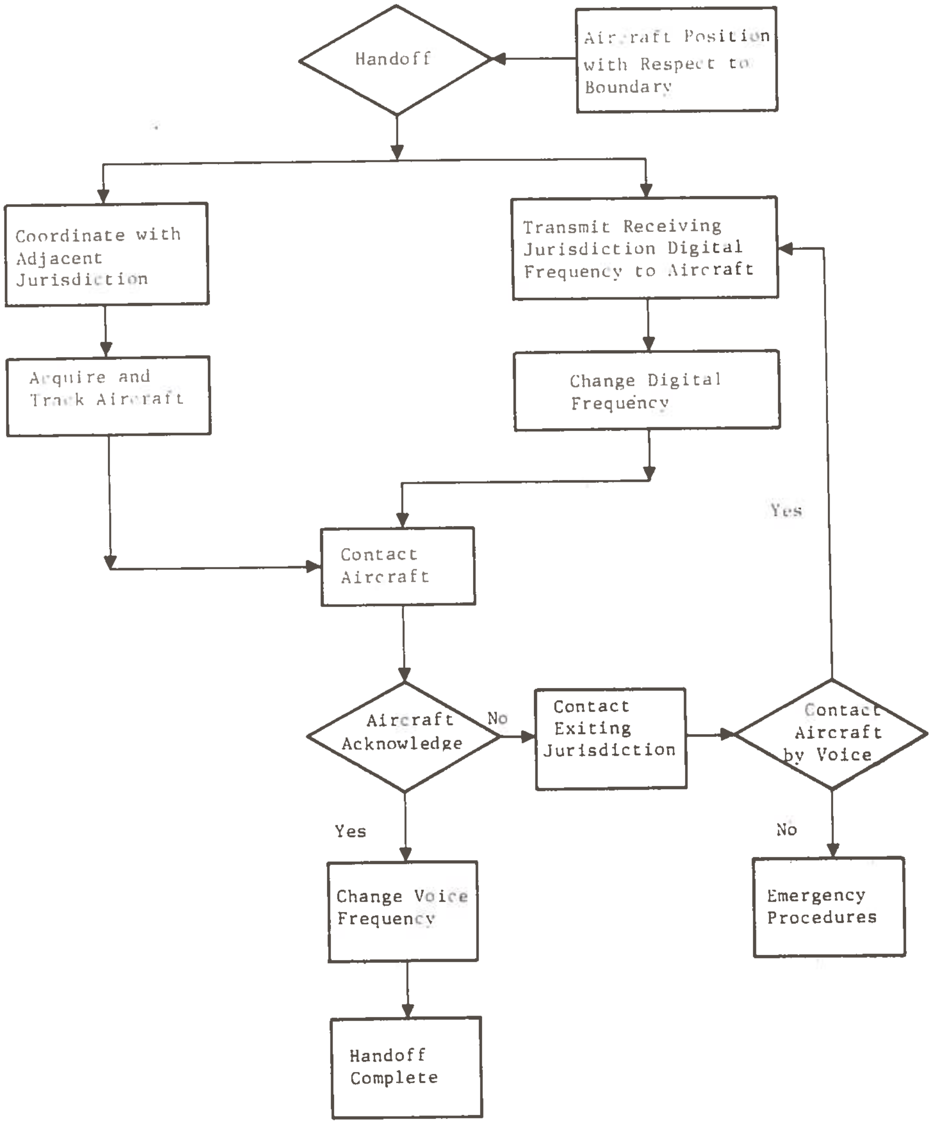


Figure 1.2-5. Handoff Function

and/or to relay nonstandard information. The aircraft will contain display equipment that is human factored to assure pilot cognition and compliance. The control personnel will also have appropriate displays to provide monitoring of the system. Control, however, will generally be provided by the human controller only in problem situations. All spacing commands will be determined by the computers and automatically relayed to the aircraft. Figure 1.2-6 illustrates the flow of the logic process followed to maintain spacing of airborne aircraft.

1.2.1.3.6 Path Merge

The path merge function pertains to the case where aircraft flying on several routes converge on a single point and proceed to fly in trail. This situation primarily occurs when aircraft are arriving at a terminal from several directions. The aircraft ultimately merge to a single path and land on a common runway. Whenever path merges occur, the ground based computer performs a computation to determine if the merge will result in a conflict. If a problem exists, the computer cycles through a routine to determine the most appropriate control parameter change to resolve the problem. After the appropriate corrective actions are determined, the instructions are automatically relayed by data link to the aircraft.

The path merge function usually is not necessary while aircraft are in the enroute portion of their flight. However, conflict prediction and intervention will be provided to assure that safety requirements are maintained. The merge function is illustrated in Fig. 1.2-7.

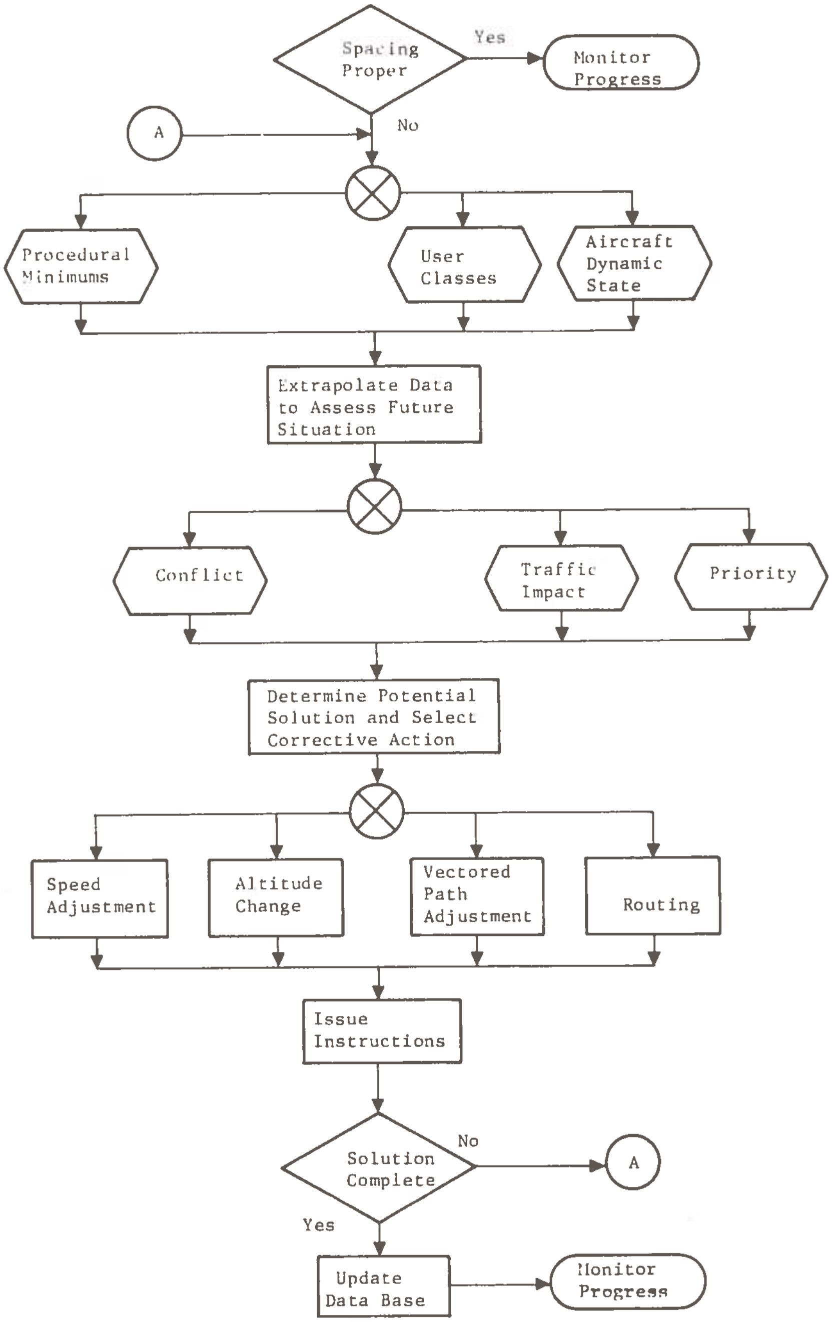


Figure 1.2-6. Spacing Function

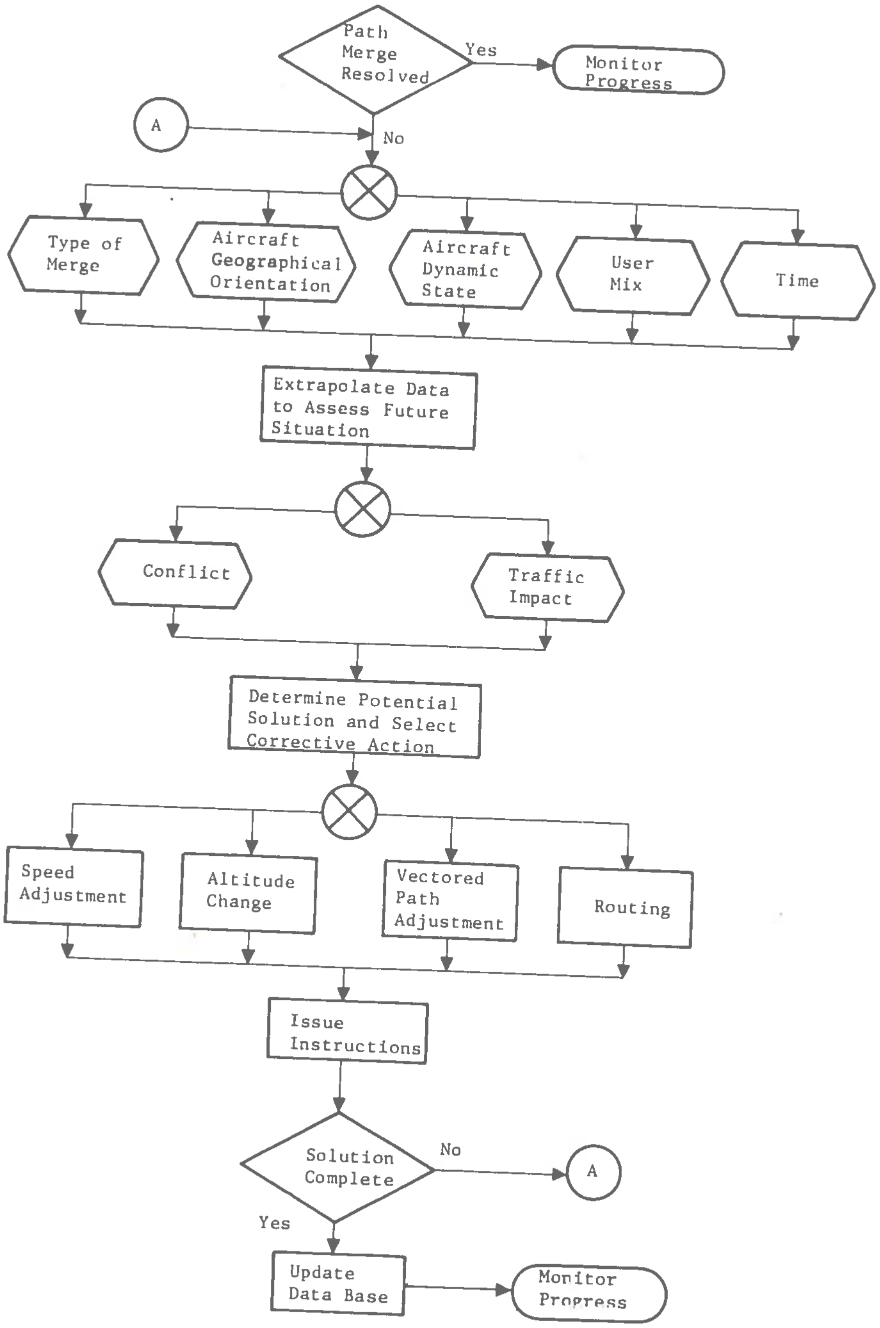


Figure 1.2-7. Path Merge Function

1.2.2 User Classes

As the SAATMS operational concept becomes better defined, 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 past, Autonetics and others have classified users solely on the basis of their avionics (Ref. 2 and 3). At least six basic categories were established, ranging from no avionics to a sophisticated 4D area navigation (RNAV) capability with accurate surveillance, communication, and air-to-air equipment. The right of aircraft to fly in a given airspace was determined only by the avionics equipment on-board.

This method of defining user classes does not take into account the aircraft performance capabilities nor the proficiency of the pilot. For 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 both avionics and performance capabilities. The minimum avionics required for entry into an airspace category as a controlled aircraft is stated, with upgrades in avionics changing the level of service received, not the airspace in which the aircraft flies. Pilot proficiency would determine the type of control provided, and pilots of low proficiency are prevented from flying in certain regions when the traffic density is high. The following paragraphs describe the user classes.

1.2.2.1 Aircraft Performance Is Used in Determining User Class

Aircraft are grouped into three distinct performance classes based upon their weight, preferred landing speed, preferred cruise speed, and preferred cruise altitude. The three classes are shown in Table 1.2-2.

Table 1.2-2. 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 may be in more than one category. For example, the Rockwell International Turbo Commander 690 is in the Class 1 category for weight and landing speed, while it is in Class 2 for cruise altitude and cruise speed. In general, cruise altitude and cruise speed are important during enroute portions of the flight, while weight and landing speed are important during approach and landing. Therefore, the assignment of an aircraft to a performance class will depend upon its flight phase.

User Class 1 consists primarily of light general aviation aircraft and STOL aircraft, such as the DeHaviland Twin Otter which is used in regularly scheduled commuter flights. Also included in this category, for approach and landing, are many pressurized twin engine general aviation aircraft, who, in enroute airspace, are in Class 2. User Class 2 includes most piston and turbo prop airliners, such as the DC7, Lockheed Electra, and Fairchild F27. In the landing and approach phase, many business jets are in this class, including the Lear Jet, Lockheed Jet Star, and Rockwell International Sabreliner. These aircraft would be in Class 3 during their enroute portions of flight. Class 3 aircraft include virtually all commercial and military jets.

The airspace is laid out to conform to the aircraft performance classes. One of the advantages to this kind of airspace structure is improved safety due to the minimization of wake turbulence effects. Enhanced capacity and fewer delays also result because of more efficient metering and sequencing, since aircraft of differing performance characteristics spend a minimum amount of time in trail. Wake turbulence effects are minimized by grouping aircraft together according to their weights. That is, wake turbulence effects on aircraft of similar weights are less severe than would be for aircraft of widely differing weights.

In enroute airspace, aircraft tend to naturally segregate themselves by altitude and airspeed. Most light aircraft are relatively slow and are unpressurized, thus limiting their service ceiling. Multi-engine aircraft that are pressurized will generally have better engines, thus permitting them to fly higher and faster. Jet aircraft, of course, fly fastest of all and cruise most efficiently at high altitudes.

When controlled aircraft arrive at a terminal for landing, natural segregation between performance classes is no longer feasible. All aircraft converge on paths leading to the runway and descend through the same altitudes. Therefore, aircraft of different performance classes will tend to fly close together. This is undesirable from both a safety point of view because of wake turbulence effects and from a capacity point of view because of speed differentials between arriving aircraft.

To alleviate these problems, the terminal airspace is structured to segregate aircraft by performance class. Where possible, different runways are used for separating large aircarrier jets from small GA aircraft. The algorithm used by SAATMS for metering, sequencing, and spacing aircraft on arrival takes into account their performance class. Aircraft are assigned to approach paths in the arrival tube based in part on their performance class. Likewise the rate at which arrival slots for each terminal runway are filled is affected by the speed characteristics of the arriving aircraft.

Aircraft weight is also important in runway assignment. Each runway has a finite load bearing capacity, thus placing restrictions on which runways are available for large aircraft.

In summary, controlled aircraft can be classified into three performance categories. In enroute airspace, the aircraft tend to naturally segregate themselves on the basis of cruise altitude and cruise airspeed. In the approach and landing phase of flight, the significant performance parameters are landing speed and weight. The important point is that regardless of performance class (and hence airspace assignment) all aircraft containing the required avionics and desiring to fly controlled will receive the same type of planning and control services from SAATMS.

Cooperative aircraft operating at secondary and feeder airports will not have the luxury of segregated facilities that are available at the terminal airports. These aircraft will approach and land at the airport via a standard traffic pattern. The controller, whether man or machine, will have to take into account aircraft performance characteristics in sequencing aircraft into the pattern and spacing them for efficient landing. In 1973, this job is dependent upon the experience and artistry of the controller. In 1995, automation aids will be available to assist him in this function.

1.2.2.2 Pilot Proficiency Is a Part of the User Class

Regardless of the aircraft performance capabilities or the avionics carried on-board, the ability of an aircraft to receive and accept control commands from the system is dependent upon the pilot's ability to respond to those commands. For example, an aircraft with Category IIIC equipment on board cannot make a Category IIIC landing if the pilot is not rated for instrument landings. The system must know this and not route him in such a manner that his capabilities are exceeded.

Four levels of pilot proficiency are proposed, each specifying a level of control to which the pilot is capable of responding. Three of the four levels concern pilots who are qualified to fly in controlled airspace. Since a requirement for flying in controlled airspace is that a flight plan be filed, the pilot's rating is part of that flight plan. This provides the necessary data to the system concerning pilot proficiency. The fourth pilot proficiency category is reserved for pilots who are only qualified to fly in cooperative airspace.

The first or highest level of proficiency consists of those pilots who are capable of flying in controlled airspace and are capable of landing in Instrument Meteorological Conditions (IMC). They must be able to prepare and file flight plans; obtain and use navigation data to make good their courses as planned; and interact with the system for the purpose of requesting services, changing their flight plans, receiving and correctly responding to system intervention commands, and operating in a backup mode; and they must be capable of making an instrument approach and landing. For Category I landings, the pilot would have to be skilled in making VVOR approaches. For Category II, he would have to know how to use the Microwave Landing System (MLS). Such a pilot would be permitted, with the properly equipped aircraft, to fly into or out of any airport in any weather conditions at any time. It is assumed that all airline pilots and most business jet and military pilots are in this category.

The second level of proficiency consists of those pilots with the capability of the first level, except that they are learning to make IMC landings. Unlike the present system where an instrument rating qualifies a pilot to make instrument landings and fly controlled enroute, it is assumed that in 1995 a pilot can be rated separately for flying in controlled airspace and for making instrument landings. In a sense, such a distinction exists today in that all airline pilots are not rated for Category IIIB but can fly Instrument Flight Rules (IFR). This level of proficiency would permit the pilot to fly under the same conditions as the first level pilot with the exception that he would be barred from making instrument landings at certain airports during busy hours. It is further possible that when the pilot is practicing instrument landings, the system may go into a special surveillance and control mode, e.g., increased surveillance rate, specially tailored to the needs of the student pilot. This might be particularly true for pilots learning to make VVOR approaches.

The third level of proficiency is similar to the second level, but this category of pilot has no instrument landing capability and is not a student acquiring such a capability. The system must be aware of this pilot's rating and not give him commands for approaches to runways operating in IMC.

The fourth level of proficiency consists of all pilots who are capable of flying in cooperative airspace only. Included in this category would be today's general aviation private pilot who has a Visual Flight Rules (VFR) rating only. Such a pilot navigates via dead reckoning and VVOR. He can file a VFR flight plan which notifies the system of his intent and he will be provided with search and rescue services. He is not proficient, however, in filing a fully controlled flight plan which involves, among other things, an interaction with flow control, nor is he proficient in navigating with the required precision to make good his flight plan. This group also includes student pilots, both novices and private pilots, who are learning to fly in controlled airspace. The latter pilot is licensed, can carry passengers, and is currently taking instruction to learn the procedures for flying in controlled airspace. He will file a flight plan like any other pilot wishing to fly in controlled airspace. The system will provide him with planning and conflict intervention services, but his practice flights will take place mostly in mixed airspace. When qualified to solo, he will be permitted to fly in controlled airspace and land at controlled airports along low density training routes and during off peak hours.

In summary, pilots are grouped into two main categories: those qualified to fly in controlled airspace and those qualified to fly only in cooperative airspace. In the case of pilots flying in controlled airspace, a distinction is made between those who are and are not qualified to make instrumented approaches and landings. This differs from the present day practice of providing a single IFR rating covering both controlled flight and instrument landings. In all cases, the SAATMS is aware of the pilot's rating by means of the flight plan (or lack of flight plan) and will provide intervention commands consistent with that rating.

1.2.2.3 Avionics Capabilities Define Three User Classes

There are three basic avionics classes in the SAATMS: controlled, cooperative, and uncontrolled. These avionics classes define the minimum price of admission into controlled, cooperative, and uncontrolled airspace. Both controlled and cooperative users share mixed airspace.

Uncontrolled users have no avionics requirements and are not considered to be part of the SAATMS. They are confined to posted regions in low density areas at altitudes below 3,000 ft AGL. They may not intrude into cooperative airspace nor may they land at airports with control towers. These aircraft receive no services from the system. Since they do not carry surveillance or communications equipment, uncontrolled users cannot be permitted into cooperative or controlled airspace under any traffic density conditions.

The cooperative user requires the following avionics as a minimum price for entry into the system:

(1) Surveillance transmitter

(2) Two-way digital L-band communications

(3) Two-way L-band voice communications

(4) VVOR display and control panel

For this price, the cooperative user receives the service of separation assurance. In addition, the VVOR system provides him with a form of RNAV. This user can also fly in controlled airspace in off peak hours with a clearance from the system.

To fly in controlled airspace the following equipment is required:

(1) Surveillance transmitter

(2) Two-way digital L-band communication

(3) Two-way L-band voice communications

(4) Satellite navigation processor

(5) Satellite navigation display

(6) All of the above must be backed up

(7) 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.

A basic upgrade over the minimum avionics required for controlled flight is instrument landing equipment. With the minimum navigation and surveillance package, the aircraft is capable of flying with sufficient accuracy to meet the requirements for positive controlled airspace. The VVOR system will provide him with a capability of making Category I approaches. SAATMS, however, as presently conceived, will not have sufficient accuracy to enable a precision approach and landing in Category II or III conditions using just navigation and surveillance data. Therefore, if the pilot wishes to land in these conditions, he must have an MLS capability.

An additional optional equipment capability for controlled users is the Collision Avoidance Subsystem (CAS). This air-to-air mode capability is primarily contained in the basic avionics package for the controlled user only. Additional processing 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.

In summary, there are basically two types of users operating within the system: those who are qualified to fly in controlled airspace and those restricted to cooperative airspace. The minimum requirements for flying in controlled airspace consist of a combination of pilot proficiency and surveillance and satellite navigation equipment. Within controlled airspace, aircraft will be segregated by performance class. The minimum requirements for cooperative airspace are (1) a surveillance transmitter and (2) two-way communications. Within each airspace, the degree of service is dependent upon pilot proficiency and avionics.

1.2.3 Airspace Structure - Safety, Freedom, and Flexibility

The SAATMS operational concept postulates four categories of airspace: controlled, mixed, cooperative, and uncontrolled. These airspace categories occur in four regions: enroute CONUS, enroute oceanic, high density terminals, and airports. The location of each airspace category and the route types that are available in each are summarized in Table 1.2-3 and discussed in this section. Also presented is a detailed description of the Los Angeles, California, terminal area.

1.2.3.1 Enroute CONUS Airspace

1.2.3.1.1 Controlled - Flexible Routes with Separation Assurance

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, surveillance, highly accurate satellite navigation and two-way digital data link plus two-way voice equipment. It is anticipated that mostly high class users consisting of 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 for demand level 4, this airspace can be characterized as relatively low density. The worst-case 48 × 60 nmi area, located over New York City, has no more than 23 enroute aircraft at any 1000 ft altitude band. Therefore, flight planning can result in relatively conflict free routing.

The flight planning process will define three dimensional (3D) routes for each aircraft. That is, the path over the ground plus the altitude for each leg will be specified. Two aircraft traveling between the same two points at roughly the same time will either fly parallel paths at least 2 nmi apart or fly at different altitudes. The planning process will also attempt to provide altitude separation between crossing traffic. Aircraft wishing to deviate from their plans either by changing course or altitude must obtain clearances from the system.

In addition to the safety afforded by a centralized planning process and the requirement for system clearances to deviate from plans, the system will provide separation assurance. The system will use surveillance data to determine if two aircraft are too close to each other. If so, it will guide one or both of them to avoid a collision. SAATMS will also guard the boundaries of this airspace to protect it from intruders.

1.2.3.1.2 Mixed - Priority for the Controlled User

Mixed enroute 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, some of which are the jumbo jet variety.

TABLE 1.2-3 SAATMS AIRSPACE STRUCTURE

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

The controlled users of this airspace will be required to carry the same equipment and perform the same planning functions as the aircraft flying above 12,000 ft. They will receive the same services as other controlled aircraft and fly the same type of routes. In addition, they will be given priority over the cooperative aircraft when each is contesting for the same airspace.

1.2.3.1.3 Cooperative Airspace - Freedom of Flight With Safety

Enroute airspace reserved solely for cooperative aircraft extends from the surface to 6,000 ft MSL with two exceptions:

(1) Up to 3,000 ft above ground level (AGL) within 5 nmi of an airport with a control tower or up to 1,200 ft AGL within 1 nmi of an airport without a control tower; the latter airspace is reserved for traffic arriving or departing from that field.

(2) Uncontrolled airspace.

Cooperative aircraft can also fly in mixed airspace. Aircraft using cooperative or mixed airspace must have surveillance, two-way digital communications plus two-way voice, and VVOR equipment. These aircraft will be almost entirely small GA aircraft who will operate largely in VMC.

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.

1.2.3.1.4 Uncontrolled Airspace

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. It is expected that users of this airspace will consist of aircraft such as crop dusters and some home built experimental aircraft.

1.2.3.2 Enroute Oceanic - No Separate Equipment Requirements

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.

Oceanic traffic wishing to enter CONUS airspace will be required to be suitably equipped with surveillance, navigation, and communications equipment. They will have to be flying on an approved flight plan and request a clearance to enter CONUS prior to crossing the 12 nmi limit. Since it is likely that most aircraft flying in this region will be equipped with surveillance, the system will provide traffic advisories to the extent possible.

1.2.3.3 High Density Terminals - Mixture of Large and Small Aircraft

High density terminals are defined as the region below 12,000 ft MSL within a 20 nmi radius of a primary aircarrier airport. Mitre (Ref. 4) defines primary aircarrier airports as those airports serving aircarriers and enplaning more than one million passengers per year. By implication, such airports would be expected to be located in highly populated metropolitan areas. Approximately 100 such airports should exist in 1995. According to Mitre, five such airports will exist in the Los Angeles area alone.

Since these airports are located near highly populated metropolitan areas, it is reasonable to assume that a large number of secondary and feeder airports servicing a large GA fleet will be located nearby. Therefore, the airspace in the vicinity of these terminals can be assumed to contain a high density mixture of turbine and piston aircraft of all sizes and speeds, hence, the terminology high density terminal.

The airspace below 12,000 ft MSL within a 20 nmi radius of a primary aircarrier airport consists of controlled, mixed, and cooperative airspace. No uncontrolled airspace exists in this region.

1.2.3.3.1 Controlled Airspace - Controlled Transition from Cruise to Landing

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. In this context, controlled 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. Depending upon the runway configuration, each primary aircarrier airport will have as many as four TCA arms extending out from the airport boundary to accommodate arrivals and departures from various directions. These arms merge no closer than 10 nmi from touchdown. Each TCA is an inclined cone, the lower limit of which extends upward at a 6 deg angle. The upper limit of the cone extends upward at an 8 deg angle. The lower limit of the cone is 6,000 ft AGL 10 nmi from touchdown and 12,000 ft AGL 20 nmi from touchdown. At that point, the cone passes through the ceiling of the terminal area and continues out into controlled enroute airspace for a distance of 70 nmi from touchdown. At that point, the lower limit of the cone is 42,000 ft AGL. A profile of this cone is illustrated in Fig. 1.2-8. In the plan view, Fig. 1.2-9, the TCA is 4 nmi wide from the airport boundary out to 20 nmi. At that point, the boundary widens so that it is 20 nmi wide at 70 nmi from touchdown. Therefore, aircraft approaching the airport will be funneled from a 20 nmi wide window to the runway threshold.

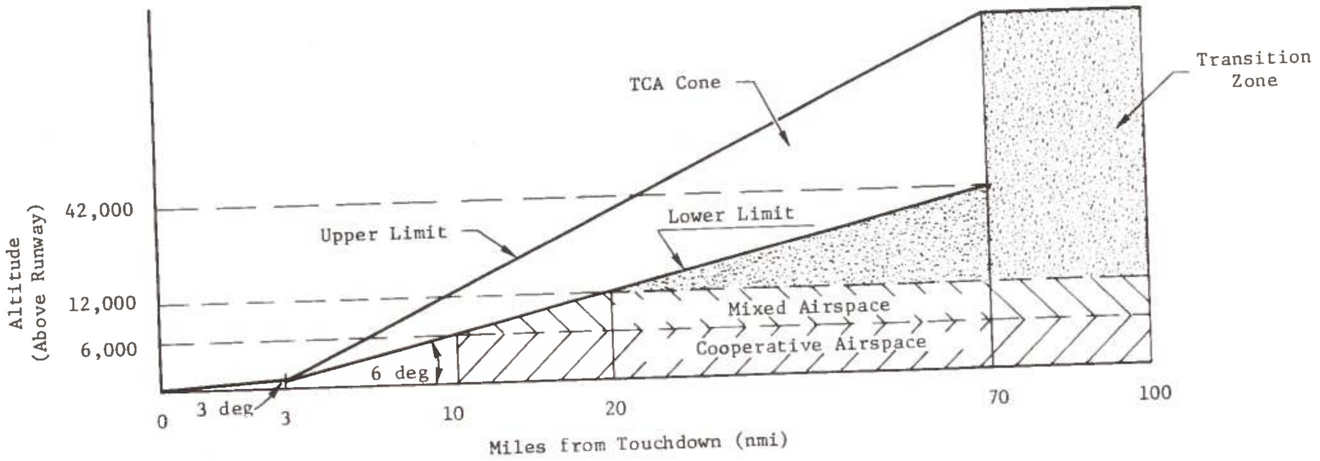


Figure 1.2-8. TCA Profile

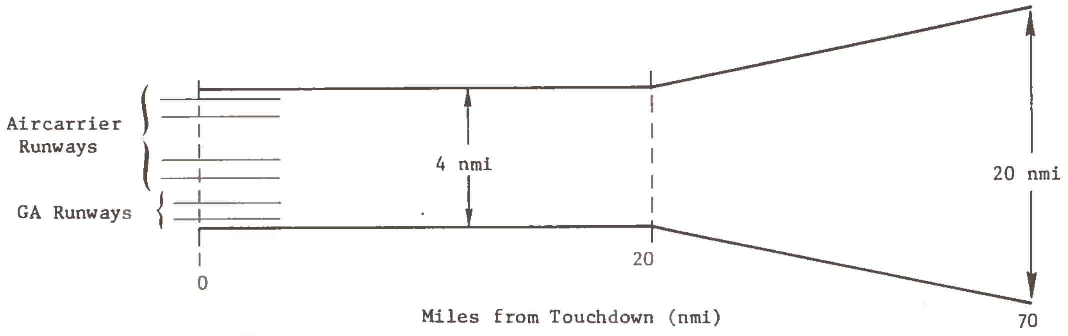


Figure 1.2-9. TCA Plan View

From Fig. 1.2-8, it can be seen that approaches to the airport are made in two stages. The initial stage involves a descent angle of 6 to 8 deg. At 3 nmi from touchdown, the descent angle becomes 3 deg for final approach.

This type of approach has several advantages. All controlled aircraft are at or above 6,000 ft 10 nmi from touchdown. Therefore, cooperative aircraft are free to use the airspace below the cone at these distances from the airport.

The aircarriers will tend to favor this type of approach because it will enable them to remain at high altitude for a longer period of time. Most aircarriers will not begin their descent until they are approximately 60 nmi from touchdown. Additionally, since the aircraft are higher and descending at steeper angles, they will use lower power settings. This results in less noise under the approach path.

The TCA contains a number of routes in much the same fashion as a multilane highway. These routes merge until, at 3 nmi from touchdown, only a single lane exists for each runway.

The close horizontal spacing of these routes is possible because of the high navigation and surveillance accuracy inherent in the SAATMS. Because a large number of closely spaced paths is available to aircraft approaching or departing the airport, the horizontal dimension of the TCA is considerably smaller than the present day TCA's (see Fig. 1.2-10). The maximum width of the TCA below 12,000 ft is 4 nmi. Aircraft approaching the airport will be assigned to paths in the center 3 nmi with the outer 0.5 nmi being used for minor path stretching.

Departures are treated in much the same manner as arrivals. Where possible, departures from one runway will use the arrival TCA of the opposite runway. Runway reversals are handled by having arriving aircraft use the departure routes and departing aircraft use the arrival routes.

Since high SAATMS accuracy results in narrow TCA's, considerably more airspace is available to GA traffic in the vicinity of a primary aircarrier airport than in the present day system. SAATMS uses surveillance data to guard the TCA boundaries against intrusion by cooperative aircraft. In the second, third, and upgraded third generation systems, this function is provided by primary radar returns received from nontransponder equipped aircraft. Such surveillance data are not totally effective when dealing with a large number of small GA aircraft. Therefore, the SAATMS terminal airspace structure will provide aircarriers with more efficient approaches to primary airports than they have today while providing more airspace and greater safety through better surveillance.

A detailed analysis of the Los Angeles basin was made to demonstrate the application of the TCA concept previously described. The results of this analysis are presented in Fig. 1.2-10. The analysis was presented to airspace structure experts in the Federal Aviation Administration located at Los Angeles International Airport. Their suggestions have been incorporated into Fig. 1.2-10.

The Los Angeles basin contains a large mixture of aircarrier and GA traffic. Generally, it has good weather but a highly varied terrain consisting of ocean, mountains, flat metropolitan areas, high desert, and low desert.

The airport categories and demand data for the LA area were generated by Mitre Corporation in their requirements specification. Whereas in 1973 LA has one primary aircarrier airport with a TCA, in 1995 there will be five such airports: Los Angeles International (LAX), Hollywood-Burbank, Ontario, Orange County-Santa Ana, and Palmdale. In 1995, the region is expected to contain 48 airports, 5 of which will be military bases. The peak Instantaneous Airborne Count (IAC) in 1995 will be 1840 aircraft of which 278 will be IFR (controlled in the SAATMS terminology). About half of the controlled aircraft will be aircarriers.

The results presented in Fig. 1.2-10 show approach and departure routes to four of the five airports; Palmdale was not analyzed since it was remote from most of the other airports. Departure routes are specifically shown for LAX, Hollywood-Burbank, and Orange County. In the case of Ontario and departures to the north from Orange County, the departures take place in the arrival zone for the opposite runway.

The circled numbers 6 and 12 on the figure show the 6,000 and 12,000 ft altitude points which are located 10 and 20 nmi, respectively, from touchdown. The TCA's, of course, extend out 70 nmi from touchdown but are not shown beyond the 20 nmi point since they pass through the ceiling of the terminal area. Care was taken to provide altitude separation between arriving and departing traffic both within the TCA and from nearby airports (e.g., Santa Monica and Long Beach).

A conflict point appears to exist in the center of the basin between westerly arrivals to Ontario and easterly arrivals to Hollywood-Burbank. Aircraft on these two routes would be at 12,000 ft at the same time. The demand data were analyzed to see if there was likely to be a large number of aircraft at this point at one time. It was found that of the 278 controlled IAC, only 8 would be on these routes. These eight aircraft could be distributed over a wide region so that it would be unlikely that more than two aircraft would arrive at the 12,000 ft altitude point simultaneously. There are more than enough lanes available to safely accommodate two simultaneous aircraft.

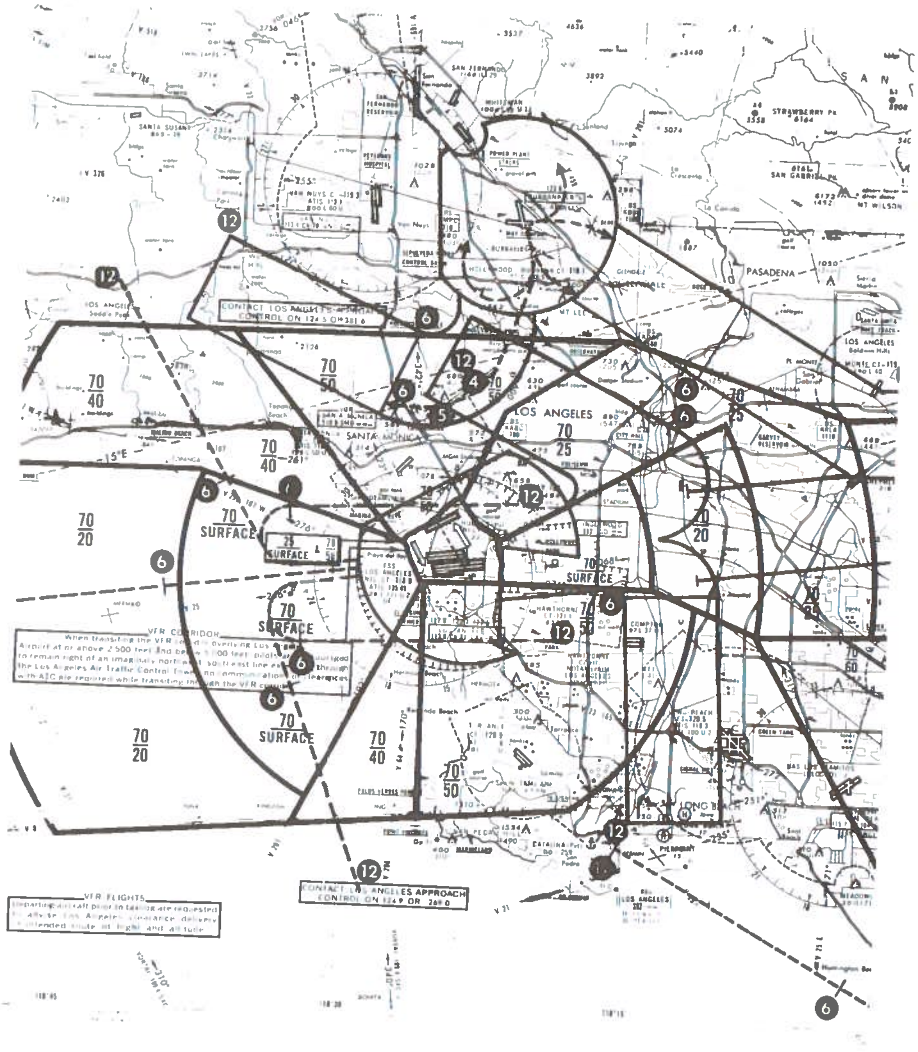
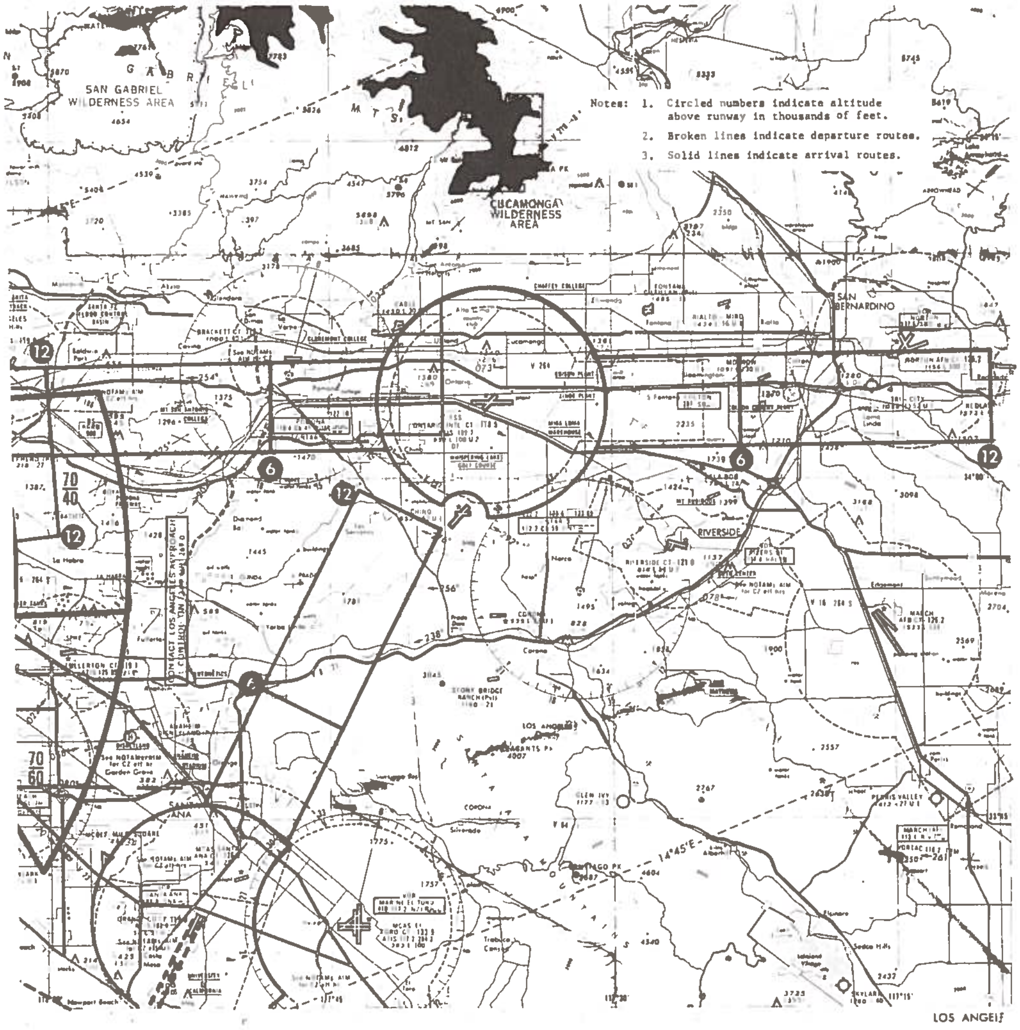


Figure 1.2-10 Terminal Control Airspace for LA Basin



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

Figure 1.2-10 Terminal Control Airspace for LA Basin (Continued)

The analysis illustrated in Fig. 1.2-10 indicates that terminal control airspace can be set up for four airports in a high density region like the LA basin. The TCA's can be laid out to provide ample airspace for GA aircraft without shutting out existing airports. In 1995, the LA basin airspace may not look exactly as depicted in Fig. 1.2-10, but the changes that are made should in no way negate the feasibility of such an airspace structure.

1.2.3.3.2 Mixed Airspace - Standard Arrival and Departure Routes

Mixed airspace in the terminal areas will be similar to mixed enroute airspace. The airspace will extend from 6,000 to 12,000 ft MSL except for approaches and departures to airports other than primary aircarrier airports. Controlled aircraft will use Standard Arrival Routes (STAR) and Standard Instrument Departures (SID). The Regional Control Center (RCC) will keep cooperative aircraft out of the STAR and SID airspace when controlled aircraft are using these routes.

1.2.3.3.3 Cooperative Airspace - Freedom of Flight with Safety

Cooperative airspace in terminal areas is identical to that in enroute regions. The primary difference for the user of this airspace is that there are TCA zones posted in which he cannot fly. The GA user will probably have to make much more extensive use of his VVOR capability in terminal areas to assure that he stays in his own airspace. The system will assist him by guarding the TCA boundaries as well as by providing him with separation assurance.

1.2.3.4 Airports

Within the SAATMS concept, there are five types of airports: (1) primary aircarrier, (2) secondary aircarrier, (3) feeder with control towers, (4) feeder without control towers, and (5) military. In Table 1.2-3, the primary aircarrier airports are shown as controlled, the secondary and feeder airports with control towers were combined and are shown as mixed/cooperative, and the feeder airports without control towers are shown as uncontrolled. Military airports were not analyzed.

1.2.3.4.1 Controlled Airports - Separate Runways for Aircarriers and GA

Primary controlled airports contain segregated facilities for aircarriers and GA traffic. They may have two sets of parallel aircarrier runways, four in all, and a pair of GA runways. The boundary of the airport is a 5 nmi radius around the runways extending from the surface to 3,000 ft AGL. This boundary defines the control jurisdiction of the Airport Control Center (ACC).

The facilities at this airport consist of the following:

(1) A control tower that operates in much the same fashion as present day towers. The tower is the heart of the ACC and is manned by personnel performing functions similar to today's local and ground controllers. Automation aids will include surveillance data on aircraft within a 20 nmi radius transmitted from the RCC, digital as well as voice communications, and data processing to help with metering and sequencing traffic.

(2) Microwave Landing System (MLS) for all weather landings.

(3) Ground surveillance and guidance for all weather taxi and takeoff.

(4) Automated flight service station terminals for use primarily by GA pilots.

In busy hours, only controlled aircraft are permitted to use this airport. If space is available, the RCC may permit cooperative users to enter the TCA and proceed to the airport. Such permission will only be given after a request is made by the cooperative aircraft and if there is room to fit it into the flow of traffic without delaying other aircraft. All aircraft in the ACC will receive separation assurance from the system both in the air and on the ground. Small GA aircraft will seldom land on the same runways as large aircarrier jets at this airport.

1.2.3.4.2 Mixed/Cooperative Airports - Operate Like Today's Airports With Control Towers

All airports with control towers, but not in the primary aircarrier category, fall into this category. They too will have an ACC whose boundaries are a 5 nmi radius around the runways extending 3,000 ft AGL. The functions performed in the control tower will be similar to those performed at the primary airports. The differences from the primary airports are as follows:

(1) Since there is no TCA, the route structure leading into the ACC will differ from the primary airports. Aircraft wishing to enter the ACC must first request and obtain a clearance from the tower. A normal traffic pattern consisting of a 45 deg radial to a downwind leg, a base leg, and a final leg will be used. The tower is free to clear aircraft into the pattern at several points and will normally try to give controlled traffic straight in approaches if possible.

(2) Most runways will not have MLS.

(3) These airports will often have a greater number of operations per hour per runway in VMC than the primary airports. The demand will come primarily from cooperative aircraft. Where possible, GA traffic will be segregated from aircarriers but most often they will share the same runways.

(4) Large jets will be banned from feeder airports.

(5) Inside the ACC boundary, no distinction will be made between cooperative and controlled traffic. Everybody is under control of the tower.

(6) Ground surveillance but not guidance will be available.

(7) To keep capacity high in VMC, visual flight rules will be employed inside the ACC. The tower will provide separation advisories but will not be responsible for separation assurance other than spacing on the runway. During Instrument Meteorological Conditions (IMC), the demand will be less and normal separation standards can be applied without affecting capacity.

1.2.3.4.3 Uncontrolled Airports - Traffic Advisories Available from the RCC

Uncontrolled airports have no operating control towers. The airport boundary is 1 nmi around the runways extending to 1,200 ft AGL. Traffic is organized by standard published traffic patterns and no clearances are required to fly in and out of these airports. Inside the airport boundary, visual flight rules apply; but, based upon surveillance data, the RCC will provide traffic advisories.

1.2.4 Rules and Procedures

The rules and procedures relate the airspace structure to the management concept. They relate how aircraft fly to where aircraft fly. In this section, the requirements for entry and exit from the system, operation in each airspace category, transition from one jurisdiction to another, and emergency operations are given.

1.2.4.1 Entry into the System - Acquisition of the Surveillance Signal Required for Flight

The overriding requirement for operation within the SAATMS is that the aircraft contain surveillance. Any aircraft that does not have a surveillance capability is classified as an uncontrolled aircraft. This aircraft may not under any circumstances intrude into airspace protected by the SAATMS. Those aircraft which contain surveillance must be acquired by the system before they take off. The procedure is as follows.

The surveillance transmitter is connected to the aircraft's engines. When the engines are turned on, the surveillance triplet begins to be transmitted at a rate of one triplet every 2 sec. The signals are detected and routed to an acquisition computer where a position computation is made. Based upon this computation, the responsibility for tracking the aircraft is assigned to one of the two RCC's. A message is then sent to the aircraft informing it that it has been acquired and instructing it to change its surveillance rate from once every 2 sec to once every 8 sec.

The aircraft is not permitted to take off until it has received the digital acquisition message. Further, by tying the surveillance transmitter to the engines, it is assured that the pilot will neither forget to turn on his surveillance nor shut it off in flight.

1.2.4.2 Exit from the System - Intent to Exit Should be Provided

Exit from the system is completed when the surveillance signals are no longer being transmitted, usually when the aircraft lands and shuts off its engines. However, signals may cease to be transmitted if the surveillance link malfunctions or if the aircraft crashes.

The normal method for exiting the system is to digitally inform the RCC of intent to shut down the engines. In this case, there is no ambiguity about why the signals are no longer present. If the aircraft shuts down its engines without first transmitting intent to exit, the system will look for the surveillance pulse on each of the next six update cycles. When the pulse does not reappear, the system determines the last known position. If it was inside an airport boundary, an assumption is made that the aircraft landed; then it is removed from the track file. If the last known position was not inside an airport boundary, an emergency situation is assumed. Control is transferred from the computer to a contingency controller, probably a human. This controller will first try to raise the aircraft on the communications link. Failing this, other aircraft in the vicinity may be contacted either digitally or by voice and asked to keep a lookout for the missing aircraft. The emergency will exist until the aircraft is found.

1.2.4.3 Operation in Each Airspace Category - Avionics, Pilot Rating, and Flight Plans

The basic requirements for operation in an airspace category are that the aircraft be suitably equipped and that the pilot contain a proficiency rating compatible with that airspace.

An aircraft operating in cooperative airspace must contain a surveillance transmitter, two-way L-band digital communications, two-way L-band voice communications, and a VVOR control and display panel. The cooperative pilot must navigate with sufficient accuracy to avoid intruding into controlled or restricted airspace. He must yield the right-of-way to controlled aircraft in mixed airspace when instructed to do so. He must request a clearance before entering an ACC and he must adhere to published traffic patterns at all airports. The cooperative pilot is obliged to familiarize himself with the airspace structure in the region in which he is flying. He is also obliged to study published airport data concerning his departure and destination fields. He is further obligated to respond quickly and accurately to intervention commands.

An aircraft operating in controlled airspace must contain all of the equipment required of cooperative users plus backup voice and digital communications, a satellite navigation processor, and a navigation course and steering display. In addition, the aircraft must have an approved flight plan which contains the pilot's rating. The pilot is obligated to navigate his aircraft with sufficient accuracy to make his flight plan good. Should he wish to deviate from or modify his flight plan, he is required to inform the system of his intent and obtain a clearance before implementing the change. Like the cooperative user, he must respond quickly and accurately to intervention commands.

1.2.4.4 Transition Between Jurisdictional Areas Uses Positive Communications

SAATMS is designed with a minimum number of jurisdictional boundaries. These boundaries lie between CONUS and oceanic regions, between RCC and ACC, between RCC and RCC, and between an RCC and uncontrolled airspace. Whenever an aircraft crosses one of these boundaries, a handoff is required. There are essentially two types of procedures: one for transition between an RCC and uncontrolled airspace and one for transition between an RCC and controlled airspace.

The first procedure concerns transition between the RCC and either an airport without a control tower, posted uncontrolled airspace, or oceanic airspace. Traffic exiting from the RCC will receive a digital message informing them that the RCC is no longer providing the separation assurance service; however, these aircraft will receive traffic advisories. In effect, these aircraft are being handed off to themselves. Aircraft entering the RCC from these three regions will be informed digitally that they are now under the control of the RCC and are expected to obey the established rules and procedures. At this point, they start to receive the separation assurance service.

The second procedure concerns transition between an ACC and an RCC or between the two RCC's. In this case, the handoff involves establishing positive communications between the aircraft and the receiving jurisdiction. The procedure is as follows:

(1) The jurisdiction from which the aircraft is departing instructs the aircraft to switch digital communications to the frequency of the receiving jurisdiction.

(2) The receiving jurisdiction digitally informs the aircraft that it has been acquired and is being tracked.

(3) The aircraft digitally acknowledges this message.

(4) The aircraft then switches voice communications to the new frequency.

(5) If the aircraft does not acknowledge in step (3), the receiving jurisdiction contacts the exiting jurisdiction and requests that it make voice contact with the aircraft.

(6) If contact is made, the procedure is repeated until positive communications are established. If contact is not made, the system goes to an emergency mode of operation.

1.2.4.5 Emergency Operation

Emergencies can occur either because of problems in the air or malfunctions in the system. SAATMS is highly automated with considerable backup and redundancy built in to provide fail operational service. In the event of the loss of a complete RCC, the CCC will take over most functions. These include separation assurance, airspace boundary intrusion protection, and VVOR. In the case of arrivals at primary airports, however, the CCC will not provide the complete, automated, 4D metering and spacing that was provided by the RCC. Much of the automation plus manual approach control will be performed by the ACC in this backup mode. This will result in aircraft spending more time in trail and the use of a less complex arrival route structure. The system will be required to inform all aircraft in the transition and arrival phases of this contingency mode and provide them with a new set of backup instructions.

Aircraft in the arrival and approach phase at the time of the failure would not experience any change in operation, since path conformance is an air managed control. The personnel at the ACC assisted by the ACC processors would undertake the planning and merging functions. Separation assurance is always provided by the CCC. In the event of this type catastrophic failure (a total RCC), the primary concern of the system is to fail safely.

When malfunctions or emergencies occur in the air, the pilot is required to contact the RCC and inform it of the problem. The system will continue to process the aircraft's position and provide conflict intervention. In addition, the data will be given to a human controller who will contact the pilot by voice and work out a solution to the problem.

1.2.5 Management Concept - Air Managed Conformance, Ground Managed Safety

The management concept is that portion of the operational concept that is concerned with 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.

The management concept describes functions that are performed to provide five basic services: planning, conformance, separation assurance, advisories, and emergency assistance. These are described in the following paragraphs followed by a presentation of the SAATMS control concept. The control concept describes how each function is performed in different airspace categories and for different user classes.

1.2.5.1 Planning

The planning functions include all activities associated with scheduling and routing aircraft. Several types of planning are involved. These are described below.

1.2.5.1.1 Flight Planning - Flexible Routing and Reservation at Destination

A flight plan is a contractual agreement between a pilot and the system and describes how an aircraft will proceed between two points. All controlled aircraft must have an approved flight plan. In return for accepting control from the system, the controlled aircraft will receive a reservation at its destination guaranteeing it the first available slot when it arrives. It will also be given preference in the use of the airspace in which it is flying.

When a pilot files his flight plan, he indicates preferred departure and arrival times, a preferred route, and a preferred altitude. The route selected will depend upon winds, and the route with the shortest time for the most economical aircraft speed will usually be desired. The preferred enroute altitude will be a function of the aircraft's performance capability. Several altitude layers within each altitude band are available, the number of layers depending upon the accuracy of the surveillance system and the separation standards.

Within broad limits, several altitudes are equally preferable for a given aircraft. For example, assuming no difference in winds, a jet airliner can fly at 30,000 or 32,000 ft. If the surveillance system accuracy permitted 500 ft vertical separation, then, for the example, the aircraft would have five equally preferable altitudes from which to choose. The same route flexibility exists in the horizontal axis. The area navigation capability and accuracy inherent in the SAATMS make it possible to select several parallel offset routes between the same two points. In most cases, the enroute time differences for the parallel routes will be negligible.

The pilot will use weather and route data provided by the National Flow Control Center (NFCC) to assist him in making his flight plan. The data will be presented to him on an automated flight service station terminal. When he has completed his flight plan, he will enter it into the terminal where it will be sent to the NFCC for approval and inclusion in the flow plan.

1.2.5.1.2 Flow Planning - Master Scheduling Prevents Planned Conflicts

The NFCC will check the flight plan for errors and potential conflicts. Conflicts are predicted from ETA's at various waypoints that appear on several flight plans. If a potential conflict exists, alternate routes, altitude, or time will be suggested to the pilot. Likewise, from other flight plans, the NFCC can predict potential delays at the destination airport and suggest better arrival times.

The pilot is free to accept or reject the NFCC suggestions. He enters his flight plan revisions, if any, on his terminal keyboard and officially files his plan. The NFCC acknowledges by indicating that the plan has been approved. The flight plan is then entered into a master flow plan which shows the schedule and routing for all traffic for the next few hours (at least six hours). This information is transmitted periodically to concerned RCC's and destination ACC's so that they will be expecting the aircraft when it arrives.

It is important to note that the flow plan is provided only for the information of users. No attempt is made to control aircraft to make good the flow plan. Aircraft will be accepted at their waypoints and destinations on a first come, first served basis.

1.2.5.1.3 Clearances - It Must Be Safe

Once a flight plan has been approved, the pilot is expected to adhere to it to the best of his ability. However, in many cases after taking off, the pilot may wish to deviate from his plan. The most common reasons for deviating are weather cells in the aircraft's path, unexpected unfavorable winds at the aircraft's altitude, and smoother air at a different altitude.

When the pilot wishes to deviate from his flight plan, he must request the change and receive a clearance from the RCC to implement the change. The RCC will use data such as the flight plans shipped over from the NFCC and present location and state vector of aircraft in the vicinity in planning to service the user's request for the change. The form of approving the request is a clearance to implement the change.

1.2.5.1.4 Metering and Spacing - Orderly Traffic Flow into High Density Terminals

When aircraft wish to transition from enroute airspace to a high density terminal, they must contact the RCC and request a clearance into the terminal airspace (see Section 1.2.3.3). Busy terminals will receive many such requests from aircraft arriving from all directions and all wishing to land at the same airport at roughly the same time. In processing these requests, the RCC performs metering, sequencing, spacing, and merging computations to assure that there will be an orderly, safe flow of traffic over the runway threshold. The RCC must perform this planning function before it can clear the aircraft into the approach highway. The form of the clearance is an assignment to an approach path and a command speed or time over one or more waypoints. The distance covered by this function is on the order of 100 nmi with a time span of approximately 20 to 30 min.

1.2.5.1.5 Standard Routes - Orderly Traffic Flow at Nonprimary Airports

To clear aircraft into a traffic pattern, merging and sequencing must be performed by the ACC similar to the metering and spacing performed by the RCC. All airports have established traffic patterns which are published and therefore known to the pilots using the facility. Entry to a traffic pattern is usually at a 45 deg angle to the downwind leg. Pilots who approach the field from different directions, however, will request base leg or straight in entries. The ACC must perform a planning function to determine if it can safely accommodate these requests without upsetting the flow of traffic.

Other standard routes that must be assigned after relatively short-term planning include taxi routes and standard approach and departure routes. These latter routes are particularly important since they are used by controlled traffic in mixed airspace. In performing the planning function prior to assigning aircraft to SID's or STAR's, the RCC must take into account cooperative aircraft that will have to be moved out of the way.

1.2.5.2 Conformance - Navigation to Make Good a Plan

The conformance functions include all those activities associated with implementing a plan. Controlled aircraft operating on an approved flight plan will use navigation data to adhere as closely as possible to their routes. As they drift off course, the navigation data displayed in the cockpit will inform them of the error and they will change the direction of flight to get back on course.

To assure that navigation data are available, all aircraft operating in controlled airspace will be required to have a backup navigation processor and L-band receiver. This will provide redundancy for the primary mode, satellite navigation. In addition, all aircraft will have virtual VOR as an additional backup. Further, at periodic intervals the RCC will send surveillance data to the aircraft which the pilot can compare with his navigation data. If they agree, the pilot will be confident that his present position, derived from navigation data, is accurate.

In enroute airspace, the conformance function will be concerned primarily with restricting aircraft to the planned route and altitude. Although the flight plan indicates that an aircraft will be over certain points at a specified altitude at a certain time, the system does not have complete flexibility to control actual times of arrival. The system can slow down an early arrival to make the time good, but this is inefficient unless the aircraft is about to come in conflict with another aircraft. Further, such a control action would tax the system with a delay. If, on the other hand, an aircraft is late, the system has very little flexibility in speeding him up. That is, aircraft tend to fly at an optimum airspeed; and if the aircraft must increase speed by more than a few knots, the fuel consumption rates increase disproportionately and reduce operating economics. Most users will be reluctant to accept the added operating costs in the interest of making a predetermined time good.

Cooperative users will also be required to perform the conformance function when operating in and around an airport, i.e., they must conform to the established traffic pattern. In most cases they operate in a visual mode to maintain position in the pattern. In cases of reduced visibility, virtual VOR will be available as a navigation data source.

In most cases, the responsibility for the conformance function will rest with the pilot.

1.2.5.3 Separation Assurance - Safety Through Surveillance

While conformance is concerned with keeping aircraft to a plan, separation assurance is concerned with preventing aircraft from colliding. Conflict intervention, the activities for preventing collisions, occurs when two aircraft are in danger of violating a separation standard or when an aircraft intrudes into airspace in which it is not entitled to fly. Conformance intervention is based upon navigation data, while conflict intervention is based on surveillance data. The system monitors the position of all aircraft at a relatively high data rate. If two aircraft are close to each other, the system will extrapolate their future positions based upon their present state vectors. If it is predicted that their paths will cause them to come too close, the system will intervene to change the path of one or both of them. It should be noted that the system does not have to perform this computation for every instantaneous aircraft pair -- only for those pairs whose instantaneous position is within a predetermined boundary separation requiring further computation.

1.2.5.4 Advisories - Safety in VMC Without Reducing Capacity

Since all user aircraft contain surveillance equipment, all are capable of receiving the separation assurance service. However, to maintain capacity at secondary and feeder airports operating in Visual Meteorological Conditions (VMC), only traffic advisories are provided. These aircraft are permitted to fly as close together as they wish, but the responsibility for avoiding collisions rests with the pilots. The present system works in this manner at airports with control towers operating in VMC.

A review of accident and near mid-air collision reports (Ref. 5 and 6) indicates that a major cause of near and actual accidents is the lack of surveillance data. The conflicting aircraft pilots were unaware of each other. The system will be considerably safer in 1995 since the local controller will have surveillance data to assist him in sequencing traffic and providing advisories.

The issuance of traffic advisories will, of course, not be limited to the region around the airport control centers. Advisories will also be provided in enroute airspace and in terminal approach corridors as part of the separation assurance service. These advisories will alert pilots to the existence of traffic in their vicinity and warn them that conflict intervention commands might be forthcoming.

In addition to traffic advisories, the system will also provide aircraft with weather advisories and information about conditions at their destination airport. This information is provided to assist pilots in revising their flight plans to assure a smoother, safer flight.

1.2.5.5 Emergency Assistance - Human Controllers to Help

The functions described in the preceding paragraphs will be largely automated. This is particularly true in the areas of metering, spacing, and conflict intervention. When an aircraft has an emergency, however, human controllers will be able to give assistance.

It is, of course, possible to program the computer to perform this function; however, because emergencies occur at unpredictable times and under a wide variety of conditions, a rather sophisticated program approaching human decision-making capabilities would have to be written. Such a program would result in an inefficient and costly use of the computer. Therefore, it is proposed that this function not be automated in the SAATMS.

1.2.5.6 Control Concept - Conformance, the Aircraft's Job; Safety, the System's Job

The control concept defines the SAATMS control structure and allocates responsibility for performing each function to either the ground or the aircraft pilot. When the ground is responsible for performing a function, the term "ground managed" is used. When the pilot is responsible, the term "air managed" is used.

To understand the motivation behind performing each function, the terms "strategic" and "tactical" are used. Functions related to long-term planning are called strategic, while functions such as responses to contingencies that obviously result from short-term planning are called tactical. In SAATMS, the same function can be strategic in one set of circumstances and tactical in another. In that sense, the terms strategic and tactical convey no information about how SAATMS operates. Therefore, in presenting the control concept, these terms are used to describe the planning function only.

The control concept is presented in Tables 1.2-4 through 1.2-6 and is illustrated in Fig. 1.2-11 through 1.2-13. The tables show the primary and backup responsibilities for performing planning, path conformance, and conflict intervention in each phase of flight, while the figures show only the primary responsibility for planning, path conformance, and conflict intervention. From these tables and figures, it can be seen that responsibility for conflict intervention rests largely with the ground based system, while responsibility for path conformance rests with the pilot. In other words, conformance is the aircraft's job and safety is the system's job.

For controlled aircraft flying solely within controlled airspace (Table 1.2-4 and Fig. 1.2-11), 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 arrival transition zone from the cruise phase of flight, however, the system will provide vectors for the aircraft to fly. 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/wave-off decision is made.)

Table 1.2-4. Control Concept, Controlled Airspace

Flight Phase	Planning		Path Conformance		Conflict Intervention	
	Prime	Backup	Prime	Backup	Prime	Backup
Preflight	GS - 3D	GS	NA	NA	NA	NA
Departure Taxi	GT - 2D	GT - 2D	A	G	G	A
Takeoff	GT - 2D	GT - 2D	A	G	G	A
Departure	GT - 2D	GT - 2D	A	G	G	A
Departure Transition	GT - 3D	AT - 3D	A	A	G	A
Cruise CONUS	GT - 3D	GT - 3D	A	A	G	A
Cruise Oceanic	GT - 3D	AT - 3D	A	A	A	G Advisories
Arrival Transition	GT - 4D	GT - 4D	G	A	G	A
Arrival	GT - 4D	GT - 4D	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	Close Flight Plan	NA	NA	NA	NA	NA

A - Air Managed
G - Ground Managed
S - Strategic
T - Tactical
NA - Not Applicable

Table 1.2-5. Control Concept, Mixed Airspace, Secondary and Feeder Airports with Control Towers

Flight Phase	User Class	Planning		Path Conformance		Conflict Intervention	
		Prime	Backup	Prime	Backup	Prime	Backup
Preflight	Controlled	GS	GS	NA	NA	NA	NA
	Cooperative	AS	GS Advisories	NA	NA	NA	NA
Departure Taxi	Controlled	GT	G	A	G	A	G Advisories
	Cooperative	GT	G	A	G	A	G Advisories
Takeoff	Controlled	GT	GT	A	G	A	G Advisories
	Cooperative	GT	GT	A	G	A	G Advisories
Departure	Controlled	GT	GT	A	G	G	A
	Cooperative	AT	NA	A	NA	G	A
Departure Transition	Controlled	GT	AT	A	G	G	A
	Cooperative	NA	NA	NA	NA	NA	NA
Cruise	Controlled	GT	GT	A	A	G	A
	Cooperative	AT	NA	A	NA	G	A
Arrival Transition	Controlled	GS	GT	A	G	G	A
	Cooperative	NA	NA	NA	NA	NA	NA
Arrival	Controlled	GT	GT	A	G	G	A
	Cooperative	GS	AT	A	G	G	A
Approach	Controlled	GS	GT	A	A	A	G Advisories
	Cooperative	GS	GT	A	A	A	G Advisories
Landing	Controlled	GT	AT	A	A	NA	NA
	Cooperative	GT	AT	A	A	NA	NA

A - Air Managed
G - Ground Managed
S - Strategic
T - Tactical
NA - Not Applicable

Table 1.2-5. (continued)

Flight Phase	User Class	Planning		Path Conformance		Conflict Intervention	
		Prime	Backup	Prime	Backup	Prime	Backup
Arrival Taxi	Controlled	GT	GT	A	G	A	G Advisories
	Cooperative	GT	GT	A	G	A	G Advisories
Postflight	Controlled	GT	NA	NA	NA	NA	NA
	Cooperative	NA	NA	NA	NA	NA	NA

A - Air Managed
G - Ground Managed
S - Strategic
T - Tactical
NA - Not Applicable

Table 1.2-6. Control Concept, Cooperative Aircraft Operating From Airports Without Control Towers

Flight Path	Planning	Path Conformance	Conflict Intervention
Preflight	GS Traffic Pattern; No Clearances Required	NA	NA
Departure Taxi	AT Clearance Required From RCC to Enter System	A	A
Takeoff	GS Traffic Pattern	A	A
Departure	AT	A	A Until Aircraft Crosses 1 nmi Boundary; Then G
Cruise	AT	A	G Prime; A Backup
Arrival	AT	A	G Until Aircraft Enters Pattern; Then A
Approach	GS Traffic Pattern	A	A
Landing	GS Traffic Pattern	A	A
Arrival Taxi	AT	A	A

A - Air Managed
G - Ground Managed
S - Strategic
T - Tactical
NA - Not Applicable

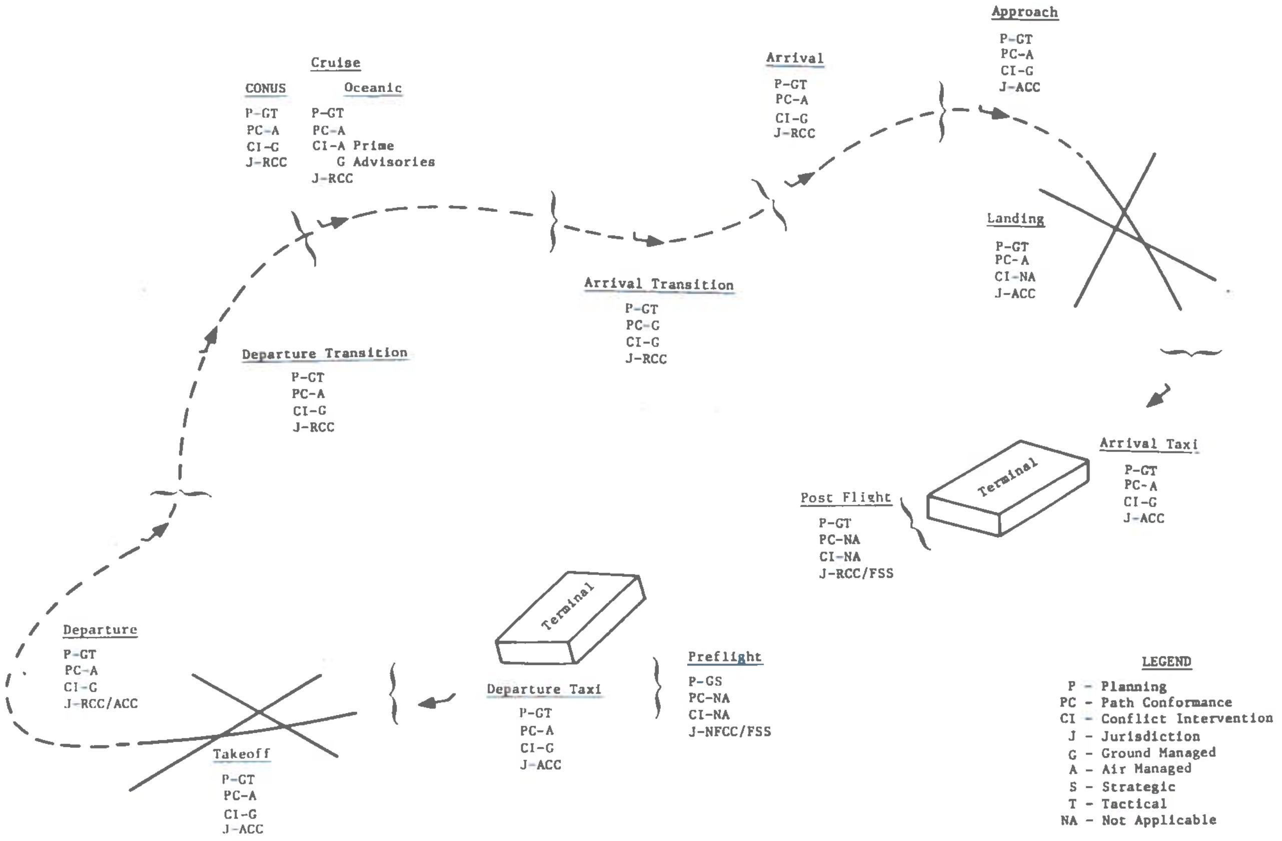


Figure 1.2-11. Control Concept, Controlled Airspace

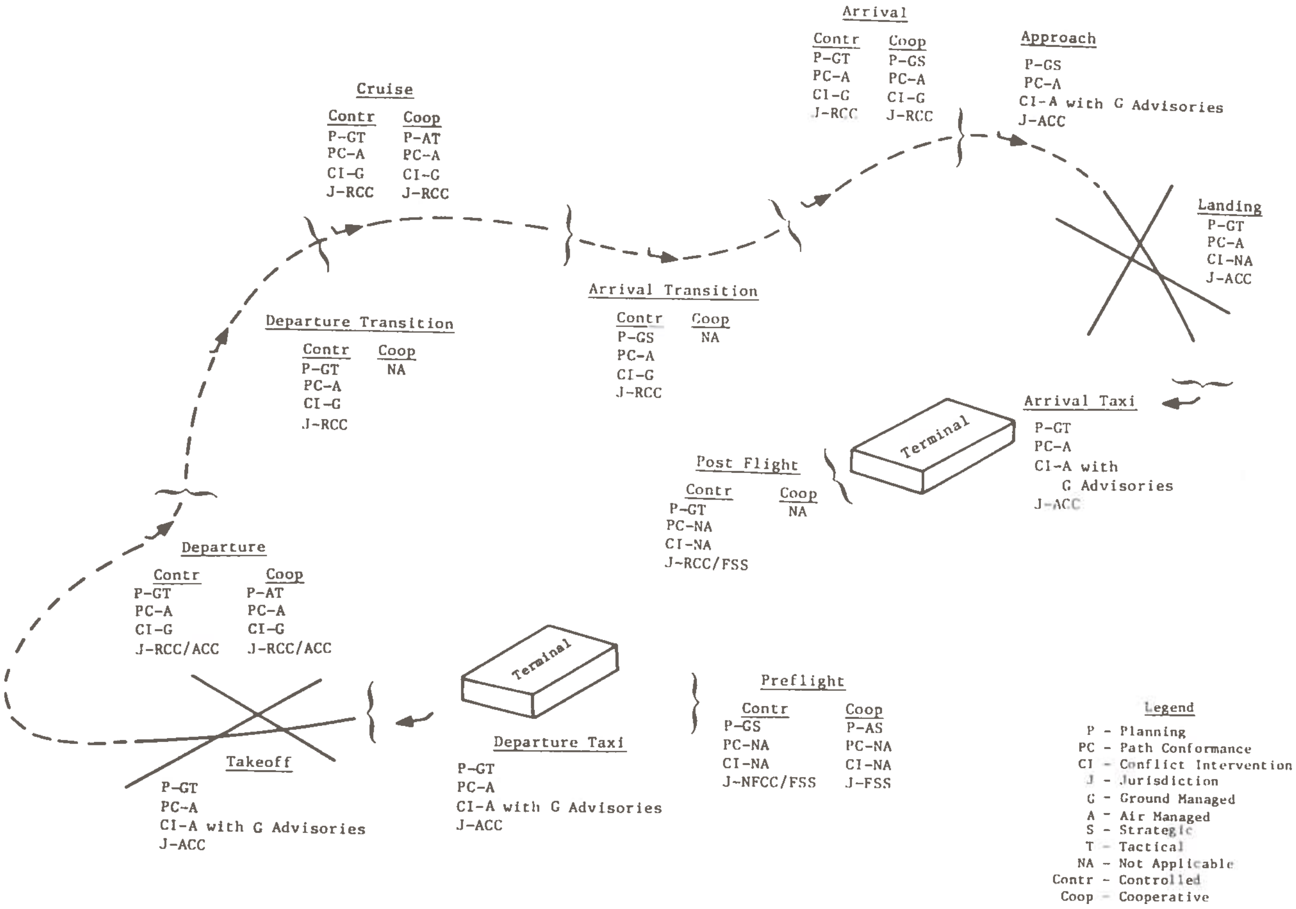


Figure 1.2-12. Control Concept, Mixed Airspace, Secondary and Feeder Airports with Control Towers

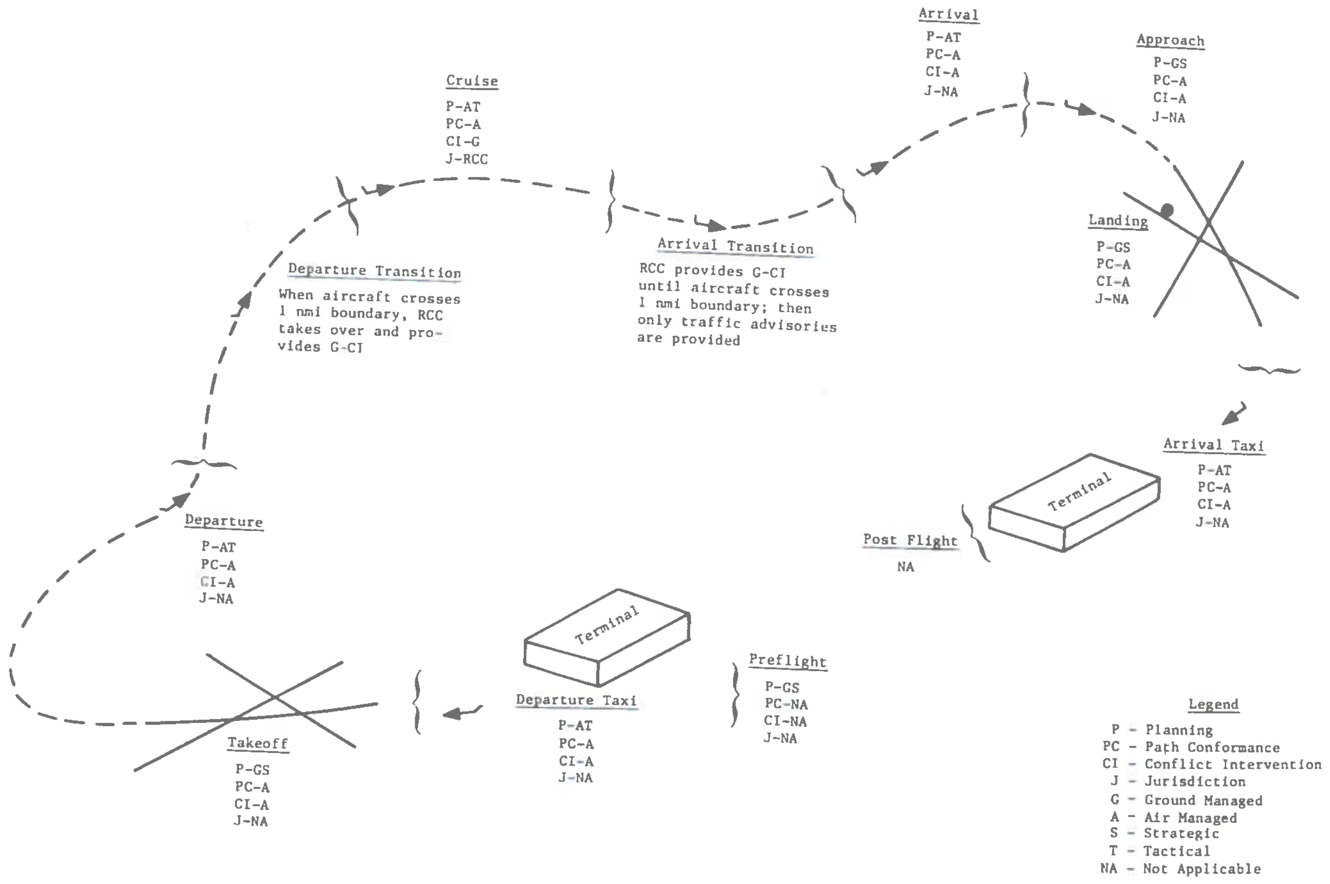


Figure 1.2-13. Control Concept, Cooperative Aircraft Operating From Airports Without Control Tower

Controlled aircraft operating in mixed airspace (Table 1.2-5 and Fig. 1.2-12) 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. When 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 air managed tactical planning. Inside the ACC, controlled and cooperative aircraft are treated alike.

For those aircraft operating from airports without control towers (Table 1.2-6 and Fig. 1.2-4), established traffic patterns are used, hence the ground managed strategic planning. All other operations are the responsibility of the pilot. Separation assurance is provided when the aircraft crosses the airport boundary.

1.3 Automation Philosophy

1.3.1 Automation Offers Potential For Greatest Cost Savings

A significant cost factor in the operation and maintenance of the present and proposed air traffic control systems is salaries and benefits for O&M personnel. The number of personnel required is tied closely to user demand. As demand increases, the number of controllers increases, thus raising the system O&M costs. For the purpose of developing cost estimates for both SAATMS and GAATMS, TSC has directed that an automation level which results in controller productivity of 40 aircraft per man be used (see Volume VII). However, the SAATMS described in Volumes II and III has the potential for a higher level of automation which would result in significantly lower O&M costs. The automation philosophy underlying the hypothesis is predicated upon not employing personnel in the demand-sensitive jobs of enroute and terminal controllers. With this automation philosophy, increases in demand would not result in proportional increases in the number of controllers required.

The means by which SAATMS would operate under this automation philosophy is presented in this section. The potential cost savings resulting from employment of this automation philosophy is presented in Volume VII.

It is recognized that the following discussion represents a radical departure from today's operation of the air traffic control system. Problems such as user confidence, acceptance by the controller community, and retraining of controllers would have to be addressed in addition to the technical problems of making the automation work. These problems would all be addressed as part of the RDT&E program (See Volume VI) where the feasibility and practicality of the automation philosophy would be established.

While the automation philosophy presented here represents a radical departure from the way humans are employed in today's system, it is not appreciably different from any system philosophy that can meet the ground rule of a 40 aircraft per man controller productivity level. In today's system, enroute and terminal controllers handle on the average four or five aircraft at a time. Peak loading is in the neighborhood of 10 aircraft at one time with the limit of human endurance appearing to be around 13 aircraft. If human controller productivity is to be increased to 40 aircraft per controller, it is clear that functions such as conflict prediction, metering and spacing, and aircraft sequencing must be automated. This is accomplished in the SAATMS automation philosophy. The SAATMS philosophy goes one step further, however, by relieving the controller of the responsibility of ensuring aircraft path conformance and hence relieving him of the burden of primary situation monitoring. This latter step appears to be a logical extension of the automation philosophy dictated by the 40 aircraft per man controller productivity ground rule. The SAATMS is able to take this additional step due to the greater efficiency resulting from universal surveillance coverage, digital communications, and centralization of control centers. These features as they apply to the automation philosophy are discussed in the following sections.

1.3.2 Digital Communications and Universal Surveillance Underlie SAATMS Automation Philosophy

The primary characteristics of the SAATMS that determine the type of automation to be employed are digital communications, universal CONUS-wide surveillance on all users at all altitudes, and high surveillance and navigation accuracy. These characteristics make it possible to automatically collect and process data on all users at high data rates. Because of the use of digital communications, it is also feasible for computers on the ground to communicate directly with airborne equipment to exchange information and provide commands and control. As a result of this capability, a basic SAATMS philosophy that all control functions can be automated has been developed.

From the previous section, it was seen that the primary function provided by the ground in the SAATMS operational concept is separation assurance and conflict intervention. Navigation is the responsibility of the pilot. This is particularly true in the enroute regions where traffic density is not appreciably high and where the traffic situation changes relatively slowly. The SAATMS surveillance subsystem continually monitors the position and velocity of all aircraft every 8 sec and predicts the location of each aircraft for the next sample. The algorithm also includes conflict prediction. When conflicts are predicted, an intervention algorithm is employed to compute a safe solution to the problem (see Volume III). The results of this computation are automatically sent via the digital link to the conflicting aircraft in the form of intervention commands. The surveillance subsystem continues to monitor the aircraft to assure that they respond correctly to these commands. No human controller is needed for this process unless the aircraft do not respond correctly.

In this approach, therefore, all traffic monitoring functions, especially those related to safety, are automated. Man is used to provide information where canned digital messages will not suffice, to react to unusual situations, and to provide emergency services. Man is also needed to program, check out, and operate the computers, to perform test and maintenance functions, and to provide basic supervisory and planning functions.

Automation in the SAATMS takes place in three basic functional jurisdictions. These are the RCC, the ACC, and the planning functions associated with the FSS and CCC. An automation philosophy for each has been developed.

1.3.3 No Manual Tasks in the RCC for Primary Control of Aircraft

The functions performed at the RCC are concerned with safety and terminal transition. The latter includes metering and spacing, conflict intervention, and boundary protection. In all cases, the control functions are automated. This contrasts with the present system where enroute safety and path conformance functions are performed manually by controllers in the ARTCC, and approach and departure controllers manually perform sequencing and spacing in the TRACONS. Automation aids in the present system are in the area of bookkeeping rather than control. This includes ARTS for the terminals and NAS Stage A for the ARTCC. Given the SAATMS operational concept of air managed conformance and ground managed safety, there are three possibilities for utilizing man in performing the ground managed safety function.

Case 1 is where the man is primarily responsible for keeping aircraft separated. He is backed up by automation. This is similar to the present day system where controllers monitor and control all aircraft in their sector. Automation assists the controller in determining if a conflict is about to occur but intervention commands are issued only by the controller, not the automation equipment. This approach is undesirable since, in the SAATMS, the controller is not actively engaged in path conformance as he is in the present system. His task, therefore, becomes more passive in nature as he must monitor a display and intervene only when a conflict occurs. Boredom resulting from such a "vigilance" task will increase the probability that the controller will not detect all conflicts thus reducing system safety. Under these circumstances, the computer is likely to detect the conflict before the controller. Therefore, the controller should be backing up the computer rather than the other way around.

Case 2 is where the computer is prime with the man serving as a backup. As stated above, this approach is likely to result in greater safety since the machine is able to respond to conflict situations more rapidly and reliably than man. In this case, the machine would not only be primarily responsible for detecting conflicts, it would also generate the conflict intervention commands. The question is, will man perform better than in the first case. In Case 1, man was primarily responsible for aircraft separation. Even though his task was one of passive monitoring until a conflict occurred, his motivation level was likely to be quite high due to the fact that he was primarily responsible. Making man a backup to the computer does not change the nature of his task but will probably hinder his ability to perform since his motivation level will likely be lower. At best, he will probably restrict his activities to monitoring the status of the automation equipment, a job that can also be automated. Therefore, this case is a poorer utilization of man than Case 1.

From this discussion, it can be concluded that it is a poor technique to utilize a man as either prime or backup safety controller if he is not also going to be directly involved in the control of the aircraft's flight path. For this reason, neither of the above is efficient for the SAATMS.

Case 3 is where automated conflict intervention is used and man is given a totally different role. This is the SAATMS philosophy. A technique for implementing the philosophy is presented in detail in Volume III. This technique must be tested and refined during the RDT&E phase.

To assure a level of safety equal to or greater than would be found with man in the loop, a high reliability fail-safe automation technique must be used. That is, sufficient safety checks and redundancy must be built into the automation to reduce the probability of error; and software fallibility must result in unnecessary interventions (false positives) rather than missed conflicts (although in an operational system, this must be kept at an absolute minimum to insure user confidence). What this means is that the computer program must be written in such a way that one part of the program will check another. For example, conflict intervention may be based upon a separation standard algorithm, but a separate position proximity algorithm would be employed as a check. If the separation criterion is violated in either computation, an intervention will occur.

The role that man is given in this automated system is to handle unusual situations, emergencies, and random (non-canned) voice communications. The analysis of how many men are required to perform these functions is based upon the frequency of event occurrence rather than demand level. An example of the frequency of event occurence is shown in Tables 2.3-4 and 2.3-5 of Volume II.

In the RCC, man would be required to provide flow advisories, traffic advisories, flight plan modifications and to handle requests from cooperative aircraft to fly in controlled airspace. Unusual situations arise for a number of reasons, such as

(1) When aircraft do not respond to conflict intervention or boundary intrusion commands

(2) Clearances and metering and spacing commands must be given by voice due to a failure in the digital links

(3) Unexpected loss of a surveillance signal

Communications between controllers in the RCC and aircraft include the following:

(1) Flow advisories from the RCC to specific aircraft - These consist of information transmitted to the aircraft concerning predicted delays and available alternates.

(2) Requests for advisories from aircraft to the RCC - These consist of voice requests by pilots for information concerning traffic, weather, and predicted delays.

(3) Traffic advisories from the RCC to specific aircraft - These consist of information on nearby aircraft and include aircraft type, location, and direction of flight. While these messages could be given automatically over the digital link to aircraft equipped with a situation display, it is assumed that the bulk of the aircraft will not be so equipped. Therefore, most of these advisories will be issued manually over the voice link. The need for the advisory will be determined automatically when two aircraft are found to occupy a common cell (see Volume III). The controller will be alerted by the system about the need for issuing the advisory and will print the necessary information on the controller's display. The controller did not monitor the situation prior to being alerted by the system nor did he make the initial decision as to the need for issuing the advisory.

(4) Flight plan modification request from controlled aircraft to the RCC - These consist of route change and/or altitude change requests. Responses to these requests are either in the form of flow advisories already covered under item (1) or discrete clearance messages issued over the digital link. It is assumed that the content of the requests made by the pilots will be sufficiently random as to make it impractical to send canned digital messages. Therefore, the requests will be by voice with a human being to receive the message and initiate a response.

(5) Cooperative aircraft request clearance to fly in controlled airspace - These messages are from cooperative aircraft to the RCC and consist of requests to cross controlled airspace. Such requests can occur at any time and the system will attempt to accommodate each aircraft if possible. However, requests will only be granted if there is room for the aircraft which implies that peak hours are not in effect.

(6) Emergency messages from aircraft to the RCC - These consist of Mayday, lost, and assistance needed messages. A human controller would be assigned to assist an aircraft in distress. He would remain in contact with the aircraft continually until the emergency is resolved. Should a given emergency occupy a controller for an inordinate length of time, supervisory or backup personnel can be employed to handle new emergencies that may occur.

(7) Manual handoffs from the RCC to aircraft - These consist of voice commands to contact an adjacent RCC or ACC over a specified frequency. This is a backup to the automatic mode. The procedure for performing a handoff is described in Section 1.2.4.4 of this volume.

(8) Boundary and conflict intervention backup commands from the RCC to the aircraft - The need for a human to issue these commands occurs when aircraft do not respond to the automated intervention commands. As was the case with the traffic advisories, the human would be alerted by the automation equipment to the need to issue the command. The situation monitoring would be accomplished by the system, not the man.

(9) Clearance backup messages from the RCC to the aircraft - These occur in the event of digital communications avionics failures. Avionic status messages are periodically sent, on request, from the aircraft to the RCC via the automated digital link. When a digital link failure is detected, the human is alerted and he takes over.

(10) Metering and sequencing backup messages from the RCC to the aircraft - These also occur when there is a digital communications failure. The comments under item (9) are applicable to this item.

In addition to controller personnel, the RCC's require computer operators, programmers, maintenance personnel, and administrative staff. These people support the operation of the ATM system, but are not directly involved in its functioning. For this reason, the SAATMS automation philosophy has little impact on the manning requirements for these support functions.

1.3.4 Centralization of Control Centers Maximizes Automation Flexibility

Since man's role in the SAATMS will differ from that in today's system and his primary responsibility will be to react to unusual and emergency situations rather than act as a primary controller, it follows that greater efficiency will be obtained if the major control centers are centralized rather than distributed into sectors as in today's system. A manpower pool will be required to perform required functions when unusual situations arise. However, there is no way of predicting where or when these situations will occur. In addition, traffic density, as defined by busy hours, shifts from place to place during a 24-hour period. Therefore, on a CONUS-wide basis, a fairly constant workload will exist; while on a sector basis, activity peaks and valleys will occur. If the entire manpower pool is centralized, advantage can be taken of the relatively constant CONUS-wide activity level with resulting manpower efficiency. The same is true for programming, operating, and maintaining the automation equipment. The number of personnel required for a centralized system would be less than the sum required for distributed sectors. In addition, the productivity of each man in the centralized center is likely to be higher because of the more level workload.

1.3.5 Manpower Level in ACC Not Demand-Sensitive

The functions performed at the ACC include assignment of runways and taxi routes, providing clearances to taxi, takeoff, and land, waving off arriving traffic, and providing traffic advisories. In the present system, these functions are performed manually by ground and local controllers. Usually, one local controller will service all traffic on a pair of runways while one or two ground controllers will handle all airport ground traffic. The number of men required at the airport is dependent upon the number of active runways rather than the demand at the airport. In other words, manpower level is not demand-sensitive. This can be seen from the fact that many airports are currently operating at saturation capacity with this type of manpower allocation.

If demand at these airports increases, either new runways have to be added or traffic delays must be tolerated. If new runways are added, manpower requirements at the airport would increase accordingly. If runways are not added, an increase in manpower will not reduce delays resulting from increased demand. Similarly, increased automation will not appreciably affect the capacity of high density airports. In fact, increased automation may reduce capacity due to the use of larger and less flexible separation standards than are currently available under today's VFR. In today's manual system, when VMC prevails, pilots are permitted to operate under VFR under reduced separation without intervention by the system. Under these conditions, a runway capacity in excess of 100 operations per hour is not uncommon.

Automation developments at airports are more in the nature of improving surveillance and taking the bookkeeping load off of the controller. It is expected that the human controllers will be required to supervise the traffic pattern and movement of aircraft on the ground. This is due to the fact that a large variety of aircraft types, pilots with varying proficiency, and a large variety of environmental conditions exist at each airport. These conditions interact to provide an almost infinite number of combinations which in turn require an extensive automation program.

1.3.6 Automated Flight Service Stations Tie Pilots to Planning Computers

Flow planning in the SAATMS will be performed at the CCC. Tasks associated with the function consist largely of constructing and keeping current a data bank of scheduled traffic, weather, and airport conditions. Flow planning is an information service for use by pilots in planning their flights. No control functions are performed by flow planning. See Volume III for a detailed description of the flow control process.

1.3.7 The Flow Planning Function is Largely Automated in the CCC

An automated Flight Service Station (FSS) terminal consisting of a keyboard and alpha-numeric display is used by the pilot to request information from the CCC to assist him in planning his flight. He does this by entering his inquiry into the FSS keyboard. The request is sent in digital form, via satellite, to the CCC where it is automatically routed to the planning computer. The pertinent data are pulled out of computer memory and sent via satellite to the FSS display. The pilot enters his flight plan on the FSS keyboard which transmits it to the computer. The computer acknowledges the plan by feeding it back on the display and then updates its memory with the new information.

All communications involved in the planning function can be via digital data link with the exceptions of Pilot Reports (PIREPS) on the weather. The data flow out of the CCC is largely canned and initiated in most cases by either requests from the FSS or as programmed events. Therefore, a human is not required in the CCC to initiate planning messages.

Communications received from the RCC, ACC, and NWS will also be in digital format. They will consist of status and weather information plus flight plan revisions. These messages constitute updates to existing data files and as such can be entered directly into computer memory without the need for human intervention.

The only voice information being received by the CCC planning center is PIREPS. These reports would automatically be recorded on tape. At periodic intervals, say each hour, a human stenographer/keypunch operator would be required to extract the information from the tapes and enter it into the planning computers to update the weather data bank. It is possible that even this task could be automated. Considerable research is being conducted on voice actuated control systems. The 1973 state of the art includes machines that can respond to a vocabulary of approximately 50 words. This vocabulary is likely to expand by 1995. If highly stylized PIREPS are used to limit the format to words contained in the machine vocabulary, these voice reports could automatically be fed into the computer to keep the weather data bank up-to-date.

1.4 How the SAATMS Operates

To demonstrate how the SAATMS operates, two scenarios have been selected for presentation. These scenarios describe how a controlled aircarrier and a cooperative aircraft on cross country flights use the system. Selected situations, although not typical of a SAATMS flight, have been included to present a better picture of the system operation.

1.4.1 Controlled Aircraft

A representative controlled flight would be TWA Flight No. TW6007, which originates at Kennedy International Airport (JFK), New York City, and flies non-stop to Los Angeles International Airport (LAX) on a daily basis. It departs JFK at 11:00 AM local time and is due to arrive at LAX at 2:00 PM local time. The route of the flight is illustrated in Fig. 1.4-1. The route to be used in 1995 between New York City and Los Angeles is not much different from the 1973 routes in spite of the use of RNAV. The main difference is that several aircraft in 1995 will be able to fly co-altitude, parallel offset paths without the need for converging on VOR stations.

Flight No. TW6007 is flown by a professional crew in a Boeing 7X7. Its operating characteristics include cruise speeds of 450 to 500 knots, a service ceiling of 45,000 ft MSL, and gross weight up to 293,000 lb. It is designed to carry passengers and cargo over distances generally in excess of 1500 nmi. It carries a full complement of avionics required for flight in controlled airspace. This includes navigation, communication, surveillance, instrument assisted landings (MLS), gyro instruments for IMC operations, and autopilot control aids as required for this class aircraft. Communications capability includes (1) company communications through the Aeronautical Radio, Inc. (ARINC), loop, (2) two-way digital L-band communications, and (3) two-way L-band voice. The digital loop includes the aircraft identification for surveillance plus a keyboard and display for both canned and random messages.

Both the captain and first officer are pilots with over 10,000 hr in multi-engine jet aircraft and have flown this particular route many times. They hold commercial and multi-engine ratings and are rated for flight in controlled airspace. They and their aircraft are approved for Category III landings, as are the terminal airports. This crew remains proficient and current on all aspects of their particular flight, not only through daily operation but also by special training programs in the air and in elaborate ground simulators. In addition, they are given periodic physical and proficiency examinations to insure that they maintain their high level of proficiency.

1.4.1.1 Preflight - Planning and Scheduling

The preflight planning, performed by both the user and the system, is based upon the careful consideration of the aircraft capability, the avionics on board, pilot proficiencies, airport of origin and destination facilities, SAATMS rules and procedures, air route structure, and terrain features and obstructions. At TWA, flights are planned in computers located in the TWA flight dispatch office and are based upon data obtained from the NFCC and National Weather Service (NWS). The crew use data pertaining to weather and pay load to plan power settings, full consumption rate, takeoff and climb profile, and other flight procedures. Because TW6007 is a regularly scheduled flight, considerable past experience exists and much of the advanced planning is already accomplished.

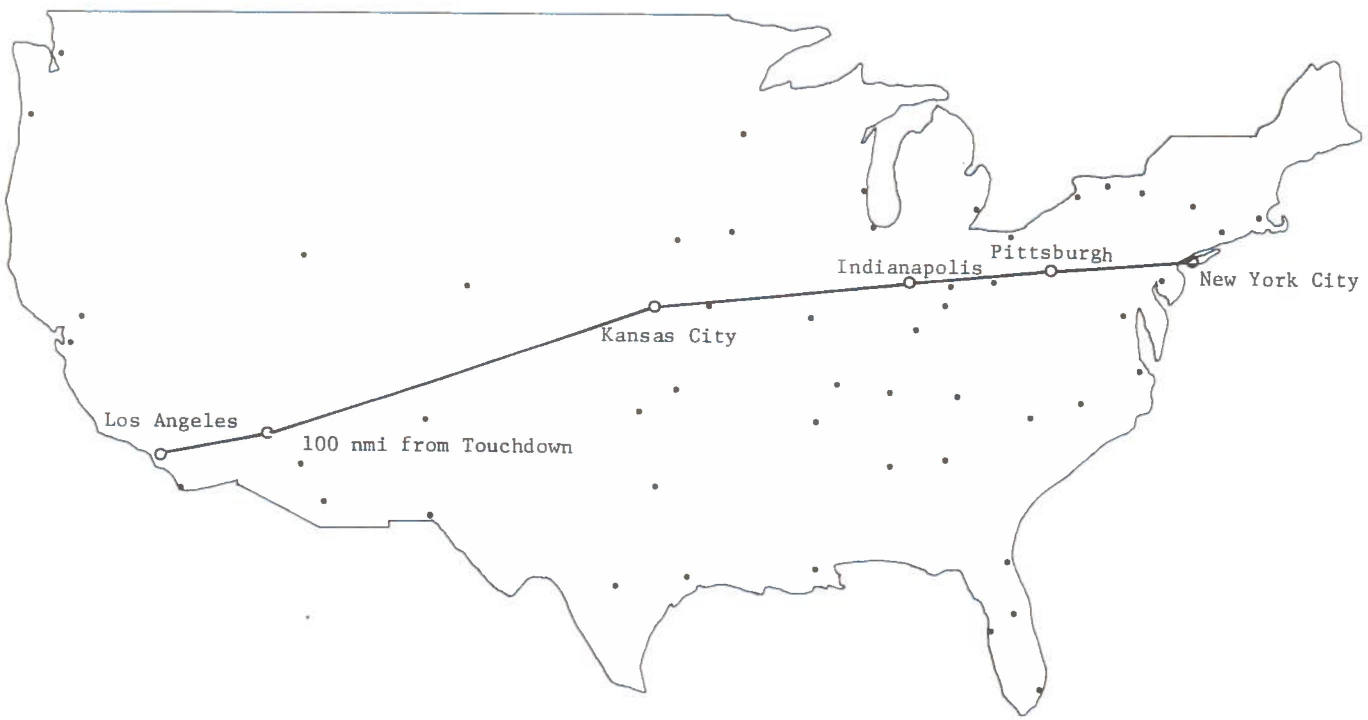


Figure 1.4-1. Route for Controlled Aircraft

Typical planning for TW6007 includes the following:

(1) General scheduling information including date, time, origin, destination, route, and aircraft cruising speed.

(2) Aircraft pay load and fuel management. The FAA requires a 45 min reserve at the destination. Added fuel is carried on-board in the event that weather conditions cause this flight to use an enroute altitude other than the optimum one of 39,000 ft MSL. The total fuel requirement is based in part on information from the NFCC which has projected possible delays due to high traffic density at LAX about 2:00 PM. Using NWS projections for LAX, the NFCC has projected instrument conditions of a 200 ft ceiling and 1 nmi visibility.

(3) Specific navigation data which include the desired JFK departure route and the enroute flight path as well as altitude. Navigation data include the latitude/longitude of the gate at JFK and specific waypoint coordinates which are entered into the navigation processor for use in generating course steering commands.

(4) Estimates are made of true air speed, ground speed, fuel remaining, time between waypoints, and total time for each leg of the flight and the total flight.

(5) Notices to airmen concerning the origin, destination, and enroute regions are studied and appropriate notations are made on the flight plan.

The flight plan is filed with the NFCC approximately 1 hr before takeoff. The NFCC compares it with other scheduled flights that have been filed and, if there are scheduled conflicts, will suggest alternate routes, altitudes, or times of arrival which the airline can accept as a revision to its flight plan.

In the present case, there is anticipated high traffic density at 39,000 ft between New York City and Indianapolis. The NFCC has suggested that TW6007 fly at 35,000 ft to Indianapolis and then climb to the desired 39,000 ft for the rest of the trip. TW6007 has accepted this suggestion and revised its flight plan accordingly. The flight plan is then filed and approved by the NFCC, after which it is disseminated to the ACC's and TWA flight watch stations such as traffic, maintenance, and crew assignment. The captain also submits an abbreviated version of the plan to the JFK ACC. This abbreviated plan informs the ACC of the intended departure time and requests clearance for a desired JFK departure.

1.4.1.2 Departure Taxi - Planning Flexibility Permits Delays to be Absorbed on the Ground

After preflighting his aircraft and boarding passengers, the captain starts the engines, automatically activating the surveillance transmitter. The system detects the aircraft's signal and acknowledges it by illuminating a light in the cockpit. Upon receipt of this light, the pilot uses the digital link to contact ground control for clearance to taxi to the active runway. Ground control uses a digital message to assign a taxi route; this route is displayed in the cockpit.

As TW6007 clears the gate area and enters the taxiway, sequencing is accomplished through digital hold/proceed transmissions from ground control. The captain uses his navigation display to make his taxi route good. The data that appear on his display are derived from a ground navigation loop that consists of taxi and runway markers that are automatically sensed by equipment on board the aircraft.

The system monitors aircraft taxi operations by means of a special ground surveillance link. The ACC receives signals from the aircraft surveillance transmitter. The signals are processed by the ACC to derive aircraft position. The data are then used to issue conflict avoidance commands when required by traffic conditions. This system also permits TW6007 to use its displays to navigate along the taxiway in IMC. This particular flight is starting out in VMC so that TW6007 is able to visually maintain proper spacing behind preceding aircraft as indicated in the clearance message. TW6007 proceeds along the taxi route until it holds short of the active runway. This completes the departure taxi phase of flight.

1.4.1.3 Takeoff

The crew of TW6007, having completed their pre-takeoff checklist, prepare for takeoff. Included is a check of the digital and voice frequency settings. The digital link is used for all primary communications with voice being used for unusual situations. The crew is satisfied with the mechanical operation of the 7X7. The pilot depresses his "request clearance for takeoff" button; the ACC will reply with a digital clearance message.

Depending upon inbound traffic on this runway, TW6007 may either be cleared into position and hold or cleared for takeoff. Any changes in departure route due to changes in conditions will also be given at this time via the digital link. Since there is no incoming traffic on this runway at this time, the ACC sends a "cleared for takeoff" message. The captain moves quickly onto the runway to begin his takeoff roll.

TW6007 did not require the use of runway guidance since there was a 200 ft ceiling and 0.5 nmi runway visual range. This provided adequate visibility for the captain to guide the aircraft down the runway. The runway guidance system was available as a cross check and, had the captain desired, it could have been fed into the autopilot for an automated takeoff.

Due to the high volume of arriving and departing traffic in the preceding hour, there was a short delay. Because of the preflight planning, however, the captain was able to take the delay at the gate, thus saving 5 min extra fuel.

Up to this point, TW6007 was under the jurisdiction of the JFK ACC. This ACC not only provided clearances and routing instructions to TW6007, it sequenced departures and interleaved arrivals and departures.

1.4.1.4 Departure

When TW6007 reaches the airport boundary, the ACC will hand over control of the aircraft to the RCC. The ACC will instruct the aircraft to switch to the RCC digital frequency. The captain can manually set in this new frequency. However, to minimize the possibility of incorrect frequencies being set in, TWA has invested in additional equipment which automatically switches frequency upon receipt of a digital command from the ground. As the aircraft crosses the ACC boundary, the RCC sends an "I've got you" message to the aircraft. The captain must respond with a digital acknowledge message. He then switches voice frequency to the RCC channel. If positive communications between the aircraft and RCC are not established, the RCC will contact the ACC and request that it contact the aircraft via voice.

The departure phase covers the period from handoff to a point where the aircraft proceeds enroute on its approved flight plan. TW6007 was cleared for a Standard Instrument Departure (SID) whose route was established to minimize environmental effects caused by noise and engine pollutants, as well as to avoid certain residential/business areas. At the same time, the route must be compatible with this heavy jet's climb performance capabilities.

The crew of flight TW6007 knows from past experience the precise SID procedures to be followed. The SID route is stored in the aircraft computer and is displayed on the navigation display in the cockpit. The aircraft makes this route good by using satellite navigation data. The captain is responsible for monitoring his aircraft position and assuring that he adheres to the route.

During the multi-stage noise abatement climb, the RCC requested a flight path deviation for path stretching purposes to avoid a conflict with other outbound traffic. The form of the digital conflict invervention message was to modify the standard 2 min turn to a 3 min turn, resulting in only a minor path stretch. The message appears on a digital communications display in the cockpit. The system continues to monitor the flight and provide conflict intervention commands when necessary. The captain, in the meantime, continues to use satellite navigation data to make the assigned SID route good. Upon reaching the navigational fix defining the exit from the SID, the captain notes his arrival time, position, and altitude. The flight then moves into the departure transition phase of flight.

1.4.1.5 Departure Transition

As the captain notes his position at the SID exit fix, he observes that, because of tail winds and the weight of the aircraft, the aircraft has not climbed as rapidly as expected. As a result, it will be necessary for him to revise the flight plan. He computes his new climb profile and digitally transmits it to the RCC along with a request for a clearance to execute this new plan. The center responds with a digital clearance message. The captain then enters the new climb profile into his navigation processor which feeds the new course into the autopilot.

The captain continues to monitor his position with respect to his programmed course using satellite navigation data. He also continues to compare fuel consumption against the flight plan to assure that adequate reserve exists in the event of contingencies. The aircraft reaches its initial cruising altitude of 35,000 ft over central Pennsylvania where the enroute flight phase begins.

1.4.1.6 Enroute

The aircraft is on autopilot with satellite navigation being used to make the planned route good. At Indianapolis, the aircraft automatically begins a climb to 39,000 ft. No communications or clearance is required for this maneuver as it is part of the approved flight plan.

Shortly before reaching St. Louis, the aircraft receives a digital message instructing it to switch to the western RCC digital communication frequency in preparation for a jurisdictional handoff. The frequency switch is automatically made and displayed to the crew. Within a minute, the western RCC contacts the aircraft informing the crew digitally that the handoff has been made. The captain depresses his acknowledge button completing the operation. He then switches voice communication to the western RCC voice frequency. As in the departure phase, the voice channel would be used in the event positive communications were not made with the receiving RCC.

When the aircraft is in the area of Kansas City, it receives a conflict intervention command. The RCC has determined that if the aircraft continues on its present course, it will come in conflict with northbound traffic flying at the same altitude. The conflict is predicted to occur in 10 min. The RCC digitally warns the aircraft of the potential conflict. The crew should digitally acknowledge the traffic advisory. If the crew were busy with other cockpit tasks when the message was sent and did not acknowledge receipt, a second traffic advisory would be sent via voice. This message should be acknowledged by voice.

A few minutes after the traffic advisory is given, the RCC sends a digital command to turn left 5 deg. The purpose of the command is to assure that the aircraft passes at a safe distance behind the northbound traffic. The captain inserts the new course into the autopilot, thereby turning the aircraft. About 90 sec later, the RCC digitally clears the aircraft to resume the planned course. The captain then depresses a mode button on his navigation panel which initiates a computation to define the shortest course that will return him to his preplanned route. When the computation is complete, the aircraft automatically turns to take up this new course.

One hundred nmi from LAX, the captain presses a request clearance button. This digitally informs the RCC that TW6007 wishes to begin its approach to LAX. This also signifies the end of the enroute phase of flight and causes the RCC to begin computing arrival instructions in preparation for transition to the arrival phase.

1.4.1.7 Arrival Transition - System Control for Metering Spacing

When the captain calls for a clearance into the LAX terminal, the RCC assigns TW6007 to an arrival slot. It does this by examining traffic on the westbound approach to LAX as well as traffic arriving from the north and south that will merge with westbound traffic about 10 nmi from touchdown. The RCC computers accomplish this task by performing metering, spacing, and merging computations as follows.

The system recognizes the request to enter the terminal zone and transmits the airport ID back to the aircraft for confirmation. After the pilot confirms the airport ID, the system then determines the airport status. This is accomplished by first computing the aircraft's estimated time of arrival at the 5 nmi approach marker using the instantaneous airport rate-of-arrival. The computation is made using the aircraft's nominal speed profile which is defined by its performance class and present load characteristics. After filling this slot based upon the aircraft's nominal speed, the computer will search for an earlier slot that the aircraft can fill without exceeding its nominal performance limits. If the nominal and earlier slots are occupied, the system then determines whether the aircraft can be path stretched to fill a later slot. If no later slot is available, the aircraft is required to be held. In any case, the system will issue either a clearance to land or a hold command. The necessary navigation data to fly the particular arrival transition flight plan will then be digitally sent to the aircraft.

For TW6007, the system determines that a 5 min delay will be required. The hold indicator illuminates along with a holding pattern identification number. The pilot simply navigates the aircraft in accordance with navigation data automatically entered into his navigation computer via the digital data link. In addition, the pilot is also informed of the estimated time to his clearance to enter the terminal arrival zone.

Five min later, the hold indicator is automatically turned off and the clearance to enter the arrival tube indicator turns on. The pilot then either engages his autopilot or manually proceeds to fly to the arrival window, which again was automatically entered into his navigation processor via the digital data link.

The output of these computations is a path for TW6007 to fly and time of arrival at waypoints during the arrival phase. The time that the aircraft should intercept the arrival path and the runway to be used are also given.

The captain navigates his aircraft according to the instructions he has received. He reduces true airspeed from 468 to 350 knots to make his time good and continues to navigate using satellite navigation data until he intercepts arrival route gamma-6 at which time he moves into the arrival phase of flight.

1.4.1.8 Arrival

When the TW6007 intercepts its arrival track, the captain compares his actual against his estimated time of arrival and notes that he is on schedule. His vertical steering bar is beginning to move off center, signalling him to begin his descent. At this point, the pilot zeroes out his steering commands and sets his thrust control. He then resets his clock to his assigned time at the approach marker.

Since the weather conditions over LAX are still poor, the captain is informed he is to use his MLS for final approach. He thus turns on the MLS and switches to the channel setting provided via the digital data link.

During all this time, the RCC is monitoring TW6007 conformance to the navigation plan provided for his safe arrival. In the event the aircraft is found outside its conformance envelope, the system provides a warning to both the pilot and a controller located in the ACC. If the aircraft continues to be outside its envelop, a waveoff is issued.

The pilot of TW6007 navigates his aircraft in conformance with his arrival flight plan. At approximately 10 nmi from touchdown, he notes that he is beginning to receive MLS data. He then compares the difference between the MLS and his satellite navigation steering errors. Noting little or no difference, he engages the MLS and feeds its steering commands into the autopilot. Had the difference between MLS and navigation steering been large, the captain would inform the RCC and ask for emergency instructions.

Just prior to reaching the 5 nmi marker, the RCC notifies the captain to switch the digital communications link to the ACC for handoff. The captain switches frequencies and is contacted by the ACC. The captain depresses his acknowledge button and then switches to the ACC voice frequency. The captain is now assured that positive communications with the ACC have been established. From this point to touchdown, the ACC will only communicate with the aircraft in the event of a mishap on the runway or if the aircraft is detected to be outside its assigned flight profile.

1.4.1.9 Approach

The captain continues flying his aircraft along a 6 deg angle of descent to the 3 nmi marker using the MLS. At the 3 nmi marker, the captain shallows his angle of descent to 3 deg and continues along this path until touchdown. During this phase, he also goes to a landing configuration by dropping his landing gear and flaps. Any deviations due to drag are detected and compensated for by increasing the power setting.

As the aircraft continues down the 3 deg approach angle, the captain continues monitoring his instruments and observes a digital "cleared to land" message. It should be noted that the approach phase from 5 nmi to touchdown is self-contained within the navigator with no other communications necessary unless a waveoff is required.

1.4.1.10 Landing

At about 1 nmi from touchdown the runway becomes visible. The captain engages the surface guidance system, flares, and touches down just beyond the numbers. While the surface guidance system keeps him rolling straight down the runway, the captain reverses thrust, deploys spoilers, and applies brakes to decelerate the aircraft. The tower has requested that the aircraft expedite its departure from the runway by taking the first high speed turnoff. The captain complies, thus completing the landing phase.

1.4.1.11 Arrival Taxi

After clearing the active runway, the captain requests a clearance to the gate assigned to him by his company dispatcher. The tower gives him a taxi course which appears on his navigation display but advises him to hold short of the adjacent runway. After a short wait, the tower clears the aircraft to cross the runway and taxi to the ramp. The captain negotiates his assigned taxi route by making reference to his navigation display in the same manner as in the departure taxi phase.

1.4.1.12 Postflight

As the captain pulls TW6007 into the gate he depresses a button on his communications panel informing the RCC that he is closing his flight plan and exiting the system. He then shuts down his engines and thanks the passengers for flying TWA, thus completing the flight.

1.4.2 Cooperative Aircraft

1.4.2.1 Description of the Flight

The cooperative scenario consists of a cross country trip from Santa Ana airport in Orange County, CA, to Freeport in the Bahamas. The trip will include excursions to New Orleans, Atlanta, and Houston. Thus, the long trip east is really represented by four shorter trips. Most of the flight will be accomplished in VMC and in mixed airspace. However, a portion of the trip will be in the Atlanta TCA. The planned flight path is shown in Fig. 1.4-2.

1.4.2.2 Aircraft/Crew Description

The flight will be performed in a private aircraft operated by the pilot-owner. The aircraft is a single engine, unpressurized, propellor driven, four place Mooney Mark 21. It cruises at 150 knots with best altitude for economy,

Figure 1.4-2. Route for Cooperative Aircraft

speed, and endurance in the range of 8,500 to 10,500 ft MSL. At these altitudes, the non-stop range and endurance with 45 min reserve are 4.5 hr and 700 nmi. The aircraft is used primarily for pleasure and is equipped for flight in cooperative airspace. It has on board surveillance, two-way digital communications, two-way voice, and VVOR.

The pilot has just received his rating for instrument landings using VVOR approaches. He is just capable of acceptable operation in IMC consisting of 700 ft AGL ceilings and visibility of 1 nmi.

1.4.2.3 Preflight

Unlike the controlled flight of TW6007 which takes place every day, this trip is a unique flight for the pilot. As a result, much advanced preparation is necessary because of unfamiliarity with the areas to be traversed, special operational procedures which differ from place to place, and the variable characteristics of the weather. The pilot performs his preliminary planning using navigation charts and grid maps of the entire United States to lay out his proposed route. This permits him to select navigational waypoints for each leg of his flight and to identify terminal control areas, cities, terrain elevations for altitude planning, and other geographical data such as airport locations and restricted areas.

Anywhere from a week to two weeks prior to flight, the pilot requests information from the Flight Service Station (FSS) so that he may choose the best possible flying conditions. The information requested consists of the following:

(1) A long-range prediction of the weather along his intended route. The pilot uses this information to select his departure date and primary route and to anticipate any significant weather conditions that might result in poor flying conditions.

(2) The location of all restricted areas and the times that the restrictions are in force. He will plot his course to avoid these areas.

(3) Special procedures in effect and other Notices to Airmen (NOTAMS). The pilot now chooses his departure time knowing that in one day he can reach Houston and the next day continue to New Orleans. The following day he may encounter some showers on the way to Atlanta, GA, but the prediction is for generally VMC weather all the way to West Palm Beach and Freeport in the Bahamas.

Further planning will include a confirmation of this long-range plan 24 hr prior to departure along with closer attention to the first leg to Houston. The pilot then enters his intended route of flight into the FSS terminal along with his estimated time of arrival at Hobby Airport in Houston, TX.

1.4.2.4 Departure Taxi

About a half hour before intended departure, the pilot interrogates the FSS for a final weather briefing. He then enters his expected departure time and requests that this flight plan be activated.

The pilot completes his preflight checklist and starts his engine, thus activating his surveillance transmitter. His signal is detected by the RCC which sets up a track file on him and sends him an "acknowledge receipt of signal" message. This message illuminates a light in the cockpit which informs the pilot that he is now in the system and can request a takeoff clearance.

The pilot depresses a button to digitally request a clearance to taxi for takeoff. Ground control responds with taxi instructions. The pilot taxis his aircraft along the assigned route to the active runway using visual checkpoints to guide him. He also keeps a sharp lookout for other aircraft or obstacles and notes any traffic advisories that may be issued by ground control. The aircraft proceeds to the runup area to complete the pre-takeoff checklist prior to requesting a takeoff clearance.

1.4.2.5 Takeoff

When the pilot is ready to take off, he depresses a button in his cockpit to send a digital "request for clearance" message. The tower responds to instruct the pilot to taxi to and hold short of runway 1R. A few seconds after an arriving aircraft lands, the tower informs the pilot to expedite his takeoff. He responds by moving quickly down the runway and straight out on the runway heading toward Riverside and the Banning Pass.

The tower clears the aircraft from the ACC jurisidction by instructing the pilot to tune to the RCC digital frequency. The RCC contacts the pilot and the pilot depresses an acknowledge button to complete the handoff. He then tunes in the RCC voice frequency, thus terminating the takeoff phase.

1.4.2.6 Departure

The pilot sets the coordinates of his first waypoint into his VVOR panel. He crosses this waypoint at 2,200 ft MSL. He then enters the coordinates of his next waypoint, turns right to a heading of 080 deg and continues to climb to 5,500 ft MSL. He holds this altitude to avoid intruding into any of the terminal control areas in the Los Angeles basin. During this phase of flight, as for the entire trip, the RCC monitors his progress and provides him with separation assurance.

1.4.2.7 Enroute

As the aircraft nears Thermal, CA, it reaches its cruising altitude of 9,500 ft MSL. The pilot then enters the coordinates of his next waypoint into his VVOR panel and proceeds toward his first refueling stop in El Paso.

After the aircraft has been airborne for some time, the VVOR display indicates some drift to the left of course. A turn of 30 deg to the right brings the aircraft back on course and a larger crab angle is adopted. Thirty min later, abeam of Blythe, a ground speed computation indicates tail winds 5 knots in excess of those predicted. The pilot calculates that he will make El Paso ahead of schedule.

The remainder of the flight is routine with the pilot inserting the coordinates of successive waypoints into his VVOR panel at the appropriate times. He continues to monitor his course and fuel and he manually recalculates his ETA at Sunland airport in El Paso as he passes each waypoint. He changes altitude on those legs that have high terrain, and he monitors the NWS frequency for updated weather briefings.

1.4.2.8 Arrival

Sunland is a feeder airport with a control tower located northwest of El Paso. It operates a left-hand traffic pattern for runway 26. There are mountains to the east and north of the field with the Mexican border to the south.

The pilot changes to the Sunland tower voice frequency when he reaches a waypoint 30 nmi west of the field and and requests a clearance to land. The Sunland tower replies with instructions that include designation of runway 26 as the active runway and assignment of a waypoint 5 nmi west of the field. He inserts the waypoint coordinates into his VVOR panel. He then flies directly to this point, descending so that his altitude will be 1,500 AGL. Upon reaching this waypoint, the RCC digitally instructs the pilot to tune to the ACC digital frequency. He is then contacted digitally by the ACC and he acknowledges this message by depressing a button in his cockpit. He visually acquires the field and descends to 1,000 AGL as he enters the downwind leg. If IMC prevailed, he would have entered the runway threshold coordinates into his VVOR panel at this time in preparation for an instrument approach. He then lowers gear and flaps, adjusts speed and trim, and then turns final.

1.4.2.9 Landing

The tower provides a "clear to land" message which the pilot acknowledges by making a routine touchdown. He exits from the runway at the first available turnoff.

1.4.2.10 Arrival Taxi

The pilot contacts ground control by voice and requests taxi instructions to the transient tiedown area for the purpose of refueling. Instructions are given which the pilot follows in the same manner as his departure taxi from Santa Ana. The tower also informs him of the frequency he can use to contact the refueling truck. Upon reaching the tiedown area, he informs the RCC of his intention to exit the system and then shuts off his motor.

While his aircraft is being refueled, the pilot finds an FSS terminal which he interrogates for up-to-date information on his next leg to Houston. He also enters his estimated departure time for this leg.

1.4.2.11 Houston and New Orleans Legs

The next two legs of the flight are identical to the Santa Ana/El Paso leg. The aircraft lands at Hobby airport in Houston and Lakefront airport in New Orleans. Both are secondary airports serving a mixture of GA and aircarrier traffic. Prior to arriving in New Orleans, the aircraft is handed off from the western to the eastern RCC.

1.4.2.12 Atlanta Leg

The pilot makes plans to land at Hartsfield-Atlanta International airport. This is a primary aircarrier airport and the pilot knows that he will not be permitted to land during busy hours. Accordingly, he plans to depart Lakefront airport in New Orleans at 5:00 PM CST. Flying time to Atlanta is 3 hr so he estimates arrival at 9:00 PM EST or a full hour past the published busy hour. Accordingly, he files his flight plan.

The flight from New Orleans to Atlanta is similar to the other legs except that there are low clouds and rain along the route. Since there are no significant terrain elevations along the route, the pilot is able to cruise at 4,000 ft MSL. Over Tuskegee, AL, 100 nmi from Hartsfield, the pilot calls in requesting a clearance into the TCA for landing. The RCC replies by giving him a vector to Fairburn, GA, located 8 nmi southwest of Hartsfield. The message further instructs the pilot to maintain speed and altitude and arrive over Fairburn in 37 min.

The pilot sets the Fairburn coordinates into his VVOR panel and proceeds to that waypoint. Upon reaching Fairburn, he is instructed to turn left to a heading of 23 deg, enter the coordinates for the runway 2L threshold into his VVOR panel, and begin his descent to runway 2L. He is then handed off to the Hartsfield ACC and completes his landing and taxi under the direction of the Hartsfield tower.

1.4.2.13 West Palm Beach and Freeport Legs

The pilot departs from Atlanta in midmorning to avoid the early morning busy hour. His departure cruise and landing at Palm Beach International airport are similar to previous legs of the trip.

After landing at Palm Beach International, a flight plan is filed for passage through the Air Defense Identification Zone (ADIZ), giving the time of penetration 12 nmi offshore.

The landing at Freeport is accomplished via straight-in approach with the waypoint established at the head of the runway for a normal VVOR approach and landing.

1.5 References

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2. QUALITATIVE ASSESSMENTS - NONMEASURABLE VALUES

The quantitative system evaluation measures (capacity, safety, delay, and cost) are based upon measurable aspects of subsystem performance and assumptions such as expected demand and cost factors. To fully evaluate the SAATMS, however, a number of factors that cannot be easily quantified must also be taken into account. These factors are discussed in this section.

The qualitative assessment of the SAATMS is concerned with three main issues. The first is assurances that the system can readily be built as defined. This issue is discussed on two levels: (1) the technical risk, which is discussed in Section 2.1, and is concerned with the status of the technology required for implementing each item in the RDT&E plan and (2) the ease with which the SAATMS can transition from the existing system in 1982; this is discussed in Section 2.2.

The second main issue is concerned with what happens to the system after it is built and conditions change from what was assumed during the development stage. Of concern here is growth potential and operational flexibility. Growth potential is discussed in Section 2.3. Growth potential itself has two levels. First, the effect of demand increases on the airport measurables, i.e., capacity, safety, and delay. Second, the effect of demand increases on the satellite links, i.e., multi-access noise and channel capacity. Excess capacity both at the airport and in the links are measures of growth potential. Operational flexibility is discussed in Section 2.4 which describes the special features of the SAATMS that lead to flexibility in responding to changing conditions. Included is a discussion of how the system adapts to changes in traffic density and to special requests; such as cooperative aircraft wishing to fly in controlled airspace. Also included is a discussion of how the airspace structure and rules and procedures change due to changes in weather or system failures.

The third main issue is system vulnerability. The vulnerability of the satellite system to intentional jamming is discussed in Section 2.5, while Section 2.6 is concerned with vulnerability to natural disasters. Here emphasis is placed on how centers are backups for each other and how the data mobility features of the SAATMS permit the system to operate in spite of the loss of a major control element.

2.1 Technical Risk - SAATMS Requires No Technological Breakthroughs

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

Thus, the risk within 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 triodes). 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.

The potential of the SAATMS design lies in the benefits offered the user. These can be categorized into three areas:

(1) Capacity and Safety

(2) Cost

(3) Operational

Capacity and safety benefits are realized from the high accuracies obtainable from the SAATMS surveillance and navigation subsystems. Cost benefits can be obtained from improved safety, which yields a higher automation potential, and the replacement of present system mechanization with more efficient techniques. Operational benefits can be obtained from the fail operational aspects of SAATMS as well as the increased freedom and user capabilities. A listing of the benefits obtainable from the SAATMS, the features of the SAATMS relating to those benefits, and their relationship to the proposed R&D activities is shown in Table 2.1-1.

By and large, the benefits and features obtainable from 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.

A more detailed listing of the SAATMS components and techniques and their present status and impact on the SAATMS concept is illustrated in Table 2.1-2. While none of the items are presently available as equipments, the technology for their implementation is, in most cases, either here today, in development, or currently under investigation. In almost all cases, a backup technology is available, which, although non-optimum, will achieve the intended purpose. This is true even in the area of automation where TSC/FAA is currently funding large efforts to improve controller productivity, through ARTS-III and NAS-A. By the 1990's, an appreciable portion of the controller's task should be automated.

Aircraft antennas of the types required for SAATMS are essentially available today. For example, omnidirectional L-band ATCRBS and TACAN aircraft antennas have been operational at 1090 MHz for some time. Airborne CAS antennas operating at 1500-1600 MHz have been used for CAS flight tests. Similarly, airborne antennas operating in the 1500 MHz band with both patterns and gains similar to that required for the SAATMS have been used during system flight tests in connection with the Defense Navigation Satellite System (DNSS) ground simulation program at Holoman Air Force Base.

Table 2.1-1. Benefits and Features of SAATMS

Benefits	System Features	R&D Associated Activities
Capacity and Safety	High navigation and surveillance accuracies	Satellite surveillance and navigation waveform
	Range independent accuracies	Satellites for surveillance and navigation
	Precision airport surveillance and navigation	Signal waveform
	Adaptive surveillance rates	Unique aircraft ID
	Down to ground coverages	Satellite surveillance and navigation
	Remote area coverages	Satellite surveillance and navigation
	Automated metering and spacing	Metering and spacing algorithms
	Independent altitude data	Satellite navigation and surveillance
	All aircraft being surveyed	Avionics transmitter
Cost	Virtual VOR (VVOR)	VVOR algorithm
	Integrated avionics	Signal waveform
	Low gain aircraft antennas	Signal waveform
	Modular avionics	Signal waveform
	Reduced requirements for MLS	High navigation and surveillance accuracy
	Low cost airport surveillance	Signal waveform
	Centralized facilities	Satellites
	High automation potential; reduced controller workload	High surveillance and navigation accuracy leading to fewer conflicts

Table 2.1-1. (continued)

Benefits	System Features	R&D Associated Activities
Operational	Voice and digital communications	Integrated avionics
	Identical equipment for CONUS and Oceanic	Satellites
	Fail operational	Satellites
	Fail Safe	Satellites
	Fail Soft	Satellites
	All aircraft with RNAV capability	VVOR algorithm
	Growth to 1,000,000 users	Signal waveform
	Freedom of flight	Operational concept

Table 2.1-2. Technology Status for SAATMS Components and Techniques

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	X					
Aircraft Processor	X							
Satellite Transmitter			X	X			X	
Satellite Receiver		X	X					
Ground Signal Processor			X					
Signal Waveform			X					
Surveillance Software			X	X				
Navigation Software			X					
Automation Software		X		X	X	X		
Surface Guidance Sensor			X	X			X	X
Techniques								
Satellite Surveillance				X			X	
Satellite Navigation			X					
Satellite Communications	X							
Surface Guidance				X				X
Operational Concepts					X			X

The feasibility of receivers using analog matched filter (AMF) surface acoustic wave delay lines for processing pseudo-noise bi-phase modulated waveforms has been demonstrated in a number of programs, including field tests on the U.S. Army RADTS program.

Aircraft transmitters generating 2 kw of peak power at L-band have been operational in airborne TACAN equipment for some time. Most recently, ceramic planar triodes have been used in these equipments. High power solid-state transmitters using a bank of several transistors in parallel have been designed and their feasibility has been demonstrated. Intensive development of transmitters of this type is currently in progress. Light weight, low cost aircraft processors are available in 1973 from several manufacturers. For example, digital area navigation processors for both civil and military applications have been produced. These include VOR/DME, RNAV, Omega-inertial, and Loran-inertial processors having 8000 to 16,000 16-bit memories and processing speeds of a few microseconds.

Satellite transmitters having the required power outputs, efficiency, and reliability are currently under investigation. An alternate technology exists in the area of dual ceramic triode or TWT applications. Satellite receivers are currently in development in connection with a number of satellite communication and navigation systems, including ATS-F, Aerosat, and DNSS.

The feasibility of the SAATMS waveforms and the ground signal processing hardware has been demonstrated in connection with a number of spread spectrum ranging systems, such as the Autonetics N58 system which was tested by the U.S. Army in 1973. The basic surveillance and navigation equations are well understood and the feasibility of the required software has been demonstrated through use of simulation programs.

Some of the SAATMS related automation software is currently under development in connection with the Upgraded Third Generation ATC program and the TRW Automation Study. However, many aspects related to system automation are currently not being investigated (e.g., CCC/RCC backup operation and VVOR). These are considered vital to the ultimate success of the SAATMS.

The feasibility of the infrared surface guidance sensors has been demonstrated in connection with missile guidance research and development programs at Rockwell International.

The satellite surveillance and navigation techniques have been and continue to be under investigation. Several major experimental programs are currently planned for the immediate future, which will serve as feasibility demonstrations of these techniques. These experimental programs include the ATS-F, Aerosat, and Defense Navigation Satellite Demonstration Programs.

Satellite communication equipment has been operational for several years, for both civil and military applications.

Several surface guidance techniques are currently under investigation by the Transportation Systems Center and several industrial organizations; these techniques have a relative minor impact on the SAATMS development schedule. A number of alternate techniques exist, which promise to satisfy the requirements, including inductive loop systems, infrared sensors, trilateration systems, and high resolution radar.

The operational concepts proposed for the SAATMS are presently being investigated by both government and industrial organizations. These are not likely to be pacing items in the SAATMS development program.

In short, the technology required for the SAATMS is fully compatible with the present state of the art, and projections as a result of employing this technology are for decreased user system costs and increased system reliability.

2.2 Ease of Transition

A smooth transition from the in-being system to the SAATMS is facilitated by the use of existing ATC facilities with common control jurisdictions while the functions of the two-systems are operating side-by-side. The SAATMS functional automation is similar to that used in the in-being system. The operational concepts of the two systems are very similar, so that problems with regard to user operations are avoided. The integrated satellite derived functions of the SAATMS make it possible to provide CONUS-wide coverage for surveillance, communication, and navigation at the time of initial implementation of the system. Ease of transition for the low cost user is achieved by means of a modular approach to the avionics equipment. This approach enables the user to equip his aircraft with certain SAATMS functions on an incremental basis, thereby reducing the initial avionics acquisition cost. Landing and airport operations in SAATMS are essentially the same as those in the in-being system, except that, during the transition period, an increasing number of control tower airports will be ACC-equipped, thus providing increased safety through airspace and surface surveillance; however, this is achieved without a major change in user operation.

2.2.1 Parallel Operation of Systems with Common Control Centers

During the eight years of Phase I of the transition, the functional ground elements of the two systems will operate fully in parallel, but the control of all aircraft will be exercised by common control centers, namely the in-being ARTCC's and TRACON's. These centers will receive the surveillance data on differently equipped aircraft from different sensors (ATCRBS/DABS vs CCC), but all control intervention messages to all aircraft within a region will originate from the same, common control center. Hence, users will continue to communicate with the same ATC centers during the entire Phase I period as they have previously. The inherent data mobility of the SAATMS, through its use of satellite relay ground-ground communications, facilitates this transfer of surveillance data from the initial SAATMS site (CCC) to the cognizant ARTCC or TRACON.

Current plans for the in-being system include the automation of many of the same functions which will be automated in the SAATMS, such as clearance processing, metering, spacing, conflict prediction, and conflict resolution. For example, in the in-being system, conflict resolution commands to DABS-equipped users will be via the IPC or ATC data link, which is completely equivalent to the SAATMS digital data link commands. Therefore, although the surveillance data may originate from a different source, the control commands received by the aircraft will be of the same type, eliminating any transition problems to the user.

Toward the end of Phase I and during Phase II of the transition, the control jurisdictions for the regions will be transferred from the ARTCC's to the RCC's by stages, including the transfer of some of the controller personnel from the original ATC facilities to the RCC facilities. This process will ease the transition of the ground based control functions of the system.

2.2.2 Similar Operational Concepts Facilitate Evolutionary Transition

The airspace structure and control concepts used in the SAATMS are very similar to those used in the in-being system. Positively controlled, mixed, and uncontrolled regions are used in both systems, although the SAATMS includes a fourth airspace region for cooperative (surveillance-equipped) users. Both systems employ ground managed conflict intervention in all of the airspace regions and primarily air managed path conformance in controlled airspace. Hence, users will experience no significant change in operational procedures during the transition period.

2.2.3 Integrated Satellite Functions Provide Full Initial Coverage

Since in the SAATMS the three primary functions of surveillance, communication, and navigation are integrated and are derived from satellites, full CONUS-wide, down-to-the-ground coverage of these functions is obtained as soon as the complete satellite constellation has been launched at the beginning of Phase I of the transition. This also includes the VVOR area navigation service, since the VVOR processing will be performed by the CCC facility which will have been implemented at the beginning of Phase I. Thus, any user anywhere within CONUS can avail himself of any of the major services and functions of the system at that time. This lack of geographic restriction of the initial coverage of system functions facilitates a user's initial entry into the system and thus promotes ease of transition.

2.2.4 Modular Avionics Eases User Transition

The SAATMS avionics equipment is so designed that the various functions provided by the airborne L-band transceiver, i.e. surveillance, digital communication, VVOR, voice communication, nagivation, and air-to-air surveillance can be added on a modular basis. This feature greatly eases the transition process for a large number of GA users, since it reduces their initial acquisition cost of entering the System. Furthermore, it permits them to initially equip the aircraft with those functional modules from which they can derive the greatest benefits and which best complement the avionics functions already carried on the aircraft. For example, for users having NAV/COMM (VHF voice communication plus VOR) equipment, the acquisition of the SAATMS transmitter provides them with CONUS-wide down-to-ground surveillance. The addition of the digital communications VVOR module provides them with automated separation assurance and universal area navigation service. Therefore, the modular avionics approach will permit an early incremental transition of GA users into the SAATMS.

2.3 Growth Potential - Long Life is Designed

The usable life of an ATM system is primarily determined by the level of service supplied to the user. If the level of service is kept high, user acceptance is maintained and system lifetime is extended. The design of the System A AATMS has built-in extended lifetime.

The demand projection for the 1990 time frame forecasts approximately 360,000 users, with approximately 10 percent or 35,000 airborne instantaneously. Beyond 1995, this demand is expected to grow to 1,000,000 users with a 100,000 peak airborne count.

The user demand will affect system function and service in two ways. First, the increased demand will place increased loading on the surveillance and communication links. This results in increased noise and increased delays in message replies. Second, the increased demand places more strain on maintaining an acceptable level of capacity and safety.

The aircraft-to-ground surveillance and communication links are asynchronous; i.e., each aircraft transmits without regard to other aircraft transmissions. Increasing the loading on these links increases the multiple access noise and lowers the user Signal-to-Noise (S/N) ratio. The SAATMS concept has been designed with system growth in mind. The present system margin, after considering equipment losses, equipment aging, antenna patterns, and constellation geometries, is in excess of 10 db. With the demand growing by a factor of three, to 100,000 aircraft, the link margin is decreased by only 2.5 db.

Several techniques are available to further increase the system margin. Among these are using an additional frequency channel or using multiple antenna beams on the satellites. Either of these techniques would increase the available margin by approximately 1.4 db. The most promising technique for decreasing the multiple access noise is range ordering.

In a range ordered system, aircraft transmissions are sequenced such that no two aircraft signals overlap at any satellite receiver. This is achieved by ordering the aircraft transmission by range from the satellite. With this mechanization, a guard time need only be equal to the difference in satellite-to-aircraft ranges. This scheme is quite efficient and easily capable of handling the demand levels projected for the time frame beyond 1995. To achieve these high levels, the aircraft would be polled (addressed) from a centralized source, i.e., the RCC. After being polled, the aircraft would transmit its ID pulse triplet.

All the equipment necessary to transmit the surveillance signal is already available on-board the aircraft, i.e., a digital receiver and a surveillance transmitter. Additional software complexity would be introduced into the RCC's to enable them to do the range ordering, but no changes to user avionics is necessary.

The impact of range ordering on the aircraft surveillance S/N ratio is illustrated in Table 2.3-1 as a function of the demand. At low demand levels, the increase in signal-to-noise is small. For example, at the nominal demand of 35,000, the improvement is only 1.7 db. At the higher demand levels, the improvement is more significant, e.g., 3.8 db at 100,000 IAC. A similar, although smaller, improvement will occur in the communications channel.

Table 2.3-1. Impact of Range Ordering on Signal-to-Noise Ratio as a Function of Demand

Instantaneous Airborne Count	S/N Improvement (db)
20,000	1.1
35,000	1.7
50,000	2.3
70,000	2.9
100,000	3.8

At the lower demand levels, the increased complexity caused by the range ordering is not warranted. However, the significant improvement afforded at the higher demand levels clearly provides system improvements and prolongs system usable lifetime. The surveillance and communication links of the SAATMS are flexible and their performance is relatively insensitive to increases in demand.

2.4 Operational Flexibility - SAATMS Responds to Changing Situations

2.4.1 Low Density Operations - No Special Rules and Procedures Required

The management concept described earlier is based essentially on a high density traffic situation. To operate efficiently, the system must be adaptive to the point of relaxing restrictions in low density situations. The management concept is capable of adapting to changing density in the following manner.

The basic rules and procedures and airspace structure remain unchanged under low density conditions. Pilots are not required to learn one set of rules for high density and another for low density. Likewise, the system does not have to protect one set of boundaries during busy hours and another set during off-peak periods. The exception would be certain posted restricted areas where a specific time of the restriction, e.g., 6:00 am to midnight, is printed on the maps. Since the management concept features air managed conformance and freedom of flight under high density conditions, little change is required at low density. Conflict intervention will be less frequent due to the low density, but the system never relaxes its safety standards.

Controlled aircraft are essentially receiving a preferred routing and reservation service from the system. To provide less control due to reduced density could result in a reduction in service. What is available is a greater control tolerance. Requests for altitude and route changes would be responded to more rapidly, in low density situations. If arrival slots are open, the system might even urge an aircraft to speed up if possible to arrive early and take advantage of the opening. In the terminal, the system would permit the aircraft to use more direct routing than would be the case for standard arrival and departure routes which are used in high density situations. In most cases, however, the difference between high and low density control will be in the ability of the system to grant requests made by the pilots. If the pilot does not request a change from his his flight plan, the system will not take any action.

Cooperative aircraft will be permitted to fly into primary aircarrier airports under low density conditions. All primary airports will have an airport control zone boundary and a TCA as in the present system. No aircraft can cross that boundary without a clearance. Cooperative aircraft always have the option of contacting the RCC or ACC and requesting a clearance for the purpose of landing. If there is room, such a clearance will be given. The aircraft will then operate under control, receiving vectoring commands, if necessary, from the system. If there is not room, the aircraft will be told how much of a wait it has before it will be permitted to enter. It is the pilot's option to wait for that clearance.

A similar situation exists involving cooperative aircraft crossing controlled routes. Under normal circumstances if such an aircraft intrudes into controlled airspace, the system will intervene to return him to cooperative airspace. Under low density conditions with no other aircraft in the vicinity, the system may not intervene, thus permitting the cooperative aircraft to proceed as desired. At all times, the cooperative aircraft has the option of requesting a clearance through controlled airspace. If traffic permits, such a clearance might be given, but the aircraft would operate under some measure of control while he was in that airspace.

It should be noted that, in a sense, the system makes no distinction between high and low density. Pilots of cooperative aircraft are always free to request clearance into controlled airspace. The system will always attempt to accommodate these aircraft and will react positively to their request when there is room for them.

2.4.2 Equipment Malfunctions - Communication Backup Results in Fail Operational and Fail Safe Operation

All users are required to have both voice and digital communications. This requirement provides a fail-operational capability for controlled users and fail-safe operation for cooperative users.

If a controlled user loses two digital communication links and, hence, surveillance, he is still capable of receiving nagivation data and conforming to his flight plan, In the unlikely event the surveillance signal is lost, the system will alert a human controller who will establish voice contact with the aircraft. The aircraft will be capable of receiving metering and spacing services in terminal areas in the same manner as in the normal mode. The difference would be that the pilot would have to report his position and altitude by voice at frequent intervals. The human controller would use these verbal reports to determine if the aircraft is in fact conforming to its plan.

If the aircraft were operating in VMC, all other aircraft in the vicinity would be alerted and asked to establish visual contact with the malfunctioning aircraft. By establishing visual contact in addition to the aircraft's ability to conform to its plan, a high degree of safety will be maintained with no decrease in capacity. If the failure should occur in IMC but not during busy hours, the controller would provide for a larger separation boundary around this aircraft to maintain safety. Because less than peak density exists in this situation, no appreciable delays will result. The only time capacity and delay would be affected would be if the failure occurred in IMC and during busy hours. Even then, the effect would be a minor one, approximately a two aircraft per hour decrease in capacity for one runway.

If the controlled aircraft were to lose satellite navigation, it would substitute surveillance data by employing VVOR. While the navigation accuracy would be degraded somewhat, the total operation should be unaffected by this failure. Since surveillance is independent of navigation, a navigation failure has no effect on safety.

Cooperative aircraft have no independent navigation mode. If they lose surveillance, the system must switch to an emergency mode in an effort to safely land the aircraft. Voice communication would be used to establish contact with the aircraft. If VMC prevails, the pilot will be asked to use visual checkpoints to establish its position. The controller would use these reports to verbally guide the aircraft to a safe landing. If IMC prevails, it may be necessary to send up a rescue aircraft in an attempt to safely guide the aircraft to a landing.

2.5 Satellite Vulnerability - An Overstated Problem

The SAATMS relies on satellites for the primary functions of surveillance, communications, and navigation. There has been concern expressed about the total centralization of these basic ATM functions and the vulnerability of the satellite link to jamming. That is, can the aircraft-to-satellite link be easily exploited to such an extent that the surveillance and communication functions, CONUS-wide, are substantially degraded. The answer lies not with the centralization of the ATM functions but with the vulnerability of the aircraft-to-satellite link and its overall effect upon system performance.

Vulnerability has two aspects, susceptibility and accessibility. Susceptibility defines the liability of the function to interference; accessibility defines the liability of the function to exploitation. To be vulnerable, a link must be both susceptible and accessible.

2.5.1 SAATMS Susceptibility - The Use of Noise is Optimum

All jamming techniques fall into three generic classes:

(1) Deception

(2) Confusion

(3) Obscuration

Deception is the generation of a jamming program which attempts to introduce false information into the SAATMS. The purpose of deception jamming is to mislead the system. Confusion is the generation of a jamming program which offers many apparent choices for system acquisition and tracking. The purpose of confusion jamming is to overload the SAATMS. Obscuration is the generation of a jamming program which attempts to cause the SAATMS to lose a parameter measurement capability. The purpose of obscuration jamming is to deny information to the system. Thus, any jamming technique attempts to mislead, overload, or deny information to the system.

Misleading (deception jamming) the SAATMS is the most difficult of the three and requires quite sophisticated equipment. To be effective, the jammer requires detailed knowledge of the signal waveform, link characteristics, and the algorithm used for processing. The SAATMS surveillance function makes use of relative measurements (time of arrival) of signals at the different satellites, orginating from a point source (the aircraft) at a single instant of time. As such, the surveillance function shares many of the non-susceptibilities of a monopulse radar. Any transmission originating on-board the aircraft tends to increase the signal-to-noise (S/N) ratio and enhance rather than degrade measurement capability. Thus, deception must originate from some source other than the aircraft. However, when the jammer is removed from the aircraft, the information concerning aircraft position and transmission time are lost, and the synchronization between the jammer and the aircraft required for deception cannot be maintained. To date, no effective means have been found to deceive monopulse type systems. Thus, we feel that the AATMS surveillance function is not susceptible to deception.

The communication function makes use of relative time measurements between two synchronized stations (the aircraft and the ground). It is planned to check each message sent, either by message repeats or parity check. Therefore, any attempt to deceive the system will be detected and the message repeated. Additionally, the code makes use of the aircraft ID signature, which is unique for each aircraft. Thus, to mislead the system, the jammer must be capable of duplicating the aircraft signature and capturing the time synchronization. All in all, the communications link is not susceptible; i.e., it is infeasible to attempt to introduce misleading information into a communications message.

The navigation function is in essence a communications link and the preceding comments apply.

Overloading (confusion jamming) the AATMS also requires detailed knowledge of the signal and link characteristics and the processing algorithms. If more signals are present than can be processed, the system is overloaded. That is, while information is being sorted and processed, other data are being ignored. Unless the system has infinite storage, data will be lost.

To effectively overload the system, the jammer need only generate a pulse coded surveillance waveform at a very high duty factor. The jammer signals will be received and the acquisition processor overloaded. However, since a special tracker is used for all active aircraft, the jammer signal will be filtered out of the tracker and will not affect those aircraft presently in the system. New aircraft will, however, find it difficult to enter the system. The communications and navigation links do not track signals and are susceptible to overload.

The data processing capability of both the surveillance and navigation links is extremely high since they must be able to handle peak loads. Thus, a secondary phenomenon will take place before overloading occurs. For any particular aircraft ID sequence, all other signals may be considered as noise. This is commonly referred to as multi-access noise. The ultimate effect of overloading the link is to increase the multi-access noise, reduce the available S/N ratio, deny a parameter measurement, and degrade system performance. All of which brings us to the third jamming category, obscuration (denial).

Noise jamming is a classical case of data denial. Since a detection system requires some minimal S/N ratio for proper operation, lowering this ratio will degrade performance. Confusion jamming is a special case of noise. Noise jamming is a brute force method, trading off average power for system intelligence. In general, noise jamming needs little knowledge of the system signal characteristics or processing algorithms and requires less sophisticated equipment but higher average power. The surveillance, communications, and navigation links are all highly susceptible to noise.

A summary of susceptibility of the SAATMS is shown in Table 2.5-1. All three SAATMS functions are highly susceptible to obscuration jamming (noise). Confusion jamming will only cause moderate degradation, and then only to communication and navigation. Deception jamming is difficult and is not very effective.

Table 2.5-1. SAATMS Function Susceptibility

Jamming Technique	SAATMS Function		
	Surveillance	Communications	Navigation
Deception	Low	Low	Low
Confusion	Low	Moderate	Moderate
Obscuration	High	High	High

2.5.2 SAATMS Accessibility - More Than 1,000,000 Watts Effective Radiated Power Required

The SAATMS has four basic links:

(1) Ground to Satellite - C-band uplink

(2) Satellite to Aircraft - L-band downlink

(3) Aircraft to Satellite - L-band uplink

(4) Satellite to Ground - C-band downlink

The C-band uplink is used for communications, via satellite, either to the aircraft or to another ground station. The L-band uplink is shared between surveillance and communications, as is the C-band downlink. Each of the four links has its own accessibility factors.

The ground-to-satellite uplink uses antenna gain to achieve high effective radiated power. Although the link is readily accessible, the jammer would have to compete with the high antenna gain. Additionally, the ground transmitter power could be substantially raised without any significant system penalty, again decreasing the accessibility.

The satellite L-band downlink provides limited accessibility due to its location, i.e., space. To be effective to any degree, the jammer must also be spaceborne, which implies a considerable investment. Although some system interference can be effected from a jammer located on an aircraft, the degradation to the system would be local. The C-band downlink can be degraded from a local jammer. The jammer must, however, compete with the satellite transmitter and antenna gain, both of which can be increased without undue system penalty. Additionally, the jammer can only enter through the receiver antenna sidelobe, approximately 40 db down. Thus, the C-band downlink has only limited accessibility.

The aircraft-to-satellite uplink, on the other hand, has certain design limitations which make it accessible. First, the design and cost constraints imposed by the GA user necessitates the use of low power, low gain transmitters. Although a high gain antenna is used on the satellite, this antenna receives the jammer as well as the aircraft transmissions. Second, if a satellite receiver is jammed, its usefulness throughout CONUS is affected. Third, a satellite receiver can be jammed from almost any point within CONUS. It should be noted, however, that jamming one satellite has no effect on the rest of the constellation. Additional jammers are needed if more than one satellite is to be jammed. This is discussed more fully in Section 2.5.3. The vulnerability of the various SAATMS functions and their associated links is shown in Table 2.5-2.

Table 2.5-2. Vulnerability of SAATMS

	Vulnerability (Noise)							
Function	C-Band Uplink		L-Band Downlink		L-Band Uplink		C-Band Downlink	
	Sus	Acc	Sus	Acc	Sus	Acc	Sus	Acc
Surveillance					High	High	High	Low
Communications	High	Low	High	Low	High	High	High	Low
Navigation	High	Low	High	Low				

Sus means susceptibility
Acc means accessibility

Based upon the susceptibility discussion, noise was selected as the most promising technique; and based upon the accessibility discussion, the L-band uplink is considered most easily degraded. To degrade this link, and therefore the surveillance function, approximately 80,000 w (49 dbw) of jamming power will be required, assuming matched jammer and transmitter bandwidths. The degradation is based upon reducing the average available energy to noise/unit bandwidth (E/No) ratio at the receiver to approximately 13 db.

However, the SAATMS equipment will have a 130 MHz total bandwidth. If required, the surveillance signal could be placed anywhere in the spectrum and, in fact, switched to a clear channel. Although this may slightly increase transmitter complexity, it will not significantly alter avionics cost since several different frequencies are already used for surveillance, communication, and navigation. To be effective, the jammer must cover the full 130 MHz. Thus, the jammer power requirements become 500,000 w or 57 dbw.

An infinite number of trades are available between jammer power and antenna gain. The trade between jammer output power and antenna size is shown in Fig. 2.5-1. A jammer requiring 100 w of output power would require a 20 ft antenna dish; one requiring 5 kw of output power would require a 3 ft dish. Obviously, the larger the output power, the smaller the dish size.

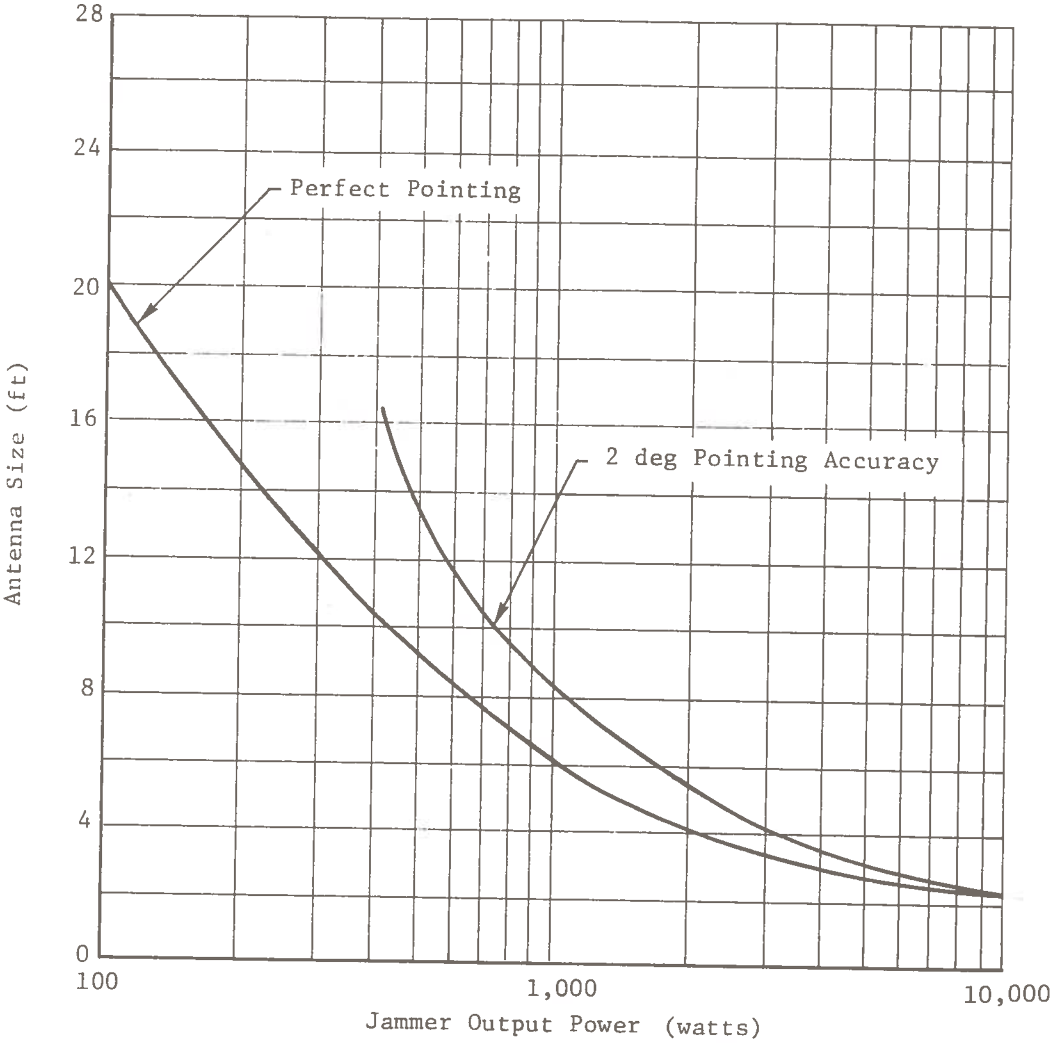


Fig. 2.5-1. Jammer Power and Antenna Size

As the output power decreases and the antenna dish size increases, the antenna beamwidth becomes smaller. Thus, a low power jammer requires accurate pointing information. Also shown in Fig. 2.5-1 are the effects of 2 deg pointing errors on the output power requirements. Low power jammers require quite precise pointing information or the antenna sidelobes, rather than the mainlobe, will be illuminating the satellites. It does not appear feasible to use an antenna much larger than 12 ft from either a mechanical or a pointing accuracy viewpoint.

The effect of pointing errors on satellite receiver S/N ratio is shown in Fig. 2.5-2, 2.5-3, and 2.5-4 for 3, 5, and 10 ft antennas. A 400 w (10 ft dish) jammer with a 3 deg pointing error would have virtually no effect on the satellite surveillance system. To compensate for the pointing inaccuracy, the jammer output power would be increased. This pointing requirement implies a precise tracking scheme including a receiver and an angle tracking technique.

The tracking problem itself is not simple. Perhaps the easiest and most inexpensive mechanization would involve buying a standard avionics receiver and matching it to a high gain antenna and a simple display such as an oscilloscope. The antenna would be scanned until a signal was received on the scope and slowly moved until the signal was maximized. Although the pointing accuracy obtained would be a function of the antenna size, mechanical coupling used, and the receiver and display sensitivities, it is felt that pointing accuracies between 1 and 2 deg could be achieved. In such case, the jammer transmitter power required to drive the system to 13 db S/N ratio is shown in Table 2.5-3.

Table 2.5-3. Minimum Power Required for Jammer Transmitter

Antenna Size (ft)	Power for Pointing Errors	
	1 deg	2 deg
3	5100 w	5300 w
5	1700 w	1950 w
10	500 w	700 w

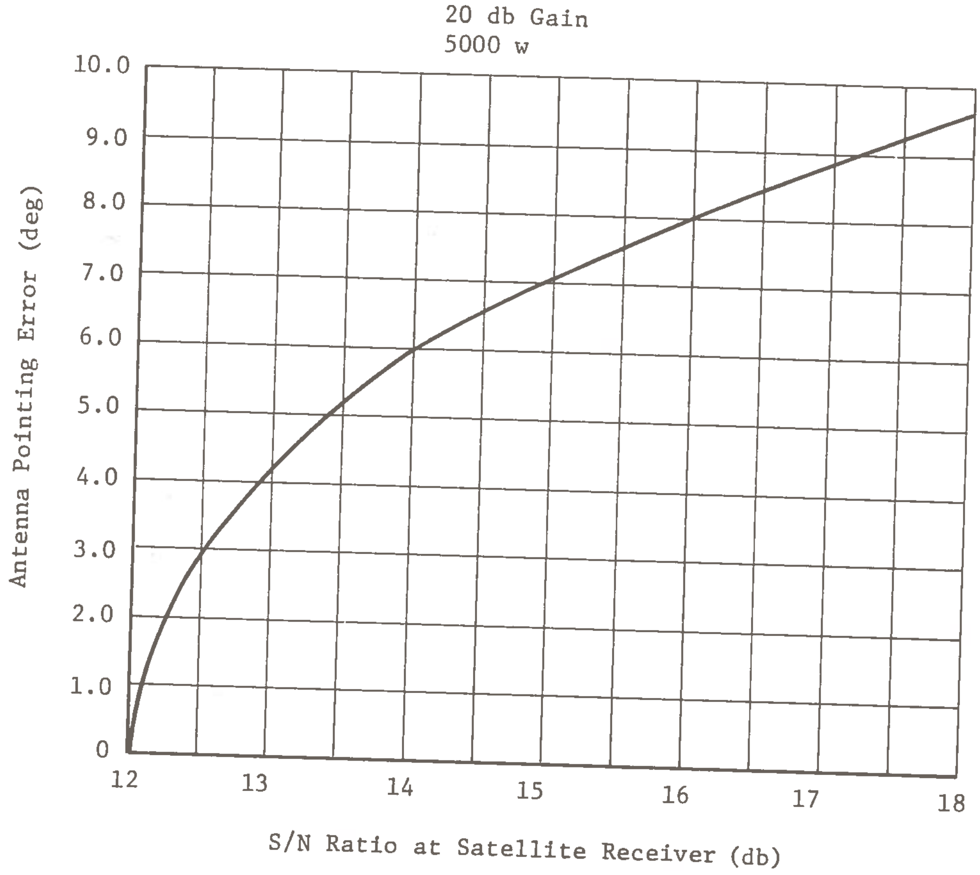


Fig. 2.5-2. Effects of Pointing Error, 3 Ft Antenna

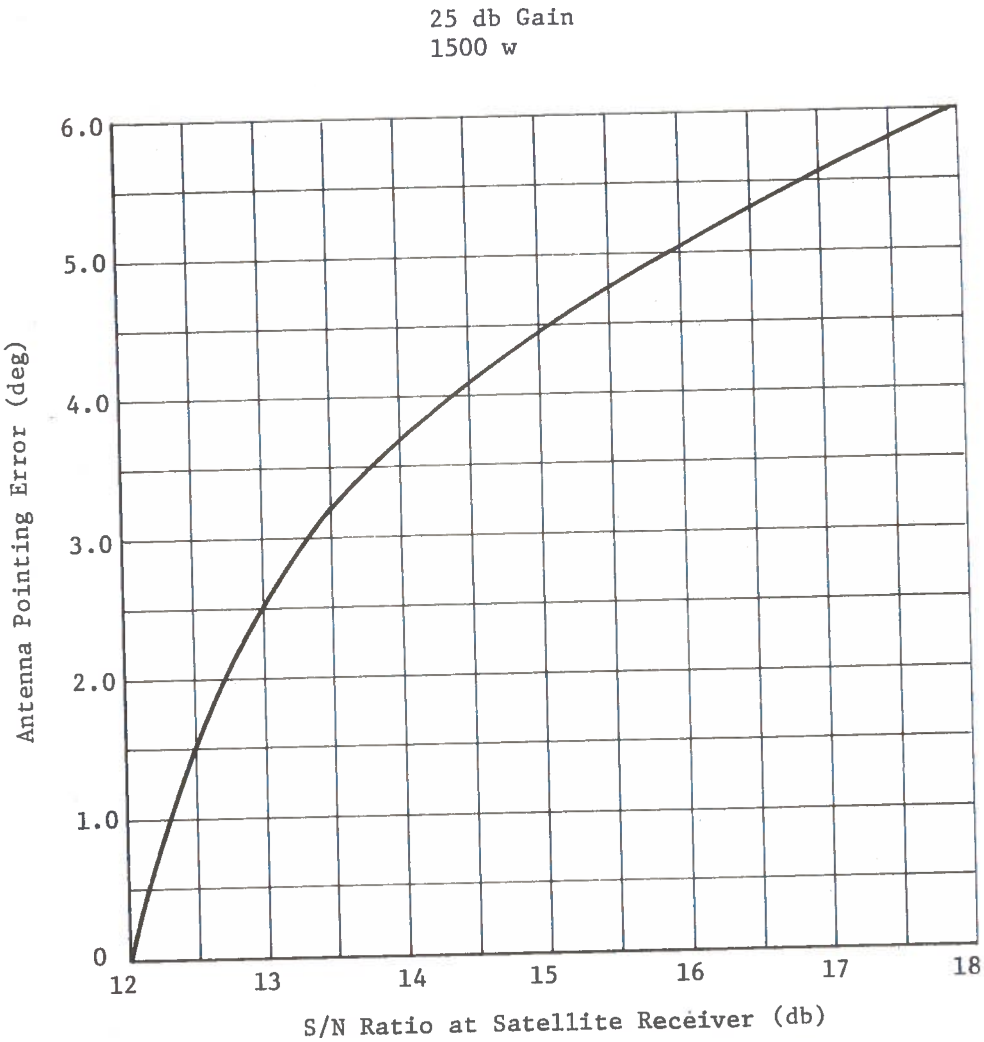


Fig. 2.5-3. Effects of Pointing Error, 5 Ft Antenna

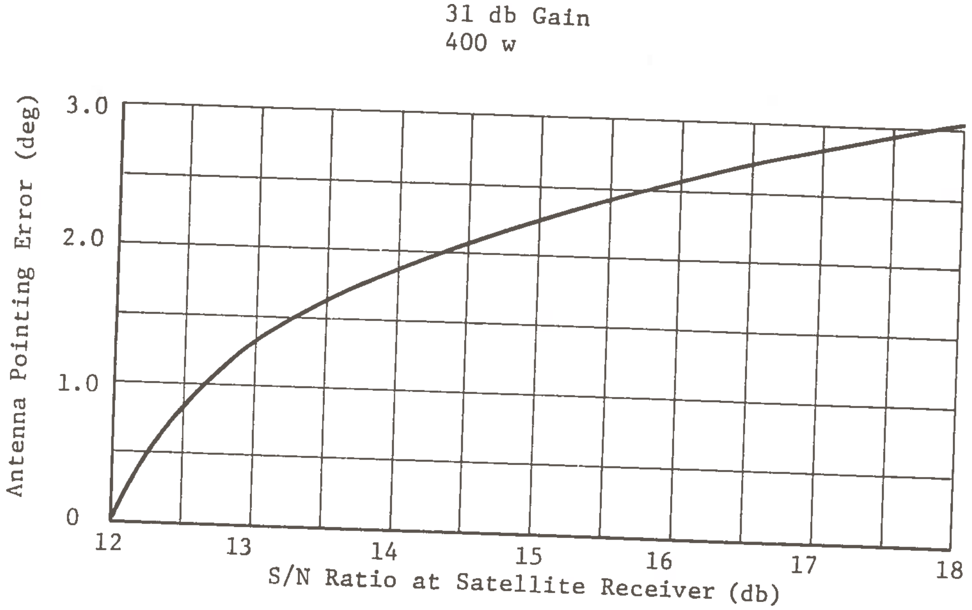


Fig. 2.5-4. Effects of Pointing Error, 10 Ft Antenna

The S/N ratio criterion of 13 db has been selected somewhat arbitrarily as the critical value for system operation. Actually, 13 db S/N ratio provides good system operation. For example, the probability of detection is greater than 0.99 with a false alarm rate less than 10^{-4}. The jamming powers listed in Table 2.5-3 will drive the S/N ratio of an average user to 13 db. The S/N ratio of a weaker than average user will be below 13 db, and his performance will be substantially degraded. To effect a substantial degradation over a large percentage of the system users, another 2 db of jammer safety margin should be added. Additionally, another 2 db should be added for miscellaneous jammer losses such as antenna efficiency, coupling, and line losses. The jammer power required to effect a substantial system degradation as a function of antenna size and pointing error is shown in Table 2.5-4.

Table 2.5-4. Jammer Power Required for Effective System Degradation

Antenna Size (ft)	Power for Pointing Errors	
	1 deg	2 deg
3	13,000 w	13,500 w
5	4,300 w	4,900 w
10	1,250 w	1,700 w

Periodically, the jamming would be interrupted and the antenna repositioned. For example, assuming a satellite range of 22,000 miles, the satellite motion would be approximately 1 deg every 3.4 min. Thus, to avoid jammer losses caused by antenna misalignment, the jammer would be disabled approximately every 4 min and repositioned. This time factor would, of course, be lengthened by further increasing the jammer power. A second jamming technique is available assuming the satellite orbit data are available. A jammer could be pointed to the satellite orbit and locked in place. The satellite's path would pass through the jammer beam and receiver degradation would occur. Since the satellites are moving, the length of time the jamming is effective would be limited. A summary of the jammer requirements is shown in Tables 2.5-5 and 2.5-6.

2.5.3 System Vulnerability - Five 1,000,000 w Jammers

The fact that a satellite receiver is degraded does not in itself mean that a particular function is degraded. The surveillance function requires that a minimum of four satellites clearly receive the signal; while the communications function requires only 1 satellite. Within CONUS, there is an average of 10 satellites in view with a minimum of 8.

Figures 2.5-5 and 2.5-6 illustrate the effects of satellite jamming on surveillance GDOP. The data in these figures represent the worst-case GDOP; i.e., the most important satellites being jammed and the worst constellation geometry. With three satellites jammed, there is little degradation in GDOP. With four satellites jammed, GDOP is substantially degraded. It should be noted that 15 min on either side of this data point, the degradation due to jamming decreases considerably. Thus, to substantially degrade the surveillance function, a minimum of five jammers would be required. Approximately 10 jammers would be required to degrade the communications functions. In both cases, the jamming effectiveness will be CONUS wide.

Depending upon the aircraft class and the area in which it is operating, a system backup is available to the surveillance function. The backup mode would involve the transfer of the air-derived navigation information through the satellite communications channel. This backup mode will be available on all controlled aircraft, i.e., approximately 30 percent of the fleet. The remainder of the fleet would have severely degraded surveillance and operate as do today's VFR users. A similar, but more limited backup, is available for the communications function for all aircraft within direct line-of-sight of a ground receiver, i.e., control center or major airport. A summary of the system vulnerability is shown in Table 2.5-7.

The last item for consideration must be the jammer practicality. Certainly, the need for a large antenna (5 to 10 ft), high output power (1.5 to 5 kw average), high input power (4 to 15 kw), high pointing accuracy (less than 2 deg), and many jammers (5 to 10) would seem to negate the vulnerability of the system to a casual jammer. The jammers cannot be built with parts available from a local electronics parts supplier.

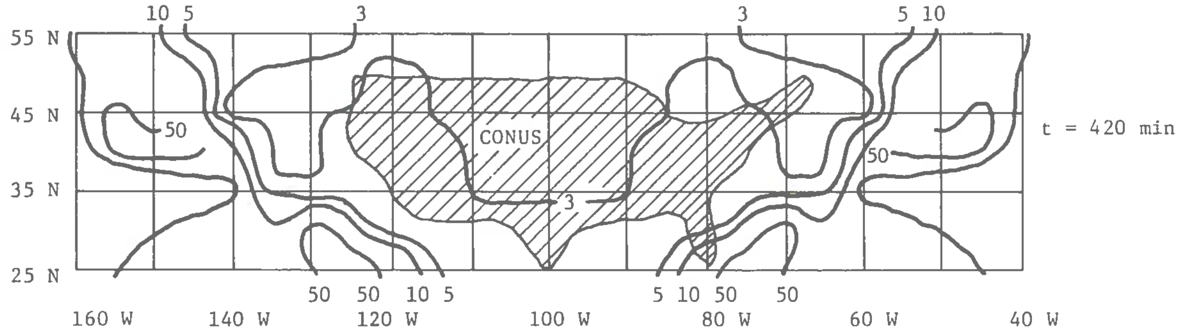
Table 2.5-5. Jammer Requirements, 10 db S/N Ratio, 1 deg Pointing Accuracy, Substantial System Degradation

Jammer Type	Angle Tracking Required	Antenna Size (ft)	Output Power (kw)	Input Power (kw)	Jamming Time (%)
Tracking	Yes	3	13	39	100
	Yes	5	4.3	13	100
	Yes	10	1.25	3.8	100
Pointed	No	3	15	45	12
	No	3	30	90	30
	No	5	5	15	15
	No	5	10	30	22
	No	10	1.25	3.8	7
	No	10	2.5	7.5	10

Table 2.5-6. Jammer Requirements, 10 db S/N Ratio, 2 deg Pointing Accuracy, Substantial System Degradation

Jammer Type	Angle Tracking Required	Antenna Size (ft)	Output Power (kw)	Input Power (kw)	Jamming Time (%)
Tracking	Yes	3	13.5	40.5	100
	Yes	5	5	15	100
	Yes	10	1.8	5.2	100
Pointed	No	3	15	45	13
	No	3	30	90	31
	No	5	5	15	13
	No	5	10	30	24
	No	10	2.5	7.5	9
	No	10	5	15	12

a. Hybrid Constellation Minus 1 Equatorial (115 W) and 2 Adjacent Inclined Orbit Satellites



b. Hybrid Constellation Minus 1 Equatorial (115 W) and 2 Inclined (Spaced One Apart) Satellites

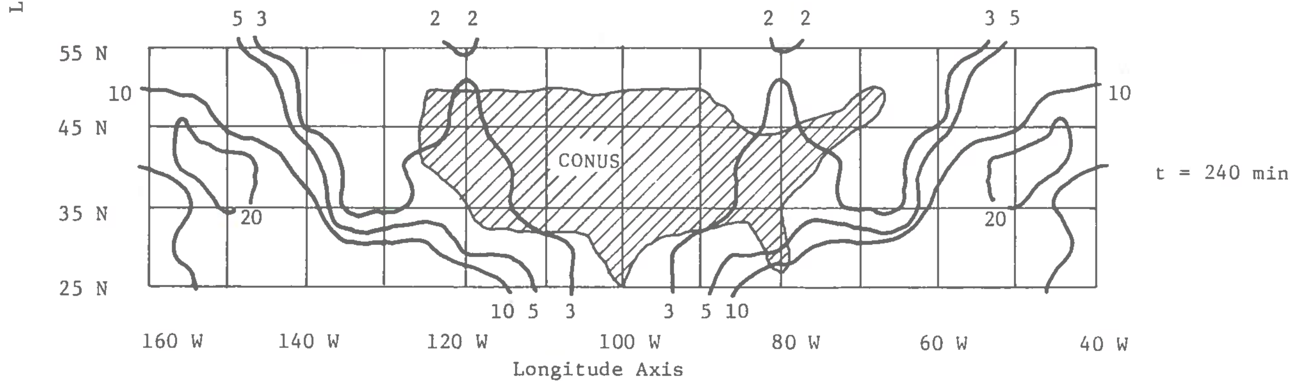
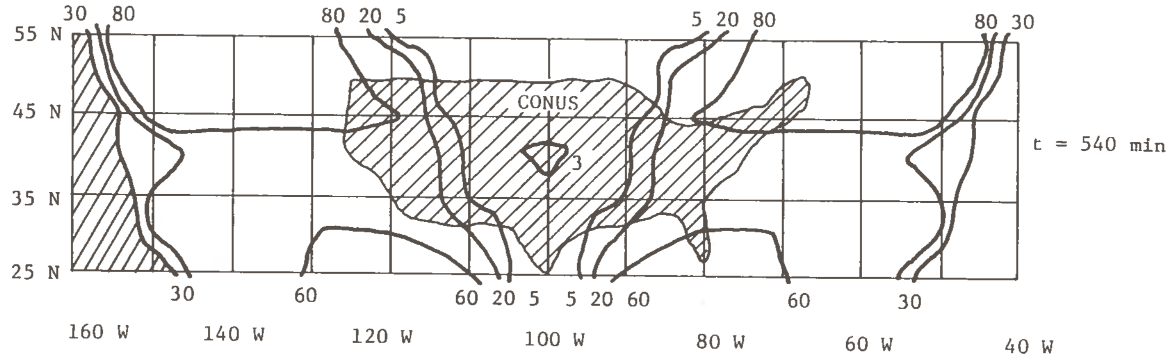


Figure 2.5-5. Satellite Non-Availability Worst-Case Results,Three Failed Satellites

a. Hybrid Constellation Minus 2 Equatorial (115 W and 85 W) and 2 Adjacent Inclined Orbit Satellites



b. Hybrid Constellation Minus 2 Equatorial (115 W and 85 W) and 2 Inclined (Spaced One Apart) Satellites

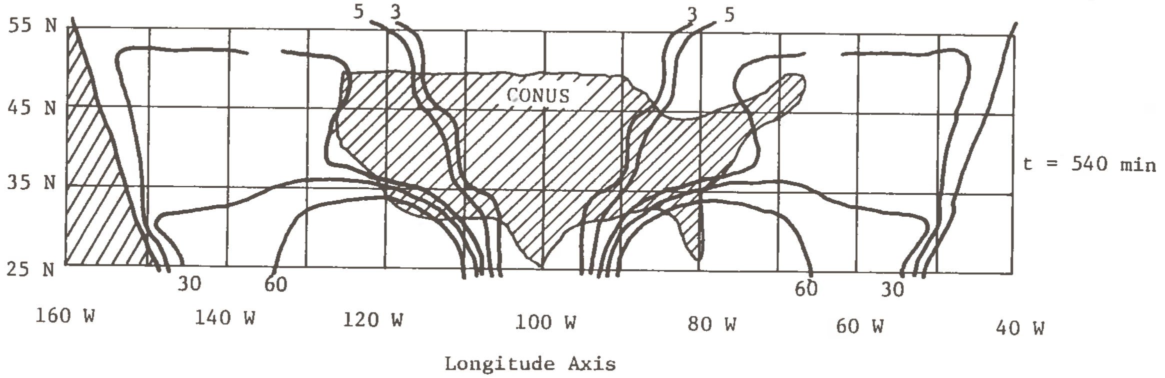


Figure 2.5-6. Satellite Non-Availability Worst-Case Results, Four Falied Satellites

Table 2.5-7. System Vulnerability and Jammer Requirements

Function	Jammer Type	Number of Jammers Required	Receiver Required	Angular Accuracy (deg)	Antenna Size (ft)	Output Power (kw)	Input Power (kw)	Jamming Time (%)	Backup Available
Communications	Tracking	10	Yes	1	3	13	39	100	Limited system backup available. Voice can be used when within line-of-sight of a ground station or airport.
					5	4.3	13	100	
					10	1.25	3.8	100	
		10	Yes	2	3	13.5	40.5	100	
					5	5	15	100	
					10	1.8	5.2	100	
	Pointed	10	No	1	3	30	90	30	
					5	10	30	25	
					10	2.5	7.5	10	
		10	No	2	3	30	90	31	
					5	10	30	20	
					10	2.5	2.5	8	
Surveillance	Tracking	5	Yes	1	3	13	39	100	Backup available by retransmission of air derived navigation data through communications channel to ground.
					5	4.3	13	100	
					10	1.25	3.8	100	
		5	Yes	2	3	13.5	40.5	100	
					5	5	15	100	
					10	1.8	5.2	100	
	Pointed	5	No	1	3	30	90	30	
					5	10	30	25	
					10	2.5	7.5	10	
		5	No	2	3	30	90	31	
					5	10	30	20	
					10	2.5	7.5	8	

2.6 Vulnerability to Natural Disasters - Decentralization Plus 100 Percent Backup

The major SAATMS control elements are the RCC's and the ACC's. The system consists of two RCC's located on either coast of CONUS. While either RCC could be struck by a natural disaster, such as flood or earthquake, it is impossible for one disaster to affect both RCC's because of their geographic separation. Both RCC's are backed up by a CCC located in Fort Worth, TX. This is approximately 1,000 nmi from both RCC's. It is therefore geographically independent of both RCC's and natural disasters are unlikely to affect all sites.

Under the normal mode of operation, the two RCC's control all CONUS traffic. The CCC serves as a command and monitor center for the entire system during normal operation. If a natural disaster should force one of the RCC's to shut down, the CCC can instantly take over its functions with no degradation in performance. All that is required is a simple reassignment of communications channels. This results in the implementation of a fail-operational backup mode.

In the unlikely event the CCC has to shut down, there would be no effect on system operation. Both RCC's would still be functioning. In the event of a national emergency, the CCC would take over control of the entire system. In this case, operation would be fail-safe in that separation assurance would still be guaranteed, but capacity and delay may suffer as all civil aircraft are ordered to land.

The ACC's are physically located at all primary and secondary airports and many high density feeder airports. Natural disasters that affect the ACC will in many cases also close the field. In those instances where the ACC is affected but the field is operational, the form of control will revert to the present type operation at airports with control towers. This provides a fail-operational mode.

The RCC will act as approach and departure control, guiding aircraft to and from the airport boundary. The tower will operate in a purely manual mode and will use voice communications if available. If no communications are available, the tower will have to resort to colored light signals to provide landing and takeoff clearance. Traffic advisories would be given from the RCC. Instrument approaches could be made to these fields using VVOR, but separation assurance inside the airport boundary will not be available.