Surveillance Vision Plan, Revision 2

United States Department of Transportation
Federal Aviation Administration
AND-440

July 1, 1996

Final Draft

U.S. Department
of Transportation

**Federal Aviation
Administration**

July 1, 1996

FINAL DRAFT

SURVEILLANCE VISION PLAN

This release of the Surveillance Plan (SVP) includes changes to Revision 1, dated March 8, 1996. This release is based on comments received from FAA organizational elements during the internal FAA coordination process. Comments and suggestions are solicited.

Additional technical information is available from:

Richard J. Lay , AND-440
US DOT/ Federal Aviation Administration
800 Independence Ave, S.W.
Washington, D.C. 20591
Telephone (202) 267-7768

U.S. Department of Transportation
Federal Aviation Administration

July 1, 1996, Rev. 2

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

A. PURPOSE

The Surveillance Vision Plan (SVP) for the National Airspace System (NAS) describes the aircraft surveillance system of the future, presents a plan for its implementation, and outlines the major plan steps in 5-year segments through 2015. The SVP describes the *transition from ground-based radar surveillance to a joint satellite-based and ground-based surveillance system* that will provide potential user and Federal Aviation Administration (FAA) operational and economic benefits. The cost, schedule, and performance of the new architecture have not yet been fully evaluated. However, assessments being conducted by government and industry indicate significant improvements over the present NAS architecture.

Examination of alternatives to the existing U.S. aviation surveillance architecture is essential for the following reasons:

- Improved aircraft surveillance (coverage of lower altitudes and non-radar areas, more accurate/frequent/reliable updates) is needed to support implementation of the free flight concept, (1) time-based control, (2) and other advanced Air Traffic Management (3) capabilities that will provide significant user economic and operational benefits.

- In light of current budgetary pressures and the availability of lower-cost, better-performing alternatives, avoidance of FAA expenditures associated with operating, maintaining, and replenishing the aging radar surveillance infrastructure is prudent.

- FAA is implementing weather radar capabilities that are independent of the aircraft surveillance equipment, so the latter systems need not provide weather functionality.

FAA has evolved a vision that will complement and guide the use of emerging surveillance technologies by the domestic and international aviation communities.

I The free flight concept applies to all flight phases and allows the user the freedom to select a flight plan -e.g., the most economic routes with preferred trajectories and altitudes. The user shares responsibility with the controller, achieving Visual Flight Rules (VFR) flying flexibility while maintaining traditional protection under Instrument Flight Rules (IFR), without restriction on specific route or speed. Controllers continuously monitor the flight and intervene only in a case of predicted conflict or to resolve a conflict on request by the pilot. Basic requirements of free flight are:

- aircraft can navigate with precision;
- reliable communications link exists between pilot/cockpit and controller;
- aircraft can transmit and receive position and intent information; and
- automation aids are available to help controllers detect and resolve conflicts.

2 Time-based control, to be implemented principally in/near terminal airspace, will require that Air Traffic Control/ Management (ATCIATM) facilities monitor aircraft adherence to a 4-dimensional (3 dimensions plus time) procedure.

3 An Traffic Management (ATM) includes both Air Traffic Control (ATC) and Traffic Flow Management (TFM).

The envisioned architecture cannot be fully implemented immediately. Resolution of budget, schedule, technical development, NAS harmonization, user equipage, and other issues will require a conservative transition period of 10 to 20 years (i.e., present to 2005-2015). This transition period reflects the difference between the projected times when (1) ground-based surveillance systems begin their end-of-life-cycle decommissioning, and (2) space-based surveillance systems are fully tested and operational. The aging ground-based systems must continue to be supported through sustainment and replacement programs until the transition period is complete. Decommissioning of current proven technology systems before new technology systems have been fully proved will negatively impact both the FAA and users. Nevertheless, it is expected that benefits will accrue to the FAA and users shortly after ADS-B initial deployment in 2000, and that positive user acceptance may accelerate full implementation.

The new surveillance architecture is based on aircraft broadcasting satellite derived position and other ATM data. Automatic Dependent Surveillance - Broadcast (ADS-B) will use 1090 MHz long (112 bit) squitter messages containing Global Navigation Surveillance System (GNSS) derived position data. It is assumed that delivery of ATC commands, weather, conflict resolution, and advisories to the pilot over a separate data link will be provided by the FAA, but a specific approach (frequency, capacity, etc.) has not yet been selected. During the transition phase, the Mode S data link (1030/1090 MHz) will be used for air traffic management purposes until an aeronautical data link is implemented.

B. SCOPE

The SVP:

- discusses the deficiencies of current and planned NAS surveillance capabilities and identifies the need for a new surveillance infrastructure;
- describes the ADS-B concept and envisioned architecture; and
- presents a transition path from the present system to ADS-B that will maximize benefits and minimize user impacts.

The surveillance function is made up of two basic elements: aircraft surveillance and weather surveillance. Aircraft surveillance acquires and tracks aircraft targets. Weather surveillance assimilates weather data required to (1) identify weather phenomena hazardous to aviation. (2) forecast meteorological events significant to aviation. and (3) prepare aviation weather products. The SVP focuses on aircraft surveillance and addresses weather only as it relates to primary radar weather capabilities.

C. ASSUMPTIONS

Several key assumptions in the SVP affect the planned implementation of the future NAS surveillance system:

- ADS-B avionics will initially be optional; subsequently, when most commercial aircraft are equipped, use of ADS-B may have to be mandated in controlled airspace to ensure full realization of its benefits.

- Sufficient resources will be available to implement the future surveillance system in coordination with overall NAS modernization efforts.

- GNSS will be fully implemented and will be internationally accepted as the standard aviation navigation system.

- During the transition period from a ground-based to a joint satellite/ground-based surveillance system, it will be possible for both systems to co-exist (taking into account a mixture of aircraft capabilities, increased use of secondary radar frequencies, and other issues).

- Advanced ATM procedures that take advantage of new surveillance capabilities will be implemented.

The SVP is a living document and will be updated and released on a regular basis.

D. NEED FOR NEW SURVEILLANCE ARCHITECTURE

The ability of the air traffic control/management system to support safe and efficient future operations is critically dependent upon implementing a high-performance, reliable, cost-effective surveillance infrastructure. Current ATC/TFM procedures and processes are based on existing radar capabilities and have not taken advantage of rapidly maturing surveillance technologies. To improve safety, capacity, and efficiency, there is a need to implement new ATM techniques which will require an improved surveillance system. An integrated surveillance system based on ADS-B is expected to provide the capability to achieve the operational improvements listed in Table ES-l.

E. ADS-B SYSTEM CONCEPT

1. ADS-B Baseline Mode of Operation

The NAS aircraft surveillance system envisioned in 2015 is illustrated in Figure ES-l. Similar but distinct architectures are planned for the en route, terminal, and surface surveillance domains. *The key to the envisioned new architecture is ADS-B - a major new system that will be used in all three domains to provide improved surveillance coverage and data quality.* Full implementation of ADS-B will enable the FAA to significantly reduce the number of primary

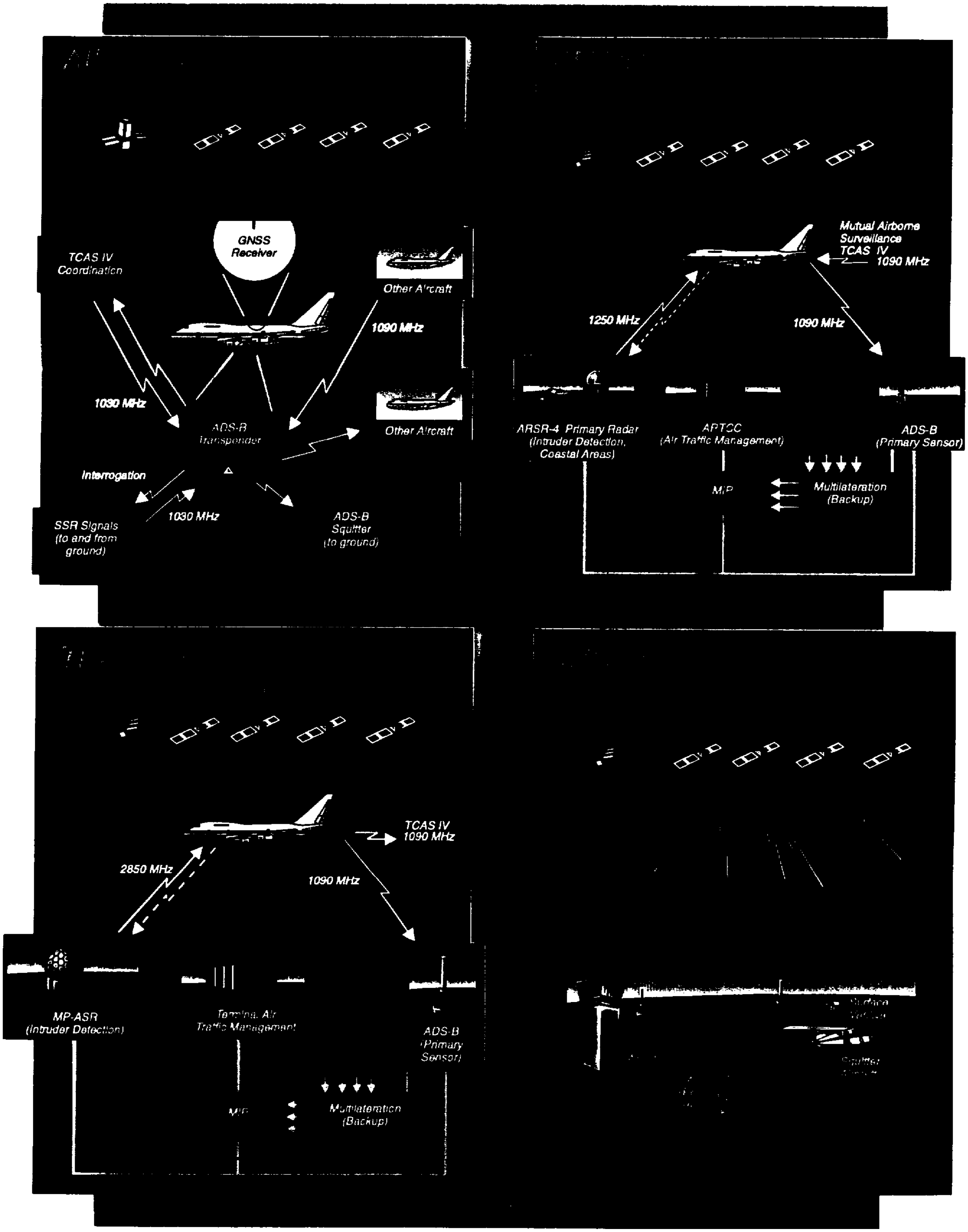

Figure ES-l. Envisioned NAS Aircraft Surveillance System (2015)

Table ES-1. Needed Operational Capabilities and Associated Surveillance Improvements

Operational Capability	Benefit(s)	Beneficiary	Surveillance Improvement(s)
Free Flight	Reduced fuel costs and flight time	Users	Wider coverage; higher accuracy/rate/reliability data
Time-Based Control	Increased airspace capacity	Users & FAA	Higher accuracy/rate/reliability data
Reduced Separation Minimum	Increased airspace capacity	Users & FAA	Higher accuracy/rate/reliability data
Increased Levels of Automation Automation	Increased controller capability and efficiency	Users & FAA	Higher accuracy/rate/reliabili data
GNSS Prec. Appr. at 8,000 GA Airports	Increased airport capacity and safety	Users & FAA	Broader and lower altitude coverage

and secondary radar installations, thereby reducing expenditures while improving surveillance capability.

ADS-B is a technique whereby: (1) aircraft position is derived by an onboard GNSS receiver; and (2) aircraft identity, altitude, and position are broadcast directly (without using satellites) to the ground and nearby aircraft. In addition, other valuable surveillance information could also be relayed to ATM facilities (e.g., ATCRBS code, velocity, heading, maneuver intentions, and in situ weather parameters). The onboard ADS-B avionics will broadcast (squitter) on the international transponder reply frequency, 1090 MHz. With current Mode S/TCAS equipment capabilities, an ADS-B equipped aircraft is expected to provide surveillance information to other in-flight aircraft at ranges up to 40 nmi (without changing the sensitivity of aircraft receivers) and to ground stations at distances up to 95 nmi (with six-sector antennas or low-noise receivers).

Squittered ADS-B messages received by nearby aircraft will provide Cockpit Display of Traffic Information (CDTI) and collision avoidance capabilities. Thus the ADS-B transponder avionics will perform three functions: (1) broadcast of aircraft identification, altitude, position, and other information to the ground and other aircraft; (2) exchange of collision avoidance related information with other aircraft; and (3) transponder turn-around of secondary radar interrogations, for use with TCAS I/II and SSRs during the transition phase. *ADS-B will provide the principal ATM surveillance capability in the en route, terminal, and airport surface domains in the post-2015 timeframe.*

There are no differences in ADS-B operation from domain to domain except for the update rates, which are adapted based on operating domain. Relatively high rates will be used in the terminal and surface domains (l- to 5-second spacing). Rates will be lower in the en route domain (5- to 12-second spacing).

The preferred ADS-B ground station configuration has triple coverage, to allow redundancy in reception of aircraft messages and to support an integrity monitoring and backup surveillance system employing ground-based passive multilateration. Multilateration will operate with ADS-B squitters, SSR Mode C/S replies and squitters, TCAS II replies and squitters, and TCAS IV squitters. Multilateration can be implemented in the near term without any change in aircraft equipment. Individual sensor sites would not have redundant equipment; in effect, the redundant equipment that would be necessary with single site coverage will be deployed at additional sites, providing better airspace coverage, greater robustness, and multilateration capability at little additional cost.

For a minimum surveillance altitude of 6,000 feet, triple coverage requires approximately 300 en route sensor sites (most using multisectored antennas). Between 5 and 11 sensor sites (using omni and multi- sector directional antennas) are needed for each of the approximately 240 TRACONs.

Up to 240 of the largest airports will use ATIDS (ASTA Target Identification System) to receive aircraft messages on 3 to 7 sensors and provide controllers with target location and identity information. ATIDS will perform multilateration on Mode A/C/S transponder replies/squitters as well as on ADS-B squitters. An additional 200 towered airports with lower traffic density will receive one ADS-B sensor site (which could also be a terminal sensor), allowing surface aircraft ADS-B messages to be collected but not providing backup multilateration capability.

During the transition period, surveillance target reports will be available from four sensor types: ADS-B, multilateration, primary radar, and secondary radar. Moreover, there will usually be redundant reports from sensors of the same type. The Multisensor Interface Processor (MIP) will fuse multiple/redundant target reports into a single report for use by aircraft trackers, thereby ensuring smooth integration of ADS-B into the existing surveillance infrastructure. Approximately 22 MIP installations will be used for the en route domain, and approximately 240 MIPS (one per TRACON) will fuse target reports from terminal and surface sensors.

Users on the surface of the approximately 8,000 non-towered airports will rely on GNSS navigation services and aircraft-to-aircraft surveillance.

2. Preferred ADS-B Backup Mode of Operation: Passive Multilateration

ADS-B involves three basic system elements: GNSS signals, avionics (GNSS receiver and ADS-B transponder), and ground station electronics. A backup mode of operation must be provided that prevents loss of surveillance capability if there is a malfunction in any one of these elements — i.e., no single point of failure. Failure of GNSS satellite signals, including unintentional or intentional radio frequency interference, would have the most impact, since it would cause loss of both surveillance and navigation capabilities for all aircraft in a region such as a metropolitan area.

The preferred method for protecting against GNSS failures is passive multilateration on the ground. Three ground stations measure the time-of-arrival (TOA) of a common aircraft message, either squittered or in reply to an interrogation. The message may or may not contain a GPS time tag. If it does, joint processing of the TOAs at a common ground sites can estimate aircraft three-dimensional coordinates, thereby also providing some protection against altimeter failure. If a GPS time tag is not included, differential (hyperbolic) processing of the TOAs can determine the aircraft horizontal position.

If the ground stations are arranged in an equilateral triangle (a pattern that provides both efficient coverage and advantageous multilateration geometry), the latitude/longitude errors will be approximately 70 ft, 2drms for either technique. When the message contains a time tag (ADS-B squitter), vertical position can be estimated. However, errors will be 10 to 17 times larger due to poor altitude measurement geometry. During normal ADS-B operations, multilateration provides an independent integrity check on the GNSS-derived data in the ADS-B messages.

Three-station passive multilateration has several advantages over other possible backup systems. *Multilateration based on air-to-ground signals can be implemented without changing aircraft equipment, and thus serve as a transition path to ADS-B.* Horizontal position estimates with three stations are significantly more accurate than for two-station configurations. Because the ground stations do not radiate, there are fewer restrictions on their siting (for example, they could be placed on telephone poles in metropolitan areas). With passive multilateration, aircraft position information derived on the ground can be transmitted to the aircraft via data link, thereby enabling “automatic dependent navigation” to be used to back up aircraft navigation.

Excepting use of primary radars, protection against aircraft equipment failures can only be achieved through additional avionics — either redundant or dissimilar to the principal equipment. It is expected that many aircraft would be equipped with redundant ADS-B transponders. However, a separate data link (e.g., using VHF or a different frequency band) could also be used to back up the squitter link at 1090 MHz. Although many aircraft will carry redundant GNSS receivers, this equipment would not be necessary with the recommended multilateration technique. Primary radars will be retained around the U.S. perimeter and in terminal areas, providing an additional level of protection against transponder failures and unequipped aircraft.

Redundant ground sites serve as the backup for individual ground stations.

3. Alternative Backup Techniques

There are several methods other than three-station passive multilateration for protecting against the loss of navigation information in the aircraft. These fall into three categories: alternative multilateration techniques, an additional navigation system, and secondary radar.

Multilateration service can be provided in the aircraft by receiving squitters from three ground stations containing site identification and GPS time (or the stations can squitter on scheduled time epochs). An aircraft with GPS time available can derive its three-dimensional position, while one with an altimeter but no clock can derive its horizontal position. In either case, the derived position information is squittered in an ADS-B message (in place of GNSS position data), supporting both ground-based and air-to-air surveillance.

With three ground stations, two-way ranging initiated by the aircraft provides the same capability as ground station squittering but removes the need for an accurate clock or altimeter in the aircraft. However, two-way ranging to two ground stations has significantly reduced accuracy near the baseline separating the two stations, where the position solution is singular. Two-way ranging initiated by the ground station has the advantage that angle measurements by the ground antennas can mitigate some of the effects of poor measurement geometry.

An alternative navigation system (e.g., VOR/DME,Loran-C, INS, or a combination of these) can be used to backup GNSS. This approach has the advantages of also backing up the air-to-air surveillance and navigation functions, and would be used with dual ADS-B ground site coverage. A disadvantage is that it necessitates retention of equipment (ground stations and/or avionics) that would otherwise not be needed. Secondary surveillance radars will be used to back up ADS-B during its introduction into the NAS. However, SSRs are not recommended as the permanent backup system due to their cost. (If SSRs were used, the backup system would be more costly than the principal system, whereas a multilateration system would he very low cost.)

F. STATUS OF ADS-B CONSTITUENT SYSTEMS

The technologies needed to implement ADS-B have been proved to be technically sound and are rapidly maturing. Some are already operational. For example, the space-based GNSS now provides accurate, three-dimensional position and velocity information to a user with a relatively low-cost GNSS receiver. GNSS for supplemental navigation and approach is now in operation; use of GNSS for sole-means navigation and for precision landing and taxiing is currently under FAA development. TCAS transponders, similar to those needed for ADS-B, are currently in widespread use. Prototype ADS-B ground stations also have been built and flight tested.

ADS-B transponder capabilities are presented in Table ES-2. To adopt ADS-B as the principal surveillance system, every aircraft operating in controlled airspace may ultimately have to be equipped with an ADS-B transponder. For multilateration to operate properly, aircraft transponders (ADS-B and earlier systems retained for backup use) must be capable of Mode C operation and must either squitter or be interrogated with 1030 MHz pulse pairs.

Table ES-2. ADS-B Transponder Capabilities

Frequency \ Mode	Transmit	Receive
1030 MHz	. TCAS interrogations* . Coordination messages to other A/C	. SSR and TCAS interrogations* . Coordination messages from other A/C
1090 MHz	. Own aircraft information'* (squittered) . Replies to SSR and TCAS interrogations*	. Squittered ADS-B and TCAS information** from other A/C · TCAS II replies

*Capability only required during transition period, for compatibility with existinq systems.
**Identification, satellite derived lattitude/longitude, altitude; optionally, GPS time, ATCRBS code, velocity, maneuver intent, weather parameters, other data.

G. TRANSITION TO ADS-B-BASED SYSTEM

The evolution from the current to the future aircraft surveillance architecture is shown in Figure ES-2. Ground-based radars will be phased out as they become obsolete at the end of their life cycles. These radars include: ARSR-1 , -2, -3; ASR-4, -5, -6, -7, -8; ASDE-2, -3, -X; and ATCBI-3, -4, -5, Mode S, PRM. Due to the critical role that secondary radars will play during the transition phase, replacement of the aging existing secondary radars with Monopulse SSRs (MSSRs) will be necessary. ARSR-4s, 22 ARSR-I s, 2s, -3s, and ATCBI-5s or MSSRs will remain in the en route domain to support Joint Surveillance System (JSS) (4) surveillance requirements.

Compatibility of ADS-B with existing systems during transition is a critical consideration. During this interim period, existing ground-based systems and multilateration on Mode C/S messages will be used until a significant portion of users are equipped with ADS-B avionics (GNSS receiver and ADS-B transponder). After a period of time, a policy of mandatory ADS-B equipage may have to be adopted for all aircraft flying in controlled airspace. Subsequently, ADS-B will provide domestic surveillance and collision avoidance capabilities in all domains. The seamless surveillance architecture envisioned is shown in Figure ES-3.

H. ISSUES AND RISKS

Some of the issue and risk areas associated with the evolution to an ADS-B based architecture include: continued technology maturation; system vulnerability to electromagnetic interference/jamming; NAS implementation timing to optimize benefits relative to costs; development of a new ATM data link; successful resolution of policy issues (e.g., GA and military equipage, support of the Global Positioning System (GPS) and geostationary communications satellites, and international acceptability); and FAA funding availability.

Several specific issues have been identified that require further analysis and decision. A summary list follows.

4 Joint Surveillance System (JSS) refers to primary/secondary radar installations on the U.S. perimeter jointly operated by the FAA, DOD, and DEA.

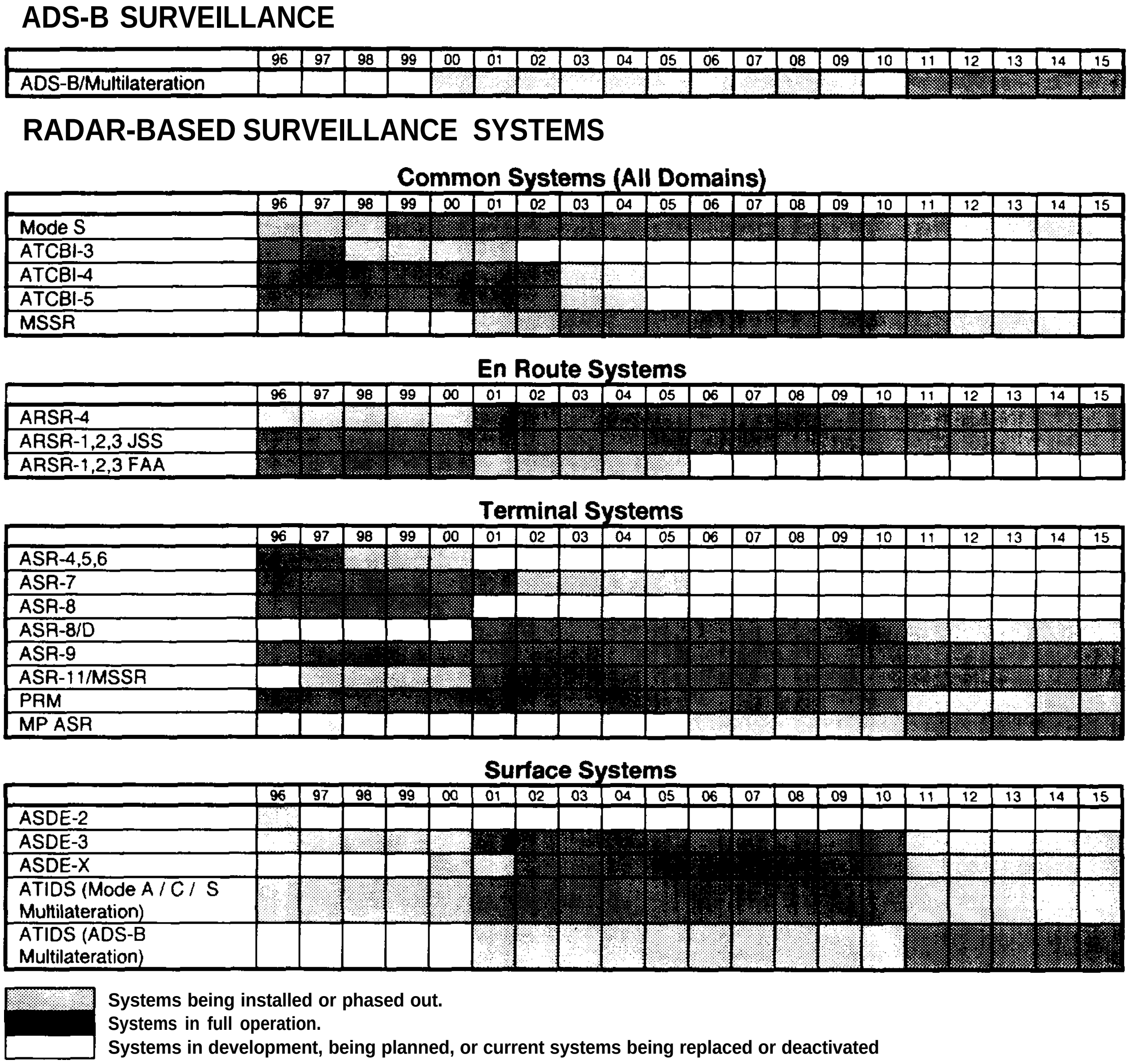

Figure ES-2. Aircraft Surveillance System Transition by Architecture Categories

- Capacity — ADS-B must demonstrate sufficient capacity to serve peak aircraft loads at the busiest terminal areas, including during the transition period when SSR replies will also use the 1090 MHz frequency.

- ADS-B Ground Deployment — Optimal density and locations for ADS-B ground stations (which are likely to be different from those for radar) must be determined.

- ATCBI Replacement System — FAA must select, procure, and field the most cost-effective secondary surveillance radar to replace the aging and increasingly unsupportable ATCBI-4s and -5s through the next 20 years.

- User Equipage — Strategy and schedule must be formulated for encouraging/requiring user ADS-B-equipage.

- Deployment Schedule — ADS-B deployment schedule must weigh needed new capabilities, including free flight, precision approaches at up to 8,000 airports, and time-based control.

- General Aviation User Attraction — ADS-B must provide perceived benefits to general aviation users if they are to support emerging new technologies.

- Data Link — An ATC/TFM data link that is affordable to all users must be selected.

- Automation Programs Coordination — ADS-B capabilities and schedule must be closely coordinated with automation programs that will use ADS-B data.

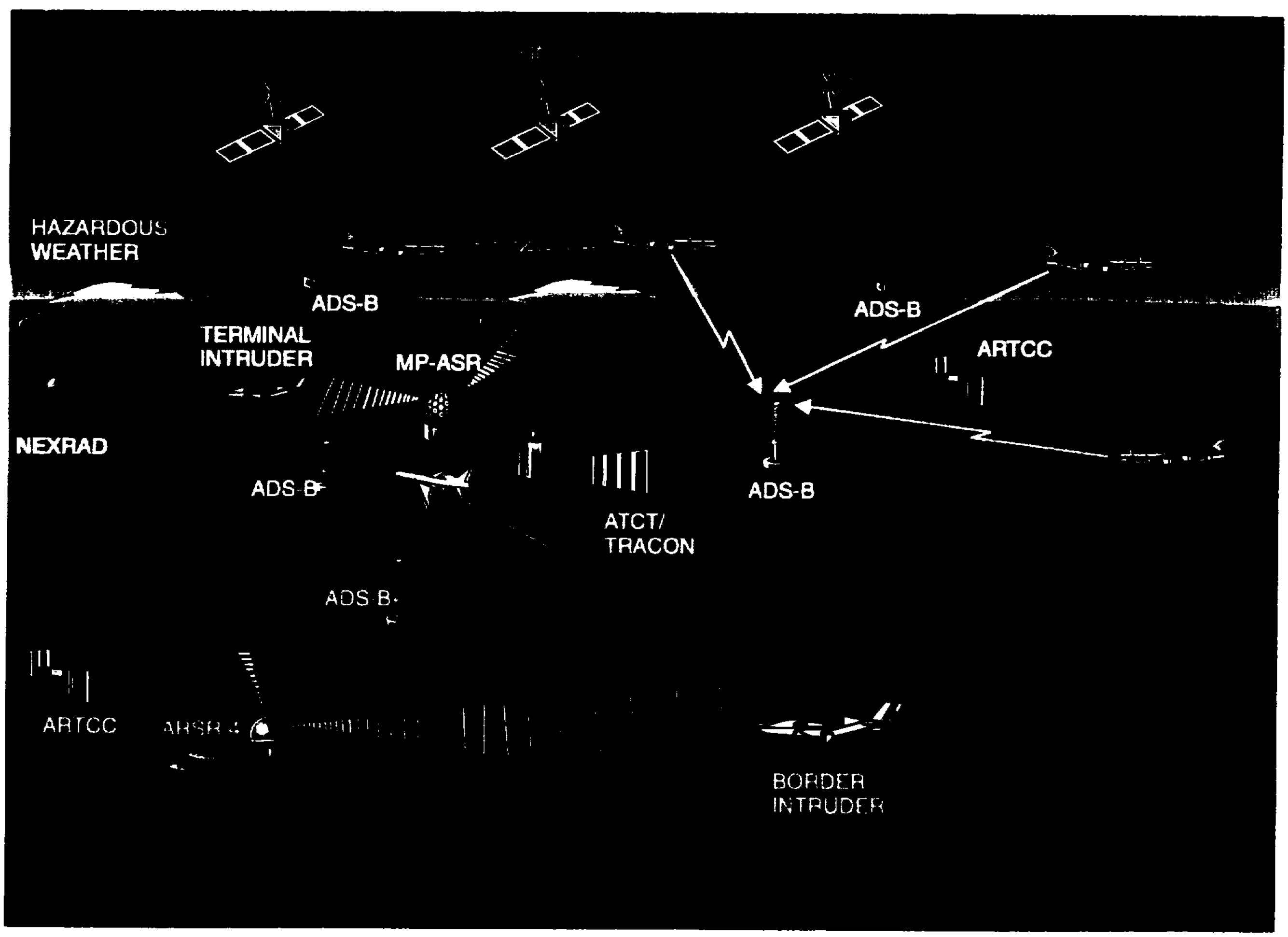

Figure ES-3. Overview of Envisioned Surveillance Architecture (2015)

I. COSTS

ADS-B selection is based, in part, on architecture tradeoffs using rough estimates of the cost of the evolution of the FAA's surveillance system, with emphasis on programs and systems under the purview of the FAA's Surveillance and Weather Integrated Product Team (IPT). Other costs considered during the planning stage were:

- User equipage (ADS-B avionics and CDTI cockpit display)
- Automation
- GPS WAAS and LAAS.
- ATC Data Link
- GPS and INMARSAT

Detailed cost-benefit analysis will be required to assess the budgetary impact of ADS-B.

J. CONCLUSIONS

The rationale for evolving the NAS aircraft surveillance system to one that places primary reliance on ADS-B is based on improving surveillance system capability (coverage, accuracy, update rate, and reliability) to a level that will support additional automation functionality — e.g., free-flight and time-based control — and improve safety through a high performance, universally available, air-to-air collision avoidance system. The resulting increases in safety, capacity, and operational efficiency must benefit all users. Cost-benefit analysis will determine the extent to which these user benefits justify the investment of capital resources and will be the basis for future funding allocations. The status of the system architecture elements is shown in Figure ES-4.

K. RECOMMENDATIONS

It is recommended that the FAA establish an ADS-B development program with the objective of initial system deployment by 2000 and Full Operational Capability by 2010.

It is also recommended that the following work tasks be performed in developing and evaluating the new space- and ground-based surveillance architecture presented herein:

- Surveillance system requirements analysis
- Cost/benefit analysis
- Operational concept development
- Research and development on issues and risk areas
- Siting analysis
- Test and Evaluation Master Plan preparation
- Transition strategy and development schedule
- Airspace structure and operational procedures development
- External (government, non-government, and international) coordination
- Prototype system development and testing.

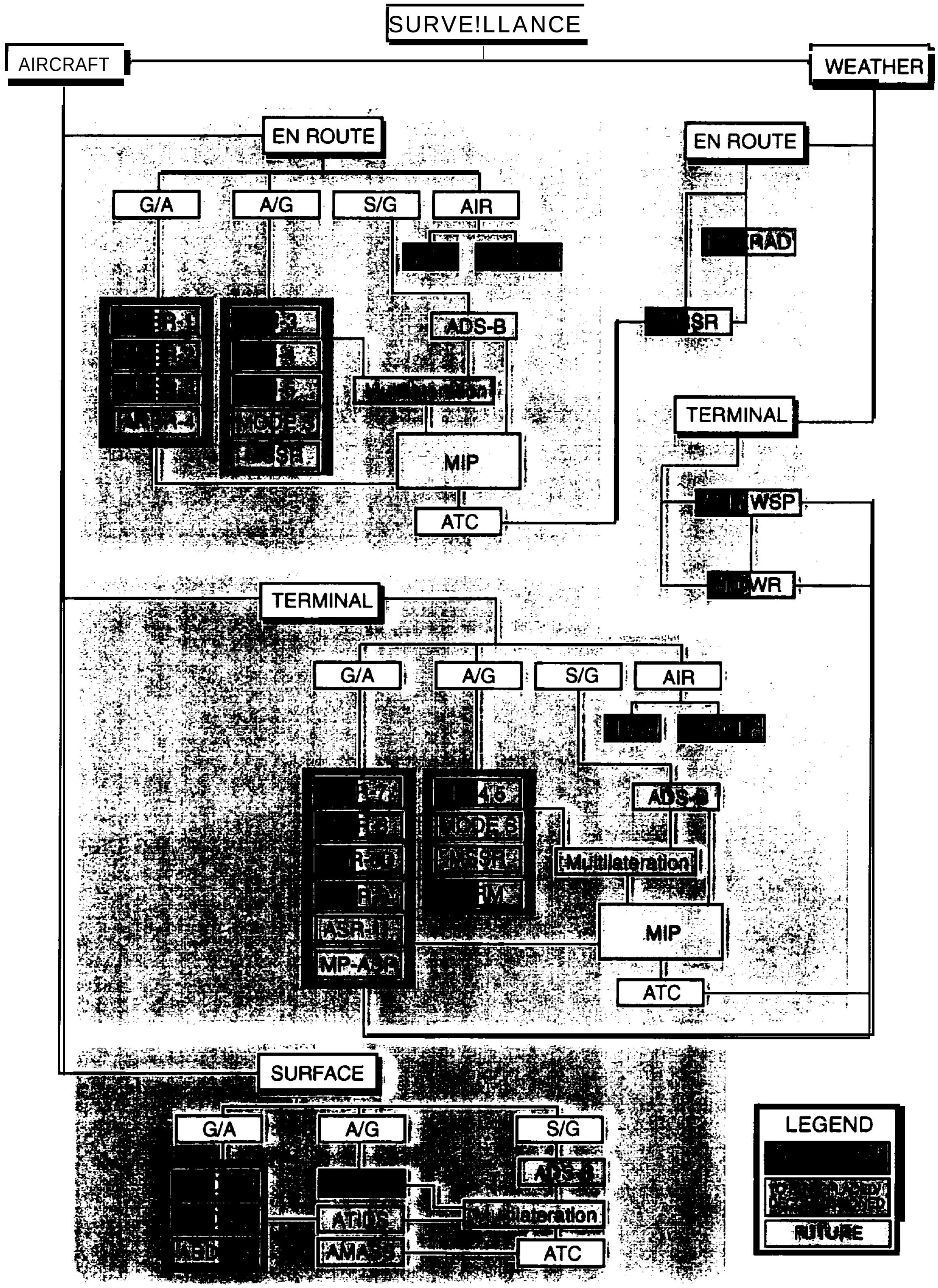

Figure ES-4. Surveillance Systems Growth Path

I. INTRODUCTION TO NAS SURVEILLANCE

A. BACKGROUND

1. Introduction to Surveillance

Surveillance is the process by which the Air Traffic Management' (ATM) system on the ground obtains information concerning: (1) the position and other important characteristics of aircraft in the airspace being managed; and (2) hazards, particularly weather phenomena, in and near this airspace.

Surveillance sensors include: ground-based primary radars (first introduced in the 1940s); secondary radars having ground and aircraft elements (introduced in the 1950s); and aircraft navigation sensors interfaced to an air-to-ground data link (introduced in the 1990s). In this context, the ATM system refers to the personnel on the ground responsible for performing Air Traffic Control/Traffic Flow Management (ATCITFM) and the automation systems (computers, displays, and software) that process surveillance data and support the ATC/TFM personnel with automation aids.

Traditionally, surveillance systems have been developed by organizations within the Federal Aviation Administration (FAA) dedicated to that purpose (AND-400).The FAA Air Traffic organization is the primary customer of surveillance information. Aircraft and their operators are users of the ATM system. FAA technicians who maintain the surveillance system are also stakeholders in the surveillance system and its evolution.

2. Need for New Approach to Surveillance

It is widely agreed that the U.S. aviation community is at a point where it must re-evaluate, and almost surely revise, its approach to aircraft and weather surveillance. The most important factors driving this re-evaluation are:

- Most of the FAA's installed inventory of 376 primary and 338 secondary (not including 144 Mode S) radars, which are the basis of the agency's current surveillance system, are nearing the end of their service lives and have become inordinately expensive to maintain and replace in the current budgetary environment.

- Ground-based radars are limited in their coverage by line-of-sight geometry considerations, while higher levels of air traffic and the drive toward free flight impose a need for increasing the airspace coverage (wider areas, lower altitudes, lack of "blind spots," etc.).

5 Air Traffic Management includes both Air Traffic Control (ATC) and Traffic Flow Management (TFM).

- Improvements in ATM such as free flight, time-based control, and reduced separation standards would be better supported with higher quality surveillance data (e.g., higher target update rates, elimination of garble, elimination of phantom targets, improved azimuth accuracy) than a radar with a mechanically rotating antenna can provide.

- More accurate and timely weather information must be made available to pilots and controllers to improve traffic flow efficiency while maintaining or improving safety.

The investment decision confronting the U.S. aviation surveillance community amounts to several billions of dollars, and will impact the basic ATM system capabilities over the next two decades. It is imperative that the system and transition selected provide the optimum mix of benefits relative to costs.

B. DOCUMENT PURPOSE AND SCOPE

This document constitutes the Surveillance Vision Plan (SVP) for the National Airspace System (NAS). Its primary purpose is to capture the following under one cover:

- Current and future needs of aircraft surveillance as they pertain to the en route, terminal, and surface domain phases of flight; and

- NAS aircraft surveillance system architecture as it is envisioned in the years 2000, 2005, 2010, and 2015.

Additionally, this document identifies the research and development efforts needed to reduce the risks inherent in the evolution of the surveillance system toward the future vision.

To provide the background information necessary to understand the rationale for the SVP, this document also describes the currently installed and funded developmental surveillance systems as well as deficiencies of the current systems. The role of weather systems in this document is limited to aircraft surveillance systems that also include weather surveillance capabilities.

This document is a product of the FAA's SVP Functional Working Group (FWG). The working group was established in February 1995 in response to directions from the leader of the Integrated Product Team (IPT) for Surveillance and Weather, AND-400[6]. The FWG objectives were to: (1) serve as the focal point for planning and coordinating the introduction of new satellite-based surveillance systems with air traffic management procedures; (2) develop a broad customer-motivated vision plan to include a Plan of Action (Implementation Strategy) and Milestones; (3) recommend to the Administrator the surveillance-related research and development projects and sustaining projects required for the transition from ground-based to a

[6] Jack Loewenstein. IPT Leader.

mixture of ground- and space-based surveillance systems; (4) recommend transition priorities; and (5) ensure that the required internal coordination is effected throughout the period.

C. CURRENT RADAR SURVEILLANCE SYSTEM OVERVIEW

Since the introduction of radars into the U.S. civil aviation system (i.e., since real-time, accurate aircraft surveillance has been possible), the FAA has divided its surveillance sensors by the flight domains of the aircraft being served. These domains are: (1) en route, (2) terminal area, and (3) surface. Several generations of surveillance radars have been designed and deployed for these domains. The ATM personnel and systems that use surveillance data have been deployed in facilities corresponding to (and generally located nearby) the radars or radar data processing facilities from which they obtain data.

1. Primary and Secondary Radars

Surveillance radars fall into one of two mutually exclusive categories: *primary* and *secondary*. Primary radars transmit pulsed electromagnetic energy that is reflected by the desired targets (aircraft or particulate matter associated with a weather phenomenon) and by undesired objects.

Secondary radars are useful only with cooperating aircraft targets. The radar ground installation transmits electromagnetic energy, normally a pulse pair. By international agreement, 1030 MHz is the carrier frequency used for interrogation of the aircraft transponders. A cooperating aircraft carries a transponder that receives the signal from the ground and transmits a signal of its own, on 1090 MHz, which is received by the ground radar.

Secondary radars have several advantages over primary radars: (1) they are less costly (a few million dollars per installation versus approximately ten million of dollars), primarily due to the lower power that is generated by the transmitter; (2) the data received on the ground includes an aircraft identification tag and altitude information; and (3) the signal collected by the ground radar contains far less clutter than a primary radar echo.

Secondary radars, sometimes called Secondary Surveillance Radars (SSRs) or beacon radars, are the principal aircraft surveillance sensors used in the NAS today. All aircraft operating in class A, B, or C airspace (7) are required to carry one or more transponders, unless otherwise authorized by ATC. (8)

---

7 Class A airspace extends between 18,000 ft and 60,000 ft and is restricted to aircraft operating under Instrument Flight Rules, Class B airspace surrounds the nation's busiest airports in terms of passenger enplanements or IFR operations; Class B airspace generally has the shape of an inverted wedding cake, and extends from the surface to I0.000 ft above Mean Sea Level (MSL). Class C airspace surrounds medium density airports; it usually has the appearance of a two-layer wedding cake and extends to 4000 ft above the airport elevation.

8 Additionally. the FAA. after 1997, intends to issue a Notice of Proposed Rulemaking (NPRM) requiring that all aircraft operating above 6000 ft under Visual Flight Rule (VFR) and all aircraft under Instrument Flight Rules (IFR) carry a beacon transponder.

The main advantage of primary radars is that they do not require a cooperative target. Primary radars must be used to detect: *(1) blunders,* aircraft that inadvertently enter Class A, B, or C airspace without a transponder, or with their transponder accidentally turned off or malfunctioning; (2) *intruders,* aircraft that intentionally enter Class A, B, or C airspace without an operating transponder; and (3) *weather-phenomena.*

2. Surveillance System Structure by Flight Domain

The surveillance systems used in each domain today are summarized in this section. Primary and beacon radar systems, today and as projected for the future, are summarized in Table I-l.

Table I-1. Surveillance Radar Inventory - Current Year and Planned

Radar Type/Domain	1996	2005	2010	2015
En Route Primary				
ARSR-1	29	5	5	5
ARSR-2	18	7	7	7
ARSR-3	22	3	3	3
ARSR-4*		41	41	41
ANIFFS-20	45	6	6	6
Totals	114	62	62	62
Secondary				
ATCBI-3	86			
ATCBI-4	85			
ATCBI-5	167	5		
MSSR		199	138	138
Mode S		144	144	144
Totals	**338**	**348**	**282**	**282**
Terminal Primary				
ASR-5, FPS (1+5)	6			
ASR-7	34			
ASR-8	71			
ASR-8D		61	68	68
ASR-9	122	120	120	120
ASR-11		37	46	46
PRM	5	7	12	
Totals	**238**	**225**	**246**	**234**
Surface Primary				
ASDE-2	2			
ASDE-3	20	38	38	
ASDE-X			35	
Totals	**22**	**38**	**73**	
Weather				
NEXRAD	154	154	154	154
TDWR	45	45	45	45
Totals	199	199	199	199

* JSS = Joint Surveillance System (combined FAA/DOD organization).

En Route — Both primary and secondary radars are used today for en route surveillance. Primary radars are termed Air Route Surveillance Radars (ARSRs) and are often referred to as Long Range Radars (LRRs). These radars have a range of approximately 200 to 250 nmi, and detect weak echoes from aircraft at maximum range) that rotate approximately once each 10 to 14 seconds.

The original en route primary radars, designated AN/FPS-117, were provided by the Department of Defense (DOD). FAA, jointly with the DoD and other government agencies, has since developed the ARSR-1 , -2, -3, and -4 radars. Each has some weather detection capability, in addition to the ability to detect aircraft. The ARSR-4 is now being deployed around the perimeter of the U.S. to replace earlier LRSRs.

Secondary radars are collocated with each en route primary radar. Three series of Air Traffic Control Beacon Interrogators (ATCBI) are currently deployed: ATCBI-3, -4, and -5. These have the capability to operate in Modes A and C (i.e., to determine aircraft identification, range, bearing, and transmitted barometric altitude). In 1996, the ATCBI-3s have all been in service for over 30 years. The newest ACTBI-4s have been in service 27 years, and the newest ATCBI-5s have been in service 23 years. Commercial firms offer monopulse SSRs (MSSRs), which are similar in functionality to the ATCBI series with and without discrete addressing capability.

During the 1990s deployment of Mode S SSRs was begun. Mode S radars have four advantages over the ATCBI series: (1) improved range and azimuth accuracy; (2) elimination of synchronous garble ("collision" of replies from aircraft at nearly the same range and azimuth) by interrogating aircraft individually; (3) an air-to-ground data link capability; and (4) fewer interrogations are needed. Mode S SSRs have the capability to interrogate using Mode A and Mode C formats.

The MSSR and Mode S SSR's monopulse antenna is located on the same revolving shaft, either as a "chin-mounted" antenna or immediately above the primary radar's antenna. For example, on ARSR-4, the beacon antenna is chin-mounted. Other beacon sites employ NADIF (NAFEC Dipole Fix) secondary surveillance antennas, which are integral to the primary radar antenna and use its reflector. There are also a few "beacon only" sites, where a secondary radar is installed without an associated primary radar.

Terminal — Terminal area surveillance today has the same basic architecture as the en route domain. Terminal area primary radars are termed Airport Surveillance Radars (ASRs), and are usually located near one or more airports having air carrier service. ASRs have a range of approximately 60 nmi and transmit on 2700-2900 MHz. To obtain the more frequent surveillance data needed for terminal ATC, ASR antennas rotate once each 4 to 5 seconds. ASR-4, -5, -6, -7, -8, and -9 units are now installed. (Systems from the ASR-4, -5, and -6 series will be phased out over the next few years.) The ASR-11 with integrated MSSR is now under development, and a multi-purpose airport surveillance radar (MP-ASR) is being researched.

A beacon radar is collocated with each ASR. These SSRs have the same basic designs as those used for en route surveillance and are drawn from the ATCBI-3, -4, -5, or Mode S series. However, since the service range is shorter, a lower power transmitter is used.

Surface — At larger airports, surveillance of aircraft on the surface is performed by a primary radar, termed Airport Surface Detection Equipment (ASDE). The ASDE-3 is the latest generation of that series and is currently operational at many major airports. Other airports must rely on visual surveillance from the airport tower. The FAA is currently investigating using smaller, low-cost X-band marine radars (termed ASDE-X) at airports where ASDE-3s may not currently be cost beneficial.

D. RADAR TECHNICAL LIMITATIONS

1. Primary and Secondary Radars

Primary radars, and by necessity collocated secondary radars, have siting restrictions imposed by the need to minimize clutter. Primary radars are sited to look at aircraft above the horizon (i.e., against the sky as background). For example, to operate effectively in a terminal area, an ASR radar must be placed on or near the busiest airport, so that the propagation paths are essentially horizontal or somewhat upward looking. Placing an ASR at an elevated location where it would "look down" on the terminal area could generally provide better visibility of aircraft, but would introduce unacceptably large levels of clutter from terrain, structures, automobiles, etc. (9)

A major disadvantage common to primary and secondary radars is that they can only detect targets within line-of-sight of their respective antennas. As shown in Figure I- 1, a radar can suffer "blind spots" at one or more azimuth angles due to signal blockage by terrain and man-made structures. To achieve the gain necessary to detect distant targets, primary and secondary radar antennas can only see targets up to elevation angles of 30 to 40 degrees. There is a cone-shaped region directly above the radar ("cone of silence") where targets cannot be detected. The curvature of the earth imposes a minimum altitude requirement for aircraft to be visible to a radar. Aircraft 40 nmi from the radar site must be above 1000 feet to be detected, while aircraft 200 nmi away must be above 26,500 feet to be seen.

2. Primary Radars

One major shortcoming of primary radars is that they do not automatically associate an identification tag with a target. Controllers can (and do) create an identification tag, often after requesting, via voice communications, that an aircraft change heading. They may then select the aircraft whose displayed track changes correspondingly. However, this process is time-consuming and increases controller workload. Second, despite the clutter-rejection capabilities

---

9 ADS-B overcomes this limitation; see Chapter II.

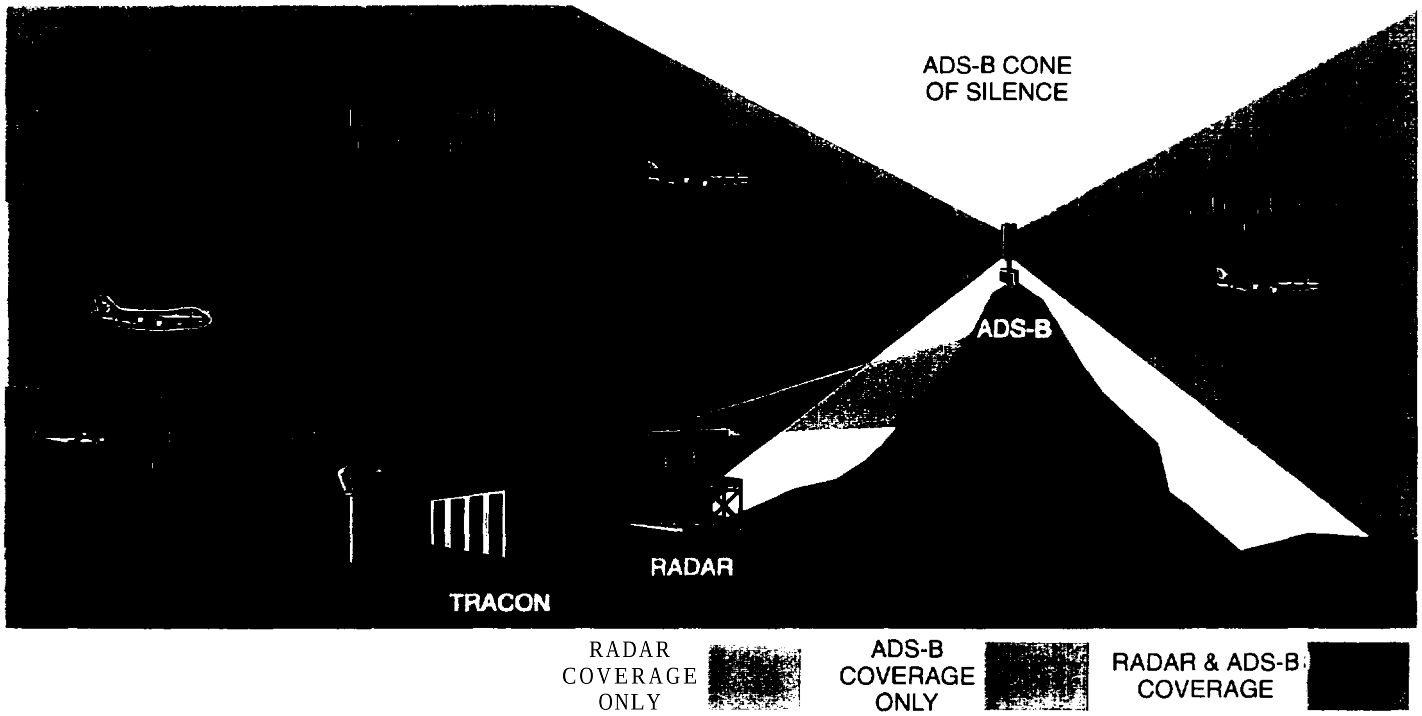

Figure I-l. Radar Coverage Limitations

of modem Moving Target Indicator and Detection (MTV/MTD) circuitry, clutter caused by precipitation and moving objects remains a problem. Anomalous propagation, or cars moving on a nearby roadway, can distract the controller and mask aircraft returns. Primary radar specifications only require detection of at least 80% of the targets in a single scan in their coverage region. Another major shortcoming of primary radars is that they provide no altitude measurement capability except for ARSR-4, which has 3,000 feet altitude accuracy.

3. Secondary Radars

Secondary radars can only detect cooperative targets carrying transponders. Aircraft that enter the surveillance coverage area without an operating transponder — either inadvertently (blunders) or intentionally (intruders) — are not detected.

For the ATCBI-3, -4, and -5 equipment series, fruit, synchronous garble, and azimuth accuracy are significant technical issues. All secondary radars operate on the same frequencies (ground interrogations on 1030 MHz, aircraft replies on 1090 MHz). It is not unusual for an aircraft to be within the coverage area of two or more beacon radars at the same time, and generating replies to all interrogators. Fruit refers to the interference (to the reply from a given aircraft to a given ground station) caused by replies from other aircraft to other radars. Synchronous garble refers to the mutual interference that arises when the replies from two aircraft to a given interrogation overlap for several scans. Both fruit and synchronous garble cause some transponder returns to be unintelligible. The sliding window technique (detecting sequences of target replies during the antenna dwell time) used by the ATCBIs for measuring azimuth requires many more interrogation/reply pairs than does the monopulse technique employed by Mode S. This significantly increases the likelihood that fruit and garble will occur. The ATCBI azimuth measurement error is twice that of the ASR-9 and four times that of the Mode S.

The Mode S design includes features that address the shortcomings of the ATCBI radars discussed above. Nevertheless, it is estimated that Mode S fails to detect up to 1 percent of the cooperative targets in its coverage region.

E. SOLUTIONS TO RADAR LIMITATIONS

Technology advances in satellite navigation, data communications, and solid-state electronics have enabled development of alternative surveillance techniques that overcome many of the limitations of mechanically scanned radars. Two new related systems are the Traffic Collision Avoidance System (TCAS) and Automatic Dependent Surveillance - Broadcast (ADS-B). Both are discussed briefly in this section.

1. Traffic Collision Avoidance System

The term “collision avoidance” refers to aircraft-to-aircraft interactions intended to avoid in-air collisions of the aircraft involved. Collision Avoidance Systems (CASs) serve as a “last line of defense” and only provide warning or instructions to the flight crew when a near-miss situation is imminent. CASs are not substitutes for “general purpose” ATM surveillance systems that provide information about all aircraft within a coverage region of thousands of square miles.

During the early 1990s the FAA required certain commercial aircraft to carry Traffic Alert and Collision Avoidance System (TCAS) equipment. TCAS uses the 1030/1090 MHz frequency bands, the same frequencies used for secondary surveillance radar systems. TCAS aircraft randomly “squitter” their identity and altitude at 1090 MHz so that other TCAS-equipped aircraft can identify their presence. When both aircraft are TCAS-equipped, the TCAS equipment will communicate on the 1030 MHz band and agree upon a coordinated collision avoidance maneuver. TCAS also uses whisper/shout interrogation on 1030 MHz to protect itself against Mode A/C-equipped aircraft and to obtain range on other TCAS aircraft when their presence is detected based on squitter reception.

The FAA is now developing a TCAS IV system. TCAS IV uses some of the same aircraft equipment as ADS-B. The aircraft periodically broadcasts an ADS-B message on 1090 MHz containing the aircraft’s identification, GNSS derived position, and other information (velocity, maneuver intentions, etc.). A second TCAS IV-equipped aircraft in range will receive this message and thus know the relative location of both aircraft. If the second aircraft determines that coordinated changes in trajectory are required, it will communicate with the first aircraft on 1030 MHz.

2. Automatic Dependent Surveillance - Broadcast

While TCAS is a specialized system, used for aircraft-based surveillance of other nearby aircraft, ADS-B extends the same techniques to ground-based surveillance over significantly greater ranges. ADS-B is intended as an eventual replacement for ground-based radar surveillance.

ADS-B uses aircraft broadcast of satellite-derived navigation data to a network of ground stations. The same broadcast information is also received by nearby aircraft, where it is used for collision avoidance. The ADS-B concept is fully described in Chapter II.

II. ADS-B CONCEPT

A. CONCEPT DESCRIPTION

The most promising new surveillance system is ADS-B, which provides both ground-based and aircraft-based surveillance. Aircraft position is derived by an onboard satellite navigation receiver and is broadcast using a transponder to ATM facilities on the ground and to other aircraft nearby (Figure II- 1). The navigation system is one of the Global Navigation Satellite System (GNSS) constituent systems, particularly the Global Positioning System (GPS) and the Wide Area Augmentation System (WAAS) associated with it. Aircraft broadcast communications follow line-of-sight transmission paths on the international transponder reply frequency, 1090 MHz.

The preferred ADS-B ground station configuration has triple coverage. In addition to providing better airspace coverage and greater fault tolerance for ADS-B, triple coverage enables passive multilateration to be implemented at the ground stations with only a software change to the equipment used for ADS-B and no change to aircraft equipment (see Figure II-2). (10) During the transition period, multilateration will operate on Mode C/S replies and squitters, TCAS II replies and squitters, and TCAS IV squitters. Multilateration will initially be a backup to Secondary Surveillance Radar (SSR), then will become the principal surveillance system for non-ADS-B aircraft. When ADS-B avionics become widely used, multilateration will furnish real-time integrity monitoring on GNSS data in ADS-B messages and will also serve as the backup system in the event of GNSS signal or equipment failure.

For a minimum surveillance altitude of 6,000 feet, triple coverage requires approximately 300 en route sensor sites (most using 6-sectored antennas). From 5 to 11 sensor sites will be needed for each of the approximately 240 TRACONs. Individual sensor sites will not have redundant equipment; in effect, the redundant equipment that would be necessary with single or double coverage will be deployed at additional sites. This will provide better coverage, greater robustness to failures, and multilateration capability at little additional cost.

The technical advantages of ADS-B derive in part from the fact that it does not involve direct measurement of the aircraft position relative to a ground station (see Table II-l). ADS-B ground stations receive accurate aircraft-derived position information using a communications link involving small non-rotating antennas. The azimuth measurement accuracy limitation imposed by scanning radar antennas is thereby overcome.

Without a scanning antenna, ADS-B surveillance data rates can be significantly higher than radars provide. Higher rates will support FAA and user operational benefits. For example, studies

---

10 Information provided by Carmine Primeggia, ASD- 100.

being conducted under the free flight program have shown that the conflict rate is significantly reduced when the separation minimum is reduced to below 3 miles. (11) The improved accuracy of

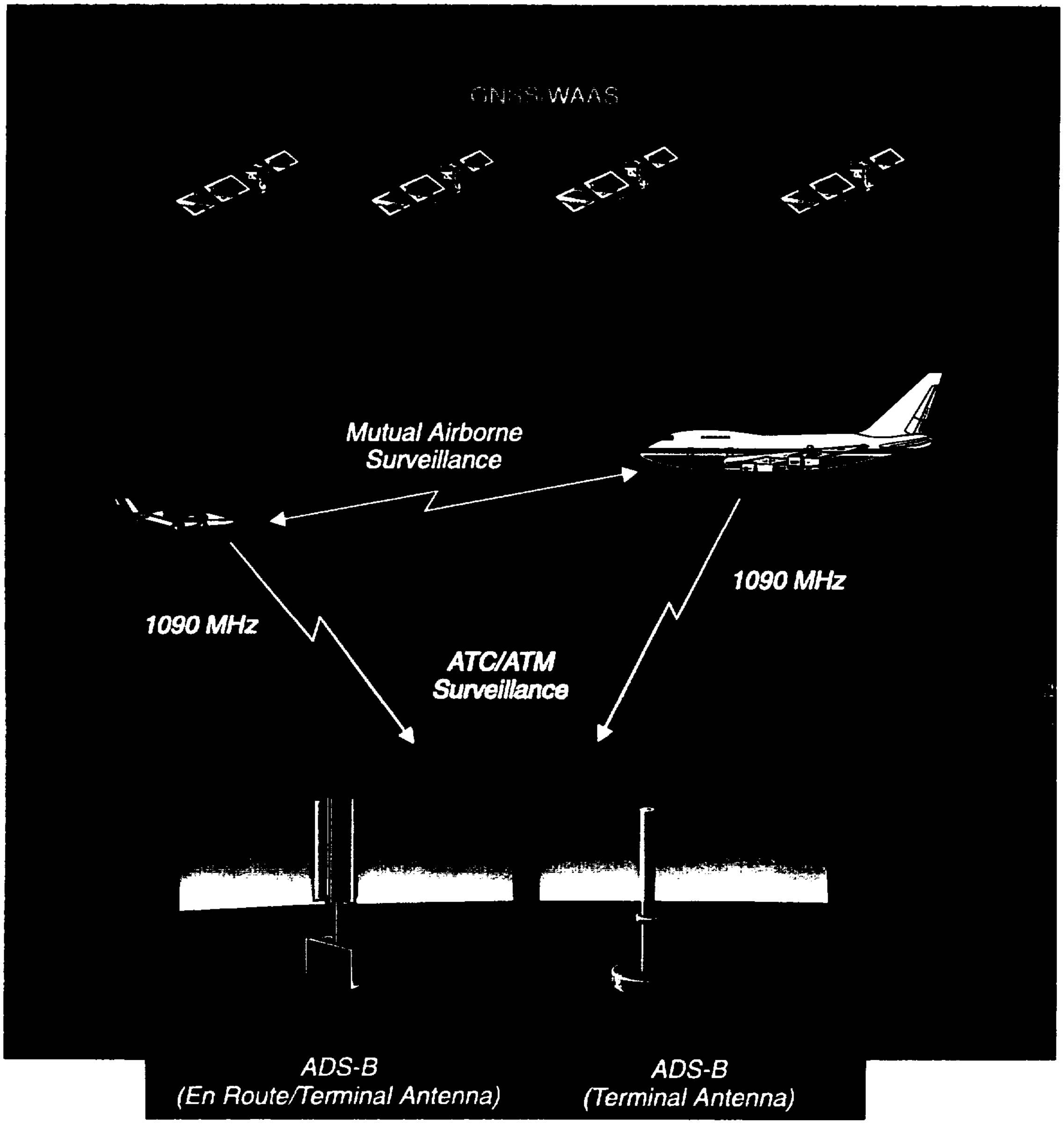

Figure II-l. ADS-B Concept

Mode S and MSSR systems will permit use of 3-mile separation out to the full 60-mile range of terminal radars. To take full advantage of the benefits available from the use of smaller separation minima, it may be necessary to reduce the en route scan time below the current 10 to 15 seconds (to be verified). ADS-B will provide both the higher accuracy and data rates needed to support the use of reduced separation minima throughout the NAS, wake vortex conditions permitting.

---

11 Information provided by Lewis M. Buckler, AND-400.

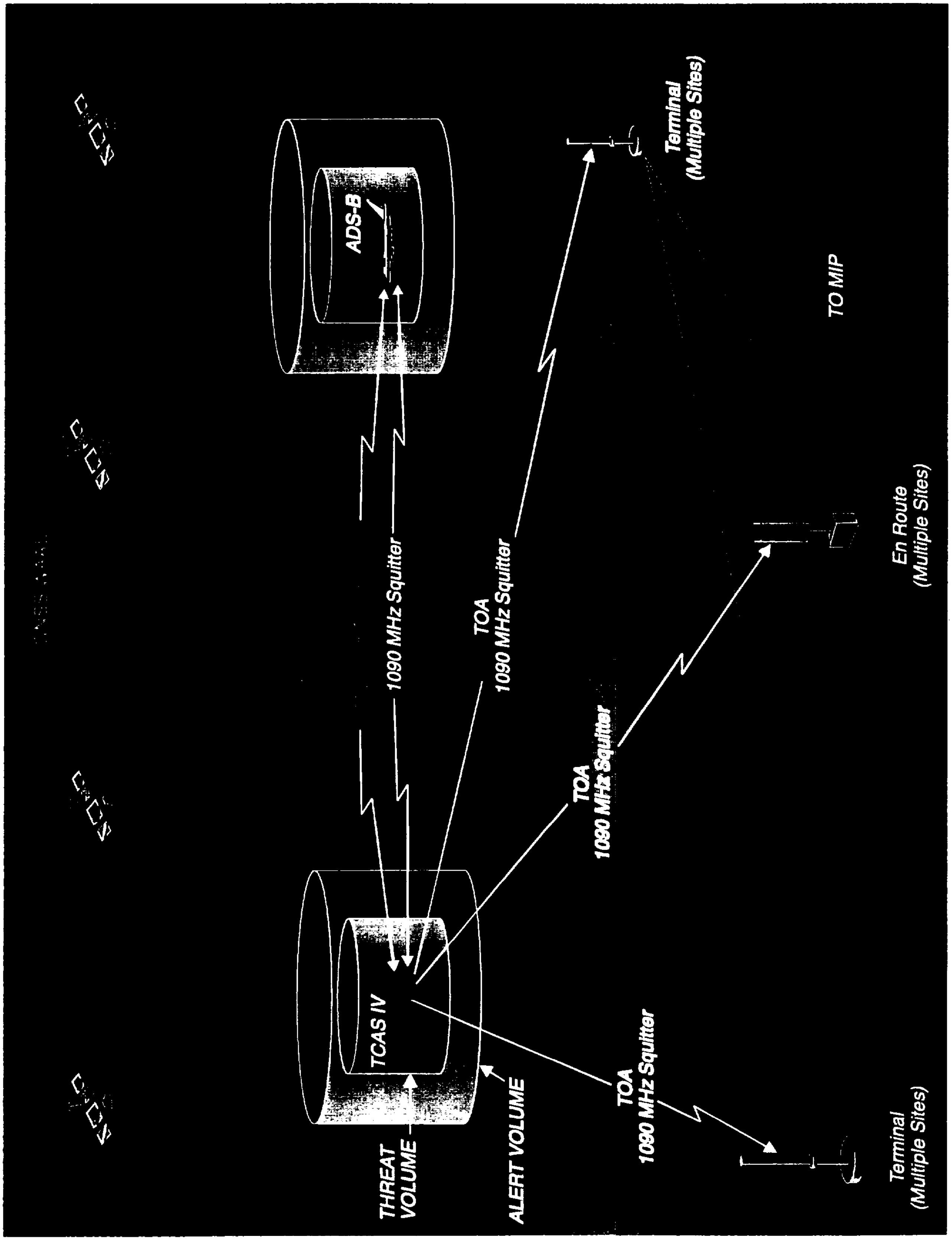

Figure II-2. Multilateration Concept

Table II-l. ADS-B Advantages and Disadvantages

Advantages	Disadvantages
Involves simple, low-cost ground stations, enabling significant FAA cost savings and installation of stations providing redundant coverage	Users must purchase new avionics, possibly prior to end of useful life of current transponders
Surveillance data rate not limited by mechanically rotating antenna	Reduces the current independence between surveillance and navigation functions
Azimuth accuracy not limited by size of ground antenna	Required capacity of air-ground data link in terminal areas may exceed 1090 MHz capabilities
Stations can be sited on hilltops, rooftops, and other elevated locations, providing better aircraft visibility	Weak satellite navigation signals are susceptible to interference over wide areas, necessitating a capable backup system
Aircraft can provide ATM with more than position and ID information: e.g., velocity, altitude, maneuver intentions, weather data	Automation system development must be closely coordinated with surveillance
Provides improved surveillance data quality that will facilitate automation of ATM functions	
Multilateration system can be implemented with the same ground stations and additional software, providing both a transition surveillance system using current aircraft transponders, and integrity monitoring and backup capability with ADS-B.	

ADS-B ground station antennas do not suffer from the siting limitations imposed on primary (and by necessity collocated secondary) radars. Primary radars must be placed at low elevations in order to "see" aircraft against (mostly) a sky background, thereby minimizing clutter returns from terrain, man-made structures, automobiles, etc. In contrast, ADS-B sensors are placed at the highest available location to provide improved coverage, particularly for low-flying aircraft. (12)

Cost of an ADS-B ground station is a small fraction of that for any FAA radar. Consequently, while a single radar installation could be justified for a given area (e.g., terminal area or airport surface), several ADS-B ground stations could be deployed in the same area to provide broader and more robust coverage at a lower total cost.

ADS-B transponders are expected to have the capabilities shown in Table II-2. To adopt ADS-B as the principal surveillance system, every aircraft operating in controlled airspace will ultimately have to be equipped with an ADS-B transponder. With current Mode S/TCAS equipment capabilities, ADS-B will provide squittered surveillance information to other in-flight aircraft at ranges up to 40 nmi (without changing the sensitivity of aircraft receivers) and to ground stations up to 95 nmi in range (with six-sector antennas or low-noise receivers).

[12] **Information provided by Dr. Douglas Campbell, Conwal.**

Table II-2. ADS-B Transponder Capabilities

Frequency I Mode	Transmit	Receive
1030 MHz	• TCAS II interrogations* • Coordination messages to other A/C	• SSR and TCAS II interrogations* • Coordination messages from other A/C
1090 MHz	• Own aircraft information" (squittered) • Replies to SSR and TCAS interrogations*	• Squittered ADS-B and TCAS information** from other A/C • TCAS II replies

*Capability only required during transition period, for compatibility with existing systems.
**Identification, latitude/longitude, altitude; optionally, GPS time, ATCRBS code, velocity, maneuver intent, weather parameters, other data.

From the user's perspective, there is no difference in ADS-B operation from domain to domain except for the update rate, which is adapted based on operating domain. A relatively high rate will be used in the terminal and surface domains (1 to 5 second spacing). The rate will be lower in the en route domain (5 to 12 second spacing).

ADS-B will incorporate Remote Maintenance Monitoring System (RMMS) functions. As for all new systems, a number of issues must be resolved before ADS-B can be implemented on a widespread basis.

B. ADS-B GROUND FACILITIES AND COMMUNICATIONS

1. General Description

ADS-B requires a ground infrastructure comprised of three facility types — sensors, servers, and Multisensor Interface Processors (MIPs) — and interfacility communications links. Approximately 300 en route sensor facilities are arranged in a mesh of interlocking triangles. Figure II-3 shows a simplified block diagram of the en route infrastructure. An ADS-B server (processing facility) is collocated with each en route sensor. All ADS-B messages received by a sensor are fed to the collocated server and the servers at the nearest stations. After processing by the server, target information is sent to the MIP. Approximately 15 servers will feed one MIP, which may be located at an ARTCC. ARSR (JSS) primary radars and collocated secondary radars will also supply data to MIPs. Figure II-4 depicts the data flow between a typical en route sensor site (at center of the diagram) and the server facilities with which it interacts.

Terminal area ADS-B systems have the same three facility types as the en route system. However, they are interconnected differently, to account for the different traffic loads, distances, and geometries involved (Figure 11-5). Each of the approximately 240 terminal area ADS-B systems has between five and eleven sensor facilities. Data from all sensors in a terminal area are fed to the single terminal ADS-B server, and then to the MIP for that terminal area. Both are expected to be located at the TRACON. In addition, the terminal ASR and collocated SSR will provide data to the MIP.

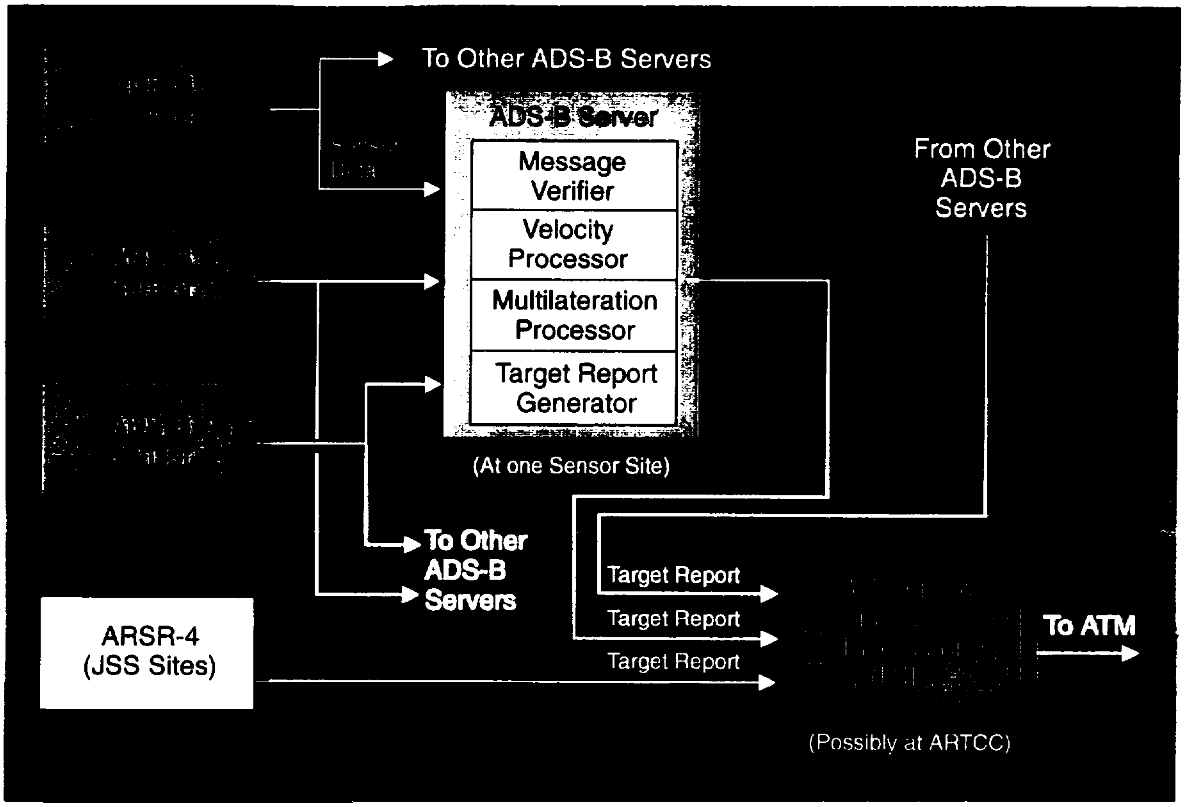

Figure II-3. Simplified Block Diagram of ADS-B En Route Ground Infrastructure

To facilitate air traffic management and expedite the introduction of Free Flight, target data from the terminal server will be provided to nearby en route MIPS. Similarly, data from en route servers will be fed to terminal MIPS.

Up to 240 of the largest airports will use ATIDS (ASTA Target Identification System) to receive ADS-B messages from 3 to 7 on-airport sensors and provide controllers with target location and identity information. For ATCRBS-equipped aircraft, ATIDS will perform multilateration on Mode A/C/S transponder messages. The remaining 200 towered airports with lower traffic density will receive one ADS-B sensor site (which could also be a terminal sensor), allowing surface aircraft messages to be collected but not providing backup multilateration capability. The terminal area MIP will receive target messages from ATIDS (for larger airports) or a single airport sensor (for smaller towered airports). Users on the surface of the approximately 8,000 non-towered airports will rely on GNSS navigation services and aircraft-to-aircraft surveillance. Table II-3 summarizes the projected inventory of ADS-B ground facilities.

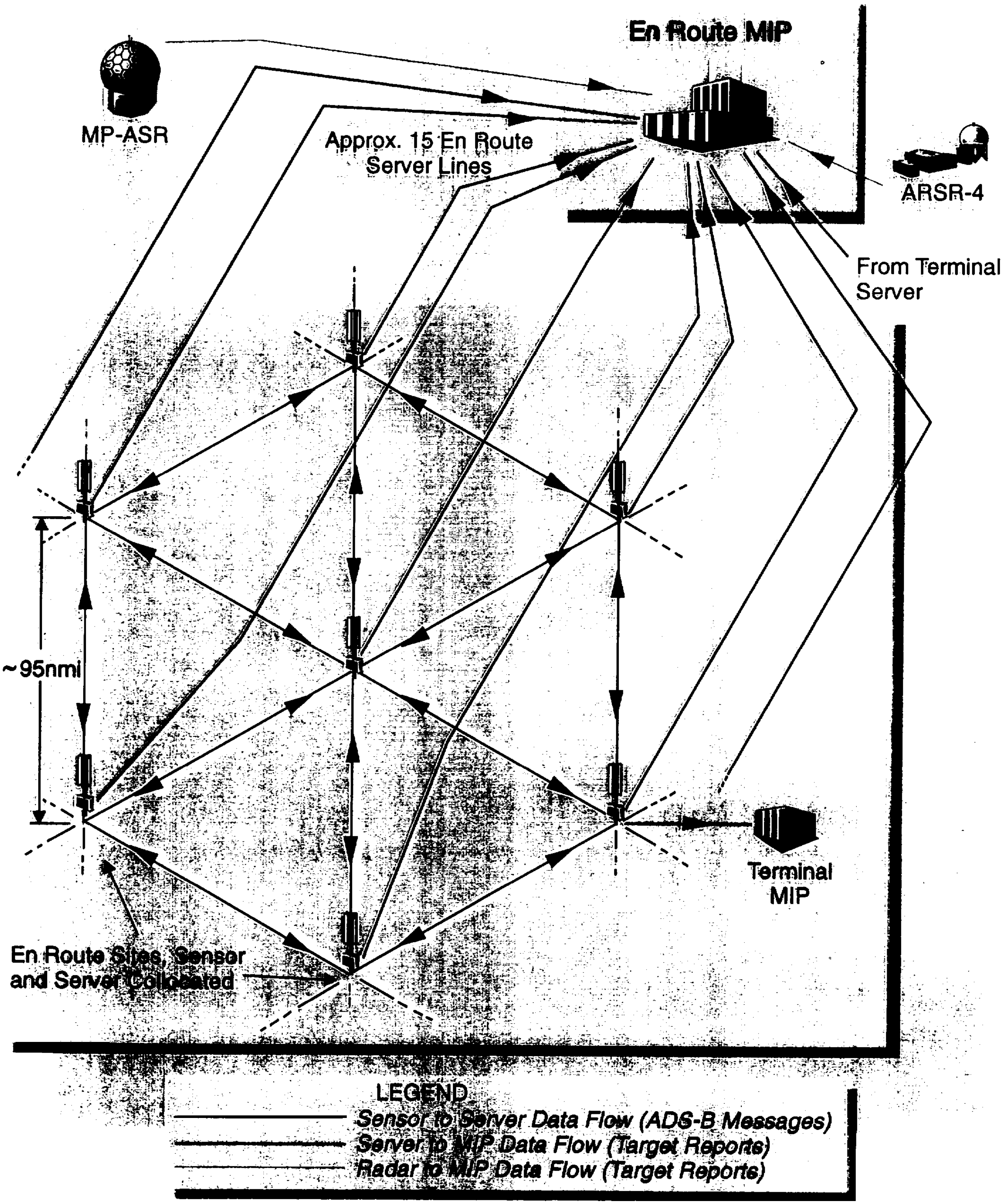

Figure II-4. Data Flow Between ADS-B En Route Facilities

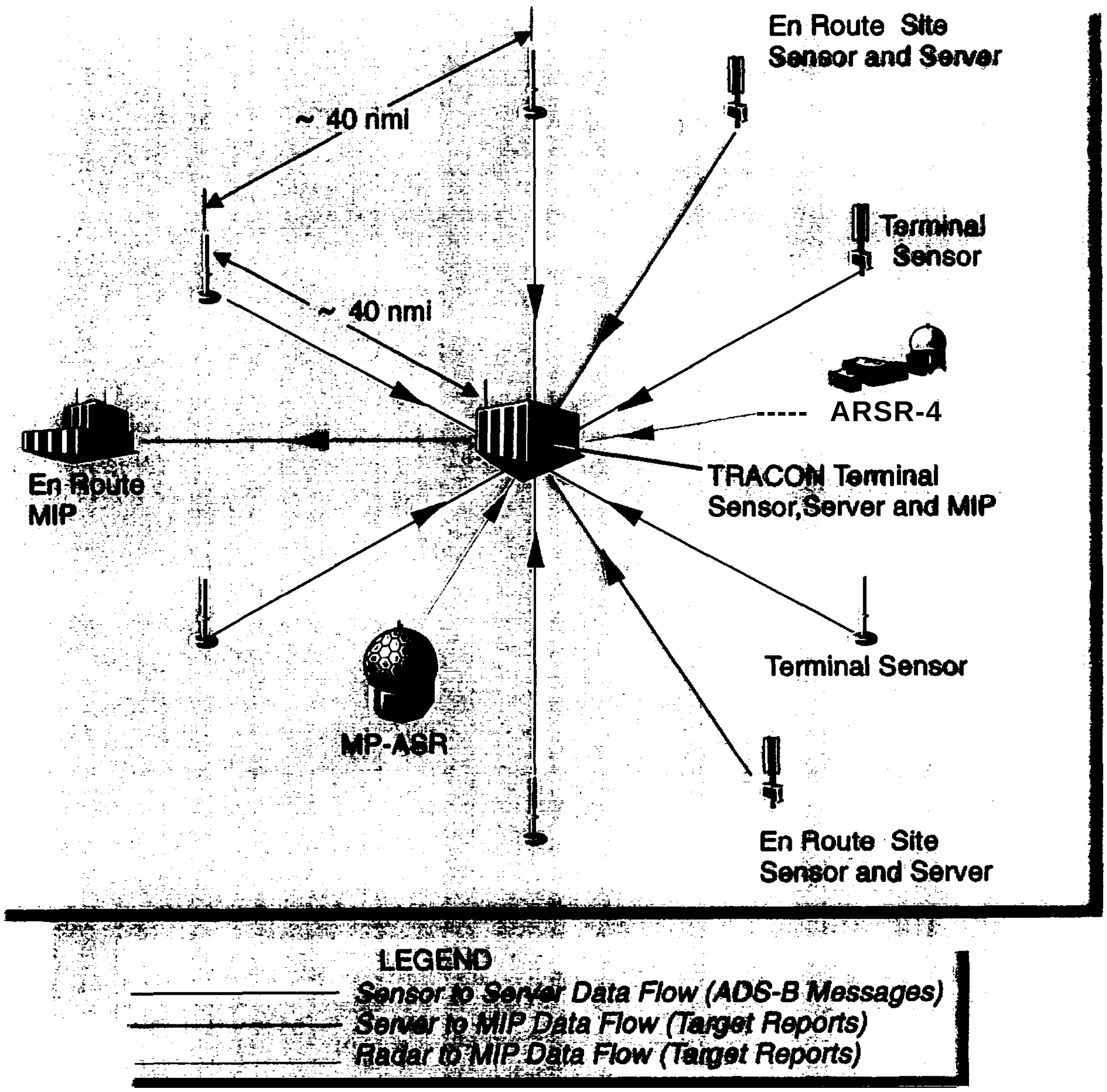

Figure II-5. Data Flow Between ADS-B Terminal Facilities

Table II-3. Projected ADS-B Inventory

Domain/Facility	2000	2005	2010	2015
En Route				
Sensor	100	200	300	300
Server	100	200	300	300
MIP	0	5	20	22
Terminal				
Sensor	560	1320	1680	1680
Server	80	160	240	240
MIP	80	160	240	240
Surface				
ATIDS	210	500	930	1640*
Server	35	100	120	240
MIP	0	0	0	0

*240 towered sites with 6 sensors each and 200 towered airports with 1 sensor each.

2. Sensor Facilities

ADS-B sensor facilities comprise an antenna, one or more 1090 MHz receivers, a data management computer, and modems for communicating with remote ADS-B server facilities. En route sensor facilities will usually have a six-sector antenna, to provide sufficient gain to detect squittered messages from aircraft up to 95 nmi away. Each sector of a multi-sector antenna will have a dedicated receiver.

Terminal and surface sensor facilities normally have an omni-directional antenna and a single receiver, providing a coverage radius of approximately 40 nmi. For some terminal sites, a low-noise receiver can be used to extend the surveillance range. The data management computer at a sensor facility will validate received ADS-B messages and format a corresponding message for transmission to ADS-B server facilities. Typically, dedicated landlines are used for interfacility communications in all domains.

3. Server Facilities

An ADS-B server facility will host four computational functions: (1) Message Verifier, (2) Velocity Processor, (3) Multilateration Processor, and (4) Target Report Generator. It is expected that these can all be performed in a single work-station class computer, but sizing and timing investigations have not been performed.

All aircraft messages received from sensor sites are routed to the message verifier. Here, redundant, normally identical, messages are compared to identify errors that may have occurred in transit from the aircraft. However, redundant copies of all messages are not always received, so verification of correct transmission is not always possible.

Some ADS-B messages contain aircraft velocity (rather than latitude/longitude) data. When a velocity message is received, the velocity processor calculates a new aircraft position using the current velocity and previous position information.

All verified messages are sent to the multilateration processor. Messages from the same aircraft squitter are processed in combination — using the rho-rho-rho technique if a GPS time tag is included in the messages, or the hyperbolic technique if there is no time tag but barometric altitude is included — to derive the aircraft's position. When the ADS-B message contains latitude/longitude or velocity data (baseline mode of operation), the multilateration solution serves as an independent integrity check on the aircraft navigation data. When the aircraft message does not contain navigation information, the multilateration solution serves as a substitute source of surveillance data.

The target report generator selects among the available aircraft position information, generates an aircraft target report, and forwards it to the MIP. Target reports sent to the MIP should include data fields to indicate: (1) the message type used to generate the position report (ADS-B position, ADS-B velocity, or multilateration), to facilitate subsequent target tracker calculations; and (2) the amount of corroboration of the position report (e.g., number of verifying ADS-B messages if any, and degree of agreement with multilateration solution if any).

4. Multisensor Interface Processors

The MIP performs data fusion, combining redundant target reports from (1) sensors of the same type, and (2) different sensor types. There are usually redundant reports from several ADS-B servers. Aircraft flying near the minimum surveillance altitude can trigger reports from three en route ADS-B servers, while aircraft at FL 400 can cause ten or more reports. Target reports from dissimilar sensors are also prevalent. During the transition period reports are derived from four different sensor types: ADS-B, multilateration, primary radars, and secondary radars.

Data for the different sensor types are expressed in different coordinate frames. Primary and secondary radars measure range and bearing of aircraft relative to the radar site (rho-theta coordinates). Secondary radars also provide barometric altitude for aircraft equipped with Mode C reporting transponders. GNSS receivers measure aircraft latitude, longitude, and altitude relative to the global WGS84 ellipsoidal model for the earth; ADS-B reports may use WGS84 or transform the data to another frame such as NAD83. Multilateration measures aircraft 2- or 3-dimensional position relative to the ground stations.

Depending upon the design of the target trackers employed after ADS-B is introduced, the MIP may be required to transform target reports to a common coordinate representation. The transformations themselves are straightforward calculations. However, to obtain full benefit of ADS-B accuracy, the characteristics of the sensor must subsequently be provided to the tracker. (13) This can be done by forwarding data provided to the MIP by the server concerning the type of sensor used and the degree of agreement with redundant measurements.

An important issue in developing algorithms for the MIP is reconciling systematic differences among the sensor types (target registration problem). At present, time-coincident

[13] The reduced azimuth accuracy of radars is built in to current tracker algorithms, and causes lags in the detection of aircraft turns. Redesigning the trackers to build in the error characteristics of other sensors allows such lags to be significantly reduced. Providing maneuver intention information may enable a further improvement in tracking.

target reports from dissimilar sensors are likely to have unacceptably large, relatively constant offsets. To effectively combine ADS-B and radar data, it is likely to be necessary to survey radar sites in WGS84 coordinates. Similarly, to combine multilateration and ADS-B data, the ADS-B ground antennas would have to be be surveyed in the WGS84 or NAD83 frame. (Surveys relative to the WGS84 frame to an accuracy of approximately 1 meter can be done simply by placing a GPS/WAAS receiver at a site and averaging the readings over a week or so. Surveys to a few centimeters of accuracy can use GPS kinematic techniques, whereby the site's location relative to permanent geodetic reference points is determined.) To combine radar and multilateration data, the relative positions of the two sensor sites must be known. These measurements can be made using classical surveying techniques or GPS methods.

It is also possible that the current radar data processing software will be found to introduce offsets that do not affect the relative positions of the targets; they will have to be eliminated if the radar data are to be combined with data from other sensors. A common time reference for all sensors is needed to accurately combine their data.

C. ADS-B BACKUP MODES OF OPERATION

ADS-B surveillance involves three basic elements : GNSS satellites, avionics, and ground station electronics. Backup modes of operation must be provided that ensure retention of surveillance capability in the event of malfunction of any single element. That is, the system must not have a single point of failure. Table II-4 summarizes the effects of element failures and identifies backup options. The following paragraphs address the elements individually.

Table II-4. ADS-B Element Failure Effects and Backup Options

System Element	Number of Aircraft Affected by Failure	Function(s) Lost by Failure	Backup Options (for at least Ground Surveillance)
Ground Station	• All in area approx. 190 nmi diameter	• Ground surveillance	• Redundant equipment (at single coverage stations) • Redundant coverage (additional stations)
Avionics **- GNSS Receiver** **- ADS-B Xponder**	• One	• Ground surveillance • Air-to-air surveillance • Navigation	• Redundant similar equipment • Additional dissimilar equipment
GNSS Signals	• All in area several 100 nmi diameter	• Ground surveillance • Air-to-air surveillance • Navigation	• Multilateration (several options) • Separate navigation system • Secondary radar

1. Ground Station Failures

Redundancy Options — ADS-B service can be maintained in the presence of a ground station failure either through the use of redundant equipment at that station or by utilizing data from another station that provides redundant coverage. With redundant coverage, the need for redundant equipment at individual stations is correspondingly reduced. For example, to achieve a given level of reliability throughout a region, providing double coverage would not result in doubling the amount of equipment used for single coverage.

Deploying stations that provide redundant coverage has several advantages over redundant equipment at fewer stations, and is recommended. Redundant stations provide better coverage of the airspace (signal paths are shorter and have higher elevation angles at ground stations). Redundant coverage is also more robust to certain failures -e.g., interference to the ADS-B messages, loss of power, or physical damage to one station. Third, with redundant coverage, multilateration techniques can be used to protect against failure of the GNSS signals with very little additional equipment costs.

Figure II-6 shows a plan view of stations providing single coverage of an area. For surveillance coverage down to 6,000 feet, the coverage radius of an en route station is 95 nmi (presuming a six-sector antenna or a low-noise receiver is used). An estimated 100 stations are needed to provide coverage of CONUS en route airspace. Geometrically, the stations are located at the vertices of interlocking equilateral triangles having sides equal to 63 (approximately 1.7) times the coverage radius of a station (two triangles are outlined by dotted lines in the figure).

Dual coverage can be achieved by adding a second similar grid of stations at the center of half of the single coverage triangles (illustrated in Figure II-7 by adding new stations using red symbols at the center of the “north pointing triangles” in Figure II-6). Triple coverage can be attained by adding another set of new stations at the centers of the other half of the single coverage triangles (green symbols in Figure II-8). Thus a set of stations providing single coverage can be augmented, without shifting the location of the original stations, to achieve the most efficient dual and triple coverage patterns. This feature may be particularly useful in high density areas. For triple coverage, the stations form a mesh of equilateral triangles with sides equal to their coverage radius (e.g., shaded area at upper left-hand comer of Figure II-8). (14)

2. Avionics Failures

Barring the use of primary radar, avionics failures can only be redressed by alternative equipment on the aircraft. For both the ADS-B transponder and GNSS receiver, either redundant units of the primary equipment or dissimilar avionics may be utilized. For some impossible system configurations, the ADS-B transponder serves as part of a backup system to the GNSS receiver.

Redundant ADS-B transponders will likely be carried by most non-recreational users. However, alternative squitter links could be employed — e.g., VDL (VHF digital voice and data link) — to back up the 1090 MHz squitter link. Primary radar will be retained in terminal areas, providing additional protection against transponder failures and unequipped aircraft.

Redundant GNSS receivers will be carried by many aircraft. Aircraft may also carry avionics for other navigation systems such as VOR/DME, Loran-C, INS, or a combination thereof. However, VOR/DME and Loran-C are scheduled to be phased out, and INSs have been too costly

14 Information provided by Dr. E. Michael Geyer, TASC.

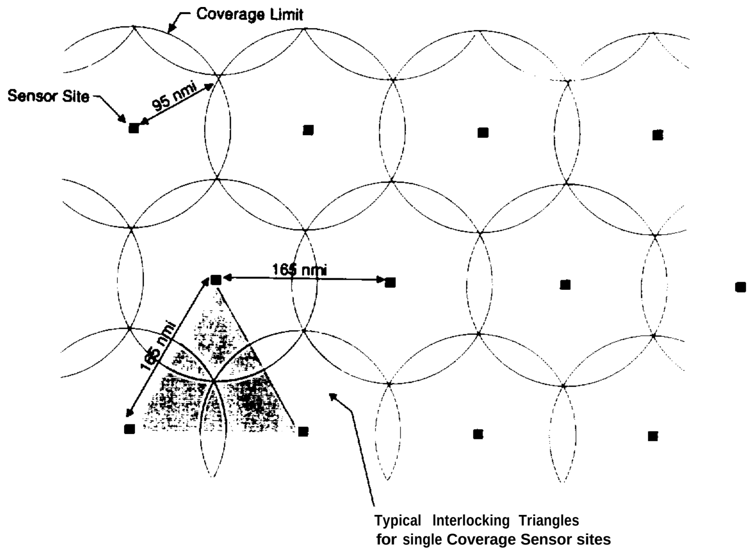

Figure II-6. Single Coverage Ground Station Arrangement

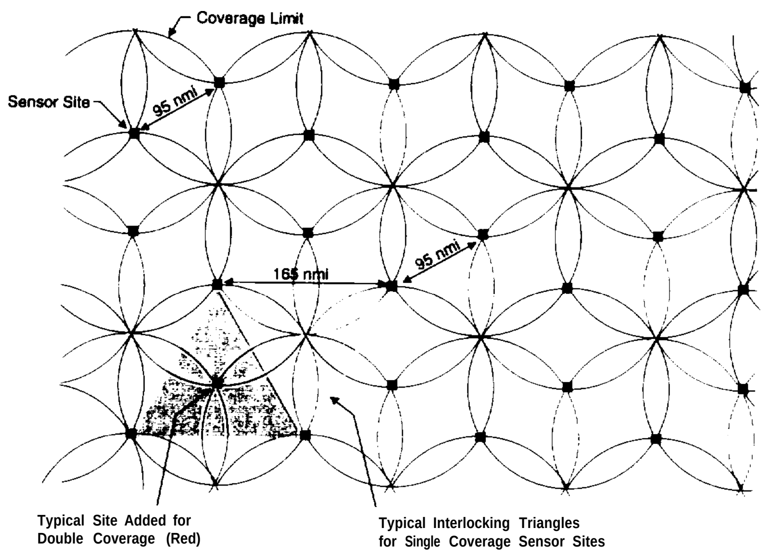

Figure II-7. Double Coverage Ground Station Arrangement

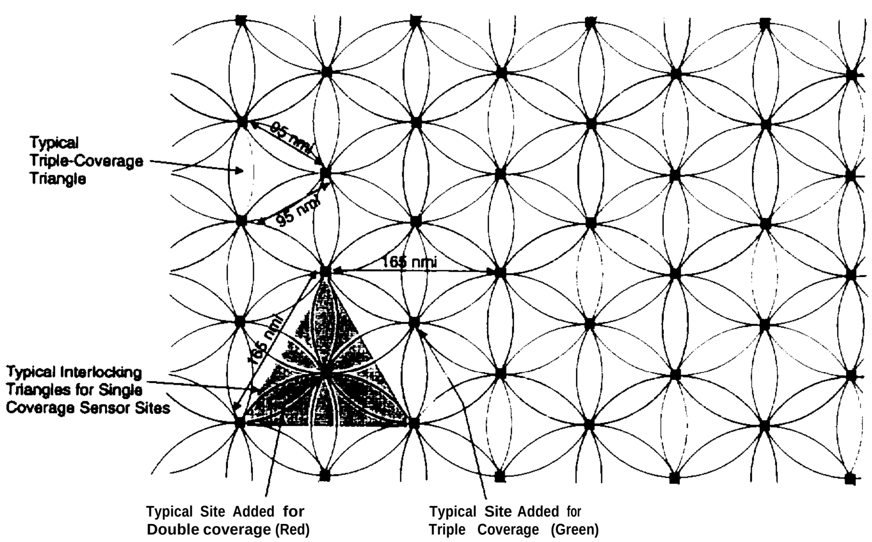

Figure II-8. Triple Coverage Ground Station Arrangement

for most general aviation users. If (as recommended) a multilateration technique is used to back up the GNSS signals, navigation capability can be provided to the aircraft via "automatic dependent navigation" (data linking position information to aircraft) or by an air-derived multilateration solution.

3. GNSS Signal Failures

Preferred Multilateration Technique — Multilateration refers to calculation of aircraft position, either on the ground or in the aircraft, using measurements of true ranges or pseudoranges between aircraft and ground stations. True range can be measured using two-way RF transmissions (initiated either by the aircraft or the ground). True range can also be measured using one-way RF transmissions in either direction, provided there are synchronized clocks on the ground and in the aircraft; either a time tag can be inserted in the message or transmissions can follow a prearranged schedule. Rho-rho (for two available ground stations) or rho-rho-rho (for three available stations) processing is used with true range measurements. Pseudoranges are range measurements corrupted by an offset between ground and aircraft clocks, and can be obtained by one-way RF transmissions without synchronized clocks. Hyperbolic processing based on differences in signal Time of Arrivals (TOAs) is used with pseudorange measurements. On the ground, true range or pseudorange measurements can supplemented with angle measurements from a multisector antenna.

A total of 14 multilateration configurations were considered for the ADS-B backup system. In all cases, it was assumed that the aircraft measures and reports its barometric altitude, and that multilateration provides an alternative method for determining aircraft latitude and longitude. The multilateration solution is used as a backup to GNSS-derived position data and to provide an independent integrity check on GNSS information during normal operations.

The preferred method for protecting against GNSS failures is *passive multilateration on the ground.* Three ground stations measure the Time-Of-Arrival (TOA) of a common squitter message. The squitter message preferably contains a GPS time tag. If so, joint processing at a common ground site can estimate aircraft three-dimensional coordinates, thereby also providing some protection against an altimeter failure. However, if a GPS time tag is not included, hyperbolic processing of the TOAs at a common site can determine the aircraft horizontal position.

When the ground stations are arranged in an equilateral triangle (this pattern provides both efficient coverage and advantageous multilateration geometry), the latitude/longitude errors will be approximately 70 feet 2drms. Errors in vertical position estimates using multilateration without barometric altitude information can be 10 or more times larger due to poor measurement geometries.

Three-station passive multilateration has several advantages. It can be implemented with current avionics using SSR Mode C/S replies and squitters, TCAS II replies and squitters, and TCAS IV squitters (in addition to ADS-B squitters). Three-station horizontal position estimates are significantly more accurate than for two-station multilateration. Also, because the ground stations do not radiate, there are fewer restrictions on their siting (for example, they could be placed on telephone poles in metropolitan areas). With passive multilateration, aircraft position information derived on the ground can be transmitted to the aircraft via the aeronautical data link, thereby enabling “automatic dependent navigation” to be used to back up aircraft navigation.

Alternative Multilateration Techniques — One alternative to the preferred approach is to provide multilateration service to the aircraft by squittering from triple-coverage ground stations. An aircraft with GPS time available can derive its three-dimensional position, while one with an altimeter but no clock can derive its horizontal position. Changes to the aircraft are needed in either case. The derived position information is squittered in an ADS-B message (in place of GNSS position data), supporting both ground-based and air-to-air surveillance, as well as aircraft navigation.

Two-way ranging initiated by the aircraft has characteristics similar to ground station squittering, but removes the need for an accurate clock or altimeter in the aircraft. Two-way ranging initiated from the ground has characteristics similar to aircraft squittering. Two-way ranging can be accomplished with an interrogation-response technique similar to that used by TCAS.

Squittering and two-way ranging multilateration techniques were also considered for double-coverage ground station configurations. The main disadvantage of double-coverage is significantly reduced accuracy near the baseline separating the two stations, where the position solution is singular. Techniques for which the position solution is derived on the ground (i.e., aircraft squittering with an airborne clock or two-way ranging initiated by the ground) can mitigate some of the effects of poor measurement geometry by utilizing angle measurements by the ground antennas.

Squittering and two-way ranging multilateration techniques can also be used with single-coverage ground stations. The ground antenna must be used to provide a second measurement (i.e., angle). Thus only techniques with ground-derived position solutions are possible. Azimuth accuracy depends entirely on the ground station antenna, and can be as poor as 3.4 nmi at the outer limit of a station’s coverage region (for 2 degree azimuth accuracy).

Separate Navigation System — An alternative backup for GNSS signals is a separate, independent navigation system. VOR/DME, Loran-C, INS, or combinations of these systems could bc used for this role. The principal advantage of this approach is that it also backs up the air-to-air surveillance and navigation functions. A principal disadvantage is that, except for INS, which is not a viable alternative for general aviation, it requires retention of a network of ground stations that is not otherwise needed. A second important disadvantage is that these systems are not sufficiently accurate for use on the airport surface, where multilateration is already being implemented.

Secondary Radar — Another potential backup for GNSS signals is retention of a secondary surveillance radar network. In fact, during the transition to ADS-B, the beacon system will operate simultaneously with ADS-B. However, in the longer term, SSRs are not recommended due to their costs: If SSRs were used, the backup system would be more costly than the principal system, whereas a multilateration system would incur very little additional cost.

D. ALTERNATIVE ADS-B SURVEILLANCE LINK TECHNOLOGIES

The advantages of aircraft broadcast of GNSS derived position to other aircraft and ground-based ATM facilities has become widely recognized over the past several years. However, there is not universal agreement on the surveillance link technology (frequency, modulation, access protocol, etc.). In addition to the link technology recommended herein (1090 MHz carrier with Mode S access protocol and message format), several others have been investigated. This section presents brief descriptions of three.

Two of the alternative surveillance link technologies — Universal Access Transponder (UAT) and Self-organizing Time Division Multiple Access (STDMA) — employ time division multiple access techniques somewhat similar to that used by Mode S squitter. Table II-5 displays the characteristics of Mode S GNSS squitter and these two alternatives. As for Mode S, UAT and STDMA participants (aircraft, ground vehicles and ground stations) all broadcast on the same frequency. However, unlike Mode S, each user broadcasts within a defined time slot. The third alternative which has been suggested for the ADS-B surveillance — Aeronautical Telecommunications Network (ATN) — does not have specified physical characteristics but is also discussed below.

1. Universal Access Transponder (UAT)

UAT is a recent candidate ADS-B surveillance link technology. UAT is being designed with a “clean slate mindset”- i.e., without regard of compatibility with current systems. An experimental UAT system is currently being tested at Florida Institute of Technology; one ground site and three aircraft are involved. The test system uses 966 MHz (within the DME band) as the carrier frequency.

UAT restricts emissions by the three different classes of users (aircraft, ground vehicles, and ground stations) to distinct time periods. Within the period for aircraft, 700 time slots are defined within a 1 sec frame. Users would normally select one slot at random each second for transmission. The message size (160 bits) and calculated capacity (298 users) slightly exceed those of a Mode S link (1 12 bits and approximately 280 users).

UAT is not recommended for ADS-B service primarily based on its immaturity. In contemplating the development of a new system, immaturity engenders technical, cost risk, and schedule risk. When compared with the relatively small apparent advantages relative to Mode S, these risks are judged to be too great. Other factors weighting against UAT are its lack of an internationally agreed upon frequency and the incompatibility of its waveform with performing ranging measurements (which are needed for the recommended multilateration backup technique).

Table II-5 GNSS Squitter, UAT, and STDMA Technical Characteristics

Characteristic	GNSS Squitter	UAT	STDMA
Carrier Frequency	1090 MHz for aircraft broadcast (internationally agreed upon)	966 MHz (experimental use, no international agreement)	VHF Comm. Sub-band (no international agreement on channel)
Bandwidth	1030 MHz: 6 MHz 1090 MHz: 8 MHz	Approx. 1 MHz	75 kHz (3 VHF channels)
Modulation	1030 MHz: DPSK 1090 MHz: PPM	Continuous-Phase Frequency Shift Keying	Differential 8-Phase Shift Keying
User Access Protocol	Random time of emission for each message	Random selection of time slot for each broadcast	Most Areas: Random selection of initial time slot; fixed thereafter High Density Areas: Assigned slots
Aircraft User Time Slots	Not slotted system; 112 bits of user data	700 slots in 1 sec, each containing 160 bits of user data	145 slots in 1 sec, each containing 180 bits of user data
User Data Error Protection	Parity Checking	Forward Error Correction and Error Detection	Not known
Compatibility with Measuring Range	Good	Not good (waveform designed for spectral efficiency)	Not good (waveform designed for spectral efficiency)
Capacity (Given user, 99.5% Reliability in 5 sec)	280 users within interfering distance	298 users within interfering distance	Maximum 145 users within interfering distance.
Risk	Low (developed technology)	High (immature technology)	Moderate (some testing)

2. Self-organizing Time Division Multiple Access (STDMA)

The STDMA concept was formulated in Sweden in 1991 and has evolved since then. As currently defined, STDMA involves approximately 145 time slots for user aircraft within a 1 second frame. To use these efficiently, a new participant to a net must select an unused slot. If contention arises for the slot, the user moves to another unused slot. In high traffic areas, slot assignments are made from a ground station.

STDMA uses aeronautical VHF communications frequencies, and its equipment suite includes modified VHF transceivers, thereby reducing costs. STDMA is more mature than UAT, and there is less risk associated with its continued development. STDMA has undergone several tests in both the U.S. and Europe, appears to be suited to use on airport surfaces.

STDMA is not recommended for ADS-B for several reasons. Most importantly, the capacity is limited to a maximum of 145 aircraft, approximately one-half that for Mode S, and it is not clear whether this level can be achieved without delay in finding an open slot. Second, the lack of an internationally agreed upon frequency band is an impediment to its acceptance. Third, the waveform is not conducive to ranging measurements, limiting its utility to support a backup multilateration system.

3. Aeronautical Telecommunications Network (ATN)

ATN is not a physical communications or surveillance link technology. Instead, ATN is a technique for interconnecting multiple air and ground aviation users using multiple technologies. It is expected to play a major role in future aeronautical communications-somewhat analogous to the role of the intemet in terrestrial communications.

The ATN was not considered for ADS-B because it is unsuited to this application. Most important is ATN's lack of a physical description. Second, even if a physical link is selected, ATN's flexible connectivity (the ability of any one user on the network to send an message to any other user) imposes a significant overhead penalty that is unnecessary for a broadcast system and unacceptable in a system whose capacity is an area of concern.

III. EN ROUTE SURVEILLANCE

A. CURRENT ARCHITECTURE AND PLANNED IMPROVEMENTS (1996-2000)

The existing en route aircraft surveillance system consists of primary radars, secondary (beacon) radars, and weather radars. The en route architecture includes four Air Route Surveillance Radar (ARSR) designs and two AN/FPS long-range primary radar designs. Each long-range primary radar is collocated with an Air Traffic Control Beacon Interrogator (ATCBI) on the same tower; three designs of ATCBIs are installed. Secondary Surveillance Radar (SSR), in addition to providing more reliable self-identifying target reports, is used for precise altitude determination and for the military Mode-4 function. The primary and secondary radars share the same pedestal, rotary joint, and timing. Both antennas are protected by a radome. Figure III-I shows the most recently developed long-range radar, the ARSR-4, with a collocated SSR.

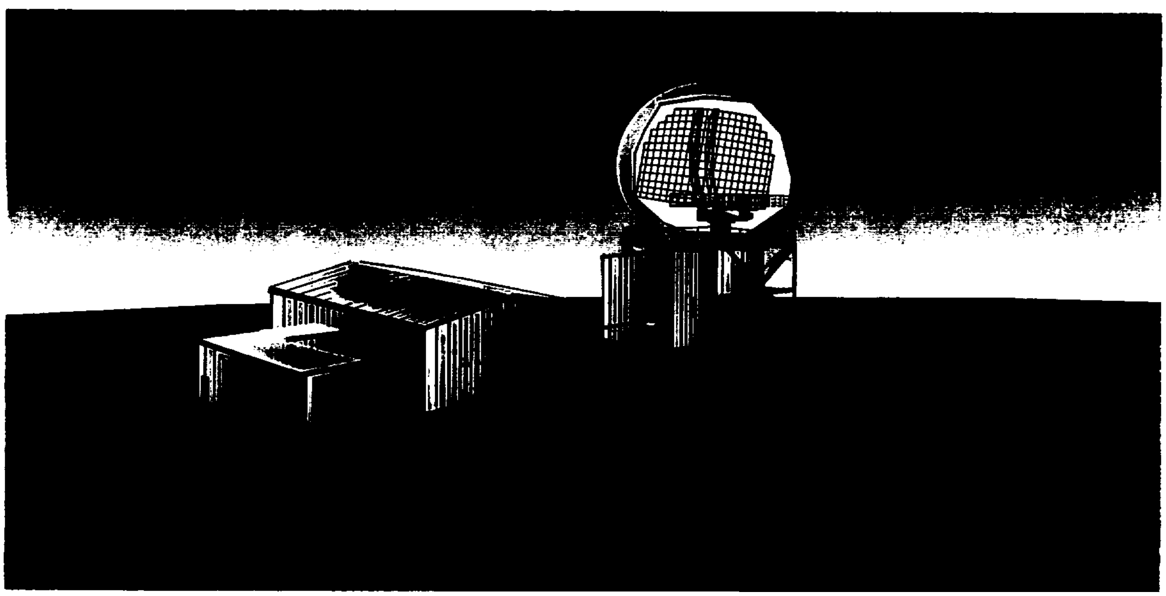

Figure III-1. ARSR4 Long-Range Radar with Collocated SSR

A recent report (15) provides a useful reference point to help understand the paradigm shift embodied in the Surveillance Vision Plan (SVP) presented herein. As recently as 1993, Federal Aviation Administration (FAA) plans called for (1) a small increase in the number of en route primary radar and beacon sites, (2) some modernization of certain primary radars, and (3) essentially wholesale replacement of the then-installed ATCBIs with newly developed Mode S equipment. By the year 2000, the number of primary/secondary sites would grow from 116 to 124, and the number of en route beacon-only sites from 22 to 32. The “first buy” of 144 Mode S ground-based systems was slated to provide 25 replacements for aging en route ATCBI-3 and -4

[15] DOT/FAA/NR-94-1; *Reconrnrendation on Transition from Primary/Secondary Radar to Secondary-Only Radar Capability,* Janis Vilcans, Richard J. Lay, Final Report, October 1994.

interrogators, including 2 beacon-only sites. Future Mode S procurements were expected to replace the remaining, aging ATCBIs, but the final decision had not yet been made.

In August, 1993, the FAA made a decision to deactivate Long-Range Radars (LRRs) (16) in the en route environment within the interior of CONUS. The phase-out schedule is dependent upon when Next Generation Weather Radar (NEXRAD) weather products can be provided to Air Route Traffic Control Center (ARTCC) controllers. A major impetus to this decision was a study that found that 97 percent of the Instrument Flight Rule (IFR) aircraft in the en route airspace were beacon-equipped. Thus, the major value of LRRs was as a source of en route weather data. With the availability of weather information from new NEXRAD radars and the installation of additional beacon-only sites to provide overlapping coverage on high density air routes, primary radars would no longer be needed. It was estimated that this decision would save the government $1.4 billion by eliminating the need to replace 78 primary radars.

The decision to deactivate interior long-range primary radars was effectively a decision to shift the en route aircraft surveillance system from an SSR-primary/LRR-backup architecture to one that places total reliance on secondary radars after 2005 or so. To ensure that flight safety not be reduced in any way, the following principles were adopted for the transition to the new architecture:

- Surveillance system performance will at least remain equivalent to the SSR-primary/LRR-backup architecture capabilities.

- Radar beacon coverage down to 6,000 feet above Mean Sea Level (MSL) will be available by the year 2000 (an improvement from the previous lO,OOO-foot minimum coverage requirement).

- A Notice of Proposed Rule Making (NPRM) will be promulgated requiring that all Visual Flight Rule (VFR) flights over 6,000 feet Above Ground Level (AGL) or Minimum En Route Altitude (MEA), whichever is higher, and all IFR flights be equipped with beacon transponders.

- Procedures will be developed to handle aircraft with failed transponders.

The maximum altitude requirements for en route radars, and minimum altitude requirements for NAS surveillance coverage, are shown in Figure III-2. The altitude capabilities of many radars significantly exceed requirements.

During the past year-and-a-half, there have been several important developments in the en route surveillance system. Initial planning steps implementing the 1993 decision to deactivate CONUS-interior primary radars have been taken, and operational testing of the ARSR-4 radar is underway. The question of which secondary radar should be selected for the SSR "second buy" of approximately 204 units has been investigated. The conclusion is that Monopulse Secondary

[16] *Ibid*. Appendix A.

Surveillance Radars (MSSRs) should be purchased as Non-Development Items (NDI), rather than additional Mode S units designed to government specifications. MSSRs provide monopulse azimuth accuracies. They do not provide data link capabilities, but may provide discrete addressing.

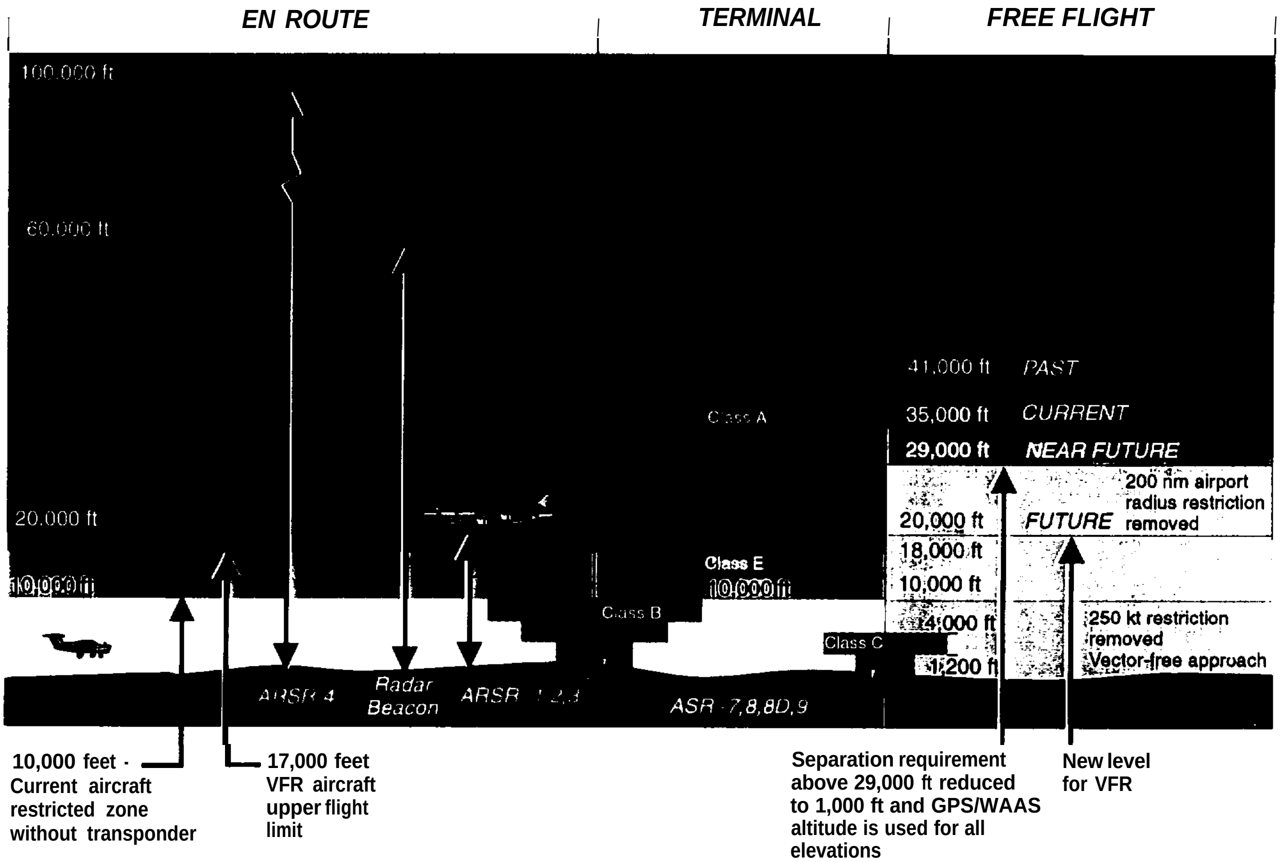

Figure III-2. NAS Required Vertical Minimum and Maximum Radar Coverage

The Automatic Dependent Surveillance-Broadcast (ADS-B) technique, as it has evolved over the past few years, is now considered technically feasible. Flight tests conducted by the MIT Lincoln Laboratory at Hanscom Air Force Base have demonstrated the ability to communicate aircraft identity, Global Positioning System (GPS) position information, and other data to a six-sector antenna on the ground. While considerable additional developmental and operational steps must be completed, the FAA has concluded that ADS-B has the potential to be a major element of the future U.S. surveillance system architecture.

Another factor affecting plans for the future U.S. surveillance system architecture is the successful deployment of the Traffic Alert and Collision Avoidance System (TCAS), including its integration into the Air Traffic Management system. TCAS is now used routinely in the NAS, and is credited with avoiding several aircraft near-misses and collisions. Future surveillance architectures must include a mutual aircraft surveillance capability. It is planned to replace the current TCAS II aircraft systems with TCAS IV systems. TCAS IV will include a 1090 MHz transceiver (enabling an aircraft to determine the locations of surrounding aircraft and to squitter its own position), and a 1030 MHz transceiver (for aircraft-to-aircraft maneuver coordination during transition).

It is anticipated that improved en route surveillance also will be needed to implement planned automation and free flight. Better coverage, higher update rates, and improved accuracies may be needed to support en route automation systems, which will provide enhanced safety and increased capacity and efficiency benefits. Accordingly, the FAA has initiated several research and development efforts, Two pertinent efforts are summarized below.

Multilateration — R&D for en route multilateration based on the ADS-B concept was initiated in 1994. Topics currently being addressed include: design of the ground antenna (including its gain and directivity), range of the system, geometric configuration of the ground sites for optimal coverage, and inter-site time synchronization.

MIP — R&D on the Multisensor Interface Processor (MIP) for en route application has been initiated. Early efforts are addressing the functional requirements, interfaces, processing algorithms, and implementation hardware requirements.

B. EN ROUTE ARCHITECTURE VISION PLAN

Between February and December 1995, under the auspices of the SVP FWG, managers and technical specialists in the FAA's Research and Acquisition Directorate formulated their vision for the evolution of the NAS en route aircraft surveillance architecture over the next two decades (1996-2015). Table III-1 shows the envisioned architecture by functional category, i.e., the systems that will perform each surveillance function, broken down into 5-year intervals. (17)

A summary of the en route surveillance architecture vision is presented in the following paragraphs.

1996-2000 — During the first 5-year interval, the surveillance system will continue with an SSR-primary/LRR-backup architecture, but steps to evolve toward a beacon-only architecture will be taken. Installation of the Mode S "first buy" systems will be performed during this period, as will pre-procurement and procurement activities associated with MSSR purchases. ARSR-4s will be fully deployed during this period. ATCBI-3s will be replaced, and ATCBI-4 and -5 beacon radars will remain operational. ADS-B and multilateration developmental activities will be conducted, and development activities for MIP will be initiated.

2001-2005 — The NEXRAD radar and the Weather and Radar Processor (WARP) associated with it will be fully deployed, thereby satisfying a necessary condition for deactivation of interior-CONUS primary radars. A beacon-only surveillance system architecture will be implemented, and will include a major replacement and improvement of the beacon radar system.

17 Information provided by Claire Jurkevich, AND-450.

Installation of MSSR will continue. By request of the military, operation of approximately 22 old JSS and FAA radars (ARSR-1, -2, -3) will continue in addition to the ARSR-4 radar. Development work on ADS-B, multilateration, and the MIP will continue.

Table III-1. En Route Surveillance Architecture Vision by Function

	1996-2000	2001-2005	2006-2010	2011-2015
LRR (CONUS Interior)	FPSs, ARSR-1, -2, -3s. Operating	FPSs, ARSR-1, -2, -3s Decommissioning	22 ARSR-1, -2, -3 Operating	22 ARSR-1, -2, -3 Operating
LRR (CONUS Perimeter)	FPSs, ARSR-1, -2, -3s Operating, ARSR-4s Deploying	FPSs, ARSR-1, -2, -3s Decommissioning, ARSR-4s Deploying	ARSR-4s Operating	ARSR-4s Operating
SSR	Mode S/ATCBI-5s/ MSSRs Replacing ATCBI-3s, -4s	Mode S/MSSRs Replacing ATCBI-4s, -5s	Mode S/MSSRs Operating	Mode S/MSSRs Begin Decommissioning (except at selected sites)
Non-Radar	(None)	ADS-B/Multilateration Deploying	ADS-B/Multilateration Deploying	ADS-B/Multilateration Operating
Mutual Airborne Surveillance	TCAS I, II Operating	TCAS I, II Operating	TCAS I,II Operating TCAS IV Operating, ADS-B Deploying	TCAS I,II Decommissioning, TCAS IV/ADS-B Operating
Sensor Integration	LRR/Mode MSSR by Sensor	LRR/Mode S/MSSR by Sensor	Mode S/MSSR by Sensor, ADS-B by MIP	By MIP

2006-2010 — During this 5-year interval, the surveillance system will achieve an SSR-primary/ADS-B-backup architecture. This architecture will enable partial realization of several ATM improvements, including free flight, time-based control, and reduced controller workload. ADS-B and multilateration will achieve Initial Operational Capability (IOC) during this segment, as will the MIP. MSSR will achieve Full Operational Capability (FOC) at the beginning of this half-decade, and the ATCBI-4 and -5 replacements will achieve FOC during this period.

2011-2015 — During this 5-year interval, ADS-B will assume the role of prime surveillance system, and multilateration will become the backup. The role of SSR will decrease. The architecture that will be selected by the end of this period is shown in Figure 111-3. Carriage of ADS-B equipment may eventually have to be mandated for aircraft operating under IFR or above the minimum transponder altitude.

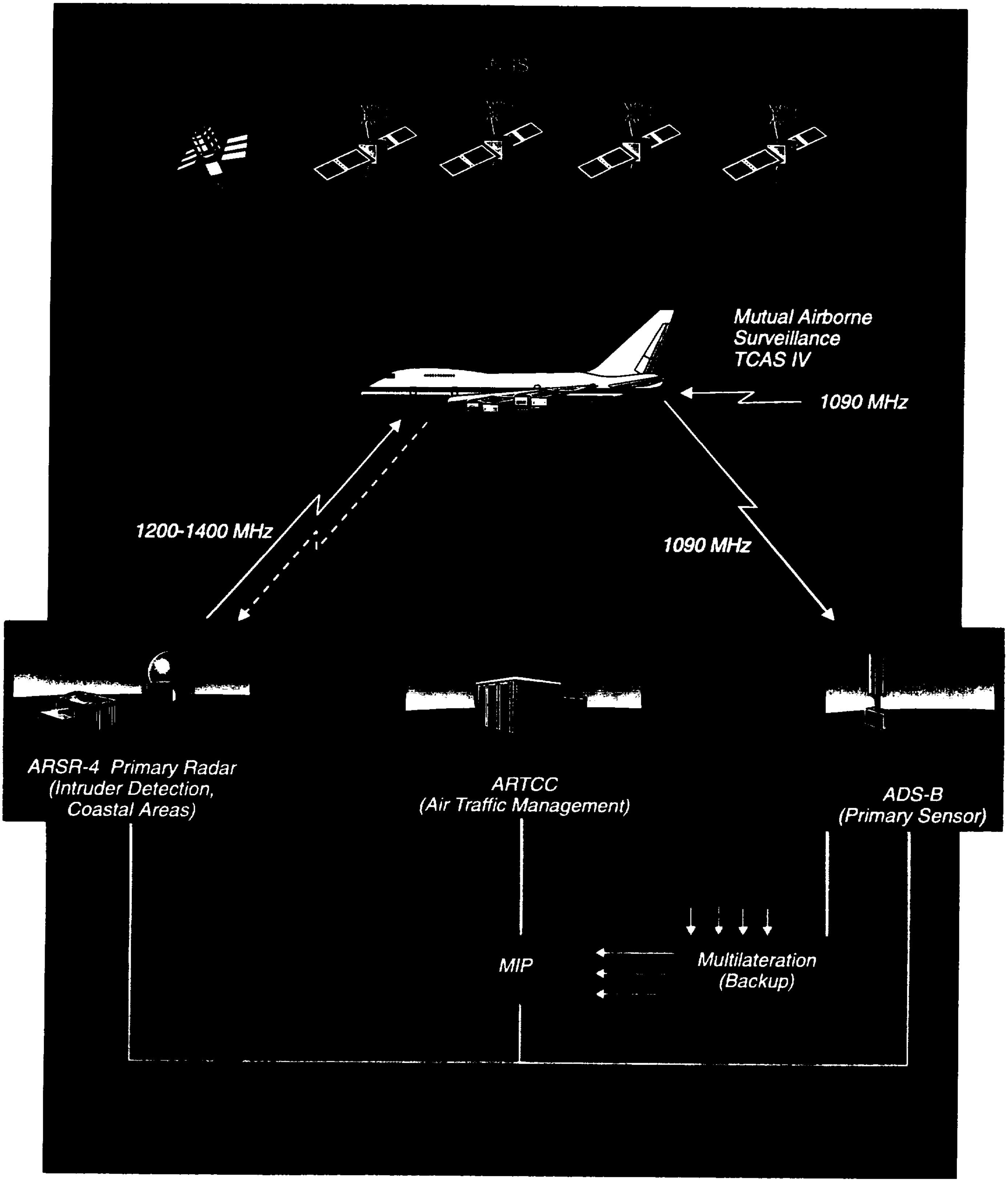

Figure 111-3. Envisioned En Route Architecture (2015)

IV. TERMINAL SURVEILLANCE

A. CURRENT ARCHITECTURE AND PLANNED IMPROVEMENTS (1996-2000)

Terminal radars provide the capability to detect aircraft and weather phenomena in a region extending to approximately 60 nmi from a radar site. At the present time, the FAA plans approximately 238 terminal radar system installations, each of which comprises a collocated primary and secondary radar. Primary radars used in the terminal area are termed Airport Surveillance Radars (ASRs); systems from the ASR-4, -5, -6, -7, -8, and -9 series are now in service. Secondary radars collocated with the ASRs are drawn from the ATCBI-3, -4, -5, and Mode S series. Figure IV-l depicts an ASR-9, the most recently developed terminal area primary radar, with a collocated integrated secondary surveillance radar.

The FAA also is deploying Precision Runway Monitor (PRM) radars to certain major airports. PRM is a specialized secondary radar that monitors aircraft approaches to dual or triple parallel runways using monopulse and electronic scanning technologies. The PRM equipment now being deployed is the first generation of systems for monitoring parallel runway approaches.

The first ASR-9 site was commissioned in 1989. When the ongoing installation program is completed in 1998, there will be 120 ASR-9 units at high- and medium-density airports, and 125 ASR-7s and -8s at medium- and low-density airports. All ASR-4s, -5s, and -6s will be decommissioned during the next few years.

Table IV- 1 details some of the key features of the ASR-7, -8, and -9. The ASR-9 has several major advantages over its immediate predecessors. First, the ASR-9 has a digital interface with the Automated Radar Terminal System (ARTS) equipment (18) used in terminal areas, allowing automated processing of the radar's output data. Second, the ASR-9 includes Moving Target Indicator (MTI) and Moving Target Detection (MTD) capabilities. MTI circuits use the Doppler shift associated with returns from moving targets (presumed to be aircraft) to distinguish them from stationary targets (presumed to be from natural terrain and man-made structures). The former are displayed while the latter are suppressed, thereby greatly improving the radar's clutter (19) rejection capability. MTD employs a stored clutter threshold map that is compared to radar echoes to reject clutter and enhance detection of zero-velocity targets.

The third major advantage of the ASR-9 is its ability to distinguish six levels of weather reflectivity from a volume of airspace; these levels correspond to different intensities of precipitation. A controller-selectable threshold is used to map these six precipitation levels into the two levels (high and low level weather) that can be shown on the controller's displays.

---

18 The Standard TRACON Automation Replacement System (STARS) is being developed to replace the ARTS.

19 Clutter is the detection/display of returns from anything except an aircraft or a hazard to flying aircraft, such as a weather phenomenon

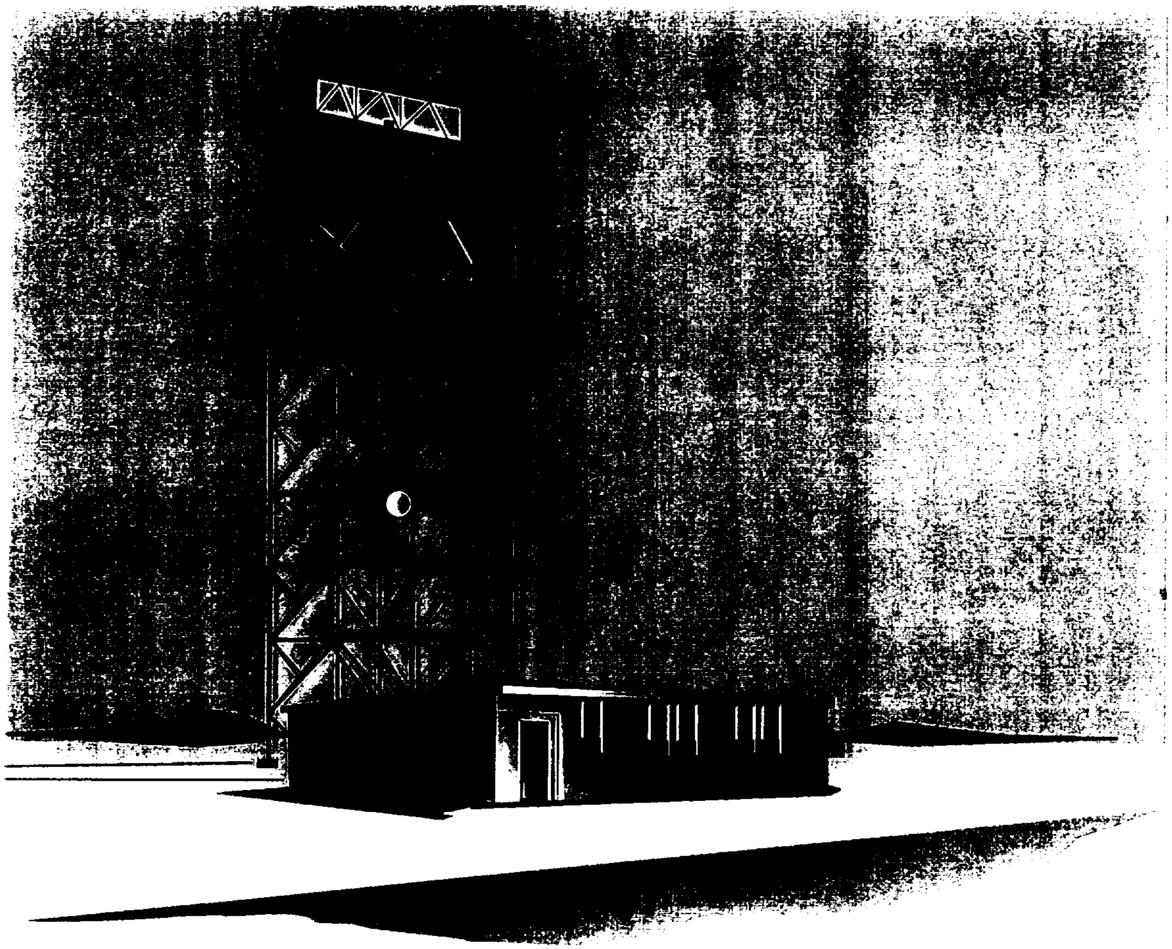

Figure IV-1. ASR-9 Primary Radar and Collocated Integrated Secondary Radar

Table IV-1. Terminal Area Primary Radar Summary

Radar Designation	First Commissioned	Planned Number	Transmitter Output Device	Weather Reflectivity Levels	ASR-ARTS Interface
ASR-7	1970	34	Magnetron	2	Analog
ASR-8	1975	71	Klystron	2	Analog
ASR-9	1989	122	Klystron	6	Digital

Planning and engineering work on programs directed at providing upgraded or new radars in the post-2000 time frame will be carried out during the next five years. The ASR-8D effort is directed at developing a new MTD processor for the ASR-8. The ASR-11 program (20) is examining the issues (e.g., technical capabilities, transition schedule) surrounding the “next generation” terminal area primary radar. The ASR-11 will be a Non-Development Item (NDI). It is currently planned that the ASR-11, with integrated MSSR, will replace the ASR-7 and the co-located ATCBI-4s and -5s when their service lives have been exhausted.

Research and development efforts are being conducted in several areas related to improving terminal surveillance capabilities. Two of the most relevant are summarized below.

Primary Radar Performance Improvement — R&D activities are addressing the effects of anomalous propagation, second-time-around clutter reduction for improved target detection, improved target detection in tangential or blind speed areas, improved small vehicle detection (e.g., gliders, balloons, parachutists), and improved bird flock detection and tracking. Recent development activities associated with the "9-pac" upgrade for the ASR-9 radars have resulted in improvements in some of these areas by providing an auto-detection or “learning” logic set that develops and improves clutter maps.

Multi-Purpose Airport Surveillance Radar (MP-ASR) — Research work in fan and spot beam radars has shown the feasibility of providing both aircraft and weather detection using a single radar, which offers the benefit of improved services at a considerable reduction in life cycle cost. Near-term R&D programs will focus on further development of weather detection algorithms, antenna scanning patterns, and Demonstration and Evaluation (DEMVAL) programs to verify that all risk areas have been addressed and that a true multi-function capability can be achieved.

During the 1996 to 2000 time frame, the FAA plans to install 118 Mode S secondary radars at high traffic density airports. Most units will be collocated with ASR-9 primary radars and will displace ATCBI-4 or -5 units at these sites. Concurrent with this process, all 86 existing ATCBI-3 units will be decommissioned. In most cases at a medium or low traffic density airport, a displaced ATCBI-4 or -5 radar will replace an ATCBI-3.

The FAA will deploy Monopulse Secondary Surveillance Radar (MSSR) as the replacement for the ATCBI-4 and -5 systems in the post-2000 time frame. MSSRs will have the same improved azimuth resolution as the Mode S, but not the data link capability, and may or may not include discrete addressing. ASR-11s will be deployed with integrated MSSRs.

[20] FAA canceled the ASR-1O development effort

B. TERMINAL ARCHITECTURE VISION PLAN

Table IV-2 shows the envisioned architecture by functional category — i.e., the systems that will perform each surveillance function — broken down by 5-year intervals. The terminal area surveillance architecture vision is summarized in the following paragraphs. (21)

Table IV-2. Terminal Area Surveillance Architecture Vision by Function

	1996-2000	2001-2005	2006-2010	2011-2015
ASR	ASR-4, -5, -6s Decommissioning, ASR-7/-8D/9 Operating	ASR-7 Decommissioning, ASR-8D/9 Operating, ASR-11 Deploying	ASR-8D/9/11 Operating	ASR-8D/9/11 Operating, MP-ASR Developing
SSR	ATCBI-3 Decommissioning, ATCBI-4, -5 Relocating, Mode S Deploying	Mode S Operating, ATCBI-4, -5 Decommissioning, MSSR Deploying	Mode S/MSSR Operating	Mode S/MSSR Decommissioning
PRM	PRM Deploying	PRM Operating	PRM Operating	PRM Decommissioned
ADS-B	(None)	Deploying	Deploying	Operating
Multilateration (Mode A/C/S/ADS-B)	Testing	Deploying	Operating	Operating
MIP	(None)	MIP Deploying	MIP Operational	MIP Operational

At the conceptual level, it is planned that primary radar systems will continue to be used and new systems developed to provide the necessary capability for intruder, blunder, and weather surveillance in crowded terminal airspace. SSR radars will be phased out and replaced by Automatic Dependent Surveillance - Broadcast (ADS-B) as the principal surveillance sensor. Multilareration will become the backup surveillance system for transponder-equipped aircraft.

1996-2000 — During the next 5 years, ASR-9 installations at high traffic density airports will be completed. In some cases, ASR-7s and -8s will be displaced to medium and low traffic density airports. All ASR-4s, -5s and -6s will be decommissioned. Mode Ss will be installed at high traffic density airports. ATCBI-4s and -5s will be relocated to lower traffic density airports. All ATCBI-3s will be decommissioned. Research and development on ADS-B, multilateration, and MIP will be initiated.

2001-2005 — During this 5-year interval, ASR-9s will continue to be used in high-density areas. Upgrades to the ASR-8s will be made to create ASR-8Ds. ASR-7s will be decommissioned and replaced by ASR-11s with integrated MSSRs, Mode S SSRs will continue in service at high traffic density airports. ATCBI-4s and -5s will be decommissioned and

21 Information provided by Angela Harris. AND-440.

replaced by MSSRs. Research and development on ADS-B, multilateration. and MIP will continue.

2006-2010 — ASR-8Ds, -9s and -11s will remain in service. Mode S and MSSRs will provide the terminal area SSR capability. MIP will achieve Full Operational Capability (FOC). ADS-B and multilateration will reach IOC and begin to be used with primary and secondary radars.

2011-2015 — ASR-8Ds, -9s, and some - 11s will remain in service while MP-ASR is being developed. MSSRs will continue to provide SSR capabilities. FOC for the MIP will be reached at the beginning of this period. Use of ADS-B will increase; by the end of the period, it will be a candidate to serve as the principal surveillance sensor. Use of multilateration will similarly increase. The envisioned architecture at the end of this period is shown in Figure IV-2.

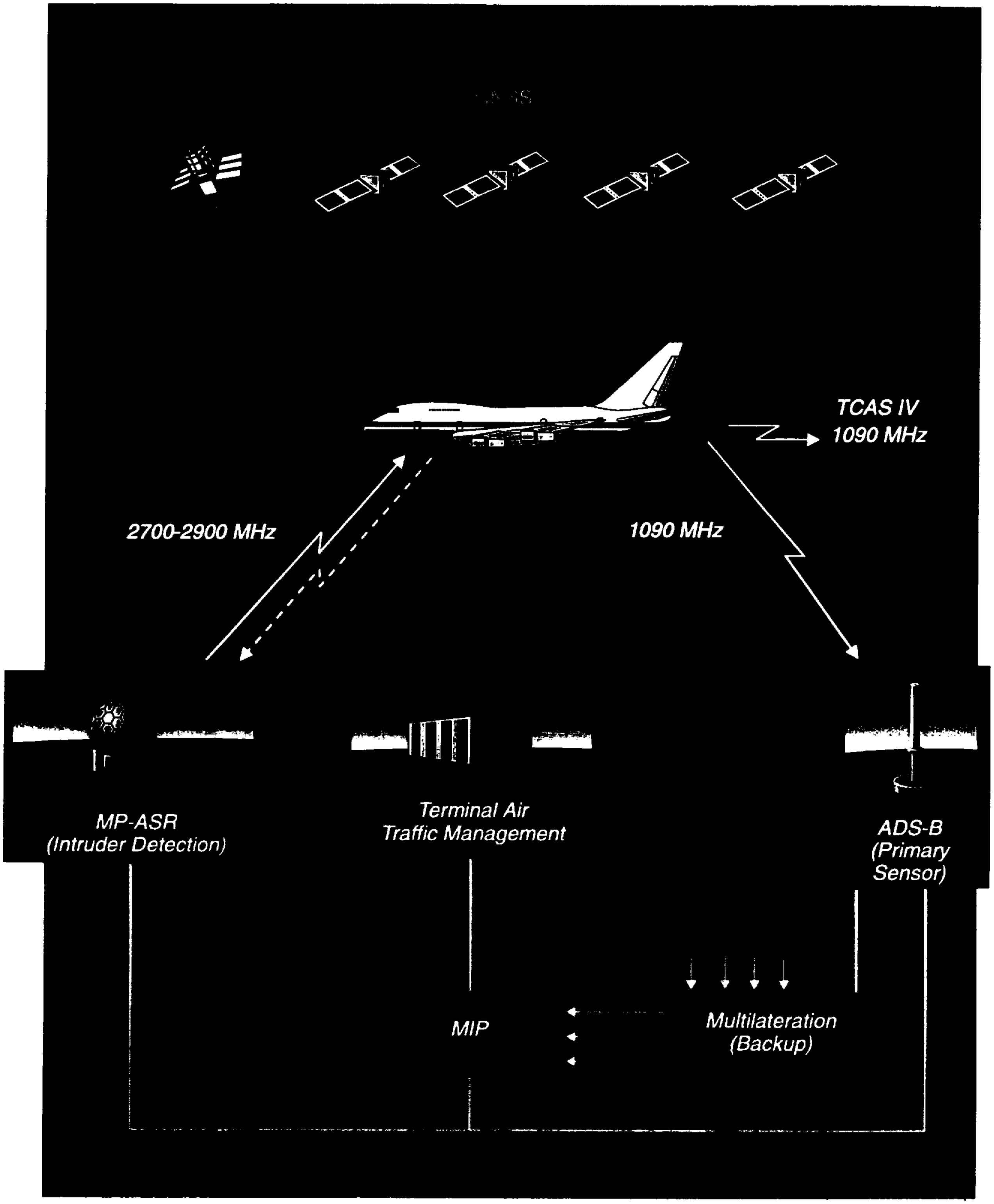

Figure IV-2. Envisioned Terminal Area Architecture (2015)

V. SURFACE SURVEILLANCE

A. CURRENT ARCHITECTURE AND PLANNED IMPROVEMENTS (1996-2000)

Surface surveillance sensors/systems have not been used nearly as long nor deployed as widely as their en route and terminal domain counterparts. Initially, controllers relied completely on visual observation and aircraft position reports for separation and control of traffic operating on the airport movement areas. (22) The limited ability to build new or expand existing airports, coupled with a steady growth in air traffic, has led to the need for more efficient use of airports without degrading current margins of safety.

Primary radars used for detecting aircraft and vehicles on the airport surface (e.g., aircraft, trucks) are termed Airport Surface Detection Equipment (ASDE). The inherently high cost of primary radars limits ASDE deployment to those airports with the highest traffic levels.

ASDEs suffer from the technical limitations generic to primary radars (e.g., targets are not self-identifying, coverage is restricted to line-of-sight, occurrence of multipath returns, etc.). Moreover, the airport surface is a difficult radar environment: large, flat concrete and metallic surfaces cause more multipath and clutter problems than occur for airborne targets. Also, because surface targets are stationary, or nearly so, Moving Target Indicator (MTI) techniques cannot be used, although Moving Target Detection (MTD) techniques are used. As a result of these factors, primary radar tracking of surface targets provides a necessary capability at acceptable but not desired performance levels.

ASDE-3 — The ASDE-3 radar is the most capable surface surveillance sensor in service today. It provides ground controllers with a display of up to 256 surface targets in all weather/visibility conditions. Twenty-five systems have been delivered, 20 of which have been commissioned. It is planned that a total of 38 units will be installed at the busiest airports in the U.S., and that older series ASDEs will be phased out.

Airport Movement Area Safety System (AMASS) — AMASS is an automation system that enhances the ASDE-3 radar by providing tower controllers with conflict alerts to aid in the prevention of runway incursions. Final approach target data from Airport Surveillance Radar/Automatic Radar Terminal System (ASR/ARTS) are combined with AMASS data in the conflict alert algorithms. AMASS is completing the testing phase, and has begun full scale development.

No automated system in service today is directed specifically at preventing runway incursions. There is no operational automated system that provides impending departure demand

22 *Ground controllers* are responsible for all airport movement areas except the runways. *Local controllers* are responsible for aircraft between the arrival or departure from the active runway and the hand-off to/from *approach control,* when the aircraft is (typically) 5-15 miles from the airport.

and ground traffic planning/sequencing information to controllers. However, research on the Departure Sequence Processor (DSP) is being performed.

Future surface surveillance systems (23) in conjunction with new aircraft and Air Traffic Management automation systems, are expected to produce demonstrable benefits in the areas of surface safety and efficiency. In the safety area, the specific goal is to reduce the number of runway incursions (inadvertent entry of an aircraft onto a runway already assigned to another aircraft). A second safety goal is to increase the awareness of pilots and controllers as to the location and status of nearby aircraft and other hazards. In the area of efficiency, the goals of surveillance are to provide the data needed to increase airport capacity and reduce taxi delays. These goals are to be accomplished while also reducing the workload on the ground controller. To achieve these goals, the FAA has initiated surveillance-related research and development and evaluation efforts. These include:

ASTA Target Identification System (ATIDS) — ATIDS is a secondary surveillance system that uses both the ADS-B and multilateration techniques for surveillance. The ATIDS will enable tracking of all transponder-equipped aircraft and other equipped vehicles on the airport surface. ATIDS will initially be used to provide identification of ASDE-3/AMASS-tracked vehicles for display on the tower cab. Later, ASDE-3 and ASDE-X will be phased out, and ATIDS will be used as the primary source for surveillance.

ASDE-X — In response to the near-term need for a primary surface surveillance radar that is affordable enough for deployment at airports that do not qualify for an ASDE-3, the FAA has acquired a lower cost commercially available X-Band radar termed ASDE-X. Operation in the X-band range was selected to reduce signal attenuation due to heavy rain. The ASDE-X antenna is designed to provide coverage to 300 feet of altitude with an azimuth beamwidth of less than 0.45 degree (capable of detecting small vehicles and people as well as aircraft). The ASDE-X is expected to have the same update rate as the ASDE-3, but with relaxed requirements in range. Initial deployment (October 1995) was at Mitchell International Airport, Milwaukee.

Additional radar testing is being planned in the near future. Among these radars are: Raytheon X-band radar, ELTA FMCW Ku-band radar, French phased array X-band radar, Hughes 74 GHz FMCW radar, and likely others.

B. SURFACE ARCHITECTURE VISION PLAN

Table V-1 shows the envisioned architecture by functional category — i.e., the systems that will perform each surveillance-related function — broken down into 5-year increments. The architecture evolution is summarized in the following paragraphs.

1996-2000 - During the next half-decade, both types of FAA primary radars will be installed. ASDE-3 installations at the busiest 35 airports will be completed, and ASDE-X

23 Information provided by Dominic R. Castaldo, AND-410.

Table V-l. Surface Surveillance Architecture Vision by Function

	1996-2000	2001-2005	2006-2010	2011-2015
Primary Radar (l-35 Busiest Airports)	ASDE-3 Operating, ASDE-2 Decommissioning	ASDE-3 Operating	ASDE-3 Operating	ASDE-3 Decommissioning
Primary Radar (36-70 Busiest Airports)	ASDE-X Testing/Deploying	ASDE-X Deploying	ASDE-X Operating	ASDE-X Decommissioning
Cooperative Surveillance	ATIDS Deploying	ATIDS Deploying	ADS-B Operating, ATIDS Operating	ADS-B Operating, ATIDS Operating
Control Backup (Busiest Airports)	(None)	RWSL Deploying	RWSL Operating	RWSL Operating
Sensor Integration	AMASS Developing	AMASS Deploying, MIP Developing	AMASS Operating, MIP Deploying	AMASS Operating, MIP Operational

installations will begin. ATIDS multilateration deployment will commence at ASDE-3 airports. Research and development on ADS-B, ATIDS multilateration, and the Runway Status Lights (RWSL) advisory system will continue.

2001-2005 - Primary radars: ASDE-3 installation will be completed, and ASDE-X installation will be completed at the end of the period. AMASS will normally be installed in conjunction with ASDE-3s. Cooperative surveillance: ADS-B research and development will continue, while ATIDS deployment will continue. Installation of RWSL at the largest airports will begin.

2006-2010 - ASDE-3 and ASDE-X primary radars will continue operations at approximately the busiest 70 airports. ATIDS will be configured, via software, for ADS-B operation and ATIDS deployment will commence at airports that do not have ASDE-3s. It is expected that reliance will gradually shift to cooperative systems (from primary radars) as aircraft equipage increases. AMASS operations will continue. RWSL operations will also continue, with a few new installations. MIP will be deployed during this time period.

2011-2015 - By the end of this half-decade, ADS-B will be fully deployed and considered the primary surface surveillance technique for all ATIDS/multilateration aircraft. ASDE-3 and ASDE-X primary radars will begin to be decommissioned. MIP will become operational. The surface surveillance architecture in 2015 is depicted in Figure V- 1.

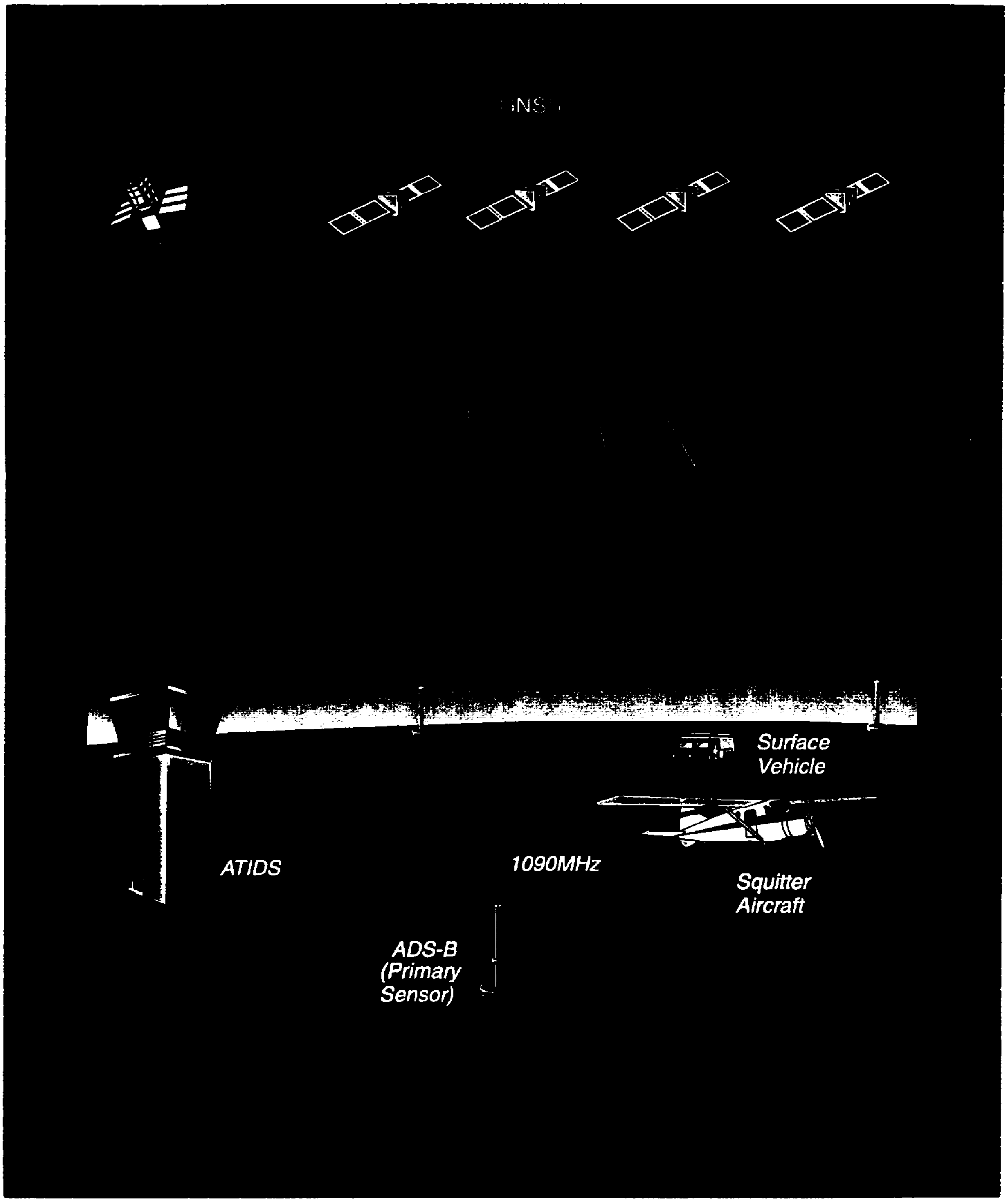

Figure V-l. Envisioned Surface Surveillance Architecture (2015)

VI. TRANSITION PLAN AND RECOMMENDATIONS

A. ADS-B ARCHITECTURE SUMMARY

This Surveillance Vision Plan (SVP) presents the United States' envisioned aircraft surveillance architecture over the next 10 to 20 years, as formulated during 1995-96 by the Federal Aviation Administration (FAA) SVP Functional Working Group (FWG). The SVP also includes the estimated transition schedule and recommended actions.

The new surveillance architecture will address the current urgent needs for:

- improved aircraft surveillance capabilities (greater coverage, higher accuracies and update rates, and greater reliability) to support implementation of the free flight concept, time-based control, precision approaches at non-radar airports, and other advanced Air Traffic Management techniques;

- reduced FAA costs for maintaining and replenishing the aging installed radar surveillance infrastructure; and

- more accurate and detailed weather data, to reduce the service disruptions and safety hazards now caused by adverse weather conditions.

Improved surveillance capabilities, combined with the implementation of an Air Traffic Management data link and advanced ATM procedures, will increase the safety, capacity, and efficiency of the NAS. The result will be reduced flight times and costs, as well as reduced pilot and controller workloads.

The SVP envisions *a transition from ground-based radars to joint satellite- and ground-based surveillance systems* over the next 10 to 20 years. High-cost/high-maintenance ground-based radars used for surveillance in the en route (ARSR/ATCBI/Mode S), terminal (ASR/ATCBI/Mode S), and surface (ASDE) domains will be phased out over the next two decades. Instead, *a single, lower cost, more effective system, Automatic Dependent Surveillance - Broadcast (ADS-B), will become the primary means of surveillance for* all *flight domains.*

The envisioned surveillance architecture in 2015 is presented in Figure VI-1. ADS-B equipment will be deployed at remote ground sites housing an antenna, receiver, and processing capability. This equipment will be passive and compact, without a radome or mechanically rotating antenna, and could be placed on telephone poles and other convenient locations without constraints regarding populated areas or radar clutter. Approximately 300 sites, primarily with six-sector antennas, will provide triple coverage of the en route airspace. Approximately six sites, primarily with omni-directional antennas, will be deployed to cover the periphery of 240 terminal areas with

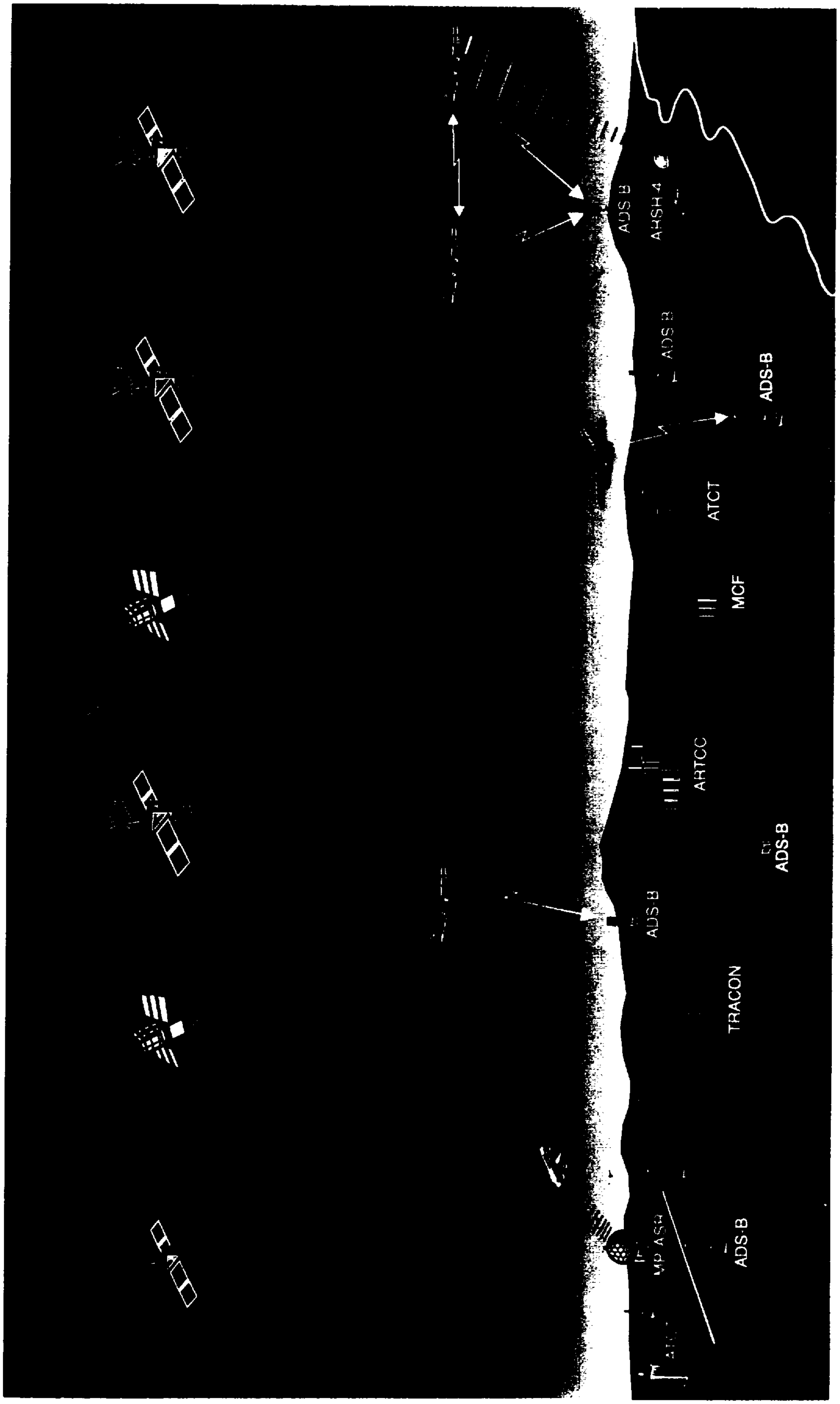

Figure VI-1. Envisioned Aircraft Surveillance Architecture (2015)

TRACONs. Three to seven sites with omni-directional antennas will be installed on airports with the highest traffic levels, and a single sensor will be located on towered airports with lower trafftc densities.

An ADS-B aircraft transponder similar to a Traffic Alert and Collision Avoidance System (TCAS) transponder will broadcast aircraft GNSS-derived position and other information on the international aircraft transponder reply frequency, 1090 MHz. ADS-B messages will be received on the ground to support ATM automation and control, and by nearby aircraft to provide Cockpit Display of Traffic Information (CDTI) for situational awareness and Traffic Situation Display (TSD) collision avoidance capabilities. The ADS-B avionics unit will provide three functions: (1) broadcast of aircraft identification, barometric altitude, position, and other data (ADS-B and multilateration backup functions); (2) secondary radar transponder (to be used during transition and for backup ranging measurements); and (3) exchange of coordinating maneuver information with nearby aircraft (collision avoidance function).

Backup system(s) will be needed to provide a margin of safety, and in the event of primary system failures. *Multilateration will provide an integrity check on GNSS-derived ADS-B data during normal operations and will serve as the ADS-B backup in all three flight domains in the event of a GNSS failure.* For non-ADS-B equipped aircraft, multilateration could become the primary means of surveillance until ADS-B is mandated. Multilateration is a technique whereby aircraft identity and position are derived at ATM facilities on the ground from the aircraft Mode C/S or ADS-B messages.

In the event of a transponder failure, a redundant transponder would be the primary backup. In the unlikely event of failure of both transponders, rules and procedures including voice broadcast of aircraft position and non-radar procedures will be investigated. ADS-B ground stations provide redundant coverage, thereby maintaining surveillance service when individual station failures occur.

B. IMPLEMENTATION TRANSITION PLAN

The envisioned architecture cannot be implemented immediately: maturation of new technologies, budgetary constraints, safety standards, schedule requirements, National Airspace System (NAS) harmonization, and other issues will require a transition period of 10 to 20 years (i.e., present to 2005-2015). This transition period reflects the difference between the times when: (1) ground-based surveillance systems begin their end-of-life-cycle decommissioning, and (2) the new space-based surveillance systems are fully tested and operational. However, benefits will accrue to the FAA and aircraft owner/operators immediately after initial deployment of ADS-B ground facilities in 2005. These benefits may cause the implementation schedule to be accelerated.

During the transition period, surveillance data from primary and secondary radars as well as ADS-B/multilateration sites will be available at ground facilities. To provide ATM personnel and facilities with a single report for each target containing the best available information about that target. the Multisensor Interface Processor (MIP) is being developed. MIP units will be deployed in conjunction with new ADS-B systems, in most instances at ARTCCs (en route domain) and TRACONs (terminal and surface domains). Figure VI-2 depicts the estimated transition schedules for the individual systems involved in the evolution from a radar-based to a ground- and space-based surveillance system.

A Surveillance Vision Implementation plan has been prepared and is consistent with the transition schedule shown in Figure VI-2. The plan is based on the Work Breakdown Structure (WBS) shown in Figure VI-3, which serves as the basis for schedule resource planning estimates. Figure VI-4 relates the WBS to the transition schedule presented in Figure VI-2 by categorizing the various surveillance and related systems to the applicable WBS elements. (24)

C. CONCLUSIONS

The surveillance architecture vision appears to be the most feasible and cost-effective replacement for the existing infrastructure, particularly when the need to meet the increased surveillance system requirements imposed by advanced automation, time-based air traffic management, and free flight are considered. However, detailed studies must be conducted to validate the concept, the architecture, and the costs and benefits of ADS-B.

The operational, functional, and technical requirements imposed by advanced automation, time-based ATC, and free flight must be derived and documented to finalize the future aircraft system design and architecture. In particular, requirements for critical aircraft surveillance data must be validated and the ADS-B system must be evaluated relative to these requirements. Closely related to these requirements is the need for an ADS-B operational concept to determine the degree of the need for ATC procedures initiatives.

The ADS-B program schedule and the NAS modernization schedules must be examined and synchronized to derive ADS-B benefits at the earliest time possible. ADS-B will be accepted by the operators and users of the NAS only after it has been demonstrated that the concept can meet the demands of the aviation community. Thus, a master test/demonstration plan must be developed that includes operator and user involvement to the maximum extent possible. It would also be useful to include international aviation interests in these tests and demonstrations.

For the SVP to succeed and be adopted as the next generation NAS surveillance architecture, its technical advantages and economic benefits must be proven superior to all other approaches.

D. RECOMMENDATIONS

It is recommended that the FAA establish an ADS-B development program with the objective of initial system deployment by 2000 and full deployment by 2010. Additional

[24] Information provided by Dr. Edward J. Koenke, GENASYS Consulting Services

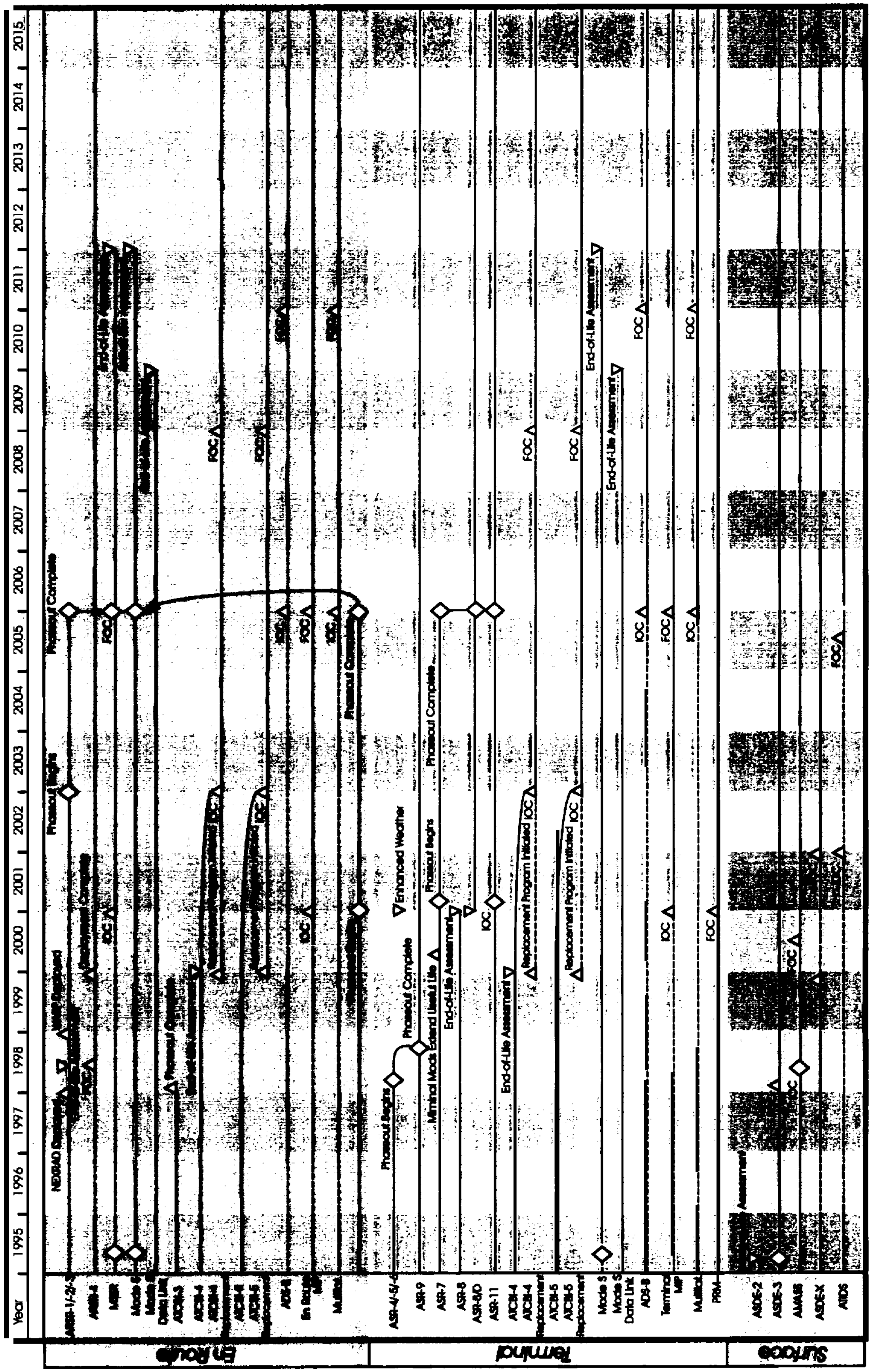

Figure VI-2. Surveillance System Transition Schedule recommendations for the implementation of the SVP are presented in Table VI- 1. These recommendations provide a step-by-step description of how to proceed with SVP implementation. The steps are not sequential, and certain steps must be done in parallel to facilitate early implementation of the future surveillance vision.

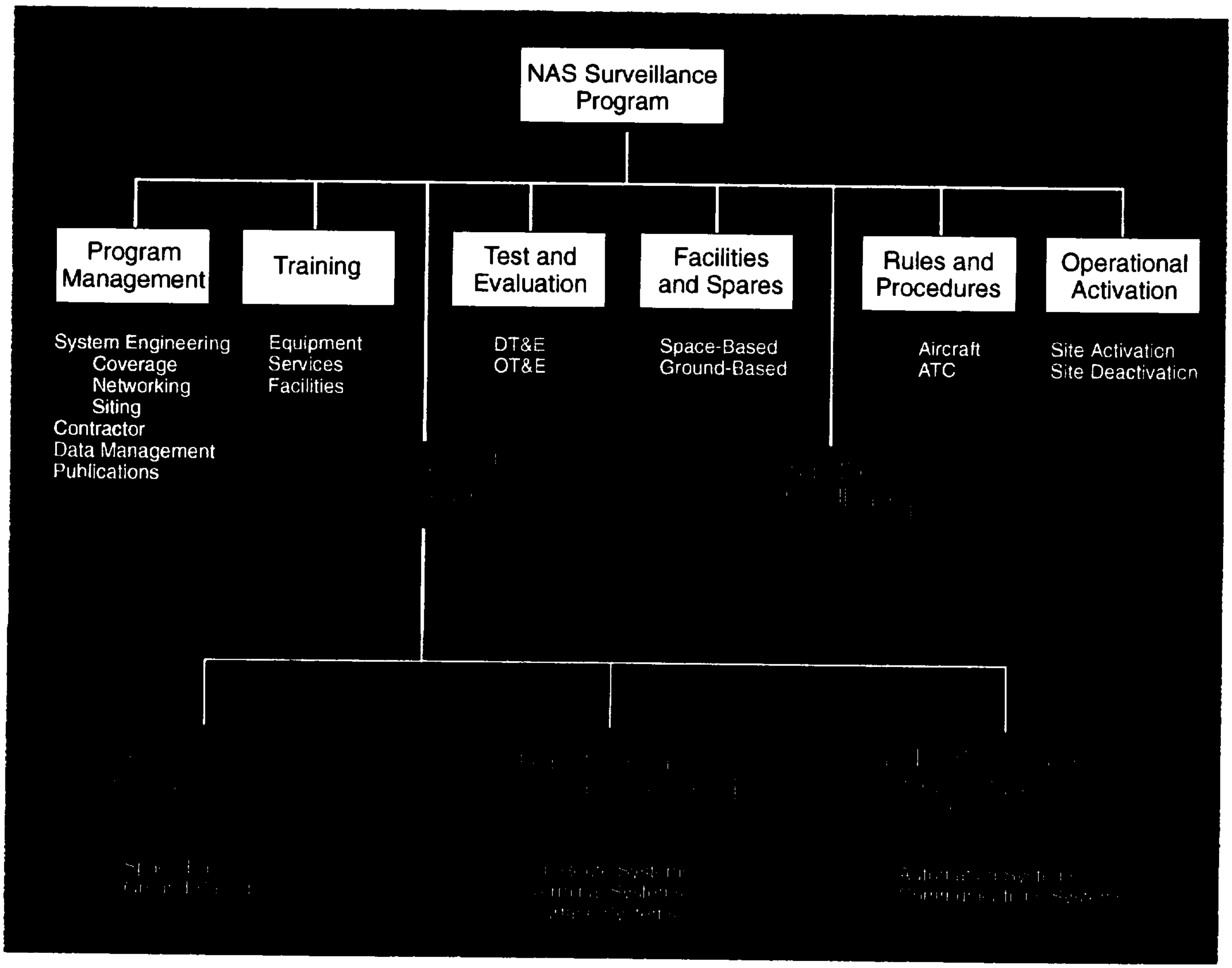

Figure VI-3. SVP Program Work Breakdown Structure

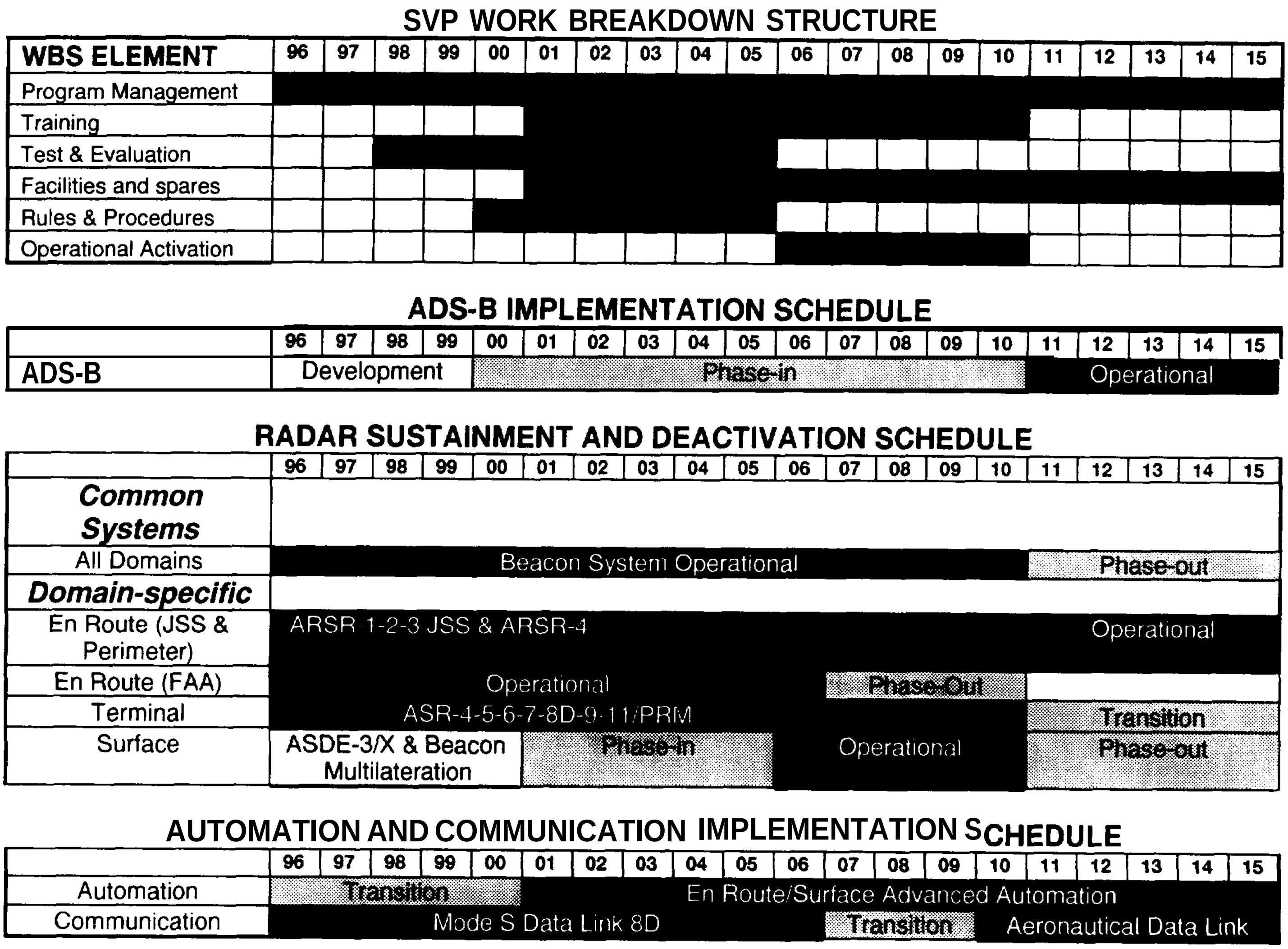

Figure VI-4. SVP Program and Implementation Schedule

Table VI-1. Recommended SVP Implementation Approach

Step	Description
Requirements Analysis	Perform an in-depth surveillance system requirements analysis including operational requirements and the functional, performance, and interface requirements associated with the advanced automation programs, free flight, and time-based traffic management as they relate to aircraft surveillance and weather surveillance.
Alternative Analysis	Validate the selection of the ADS-B with respect to the derived surveillance requirements by performing an alternatives analysis coupled with a cost/benefit analysis that establishes ADS-B as the system of choice.
Cost/Benefit Analysis	Establish the life-cycle costs for the candidates identified by the alternatives analysis. All costs must be included in these studies, including: user avionics, maintenance, ground communications, siting costs, and backup mode.
Operational Concept	Develop an ADS-B operational concept that includes the method of operation, procedural impacts, maintenance considerations, and user impacts.
Interfaces	The interfaces between ADS-B and the ATM automation system for en route (HOST) and terminal (ARTS) domains must be defined. The seamless interface of ADS-B with the oceanic ADS system must be defined. The interface with the MIP must be defined for all sensors whose surveillance data will be fused.
Capacity	Demonstrate that ADS-B has sufficient capacity to operate during transition, supporting free-flight operations while maintaining safe and reliable surveillance service in the busiest areas.
Program Plan	Develop a comprehensive and detailed WBS that includes all of the implementation steps identified in this plan. Develop a Program Evaluation Review Technique (PERT) chart and perform a critical path analysis to determine the critical program elements. Develop a Gantt chart for the program, and estimate the resources required to successfully implement the program.
Test and Evaluation	Develop an ADS-B master test and evaluation plan that can be used to guide the ADS-B T&E activities and to establish operational feasibility of the future system.
Transition Strategy	Develop an in-depth transition strategy for ADS-B. This will include synchronization of the ADS-B schedule with all other related automation schedules and will address training requirements. Examine possibilities for early implementation of the new system including siting analysis and the potential for additional cost savings.
Implementation Schedule	Establish a site-by-site implementation/deployment schedule for ADS-B that will capture the maximum benefits of the program as early as possible.
Procedures Development	Establish a program to develop the airspace structure and the operational procedures associated with the implementation of the ADS-B and related automation programs. These procedures must include fail-safe and fail-soft considerations.
NPRM	Introduce a Notice of Proposed Rulemaking (NPRM) for carriage of the ADS-B avionics in a timely fashion so that aircraft are equipped for early and smooth transition to ADS-B. Develop a strategy for military equipage with ADS-B.
DoD and International Coordination	Examine the implications associated with the transition to ADS-B for DoD and the international community. Develop strategies with respect to acceptance of ADS-B.
R&D Plan	Prepare a detailed R&D plan to mitigate technical risks, address prototype development and testing, and support the F&E program.
Interference Analysis	Conduct analyses and tests to demonstrate the concurrent proper operation of ADS-B squitter with ATCRBS, Mode S, PRM, TCAS, and ATIDS.

GLOSSARY

ACCC	Area Control Computer Complex.
ADS-B	Automatic Dependent Surveillance-Broadcast. Also (previously) known as "Satellite-Derived Aircraft Surveillance (SDAS)" and "ADS CONUS." ADS-B will either replace certain radar systems or work side-by-side with other systems.
AERA	Automated En Route Air Traffic Control.
AGL	Above Ground Level.
AI	Artificial Intelligence.
AMASS	Airport Movement Area Safety System.
AN/FPS	Long-range primary surveillance radar.
ARSR	Air Route Surveillance Radar.
ARTCC	Air Route Traffic Control Center.
ARTS	Automated Radar Terminal System.
ASDE	Airport Surface Detection Equipment.
ASDE-X	A low-cost X-Band ASDE radar.
ASR	Airport Surveillance Radar.
ASR-M	ASR with Windshear Processor.
ASTA	Airport Surface Traffic Automation.
ATA	Air Transport Association of America.
ATC	Air Traffic Control.
ATCBI	Air Traffic Control Beacon Interrogator.
ATCRBS	Air Traffic Control Radar Beacon System.
ATCSCC	Air Traffic Control System Command Center.
ATCT	Air Traffic Control Tower.
ATIDS	ASTA Target Identification Subsystem.
ATM	Air Traffic Management.
ATN	Automated Telecommunications Network.
Azimuth	Horizontal bearing or direction, referenced to North.
BOS	Beacon-Only System.
BTD	Beacon Target Detector.
CAS	Collision Avoidance System.
CAT	Clear Air Turbulence.
CBA	Cost/Benefit Analysis.
CD	Common Digitizer.
CDTI	Cockpit Display of Traffic Information.
CFAR	Constant False Alarm Rate.
CIP	Capital Investment Plan.
Clutter	Unwanted indications on display, especially radar display, due to atmospheric interference, lightning, natural static, ground/sea returns, or hostile ECM.
CNS	Communications, Navigation, and Surveillance.

GLOSSARY

Cone of Silence	Inverted cone of airspace with vertical axis centered on radars, VORs, DMEs, NDBs, and other point navaids, within which the signal strength is close to zero.
CONUS	Continental U.S., i.e., U.S. and its territorial waters between Mexico and Canada.
COTS	Commercial Off-the-Shelf.
CPU	Central Processing Unit.
CTAS	Center-TRACON Automation System.
DEMVAL	Demonstration and Evaluation.
Domestic Oceanic Airspace	Shore to 250 miles out into the ocean.
Doppler Radar	Radar that measures doppler shift to distinguish between fixed and moving targets, or serve as airborne navaid by outputting G/S and track.
DSP	Departure Sequence Processor.
DT&E	Developmental Test & Evaluation.
ECM	Electronic Countermeasures.
En Route	Between air terminals.
FAA	Federal Aviation Administration.
FADE (method)	Focus, Analyze, Develop, and Execute (method).
FANS	Future Air Navigation Systems.
F&E (costs)	Fabrication & Engineering.
FL	Flight Level.
FMS	Flight Management System.
FOC	Full Operational Capability.
FPS	Military designation for ground-based primary radar.
Free Flight	Without guidance except, possibly, simple stabilizing autopilot, under continuous controller monitoring.
Fruit	Unsynchronized beacon interference.
FWG	Functional Working Group.
GA	General Aviation.
Garble	Synchronized beacon interference.
GNSS	Global Navigation Satellite System.
GPS	Global Positioning System.
HDOP	Horizontal Dilution of Precision
Host	The ARTCC primary processor, which receives en route radar data for processing to support the display system.
ICAO	International Civil Aviation Organization.
IFR	Instrument Flight Rules.
INMARSAT	International Maritime Satellite.
IOC	Initial Operational Capability.
ITWS	Integrated Terminal Weather System.
Jitter	To send out pulses with predicted spacing (to avoid aircraft locking-on to another interrogating same beacon).
JSS	Joint Surveillance System.

GLOSSARY

LAAS	Local Area Augmentation System.
LCC	Life-Cycle Cost.
LLWAS	Low-Level Windshear Alert System.
LRR	Long-Range Radar.
LRSR	Long-Range Surveillance Radar.
MCF	Metroplex Control Facility.
MEA	Minimum En Route IFR Altitude.
Microburst	Most lethal form of vertical gust, in which core up to 2.5 km (1.5 miles) diameter forms vertical jet below convective cloud with downward velocity up to 20 m/s (4,000 ft/min), an almost instantaneous velocity difference of 80 kt, down to very low levels.
MIP	Multisensor Interface Processor.
MNPS	Minimum Navigation Performance Standards.
Mode 4	Beacon signals required for military functions.
Mode A	ATCRBS identity mode.
Mode C	ATCRBS altitude mode.
Mode S	Discrete address radar beacon mode: Proposed 1030 MHz frequency to be used to broadcast ADS-B flight management data from the cockpit to the ground.
Mode S DL	Mode S Data Link.
MOPS	Minimum Operational Performance Standards.
MP-ASR	Multipurpose Airport Surveillance Radar.
MSL	Mean Sea Level.
MSSR	Monopulse Secondary Surveillance Radar.
MTBF	Mean Time Between Failures.
MTD	Moving Target Detector.
MTI	Moving Target Indicator.
MTTR	Mean Time To Repair.
Multilateration	Position determination by use of radar or possibly communications signals received at multiple (three or more) ground sites.
NAD83	North America Datum, 1983.
NADIF	NAFEC Dipole Fix.
NAFEC [FAATC]	FAA Technical Center.
NAS	National Airspace System.
NAS-SR-1000	NAS System Requirements 1000 document.
NAS-SS-1000	NAS System Specification 1000 document.
NAV	Navigation.
NDI	Non-Development Item.
NEXRAD	Next Generation Weather Radar.
NPRM	Notice of Proposed Rule Making.
NWS	National Weather Service.

GLOSSARY

O&M	Operations & Maintenance.
OT&E	Operational Test & Evaluation.
PAMRI	Peripheral Adapter Module Replacement Item.
PERT	Performance Evaluation Review Technique.
PRF	Pulse-Repetition Frequency.
Primary Radar	One using reflection of transmitted radiation from target, as distinct from retransmission on same or different wavelength.
PRM	Precision Runway Monitor.
Radome	Protective covering over radar or other aerial, especially one with mechanical scanning; made of dielectric material selected according to operating wavelength and other factors.
RCS	Radar Cross-Section.
R&D	Research & Development.
R,E&D	Research, Engineering & Development.
RF (data link)	Radio Frequency (data link).
rho	Informal term for range.
RMMS	Remote Maintenance Monitoring System.
RWSL	Runway Status Lights.
RTCA	Radio Technical Commission for Aeronautics.
SAMF	Surveillance Advance Message Format.
SAR	Search and Rescue.
SATCOM	Satellite Communications.
Secondary Radar	A cooperative radar system in which interrogatory pulse is sent to distant transponder, which is triggered to send back a different pulse code to originator.
SMA	Surface Movement Advisor.
S/N	Signal/Noise ratio.
Squitter	Unelicited broadcast by aircraft transponder.
SSR	Secondary Surveillance Radar.
STARS	Standard Terminal Automation Replacement System.
STDMA	Self-organizing Time Division Multiple Access.
SVP	Surveillance Vision Plan.
SVP FWG	Surveillance Vision Plan Functional Working Group.
TATCA	Terminal Air Traffic Control Automation.
TCA	Terminal Control Area.
TCAS	Traffic Alert and Collision Avoidance System.
TCCC	Tower Computer Control Complex.
TDMA	Time Division Multiple Access.
TDWR	Terminal Doppler Weather Radar.
T&E	Test & Evaluation.
TFM	Traffic Flow Management
theta	Informal term for angle.
TOA	Time of Arrival.
TRACON	Terminal Radar Approach Control.

GLOSSARY

TSD	Traffic Situation Display.
UAT	Universal Access Transponder.
VDOP	Vertical Dilution of Precision.
VFR	Visual Flight Rules.
VHF	Very High Frequency.
WAAS	Wide Area Augmentation System.
WARP	Weather and Radar Processor.
WBS	Work Breakdown Structure.
WGS84	World Geodetic Survey, 1984.
Windshear	Exceptionally severe local wind gradient, recognized as an extremely dangerous phenomenon because it is encountered chiefly at low altitude (in squall or local frontal systems) in approach configuration and speeds where it makes sudden and potentially disastrous difference to airspeed and thus lift.
WSP	Windshear Processor.