Current and Future Surveillance System Evolution

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1.0 Surveillance System Objectives

Surveillance is a key function for airspace management and supports both tactical separation assurance of aircraft and strategic planning of traffic flows. The primary objective of the surveillance function is to support the following types of airspace management functions:

- Short Term Separation Assurance

The surveillance function provides current aircraft state information on controller displays and as inputs to separation automation functions, i.e. the short term Conflict Alert system for detecting immediate path conflicts, and the Minimum Safe Altitude Warning (MSAW) system for detecting potential flight into terrain. In addition, future automation functions may require inputs for path lateral and vertical conformance monitoring and for automated checking of path intent versus path clearances.

- Medium Term Separation Assurance

The surveillance function currently provides state information for sector based airspace planning and load management. In the future, additional automation functions such as Medium Term (~ 20 min. lookahead) Conflict Probe may be used to detect and resolve potential airspace conflicts, enhancing the productivity of ATC centers. These automation functions will probably require enhanced surveillance in order to provide accurate and reliable path predictions for medium term lookahead periods.

- Medium Term Airspace Planning

In the future, the surveillance function must support medium term flow planning and airport arrival /departure management in congested hubs and other areas where traffic loads can lead to flow inefficiencies and saturation of airspace throughput. Automation tools such as the CTAS arrival manager and proposed dynamic sectorization tools will require higher levels of surveillance performance if safety and capacity goals are to be achieved as traffic demand increases.

- Strategic / Long Term Planning and Flow Management

One of the goals for the future Flow Management system is to transition from a Departure Managed system to an Arrival Managed system of flow management. One enabling technology for strategic management of airport arrival slots is accurate 4-D prediction of flight paths from takeoff to arrival at airport metering fixes. The surveillance function supports strategic flow management by providing accurate state and intent information for long term path predictions.

Similarly, en-route traffic flow control automation such as dynamic sectorization requires accurate path predictions for sector load analysis and flow management.

2.0 Current Radar Based Surveillance System Performance

The current NAS airspace uses a variety of radar systems to supply surveillance data for surface, terminal, and en-route airspace management. On the airspace surface, current generation ASDE-3 primary radars are being installed at major hub airports to provide surface surveillance and incursion alerting. In the terminal airspace of most medium and large capacity airports, surveillance data is provided by an Airport Surveillance Radar (ASR) primary radar which provides position reporting on a periodic scan basis, supplemented by a co-located Secondary Surveillance Radar (SSR) which provides aircraft identification, altitude, and backup position reporting. Smaller airports may only have access to an SSR radar, or may have no surveillance capability other than that provided by voice reporting and tower controllers. En-Route airspace uses a networked system of Air Route Surveillance Radars (ARSR) which provide continuous monitoring of aircraft flying in domestic airspace above ~ 9,000 feet altitude. Each radar is networked to one or more Air Route Traffic Control Centers (ARTCC) to provide continuous monitoring of aircraft across NAS managed airspace. Considerable redundancy is built into the en-route surveillance system in that ARSR sensors are positioned to achieve at least dual radar coverage throughout NAS managed airspace, and in addition a co-located SSR provides identification, altitude and position reporting along with that of the primary ARSR radars.

Current terminal area surveillance is provided by a mix of ASR -7,8,9 primary radars and ATCBI - 3,4,5 and Mode-S secondary radars. The older generation analog ASR-7 radars are more than 30 years old and are being replaced by modern ASR-9 radars or the near term ASR-11 radar. The last-generation ASR-8 radars are also analog radars which are being upgraded to ASR-8D digital radars to perform surveillance equivalent to that of the current generation ASR-9 radars. The ATCBI-3,4,5 are older SSR radars which are being replaced by modern Mode-S radars or the near term ATCBI-6 which is a monopulse SSR with limited Mode-S functionality. (The ASR-9's for major hub airports are paired with Mode-S radars, and the ASR-11's will be paired with ATCBI-6 secondary radars.) These radars are designed to support ranges of at least 60 nm around each airport, and to scan at a rate of about one report per 5 second interval. The modern radars have azimuth accuracies on the order of one mrad rms, which means that the position reports of aircraft within terminal range are accurate to 0.1 nm or better. By contrast, the older radars have azimuth accuracies on the order of three mrad which means that the cross-range components of position reports have much greater uncertainty and aircraft tracking is significantly less precise.

Current en-route surveillance is provided by a mix of ARSR 1,2,3,4 primary radars with co-located ATCBI and Mode-S secondary radars. The ARSR 1,2 radars are very old analog radars and must be decommisioned in the near term as they are very expensive to maintain. The ARSR-4 radars are the current generation systems which are being deployed paired with Mode-S secondaries along the US coast lines and international borders, and the ARSR-3 radars will be given service life extensions to maintain service over the next 20 years. These radars are designed to provide line-of-sight (~ 250 nm range) capability and to scan at a rate of about one report per

12 second interval. The detection probability and accuracies are similar to those of the terminal radars. This means that position reports at ranges on the order of 150 nm or more are considerably less accurate than those for terminal surveillance, and as a consequence of the report accuracy and lower data rate, en-route tracking and data report quality are much lower for en-route surveillance. This is one of the reasons that horizontal separation standards are much larger in en-route airspace.

2.1 NAS Surveillance System Limitations and Deficiencies

Surveillance system performance today is characterized by the radar sensors available, the tracking and data fusion software in the ATC centers, and the display automation used for tactical control. In the terminal area, the modern ASR and monopulse SSR sensors produce high quality position data for determining aircraft state and identity, and the older less capable sensors are in the process of being replaced. Similarly, most of the processing and display limitations of the current ARTS system may be overcome with the replacement STARS automation system. A primary architectural problem, however, is the low connectivity of radars in the terminal area. This leads to an expensive system, since every airport with ATC facilities needs a source of surveillance data. One of the goals of the future system is to reduce the number of radars in each urban area to provide dual surveillance coverage of all major airports (for functional redundancy in case of system failures), and at least single coverage of other airports by networked distribution of surveillance data to ATC fusion nodes (NAS Architecture V2.0, 1996).

By contrast, current NAS en-route surveillance is characterized by a number of problem areas. The accuracy and usefulness of aircraft state data is greatly limited by the use of legacy tracking and display software. This results in fair to poor velocity estimates with considerable noise variations from scan to scan, and in large tracker lag errors (~ 30 to 60 sec lag errors during turn maneuvers). Moreover, the use of the ‘radar mosaic’ concept for switching from one primary sensor source to another as the aircraft traverses across mosaic boundaries leads to track state ‘jumping’ as the tracker shifts from one sensor source to another. In addition to these implementation problems, the current surveillance system does not provide flight path intent data for path conformance monitoring, and provides only limited coverage at low altitudes and in mountainous terrain. The implementation problems of the current system can be largely overcome by use of modern multi-sensor tracking and data fusion software, which compensates for deterministic sensor errors such as azimuth bias errors, and enables dynamic blending of the most appropriate data for aircraft state estimation. (A surveillance ‘server’ concept is advocated in NAS architecture versions 2.0-3.0, which would network multiple terminal and en-route sensors into common data fusion nodes, and distribute the global track data to appropriate ATM facilities, requesting users, and to external fusion nodes.)

3.0 Surveillance Evolution

3.1 Summary of Surveillance Evolution

The current surveillance system is based on the use of redundant primary and secondary (beacon) radars. The role that ground based radars play may be gradually diminished as GPS based ADS[1] systems become available. The evolution to next generation surveillance is complicated by interoperability and compatibility with current systems in use. Two principles which limit available options for next generation systems are:

- Compatibility with current secondary radar systems, i.e. Mode A/ C/ S,

- Interoperability with current TCAS collision avoidance systems and next generation CDTI based air-air surveillance and situation awareness.

In the near future, we will probably see a mix of radar and ADS technologies which will be integrated and fused at the major ATC centers, providing high integrity and high accuracy surveillance based on multiple sensor inputs.

The value that ADS methodology adds to surveillance is not limited to radar monitoring capability however. With ADS we can down-link extended surveillance information related to aircraft intent, and other data such as current winds aloft which are useful for predicting aircraft paths. The ability to fly Free Flight routings, for example, may depend on knowing validated and accurate path intent, as well as the ability to monitor current position and velocity states.

The value of ADS broadcast (ADS-B) for air-air surveillance and airborne separation assurance is yet to be evaluated. However, this technology will certainly play a role in areas where radar surveillance is uneconomic or not feasible. In the near future we will see the development of dual mode CDTI / TCAS systems for oceanic and remote area applications such as In-Trail Climb/Descent and for increased safety in non-radar airspace. CDTI will also play a role in the congested terminal areas of major hub airports providing additional safety and operational capabilities for equipped aircraft.

In the sections below we summarize the evolution of surveillance for surface, terminal area, en route, and oceanic operations. The emphasis of these sections is on the evolution of air-ground surveillance since the primary responsibility for separation assurance will remain with ground based systems in the near term evolution of the NAS airspace system. A possible evolution path for air-air surveillance and CDTI is then summarized.

3.2 Airport Surface Surveillance

Airport surface surveillance includes monitoring and display of the movements of all vehicles on controlled areas such as taxiways and runways, and providing sensor inputs for surface movement and incursion alert automation systems. Figure1 shows the probable evolution of surface surveillance from current radar based monitoring systems to multi-sensor radar / ADS-B systems. (The dotted arrows in the figure denote evolutionary upgrade paths, while the solid line arrows

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[1] In this section we refer to ADS in a generic sense rather than as a specific implementation. In this sense, Mode-S Specific Services, Mode-S extended squitter broadcast and contract based ADS as defined by RTCA DO-212 represent specific implementations of ADS technology.

denote inputs from sensors to automation systems.) The older generation of ASDE-2 radars is currently being phased out and newer generation ASDE-3 primary radars are being installed at 40 of the biggest hub airports in the NAS. The ASDE-3 display system will then be upgraded by Airport Movement Area Safety System (AMASS) software for automated incursion alert. Two major problems with the ASDE-3 systems are the cost of installing and maintaining the radars, and the lack of aircraft / vehicle ID for surface movement, guidance & control. At the larger hub airports, ADS-B systems will be integrated with the ASDE radars to provide aircraft / vehicle ID, and to provide a backup sensor for radar failures. At smaller airports, ADS-B ground systems will provide a less expensive means of surface surveillance for equipped aircraft and surface vehicles. The AMASS automation software will evolve into Surface Movement Guidance and Control Systems (SMGCS), for comprehensive surface guidance & control to maximize airport capacity during peak periods, while maintaining adequate safety for airport surface operations.

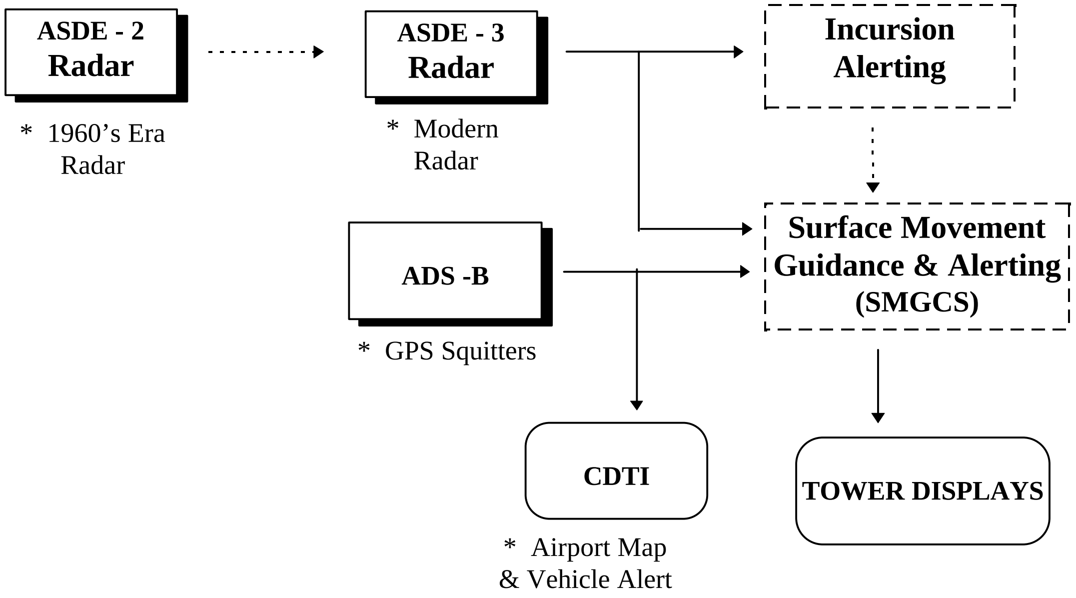

Figure 1: Airport Surface Surveillance Evolution Path

ADS-B data may also be used aboard equipped aircraft to display surface traffic and airport features on a plan view CDTI display optimized to surface operations. This would provide the air crew with redundant monitoring of potential incursions for increased safety and surface situation awareness.

3.3 Enhanced Terminal Area Surveillance

Terminal area surveillance with today's radar based technology and automation system consists of tracking and display of position and velocity states and aircraft ID for all aircraft operating within 60 nm of the airport surveillance radars. Figure 2 illustrates that future terminal area systems will evolve in several ways to provide enhanced terminal surveillance. One of the major changes will be the evolution of multi-sensor tracking systems for integrating data inputs from multiple radar systems and from ADS-B equipped aircraft to derive the most accurate and robust tracking of current aircraft states obtainable from multiple data sources. Even without ADS inputs, the use of multiple radar sensor blending has been shown to greatly improve the quality of aircraft tracking for advanced automation systems such as CTAS, and area-wide conflict probe. These systems need high quality velocity estimates with accurate steady state tracking and rapid response to aircraft maneuvers, which is attainable with state-of-the art multi-sensor tracking systems. The advent of ADS-B equipped aircraft will also require multi-sensor tracking to blend radar and ADS-B sensor inputs.

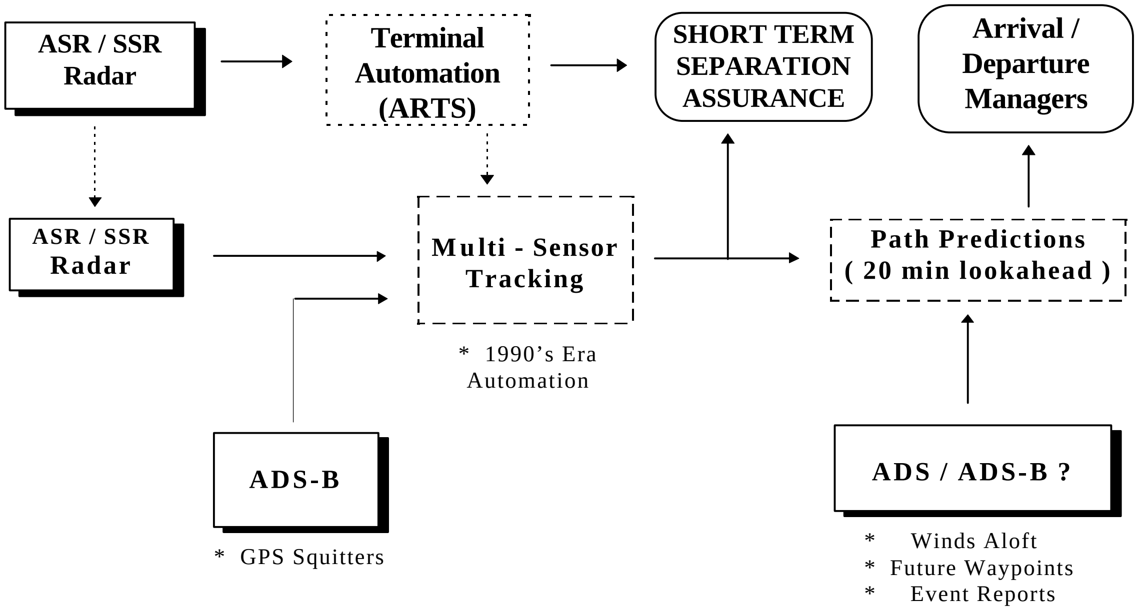

Figure 2: Terminal Area Surveillance Evolution

A second major change is that surveillance will evolve to include any data inputs that can be used for improved path predictions. This will include radar and ADS-B measurements of current position and velocity, information on current flight plan and path intent, and data related to winds aloft along the intended path. The current ADS systems for oceanic use recognize the need for such <u>extended surveillance</u>, and explicitly includes downlink of winds aloft and future waypoints for more accurate tactical and strategic path prediction. With current ground based systems, 3-4 minute path predictions are generated for conflict alert, based on current estimates of aircraft position and velocity. Automation systems such as CTAS and regional Conflict Probe require 20-30 min. predictions of aircraft path, and thus require much more extensive data fusion of wind, tracker states, and path intent to achieve high quality path predictions. In this regard, ADS systems can play a unique role not feasible with current surveillance systems, i.e. transmitting aircraft intent, including the generation of event messages when path intent changes.

It is technically feasible to transmit extended surveillance data such as waypoint intent using either ADS-B or ADS-A selective addressing. However, such data is unlikely to be of interest to the general population of air and ground users capable of receiving ADS-B messages. Thus, the current thinking is that extended surveillance data such as future waypoints and winds aloft will be obtained using selectively addressed ADS. In any event, the terminal area of busy hubs need dynamic flight intent updating to support future operational concepts such as departure and arrival automation and dynamic selection of SID and STAR routing options.

The use of ADS-B data for air-air surveillance and CDTI applications such as aids to visual approaches and visual acquisition of traffic is also important for increased safety and capacity in the future CNS / ATM system. Although separation assurance and flow management functions will primarily remain with ground based systems, cooperative air-ground use of CDTI capability can be a valuable supplement for reducing longitudinal separation standards and increasing traffic throughput during arrival and departure rushes.

3.4 Enhanced En Route Surveillance

Today's en route surveillance system is based on primary and secondary radar systems which are nearing the end of their economic life, and on 1960's era automation software which is obsolete by today's standards. Both the radar sensors and the tracking software need to be replaced to support Free Flight routings and advanced ATM initiatives. Figure 3 illustrates the likely evolution path for en route surveillance in NAS airspace. The current plan is to decommission the older radar systems, extend the networking of radar sensors to include terminal radars to reduce the need for replacing en route radars, and to replace the older beacon radars with modern monopulse SSR or Mode-S sensors.

The current era Mosaic based en route tracking system will also be replaced by multi-sensor tracking software, greatly enhancing the quality, accuracy, and flexibility of the en route tracking function. Recent studies have graphically demonstrated the performance problems associated with using Mosaic based trackers for advanced ATM automation systems such as CTAS. It is essential that multi-sensor tracker software be developed and implemented in the mid-term NAS architecture in order to support mid-term CNS/ATM initiatives such as direct path routings with reduced separation standards.

The use of Mode-S extended squitter for en route air-ground ADS-B surveillance is problematic in the near and mid-term due to insufficient reception range with low cost omni antennas. Eventually, ADS-B listening stations will probably be added to the ground infra-structure to perform enhanced en route surveillance for equipped users, and to back up the conventional en route surveillance infrastructure. In the mid term transition period when ADS-B avionics becomes available for air-air and terminal applications, a possible transition solution for enhanced surveillance is to use the Mode-S interrogation capability to obtain ADS-B equivalent information during each scan of the Mode-S radar. As we show in Figure 3, such capability is highly desired for evolution of Free Flight routings and advanced ATM automation, in any case.

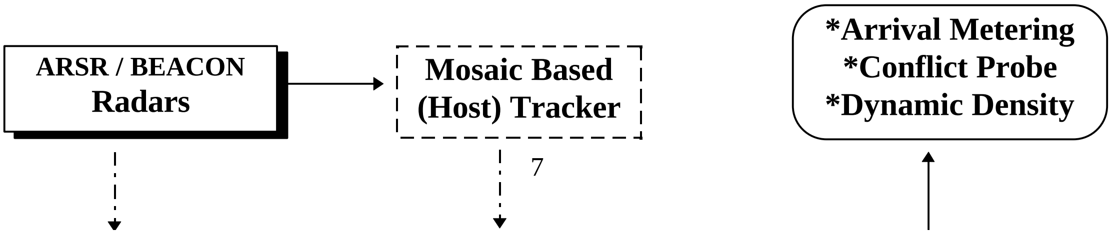

Figure 3: En Route Surveillance Evolution Path

As in the terminal area, extended surveillance is also needed to predict aircraft trajectories for nominal 20 min Conflict Probe and other ATM applications while en route. Although enhanced radar tracking and more frequently updated wind forecasts may be used in the near term to support advanced ATM automation, ADS transmission of path intent and real time monitoring of aircraft states for path conformance are seen as essential evolution steps to achieve increased capacity and efficiency in the future CNS / ATM system.

3.5 Enhanced Oceanic and Remote Area Surveillance

Today’s methodology for non-radar procedural separation involves the use of HF or VHF voice reporting at fixed latitudes in oceanic airspace or at intermediate waypoints in remote area routings. The older airspace automation systems are relatively primitive compared to those for radar based ATC and are still based on the use of flight strips for flight following. This technology is rapidly being supplanted by next generation FANS systems with ADS based surveillance, data link and satellite based voice communications, and GPS based navigation for oceanic and trans-continental routings.   The main driving forces for implementation of this technology are to increase capacity in procedural airspace and to provide more optimal wind routes and altitudes for increased flight efficiency. This evolution is shown in Figure 4. At the same time, there is a great need for increased safety in many areas of the world such as Africa and undeveloped areas of Asia. In the near term, TCAS is being mandated in some of these areas to provide increased safety for avoiding mid-air collisions. The probable next evolution for capacity and safety in these areas is the implementation of dual CDTI / TCAS systems using both ADS-B and TCAS sensors. In the near term, such systems will be developed for applications such as In-Trail Climb/Descent for enhanced oceanic operations. In the far term, the dual use of both ADS and CDTI technology will give enhanced situation awareness to both ground based controllers for traffic planning and separation assurance, and to the air crew for enhanced tactical maneuvering and Free Flight operations in low density, remote areas. The evolution to ADS based ground surveillance and ADS-B based air-air surveillance will probably enable reduced separation standards on the order of 15 nm horizontal minimums for equipped aircraft, based on redundant ground and air surveillance systems and separation assurance capability.

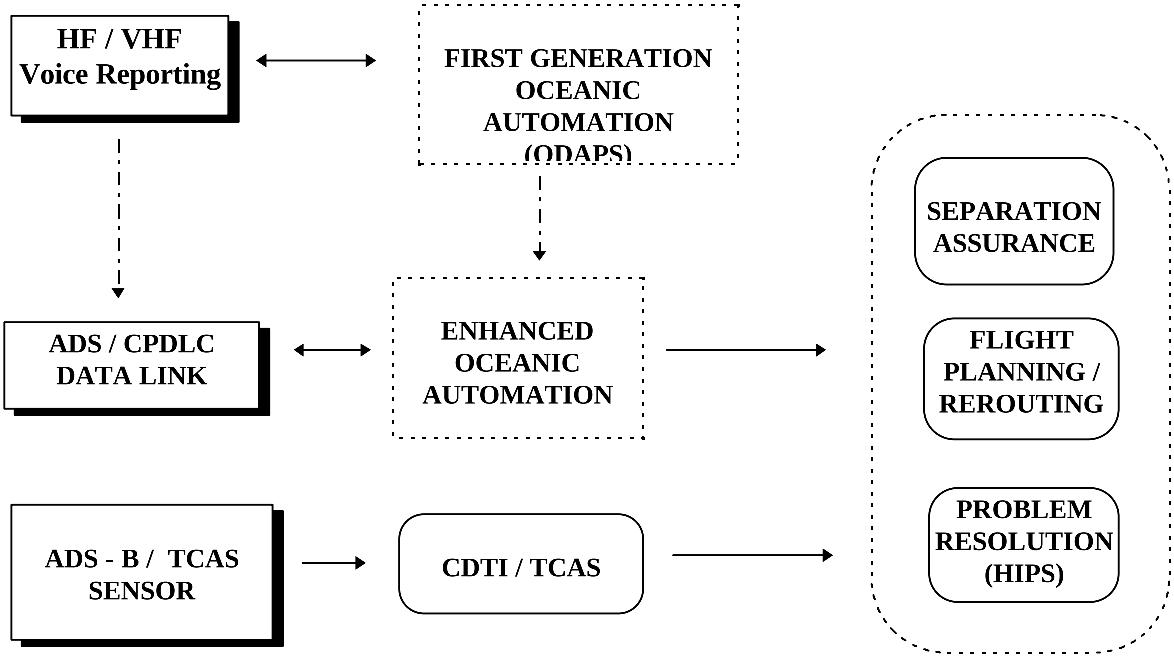

Figure 4: Oceanic / Remote Area Surveillance Evolution Path

The widespread use of ADS-B and CDTI technology for separation management may first occur in oceanic airspace. In essence, the oceanic centers would provide strategic planning and separation services for such aircraft, and the flight crews of equipped aircraft would provide short term separation services for limited tactical encounters such as track crossings. For reduced separation standards, both aircraft involved in an encounter will need to be ADS or ADS-B equipped.

3.6 Enhanced Air-Air Surveillance and CDTI Evolution

Although there are many potential applications for CDTI, a phased implementation of ADS-B / CDTI equippage is envisioned, since user benefits depend on the percentage of ADS-B equipped aircraft for each application. A few of the more noteworthy applications, and their role in the evolution of CDTI are briefly described below.

The near term applications of CDTI are for proposed functions such as In-Trail Climb, In-Trail stationkeeping, enhanced visual approaches, and on-board monitoring of closely spaced parallel approaches. These functions may be viewed as extensions of existing TCAS avionics and display systems. However, the TCAS systems were designed for collision avoidance and were never intended for such applications. From a user perspective, however, TCAS systems are expensive avionics which serve a limited, though important function. There is great interest in extending the functionality of such equipment. One likely group of users transitioning to ADS-B may be the TCAS users who have already invested in Mode-S transponders, TCAS processors and cockpit displays. Moreover, widespread ADS-B equipage by TCAS users may justify development of increased performance TCAS systems with lower false alarm rates and more accurate detection and display of intruder aircraft.

Another group of users which can benefit from ADS-B and CDTI equipage are the non-TCAS aircraft which fly in high density terminal airspace and need a lower cost system for conflict avoidance and visual acquisition of traffic. Although TCAS-I was originally intended for such users, equipage costs have proved prohibitive for most GA and military users. However, a transition problem exists for potential CDTI users since user equipage may not be cost effective unless a substantial portion of the airspace population is visible. The likely transition solution is the implementation of Traffic Information Services (TIS) which would transmit ground based surveillance data to airborne users. Eventually, as ADS-B systems are mandated in such airspace, the TIS services can be replaced with ADS-B surveillance as a primary source of CDTI input data.

The last application to be mentioned is the use of ADS-B and CDTI technology for cooperative Airborne Separation Assurance Systems (ASAS). The concept of operation is cooperative since responsibility for separation assurance is primarily a ground function as in the current system, except that during limited time encounters between two aircraft, responsibility for monitoring and assuring safe separation can be transferred to properly equipped and certified air crew. The motivation for this mode of operation is the ability to fly User Preferred Trajectories, including user specified routing, speed, and cruise altitudes for most economic flight operations. Such operations may lead to an increased number of encounters, however, compared with current operational procedures. Controller workload may be kept within acceptable bounds by transferring separation assurance to the air crew, who can perform separation monitoring during close proximity encounters and activate conflict avoidance maneuvers whenever a potential loss of separation is detected.