A Visionary Look at Aviation Surveillance Systems

George Donohue
Associate Administrator for Research and Acquisitions, ARA-1
U.S. Federal Aviation Administration

ABSTRACT

The FAA’s future aviation surveillance systems fall into four categories: Automatic Dependent Surveillance (ADS) will be used in the oceanic environment; ADS-Broadcast (ADS-B) will be used in the domestic en route environment; ADS-B will be used with a secondary radar backup in the terminal area; and ADS-B will be used with primary radar backup within the Airport Surface Traffic Automation (ASTA) system on the airport’s surface environment. Two other systems introduced in this paper are Cockpit Display of Traffic Information (CDTI) and Traffic Advisory and Collision Avoidance System (TCAS). All these systems will use navigational signals emitted by the Global Positioning System (GPS) constellation of satellites. This paper is a visionary look at these future systems.

INTRODUCTION

The FAA is changing the way it does business; budget reductions and growing customer requirements are demanding that the FAA become more efficient — to do more with less. Government and industry partnerships are being implemented at the FAA. These partnerships are an integral part of this new way of doing business. Another new way of doing business is reflected in the FAA as it transitions from an exclusively ground-based surveillance system to a space- and ground-based surveillance system tied together by distributed central processing. The FAA and industry should and must be jointly involved to ensure a successful transition. This transitional process is based on a solid systems engineering and integration approach, building on commercial technology and industry advances to provide superior levels of service and safety, yet at lower costs to the system users.

The FAA’s future aviation surveillance systems fall into four geographic categories: oceanic, domestic en route, terminal area and surface. The technologies needed to achieve this future vision are already here. For example, the space-based Global Positioning System (GPS) makes available accurate, three-dimensional position information to anyone with a relatively low-cost GPS receiver. The utility of these GPS signals for aircraft navigation, approach, landing and taxiing is currently being tested. My approach to this vision demands that the future of aviation surveillance systems be evolutionary. Compatibility with existing aircraft capabilities is a critical transition component. Automatic Dependent Surveillance (ADS) will be used in the oceanic environment; ADS-Broadcast (ADS-B) will be used in the domestic en route environment; ADS-B will be used with a secondary radar backup in the terminal area; and ADS-B will be used with primary radar backup within the Airport Surface Traffic Automation (ASTA) system on the airport’s surface environment. Let me explain the basic differences between ADS and ADS-B.

First, ADS supports only the oceanic ATC environment at relatively low update rates. For example, an update rate of every 10 minutes. ADS-B would serve air-to-ground and air-to-air applications at a very high update rate to support domestic en route, terminal area and airport surface
environments. That rate has been given as once every 1/2 second. Secondly, ADS used in the oceanic environment provides ADS reports addressed to a specific ground facility via a satellite communications link, whereas ADS-B broadcasts its position without knowledge of who or how many recipients there are receiving the information. And lastly, ADS requires a satellite and ground communications network infrastructure to support delivery of surveillance reports to the desired facility, whereas ADS-B can be used with stand-alone ground systems. ADS-B development and implementation will impact many current aviation surveillance technologies.

The role of primary radars will be classified as a passive system as viewed by the aircraft. It will become a "weather detector," "intruder detector," and "blunder detector." Weather detection includes the detection of storms and storm cells, wind shear, micro bursts, the measurement of wind fields to predict possible wake vortices, and other weather phenomena important to aviation. Intruder detection includes aircraft with transponders intentionally turned off. Blunder detection includes failed transponders or transponders unintentionally turned off.

The role of secondary radars serve the predominant role in the Air Traffic Control (ATC) automated environment and can be classified as an active system in that some action is taken by aircraft avionics. Today some of these radars interrogate each aircraft independently through the use of Mode-S radar. In the future this radar system will collect data that are broadcast to the ground from each aircraft's ADS-B. Later in this paper, the ADS-B will be shown integrated into the Mode-S.

SUMMARY OF CURRENT AND FUTURE AVIATION SURVEILLANCE SYSTEMS

The FAA's ATC system is second to none. Increasing demand and the need for efficiency in flight operations call for an even more dependable and reliable ATC system. We are leading the development of new runways at existing airports and the construction of new airports to handle the increase in airline passengers and cargo. We are seeing an increased interest by the airline industry on space-based technology, rather than ground-based technology, for communications, navigation, and surveillance to replace aging ground-based equipment. This interest is for better services at lower costs. These changes require upgrades to the FAA's ATC systems and corresponding updates to ATC procedures to manage the increased demand, to accommodate failure conditions and to manage mixed user equipage.

Observers of the industry agree that most delays and many potentially hazardous situations are caused by incomplete knowledge of the weather, or poor dissemination of the information we do have. Our future management of weather information provides one of the most fertile areas for improvement of aviation by new technology. Many of these future aviation surveillance systems can provide both surveillance and weather information. Collection of this information through improved weather sensors, and the integration of weather sensor data to provide comprehensive, timely, and reliable predictions of weather phenomena will result in major benefits to the airspace system users.

Major airports throughout the United States will employ new doppler radar systems optimized for weather detection using both rotating and phased-array technology. Real-time weather observations will be transmitted to the ground from appropriately-equipped aircraft by means of a data link. These observations will be integrated with ground-based observations from FAA and National Weather Service sensors to provide a more comprehensive weather picture.

The extensive database of weather observations will be accessed by sophisticated weather models to provide both the tactical and strategic weather planning required by civil aviation. These products will be distributed in a timely manner throughout the aviation community to operators, flight planning services, and air traffic management facilities.

For the remainder of this paper, I would like to concentrate on the future of aviation surveillance systems.

AVIATION SURVEILLANCE IN THE OCEANIC ENVIRONMENT

There are, of course, no civil ATC radar systems available today that can stretch their coverage across the oceans, or to desolate places such as the polar regions. The only way the FAA ensures separation of aircraft over these areas is through the use of high-frequency voice communications. Basically, the air traffic controller on the ground and the pilot in the aircraft will agree that the aircraft will arrive at some 3-dimensional point (that is, latitude, longitude and altitude) at a predetermined time. When the aircraft arrives at that fix in space, or waypoint, the pilot files a report with the controller and they agree to the next fix at another future time. This continues until the aircraft comes within range of ground-based radar systems and when separation can be assured by direct surveillance. This methodology requires large aircraft separation and widely spaced routes, with severe limitations on airspace capacity and use of efficient flight paths.

Adding ADS over the oceans will allow reduction in separation, open up more efficient routing and increase capacity. The aircraft's position will be communicated, using an aeronautical two-way digital data link, via communication satellites to ground-based oceanic traffic control centers. The frequent transmission of more accurate and more reliable aircraft position data and the corresponding rapid receipt of ATC instructions will allow reduced separation, quick clearances to optimize aircraft profiles — for example, climb, cruise and descent rates — and changes in routing to take advantage of more favorable wind conditions.

The success of applying ADS within a region of oceanic airspace requires all aircraft in a region be equipped with satellite navigation equipment to receive the GPS signals. The success will come when all aircraft are transmitting their
Fig. 1. CDTI/TCAS

positions by means of a data link through a communications satellite and down to a ground station.

ADS is planned to become operational with some equipped air carrier aircraft over the Pacific Ocean in 1996 and over the Atlantic Ocean in 1998. Advanced ATC automation will one day request ADS reports adaptively, based upon the proximity of aircraft, planned route modifications, and other event-driven factors. Between position updates, the data will be merged at the oceanic facilities with similar data from other aircraft to form situational displays much like those provided by domestic en route radars.

Current ATC requirements are, of course, based on the capabilities of the radar systems, not on the future capabilities of ADS. Changes will occur in the FAA's management of the National Airspace System (NAS). For example, the responsibility for Instrument Flight Rule (IFR) separation assurance may be shared with the cockpit to allow for the modification of FAA standards on IFR separation. The next generation automation equipment will be designed to take advantage of the increased information provided in the ADS message to support the automated functions needed to achieve "seamless gate-to-gate" operation.

By "seamless" I mean that an aircraft will be able to fly from country to country, across oceans, in an integrated, gate-to-gate international system where positions are accurately reported through a network of satellites, data links and ground automation equipment. Accurate three-dimensional position information, specific airframe performance parameters and current weather data will allow system users and providers to tailor each aircraft's phase-of-flight to provide the safest and most fuel-efficient routes.

AVIATION SURVEILLANCE IN THE DOMESTIC EN ROUTE ENVIRONMENT

In the domestic en route surveillance environment, surveillance is being performed by a family of radar systems called the Air Route Surveillance Radar, the ARSR-1, -2, -3 and -4. These systems are scheduled to begin their phase-out around the year 2000. FAA funding will continue to sustain these systems until full decommissioning occurs. The ARSR-4s installed around the perimeter of the U.S. will continue to be maintained through an intra-agency agreement between the FAA, the Department of Defense and the Department of Justice's Drug Enforcement Administration.
The bottom line is that the ARSR-4s around the perimeter of the U.S. will remain in place to continue their long-range surveillance.

Secondary en route surveillance was once supported entirely by the Air Traffic Control Beacon Interrogator (ATCBI) family of systems. In the future, secondary en route surveillance will be based on future available technology.

In the distant future, an aircraft in domestic airspace will broadcast its position via ADS-B. The transition to ADS-B will be market-driven. Today the architecture has not been defined, and the cost benefits still need to be better understood. ADS-B supports improved use of airspace, improved surface surveillance, and enhanced safety — such as collision avoidance — for users. One version of ADS-B allows the aircraft's Mode-S transponder to broadcast the GPS-derived information. In this version, ADS-B transmits a GPS position message every half-second and an aircraft identification code every 5 seconds. The data are received by a ground station which decodes and processes the surveillance data for an enhanced automation system. The update rate of the transmissions allows for reliable surveillance in the en route environment.

Another method of implementing ADS-B is to use the Swedish-proposed Global Navigation Satellite System (GNSS) transponder. This transponder uses a GPS receiver and a VHF data link. Any system architecture must face the issue of complexity of implementation, compatibility with existing avionics, and cost. For example, the Swedish-proposed VHF data link system requires new avionics, while the Mode-S system requires a slight modification to the Traffic Alert and Collision Avoidance System called TCAS II, equipment or replacement of an aircraft's existing transponder if Cockpit Display of Traffic Information (CDTI) is desired. The key issues are capacity, complexity of implementation, and cost, but whatever system is eventually used will be based on GPS positional data combined with a data link.

ADS-B, through its data link, will assist in tracking the position of each suitably-equipped aircraft. This will make the Air Traffic Management system more efficient by increasing capacity, reducing fuel consumption, reducing delays, and at
the same time reducing controller and pilot workloads. It appears that ADS-B will be implemented and in use before some needed advanced automation can catch up with it. While early test results have proven promising, ADS-B will become a real success when the FAA is able to use advanced automation to perform analysis, and run modeling and simulation. We have already tested this concept in a real-time environment — at Hanscom Air Force Base, Logan Airport in Boston, Massachusetts and in both high altitude and low altitude tests over the Gulf of Mexico where ADS-B is extending continental U.S. coverage into this airspace.

Except for packaging enhancements to withstand the sea-going environment and satellite relay of position data from buoys in the Gulf housing the equipment, the ADS-B system is essentially the same as the domestic en route system. ATC monitoring of ADS-B testing in the Gulf is presently underway with helicopters, a commercial airline, and general aviation aircraft.

Two alternatives are being considered for the transition from ground-based beacon radar surveillance to space-based ADS-B surveillance. One alternative is to begin replacing the aging beacon equipment with ADS-B on a unit-by-unit basis. Before full beacon replacement occurs, overlapping ADS-B and beacon output data can be integrated by means of a fusion tracker.

The second alternative is to completely maintain the existing ground-based beacon equipment until the entire ADS-B system can be operationally deployed, leaving the ground-based systems as a backup system.

In either alternative, the supportability of beacon equipment requires further investigation to determine if it will survive until ADS-B can be used as its full replacement. Our assumption is that beacon equipment costs are likely to increase as obsolete parts become scarce. Also, in either alternative, operation and maintenance of beacon equipment will continue to be accomplished for some time after any ADS-B systems are installed in order to provide a safe and reliable transition to the new system. This is to assure that the ADS-B surveillance system has sufficient operational integrity to meet NAS requirements, including sufficient user equipage.

To minimize the impact of ADS-B equipage costs to the user community, a short transition period is required which provide economic payback. The airlines have stated that such payback must occur within 5 years. The payback will be in the form of increased direct routing and free tracking. Considerable work is necessary in advanced automation to realize this capability.

For the General Aviation (GA) user, life expectancy of existing avionics equipment is the primary consideration. Life expectancy of existing avionics equipment may be up to 20 years or longer. Since the FAA would want all aircraft participating, incentives are necessary to effect a faster turnover of avionics equipment on GA aircraft. The goal is to get ADS-B capability into GA aircraft. Initially, ADS-B airborne user equipage will be voluntary. Incremental benefits will be predicated on user equipage and ground infrastructure. Incentives to speed up this transition among GA aircraft would include: a modest incremental cost to add the ADS-B capability; integration of ADS-B equipage with other desired or required avionics that would minimize space and power requirements and reduce costs; installation of ADS-B ground systems where that can provide immediate user benefits, that is, where surveillance radar coverage is not readily available today; and the integration of ADS-B and data link communication services into the same or colocated ground stations.

An immediate incentive would be the use of Cockpit Display of Traffic Information (CDTI). This system would allow the pilot in the cockpit to see other aircraft in the vicinity, whether airborne or on the surface, in much the same way that the controller sees aircraft in a ground-based facility. A CDTI capability could be achieved by receiving ADS broadcasts from nearby aircraft and displaying the positions of the proximate targets on a cockpit display. However, CDTI will only provide this benefit when all or a majority of users are equipped.

The impact of CDTI technology requires further investigation to determine any required procedural changes. To achieve direct routing, free flight capability, and more efficient airport operations, procedures are likely to be revolutionized as surveillance improves under ADS-B.

The ADS-B approach could be adapted throughout the world. The Mode-S operability and frequency assignment has already been adopted as the world standard for airborne transponder and Traffic Alert and Collision Avoidance System (TCAS) applications. TCAS II is an airborne system designed to communicate avoidance decisions between aircraft. Aircraft are tracked in both the horizontal and vertical planes, and their time of closest approach with each other is determined. If a conflict is detected, the system tells the pilot what maneuver to take to avoid collision. ADS-B complements the use of secondary surveillance radar technology for TCAS. The next generation of TCAS, TCAS IV, could use the highly accurate navigation data from ADS-B to improve its performance, resulting in reduced false alarm rates, an improved threat detection range and support of the use of horizontal conflict resolution.

In order to assure worldwide integration of the ADS-B approach and to prevent U.S. international carriers from being required to equip with a proliferation of country-specific equipment, coordination is necessary with the International Civil Aviation Organization (ICAO).

**AVIATION SURVEILLANCE IN THE TERMINAL AREA**

Terminal area surveillance systems relies on the Air Surveillance Radar (ASR) and Secondary Surveillance Radar (SSR) family of systems. New ASR radar systems are currently digitized and are able to be integrated with both enhanced Mode-S systems and future weather functions, such as wind shear processors.

In the near future, ADS-B will play a surveillance role in the terminal area. The approach to completing ground
integrated ADS-B into Metroplex Control Facilities (MCFS), Terminal Radar Approach Control facilities (TRACONs), and terminal area and surface automation systems will be to develop a fusion tracker. ADS-B track data will be correlated with radar track data using an integration processor, or fusion tracker, to assure that only one target per aircraft is displayed to the controller in the facility. In the initial phase, the fusion tracker output will emulate the standard radar interface in order to eliminate the necessity for any modification to the components of ATC advanced automation.

AVIATION SURVEILLANCE ON THE AIRPORT SURFACE

Today's surface traffic control relies on visual observation, short-term memory-dependent situational awareness, and memory-dependent traffic planning by controllers. All communications are via voice.

In the near future, automatic traffic monitors will provide safety backup, and trilateration techniques will provide identification of targets on the airport surface. At major airports, these capabilities will be provided by elements of the Airport Surface Traffic Automation (ASTA) program and the Airport Movement Area Safety System (AMASS). In the end state, ASTA will be augmented with ADS-B.

ADS-B will be used for surface surveillance once an aircraft is on the ground. Positional accuracy will be sufficient to allow ground control computers and air traffic controllers to vector aircraft on runways and runway approaches. Pilots will know their ground positions accurately, even in adverse weather conditions, from virtually any point on an airport, and pilots will be able to retransmit this information to ground traffic control computers. Both pilots and ground controllers will have real-time situational displays showing airport maps with their position, taxi routes and clearances. The location of all ground traffic can be shown in both the cockpit and on ATC displays.

ASTA will provide safety alerts to pilots, automatic visual and aural alerts to controllers of potential or actual runway incursions, target identification, and traffic planning for sequencing departures. ASTA will likely support voice recognition in the tower to get controller intent and will send signals to control airport runway access lighting using the Runway Status Lighting System (RSLS).

For example, when an aircraft is cleared onto a runway, the runway becomes a protected zone in which no other aircraft may enter. This zone is directly proportional to the velocity and performance of the aircraft on or approaching the active runway. All adjoining taxiways and intersecting runways will have their status lights — that is, "cleared" or "not cleared" to proceed — automatically changed to a "hot cleared" status. After the aircraft on the active runway passes the adjoining taxiways or any intersecting runways, the RSLS will automatically switch the appropriate status lights to a "cleared" status. These automated signals are derived from the surface surveillance systems.

SUMMARY

This paper is about future aviation surveillance systems: ADS in the oceanic environment; ADS-B in the domestic environment; ADS-B with a secondary radar backup in the terminal area; and ADS-B with primary radar backup within the ASTA system on the airport's surface environment. Each system has been planned to overlay and eventually replace some of the FAA's existing systems. All of these systems use navigational signals emitted by the Global Positioning System. The FAA is moving away from total reliance on ground-based surveillance systems and toward a combination of space-based surveillance and our next-generation terminal system. The speed at which we move will be based on a solid systems engineering and integration approach that includes the proper requirements analysis as well as the benefit analyses for both the FAA and for the users of the National Airspace System. I want to stress that this forward movement in aviation surveillance systems is evolutionary, derived from a timing that is user-benefit driven. If these systems and their components cannot derive significant benefit, then the proper business decision is to not proceed. We all have heard the expression "Technology for technology's sake." Within the FAA, we must provide services to the aviation community, provide technology to reflect direct user needs, and show benefits.

ACRONYMS

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<td>ADS</td>
<td>Automatic Dependent Surveillance</td>
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<td>ADS-B</td>
<td>ADS-Broadcast</td>
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<td>AMASS</td>
<td>Airport Movement Area Safety System</td>
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<td>ARA</td>
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REFERENCES

