VALIDATION TECHNIQUES FOR ADS-B SURVEILLANCE DATA

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Introduction

Surveillance information forms the basis for providing traffic separation services by Air Traffic Control. The consequences of failures in the integrity and availability of surveillance data have been highlighted in near misses and more tragically, by midair collisions. Recognizing the importance and criticality of surveillance information, the U.S. Federal Aviation Administration (FAA) in common with most other Civil Aviation Authorities (CAAs) worldwide has implemented a surveillance architecture that emphasizes the independence of surveillance sources and the availability of crosschecks on all flight critical data.

Automatic Dependent Surveillance Broadcast (ADS-B) changes this approach by combining the navigation and surveillance information into a single system element. ADS-B is a system within which individual aircraft distribute position estimates from onboard navigation equipment via a common communications channel. Any ADS-B receiver may then assemble a complete surveillance picture of nearby aircraft by listening to the common channel and combining the received surveillance reports with an onboard estimate of ownship position. This approach makes use of the increasing sophistication and affordability of navigation equipment (e.g. GPS-based avionics) to improve the accuracy and update rate of surveillance information. However, collapsing the surveillance and navigation systems into a common element increases the vulnerability of the system to erroneous information, both due to intentional and unintentional causes.

Surveillance Validation Prior to ADS-B

Where surveillance information is available in today's air/ground and air/air systems, it is usually based on either search radar or beacon sensor information, or a combination of the two. Search radar has the advantage of being difficult to spoof, but cannot provide altitude or identity information. A beacon sensor, which operates by eliciting a coded reply from an aircraft-mounted transceiver, is less subject to clutter interference, operates with far lower peak transmit power, and can provide altitude and identify information, but requires that a working transceiver (known as a beacon transponder) be installed on board all participating traffic. The combination of search and beacon information for air/ground surveillance provides a particularly robust data stream, by using the search radar return to validate the beacon sensor information. The integrity and accuracy of the radar-based surveillance stream is completely independent of the onboard navigation system.

Beacon surveillance in particular has become a cornerstone of efficient air traffic control in densely traveled airspace, because of its ability to relay both identity and altitude information. Beacon surveillance is actually a mix of independent and dependent surveillance. The basic range and azimuth estimates for each aircraft are derived through radar processing of the radio frequency waveform of the received transponder signal at the beacon sensor, while the altitude and identity information is encoded in the transponder signal modulation pattern. Mistakes in the encoded elements of a transponder reply, particularly the altitude information, can lead to near misses and midair collisions. This vulnerability is mitigated through several cross checks built into current air traffic control procedures.

The most basic element of data assurance in the current surveillance system is the initial certification and continuing maintenance of the aircraft and ground-based elements of the system. Installation of transponder and altimetry equipment on aircraft is subject to strict and well-defined installation procedures, and all such equipment is required to pass a biennial ground maintenance check based on the procedures defined by the FAA [1]. However, the possibility of equipment degradation and failure with time require that other, real-time cross-checks be used.

Current validation techniques focus on assuring the integrity of data from aircraft operated within the ATC system, e.g. those aircraft operating on an instrument flight rules (IFR) flight plan or

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receiving radar traffic advisories. These techniques generally make use of an independent Very High Frequency (VHF) communications channel to allow the crew and a controller to exchange validation information.

First, the aircraft identity information is associated with flight plan information that is presented to an air traffic controller in an onscreen data block. A mismatch between the identity code in the flight plan and the aircraft data block leads to an exchange via the VHF communications channel between the controller and crew to resolve the discrepancy. Second, altitude information is cross-checked at every initial contact between the crew and controller (again, via the VHF communications channel). The crew reports the altitude they are maintaining, which a controller compares to the displayed altitude for that aircraft. This cross check verifies the agreement between the separate aircraft altimetry sources, one of which feeds the crew display while the other provides altitude information to the beacon transponder. Finally, procedural measures are built into most professional crew's checklists to assure the correctness of transponder-encoded information.

The Traffic Alert and Collision Avoidance System (TCAS), mandated for carriage on all passenger-carrying aircraft with more than 30 passenger seats, also depends on the altitude information encoded in beacon transponder replies. Correct and timely collision avoidance guidance is completely dependent on correct beacon altitude information; corruption of these data due to a malfunctioning interface between the altimetry source and the beacon transponder has led to near misses, which subsequently led FAA to issue a related Airworthiness Directive [2]. Currently, because TCAS is considered a backup system which operates as a "last resort" when other methods to assure traffic separation have failed, normal maintenance and diligent response to reported problems are considered sufficient to mitigate the vulnerability to errors in the beacon altitude information. The probability of simultaneous failures in which safe separation is compromised AND an undetected equipment failure occurs that misdirects TCAS escape guidance is considered acceptably low.

Given the current use within air traffic control of beacon surveillance information, a form of dependent surveillance, and the expected transition to the use of ADS-B, it is vital to understand the integrity and accuracy of current surveillance information, and to consider means by which such assurances may be extended to ADS-B. In this paper we present the results of monitoring the *in situ* performance of beacon transponders, and then discuss methods to improve the integrity of surveillance streams that combine beacon and ADS B information. The integration of ADS-B and TCAS processing, in a technique known as TCAS hybrid surveillance provides an early example of the application of integrity assurance considerations in a currently deployed system. We conclude with proposals to extend these techniques to air/ground surveillance installations where ADS-B and radar surveillance information will be combined. The proposals are primarily focused on validating ADS B installations that use a Mode S transponder to broadcast 1090 MHz Extended Squitter [3], [4]. Similar techniques could be developed to accommodate Universal Access Transceiver (UAT)-based installations.

Measurements of Beacon Transponder Performance in the U.S. National Airspace System

It is well known that on any given day some percentage of the beacon transponders in the NAS do not work properly. In a study performed by FAA William J. Hughes Technical Center personnel in 1996 [5], a sampling of transponders installed in general aviation aircraft participating in an EAA fly-in were tested using FAA ground-based test equipment. Approximately 10% of the transponders tested had sufficient out-of-specification conditions that it is likely that surveillance of the transponders would be degraded. All of these transponders had passed the required biennial check within the previous 24 months.

Additionally, attention was focused in 1994 on the failure of certain Air Traffic Control Radar Beacon System (ATCRBS) transponders to respond properly to ATCRBS-only interrogations originating from a Mode S interrogators. Such transponders could not be acquired by either a

Mode S ground sensor or a TCAS system. In response to this problem the FAA issued an Airworthiness Directive [6] and reconfigured the ground Mode S sensors with a revised interrogation pattern to allow the faulty units to remain visible to Air Traffic.

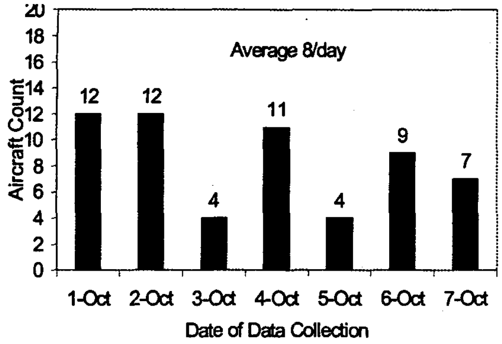

Figure 1. Non-Compliant Transponders Detected During Weeklong Data Collection At Oakland, CA Mode S Sensor. An average of 8 aircraft per day were observed with transponders that did not reply to ATCRBS-only All Call interrogations from a Mode S sensor.

In the course of preparing to remove the revised ground interrogation configuration (which has the undesirable effect of masking subsequent transponder failures and increasing 1090 MHz channel occupancy), the FAA (AOS-260) and MIT Lincoln Laboratory conducted a field test to identify how many transponders continued to ignore ATCRBS-only interrogations from Mode S sensors. The results of this test, illustrated in Figure 1, suggest that a small but observable level of non-compliant transponders may be observed at ATC facilities across the NAS. For instance, data collected from the Mode S sensor at Oakland, CA between October 1 and 7, 2001 document an average of 8 aircraft per day that carried transponders that failed to reply to ATCRBS-only interrogations. Similar results were obtained at Amarillo, TX, Covington, KY, and Windsor Locks, CT.

The results from the field test suggest that a persistent, low level of non-compliant transponders continue to operate in the NAS. While the system currently has sufficient redundancy to assure that these aircraft do not pose an immediate safety hazard, it does demonstrate that maintaining 100% availability of even a device as simple as an ATCRBS transponder cannot be assured solely through maintenance, regulatory response, and periodic ground tests. One would expect that as surveillance comes to depend on increasingly sophisticated and complex avionics suites, the necessity for some form of real time, operational monitoring of surveillance performance will become more pressing.

Integration of ADS-B into TCAS

The integration of ADS-B into TCAS offers an instructive example of how one might implement operational monitoring of ADS-B data using existing surveillance assets.

TCAS Overview

TCAS is an airborne collision avoidance system that operates independently of, and as back-up to, the ground ATC system. TCAS works by actively interrogating other transponder-equipped aircraft in the vicinity and tracking the received replies. If TCAS algorithms determine that the intruder has entered, or is about to enter, a protection volume around the TCAS-equipped aircraft, then TCAS will issue a Traffic Advisory (warning) to the crew. If the intruder continues to come closer, TCAS will subsequently issue a Resolution Advisory (vertical maneuver command).

TCAS provides protection against any transponder-equipped aircraft. If the intruder is not reporting altitude, TCAS will issue only Traffic Advisories, not Resolutions Advisories, against that intruder. If the intruder is also TCAS-equipped, the two TCAS units will exchange information over the Mode S link to coordinate their maneuvers.

The FAA mandated TCAS equipage, effective 30 December 1993, for aircraft with more than 30 passenger seats flying in U.S. airspace. The latest version of TCAS (Version 7, equivalent to ACAS, the international Airborne Collision Avoidance System) has been mandated by the International Civil Aviation Organization (ICAO), effective 1 Jan 2003, for aircraft with take-off weight in excess of 15,000 kg or authorized to carry more than 30 passengers.

TCAS uses the same 1030/1090 MHz frequencies as the ground ATC beacon surveillance sensors, and thus both TCAS and ATC interrogators vie for replies from aircraft transponders. For this reason, an important part of the TCAS design is the inclusion of "interference limiting" algorithms. Each TCAS senses the surrounding r.f. airborne environment (number and distribution of other TCAS aircraft) and limits its interrogation rate and power sufficiently to ensure that utilization of any given transponder due to all TCAS in the vicinity is limited to 2%. As TCAS is installed on more and more aircraft, it is becoming increasingly difficult to maintain a 2% transponder utilization (i.e., to protect ATC ground surveillance performance) while still providing adequate TCAS surveillance range for collision avoidance protection. The challenge has been to develop ways to reduce the TCAS active interrogation rate while still maintaining TCAS surveillance range.

TCAS Use of ADS-B

The increasing maturity of ADS-B via 1090 MHz Extended Squitter offers one method to reduce the number of interrogations required by each TCAS unit. When available, ADS-B information obtained through passive reception may substitute for information that would otherwise require active interrogation. The TCAS use of ADS-B in hybrid surveillance is limited to the reception of 1090 Extended Squitters; no method has been defined for the integration of alternative ADS-B links with TCAS.

A direct replacement of ADS-B for the current TCAS active surveillance was considered unacceptable, since a loss of GPS (or other basis for the ADS-B position report) would cause a loss of collision avoidance capability. In addition, ATC surveillance is expected to make increasing use of ADS-B, and thus an undetected error in ADS-B reported position could lead to a collision threat that would be undetectable to both ATC and TCAS [7].

These considerations led to the development of "TCAS hybrid surveillance," a technique that allows TCAS to use passive ADS-B position information to reduce its interrogation rate while still maintaining its independence as a collision avoidance system. High-level requirements for hybrid surveillance are given in the ICAO Standards and Recommended Practices (SARPs), although the detailed requirements and tests needed for development and certification of equipment do not yet exist. The current TCAS Minimum Operational Performance Standards (MOPS) allow only the receipt (but not general use of) extended squitter. The receipt of extended squitter was specifically added to allow TCAS manufacturers to implement hybrid surveillance hardware changes now, while postponing software upgrades to a later date. This would allow for the possibility of upgrading fielded units by means of a software load once detailed software algorithms are finalized.

The designation of an acceptable validation technique was essential to the use of ADS-B information within TCAS. TCAS hybrid surveillance validates ADS-B information by comparing the ADS-B information with surveillance obtained via active TCAS interrogations. Specifically, the relative range and bearing computed from own and intruder ADS-B positions are compared to the active range and bearing measurements, and barometric altitude provided in the ADS-B report is compared to the barometric altitude obtained from the active interrogation. Ideally, the TCAS interrogation utilizes Mode S TCAS crosslink capability to read the ADS-B register of the intruder, thus allowing dual processing of the same reply. If the intruder transponder does not support TCAS crosslink functions, the active and passive tracks are correlated through the Mode S (ICAO) address, and compared. Comparison of separate tracks is less accurate because of unavoidable timing differences between the sampling times for each track.

If any of the validation comparisons fall outside of accepted limits, the intruder track is declared to be an active track and future extended squitters from this aircraft are ignored for the duration of the track.

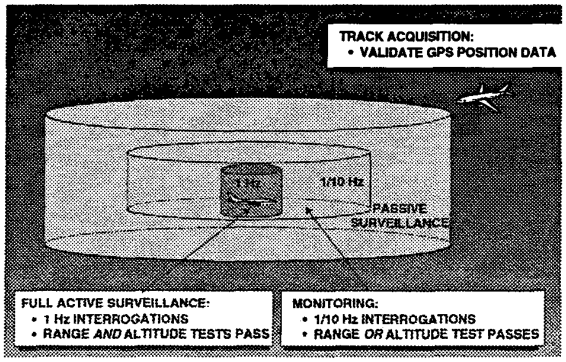

Figure 2. Transition from Passive to Active Surveillance in TCAS Hybrid Surveillance.

As illustrated in Figure 2, initial validation is performed at track acquisition, assumed to take place at relatively long range. Revalidation (monitoring) is performed once per 10 seconds if the intruder becomes a near-threat in altitude OR range. Finally, regular once-per-second active surveillance is performed on intruders that become a near-threat in both altitude AND range. In this manner, passive surveillance (once validated) is used for non-threatening intruders, thus lowering the TCAS surveillance rate. Active surveillance is used whenever an intruder becomes a near-threat in order to preserve TCAS as an independent safety monitor.

Non-threatening aircraft may safely be maintained in passive mode, since the altitude in the extended squitter is obtained by direct insertion of altitude into the squitter by the transponder. This means that the squitter contains exactly the same altitude information that would have been received by TCAS in response to an active interrogation. If the altitude had been obtained from another source, more frequent validations would be necessary, significantly reducing the benefit of hybrid surveillance [7].

The hybrid surveillance implementation of ADS-B validation trades off spectrum efficiency against the possibility of an undetected error in the ADS-B reports. In particular, the re-validation interval of 10 seconds in combination with the definition of a boundary inside of which active surveillance is always used, ensures that errors in ADS-B reports will always be detected early enough to allow appropriate Traffic and Resolution Advisories to be issued. This protection is based on an assumption that intruders maneuver with lateral and vertical accelerations that fall within predetermined thresholds; these thresholds are chosen to be well in excess of loads considered possible for commercial aircraft. Current boundaries in the SARPs are 3 nm (or ≤ 60 seconds to 3 nm) in range and 3000 feet (or ≤ 60 seconds to 3000 feet) in altitude.

The hybrid surveillance range, bearing, and altitude limits used in the initial validation and in the re-validation were based on analysis of recorded data from large numbers of encounters between TCAS-equipped aircraft and intruder aircraft equipped with extended squitter transponders. The TCAS units recorded both active measurement data and received extended squitter position data. Post-processing was used to determine the expected variation in passive and active position data. Current active/passive comparison limits in the SARPs are: range difference ≤ 200 meters, bearing difference ≤ 45 degrees, and altitude difference ≤ 100 feet.

Figure 3 shows a block diagram of an example hybrid surveillance implementation. Note that all received 1090 MHz transmissions (both active replies and squitters) pass through a common receiver and reply processor, after which only those transmissions that exceed the nominal TCAS minimum triggering level (MTL) are passed to the TCAS Surveillance processor. This means that only those extended squitters that have the possibility for active validation are passed to the TCAS hybrid surveillance function.

Extended squitters received below the TCAS MTL are passed directly to the display processor; their display symbology would indicate that TCAS protection is not being provided for these aircraft. Although not specifically shown in the diagram, only TCAS surveillance reports derived from full (once-per-second) active surveillance are passed from the TCAS Surveillance Processor to the collision avoidance (CAS) logic and can potentially generate TCAS advisories. Other TCAS surveillance reports are passed directly from the TCAS Surveillance Processor to the display processor.

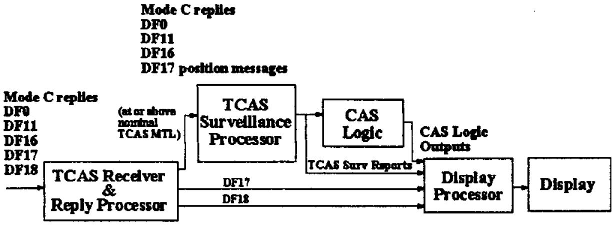

Figure 3. Example Hybrid Surveillance Implementation. Extended Squitters Correspond to DF=17. TCAS acquisition (short) squitters correspond to DF=11. DF=11 may also be obtained via active interrogation, and DF=0, 16 replies are always obtained via active interrogation. DF=18 replies originate from non-transponder devices.

Hybrid Surveillance Impact on RF Spectrum

Analysis and simulation indicate that hybrid surveillance leads to a significant reduction (generally more than a factor of 2) in the Mode S events sensed by a victim transponder for representative aircraft distributions. In addition, this reduction is realized with a very significant improvement in TCAS Mode S range capability (a range increase of a factor of 2 for two of the aircraft distributions). These results indicate the importance of TCAS hybrid surveillance implementation.

Methods to Assure the Integrity of Air/Ground ADS-B Information

Augmentation of air/ground surveillance is likely to be among the first applications of ADS-B. The Capstone Program in Alaska is a current example of surveillance in non-radar airspace based solely on ADS-B information. Although limited monitoring is performed in Capstone to ensure the availability of a valid GPS signal within airspace where ADS-B is in use, no other direct validation of ADS-B reports is performed. Extension of ADS-B-based surveillance to the rest of the NAS is likely to require independent validation. Fortunately, FAA currently operates or is in the process of deploying an extensive set of surveillance sensors which can easily provide such validation services for ADS-B reports that originate from Mode S transponders.

Use of Mode S Data Link to Validate ADS-B Information

Any ground sensor that utilizes Mode S protocols to perform beacon surveillance has the inherent capability to validate 1090 MHz Extended Squitter ADS-B information broadcast from a Mode S transponder. The ground sensor may use the Mode S datalink protocol to read the transponder register containing the transponder's current ADS-B information. The normal r.f. processing of the transponder reply yields slant range and azimuth; processing of the Mode C information yields pressure altitude (Mode C). In parallel, the data link contents encoded in the data link reply may be used to assemble the ADS-B position of the transponder. Comparison of the computed position (formed by differencing the known sensor location and the ADS-B position) and the measured position (obtained from the r.f. processing of the received waveform) provides independent validation of the ADS-B information. Comparison of the ADS-B and Mode C altitude assure correspondence between the two sources. The use of the ICAO address assures that the aircraft in question is reliably identified.

There is an inherent advantage to validation based on readout of the transponder ADS-B registers. Comparison of the surveillance based on r.f. processing with the surveillance information encoded in the modulation of the same r.f. signal removes timing uncertainties from consideration. Also, there is no chance of miscorrelating the ADS-B information from one aircraft with the r.f. surveillance from another. This is essentially different from simply comparing two independent data streams (e.g., beacon radar reports and ADS-B reports obtained via a separate receiver), because the inherent asynchronous nature of separate surveillance streams will limit the exactness of the possible match.

Existing Mode S-Capable FAA Systems

FAA has deployed one type of Mode S ground sensor already, and is in the process of deploying another. Mode S beacon sensors are installed at 118 terminal sites across the National Airspace System (NAS). These sensors all have the capability of performing the validation check discussed above without modification to the basic sensor; the validation functions can be implemented in an external workstation connected to the existing data link communications port of each sensor. Additionally, FAA is procuring airport surface detection equipment (ASDE), which will incorporate both a surface search radar and a multilateration system. The multilateration portion of this ASDE-X system will include interrogation units capable of implementing the necessary Mode S data link interrogation/reply sequences to provide independent ADS-B validation. The ASDE-X multilateration processing will yield both range and azimuth for aircraft located such that multiple ground stations with the correct geometry have line-of-sight to the aircraft; even for aircraft outside these areas, single ground station-based, range-only measurements may be performed yielding useful validation information. ASDE-X can also monitor the correspondence of altitude information encoded in the transponder and ADS-B messages.

Background ADS-B Validation

Given that the airspace within which either Mode S sensors or ASDE-X surveillance is available is a substantial portion of the NAS, it is likely that most aircraft will fly in such airspace with reasonable regularity. This opens up the possibility of providing a background ADS-B validation function. The Mode S and ASDE-X sensors may be configured to automatically compare ADS-B and active surveillance estimates whenever an aircraft is initially acquired, and use the same Mode S protocols to send a validation message back to the Mode S transponder under test. The validation message would contain a validity flag, type of validating sensor, unique sensor location, and the time of day. The transponder would archive a list of the most recent messages in non-volatile memory; the memory could be subsequently examined via a maintenance menu or passed to an external interface. Uplink of the same message format could also flag an inoperative ADS-B installation; again, such a message could either be archived or could drive an indicator on the transponder front panel. Conversations with vendors of panel mount, Mode S transponders intended for use in general aviation aircraft confirmed the essential practicality of this approach. The additional memory is quite modest, and no further interfaces to external equipment would be necessary to support this feature (embedding time-of-day in the validation message is required since current transponders are not routinely configured to maintain time-of-day internally). The availability of this continuing validation of the integrated ADS-B/transponder installation might reasonably allow an extension of the required maintenance interval beyond a biennial check, thereby increasing confidence in the integrity of the installation while reducing maintenance costs to the operator.

Active Validation of ADS-B Information

The same methods of comparing surveillance based on active interrogation with that obtained through passive reception of ADS-B may form the basis for assuring the integrity of flight critical applications, such as independent instrument approaches to closely spaced, parallel runways. In such applications, the advantages of the ADS-B information (richer information content, higher update rate) could be enabled through occasional datalink-based validation. Depending on the application requirements and geometry of existing Mode S interrogators, it might be possible to use an existing Mode S sensor for validation, even though the surveillance quality and update rate of that sensor would not, by itself, support the application in the absence of ADS-B. At locations where no existing Mode S sensors could supply the datalink-based validation, it would be a straightforward addition to a ground-based 1090 MHz Extended Squitter receiver to add a datalink interrogation capability sufficient to obtain range and Mode C altitude for comparison with the ADS-B position. Experience with both omnidirectional and sectored antennas suggests that active interrogation ranges of 50-100 nmi might be reasonably expected in such a configuration. The use of sectored antennas offers the additional advantage of allowing derivation of coarse azimuth information, even for passive replies. Thus an installation using a sectored antenna can supply range and azimuth validation using active interrogations out to moderate ranges, and azimuth-only validation for all targets out to the maximum receive-only range of the ADS-B receiver. The output of the monitoring function could then be provided to ATC as an integrity monitor, and possibly relayed to crews as well.

We expect that such validation is most likely to be applicable in areas where ADS-B is used as an augmentation to air/ground surveillance. In such cases the validation function is built into the existing ground infrastructure or is a modest addition to the capability of the ADS-B receivers that would be deployed to extend radar-like services into non-radar airspace (e.g. into the high altitude, *en route* airspace in the Gulf of Mexico). The details of how much disagreement between active and passive surveillance is allowable, the monitoring frequency, and the means by which failures are annunciated remain to be worked out and will depend on the application requirements.

Methods to Assure Integrity of Air/Air ADS-B Surveillance Information

TCAS-based implementations offer the near term possibility of using hybrid surveillance within TCAS to maintain TCAS protection ranges while reducing spectrum impact. Through the addition of an interface, the TCAS hybrid surveillance validation monitoring could be passed to other, non-TCAS functions. While this is a modest addition to TCAS, it may have the affect of making a TCAS failure more serious since it would potentially deny the aircraft the possibility of participating in an application for which airborne ADS-B validation was required.

Two other possibilities exist for airborne ADS-B validation. First, when the aircraft is in range of ground sensors that are performing ADS-B validation, the results of such validation may be relayed to the aircraft via any available datalink. Second, it is possible to make use of precision timing information at the ADS-B transmitter and receiver to allow a passive ranging technique to provide validation. A precise transmit time is encoded into each ADS-B transmission. At the receiver the time of reception is noted and used to calculate the propagation time of the signal. The range calculated from propagation time is compared to the range difference based on the ADS-B-encoded position, thus providing a form of range-only validation. Such validation has been demonstrated in test UAT systems, and is described in the UAT MOPS.

Conclusions

The unparalleled safety and integrity of current air traffic surveillance is founded on the practice of assuring independence between sources of data wherever possible and using validation techniques to cross check reported data. Beacon surveillance in particular may be considered a form of dependent surveillance and the validation procedures in place today suggest ways to extend this practice to ADS-B-based surveillance.

While the overwhelming majority of beacon transponders operate reliably and correctly, recent testing has documented the existence of a small but significant number of non-interoperable transponders. The reliance of air/ground surveillance and particularly TCAS on correct operation of beacon transponders motivated the development of methods to detect these problems.

The limited number of problems that have been documented with relatively simple ATC beacon transponders suggests that more rigorous validation techniques will be necessary to assure the correct operation of ADS-B installations, which have both greater complexity than a simple transponder and less available cross checks within the current definition of ADS-B. TCAS hybrid surveillance offers a model of how certain types of active interrogations may be used to validate ADS-B messages that come from transponder-equipped aircraft. These techniques extend naturally to deployment in ground-based surveillance sensors that use Mode S datalink. These techniques may be necessary to assure the integrity of ADS-B information in flight critical air/ground and air/air functions. The use of low cost, ground-based systems that mimic TCAS in performing validation measurements offer one approach to ground-based assurances of surveillance integrity in areas that lack Mode S, datalink-capable sensors in the current architecture.

Implementation of a means to assure ADS-B surveillance integrity is likely to be the key to a smooth transition from current, radar-based surveillance to ADS-B surveillance in heavily traveled airspace, where disruption or loss of separation due to erroneous surveillance reports is operationally unacceptable.

Further Work

Implementation of the proposals noted in this paper require considerable additional work to specify the necessary modifications to avionics, ground sensors, and certification and operational procedures. Several areas of investigation would be valuable in the near term.

First, flight tests should be conducted to collect Mode S sensor data, multilateration data, and the associated ADS-B data via datalink to allow a statistical modeling of the variations between ADS-B and ground surveillance data. Use of such statistics is essential to develop validation algorithms that combine the necessary probability of detecting an operationally significant surveillance error with an acceptable false alarm rate.

Second, discussions with transponder manufacturers and FAA certification personnel should continue, focusing on specific design changes necessary to support background validation of ADS-B information. The use of such monitoring to reduce the cost of ownership of ADS-B avionics can provide an incentive to equip.

Third and finally, the detailed design of the ground equipment to add ADS-B monitoring to existing systems should proceed. These design and specification efforts should be guided by the applications requirements for integrity monitoring, which are currently being considered in forums such as RTCA SC-186, Working Group 4.

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