Achieving Early CDTI Capability With ADS-B

Dr. Andrew D. Zeitlin
Jonathan Hammer
James Cieplak
B. Oscar Olmos

MITRE/CAASD
Mc Lean, VA USA

Abstract

Various activities are required to achieve the introduction of ADS-B and to realize benefits from the cockpit display of traffic. We discuss the development of technical requirements and display features, incremental introduction of applications, and considerations for equipment certification and operational approvals.

1. Overview

The new technology known as Automatic Dependent Surveillance - Broadcast (ADS-B) offers great promise of numerous applications to air-air and air-ground surveillance. Ranging from enhanced safety to operational flexibility and economic advantage, ADS-B has excited the aviation community, and is being widely discussed in planning future architectures for aviation information.

None of these benefits will be realized, however, until aircraft are equipped on a sufficiently wide scale. Also, only the most basic safety benefits can accrue until operational procedures are implemented to allow some changes to make use of the cockpit capabilities.

Although various classes of users would prefer to use ADS-B for differing applications (or “ASAS Services,” as they are known in the wider ICAO community), commonality among their equipment is required to the extent that interoperability is supported. Much of the community has contributed to the development of system standards at this level through RTCA SC-186, and recently this committee has met jointly with EUROCAE WG 51. The initial standard, called MASPS, describes system characteristics independent of which data link is used to broadcast reports. Subsequent MOPS will be developed for the 1090 MHz (Mode S) implementation and, later, for any other links for which implementation appears likely. Section 2 describes some of the technical work leading to establishing system requirements.

While air carriers and a few other users have had experience viewing cockpit-displayed traffic on a TCAS (ACAS) display, the characteristics of this display do not appear to be sufficient to support most applications that will use ADS-B. Section 3 describes some of the developmental work for traffic displays intended to support early applications and most likely providing a basis for an advanced set, with additional features to be added later.

An approach for encouraging voluntary equipage is described in Section 4. This approach governs the development and introduction of applications, with a distinction between early realization of benefits, versus striving for the greatest possible benefit.

Finally, Section 5 addresses the numerous activities involved in securing the approvals for installation of equipment, the certification of airborne equipment, and the operational approvals for the applications using the equipment. It would be advantageous if the various applications can be designed with sufficient commonality and can build upon their successive experiences so that the incremental steps to add applications will not be prohibitive.

2. Establishing Technical Requirements

This section discusses an outline for the specification of technical requirements and supporting analyses for air-to-air surveillance applications of ADS-B. This subject is a major responsibility of RTCA SC-186 Working Group 4.

Numerous potential applications have been described for the use of an ADS-B surveillance system. Analysis is required to (1) specify the technical requirements for these applications and (2) evaluate the safety, efficacy, operational utility and potential operational impacts of these applications

Functional and Performance Requirements

Functional requirements include requirements on the operation of the application. For example, required pilot inputs, keystrokes, display outputs, etc. define the functional requirements. Performance requirements specify tolerances on system variables.

Surveillance Performance Requirements

Surveillance performance requirements include surveillance accuracy, integrity, update period, probability of receipt, and availability of data with the prescribed integrity and accuracy characteristics. Additionally, if surveillance data is available from multiple sources that can support the application, the question of data fusion must be addressed.

Integrity requirements must be developed for all elements of broadcast information to be used in a particular application. Availability is calculated as the mean-time-between failures (MTBF) divided by the sum of the MTBF and mean-time-to-restore (MTTR).

As an illustrative example of an analysis which results in specification of accuracy and update period requirements for an ADS-B application, we examine an application for blunder detection in independent parallel approach operations for a runway spacing of 2500 ft. For this example, the model for the blunder detection algorithms is a straight-forward threshold on estimated horizontal miss distance and time to closest point of approach. We studied the sensitivity of operational metrics on surveillance parameters to determine reasonable requirements.

In Figure 1, we analyze the sensitivity of conflict detection warning times to position and velocity errors. Figure 1 was created based on results with a 1 second state vector report update period with a 0.95 probability of receipt.

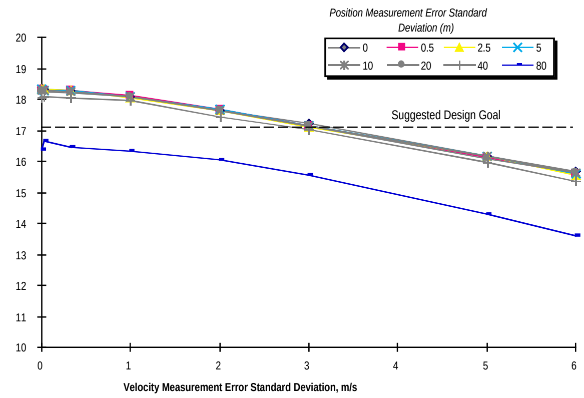

Figure 1. 2,500 ft Independent Parallel Runway: Sensitivity to Position, Velocity Errors

The warning times that were achieved may be acceptable for a realistic operation, although extensive safety analysis would need to be conducted to verify this. We observe sensitivity to position errors above 40 meters, 1 sigma, and to velocity errors above 1 m/s. 5th percentile warning times (not shown) are approximately 17 seconds with position errors of 40 m and velocity errors of 1 m/s.

Figure 2 illustrates the sensitivity of conflict warning time to report update period and probability for the 2,500 ft independent parallel runway blunder scenario. We observe reasonable warning times at update periods of 3 seconds or below.

We also examined false alarm probability for the 2,500 ft independent runway scenario, illustrated in Figure 3. We found that false alarms could be limited to an acceptable rate (about 1/1000) with position errors at or below 20 m and velocity errors below 0.3 m/s. A false alarm rate of 1/1000 may be operationally acceptable. Therefore it is likely to be false alarm rate that sets the limit on acceptable data errors for this application.

This example of a sensitivity analysis to determine requirements would need to be combined with an extensive safety analysis, discussed below.

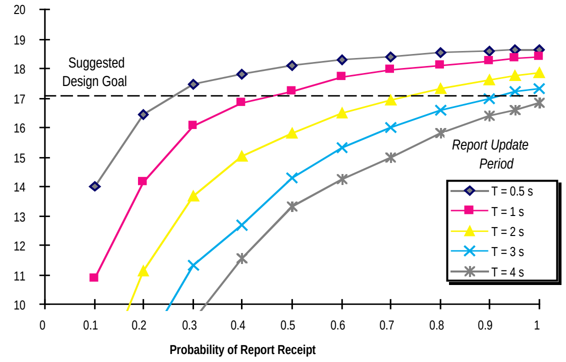

Figure 2. 2,500 ft Independent Parallel Runway: Sensitivity to Report Update Period, Pr(r)

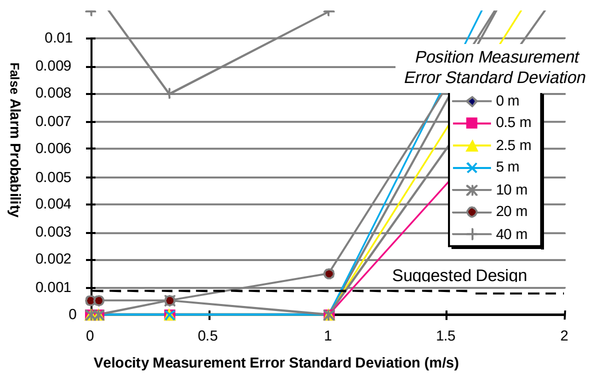

Figure 3. 2,500 ft Independent Runway False Alarm Scenario: Sensitivity to Position, Velocity Errors

Navigation and Communication System Performance Requirements

Navigation systems that support the application may be required to fly to a required navigation performance (RNP) or arrive at a particular position with a required time of arrival (RTA). Communications systems also may be required to support a particular application. Communications may be in the form of either voice or digital data.

Supporting Analyses

Depending on the application, significant supporting analysis may be required. There are three general areas of supporting analysis. First, an operational analysis should be performed which verifies that the application meets the desired operational objective. Second, a safety analysis will need to be performed that verifies that the application will meet all required safety standards. Third, the application must be analyzed from the perspective of its interoperability with other systems.

The operational analysis will attempt to develop performance metrics that measure both the efficacy and the operational side effects of the application. For example, for a conflict detection application, a measure of effectiveness might be warning time, while a measure of operational impact might be false alarm rate.

A safety analysis must also be conducted for each application. The safety analysis may consist of fault-tree analysis, including an analysis of failure modes and effects, or may also be based on Monte-Carlo simulations, or both. The objective of the safety analysis is to ensure that the application meets standards for safe operation.

Finally, an analysis of interoperability should be undertaken. This analysis should assess the impact of the application on:

- Other ADS-B applications
- TCAS
- ATC Ground systems
- Navigation / Communications systems

As an example, an ADS-B based conflict detection and resolution system may need to avoid issuing instructions that are in conflict with TCAS.

3. Establishing CDTI Display Features

The formation of RTCA SC-186 in 1995 provided an opportunity to begin researching near-term applications for ADS-B/CDTI implementation. Among other things, this committee was tasked with the responsibility of developing the MASPS (Minimum Aviation System Performance Standards) for Automatic Dependent Surveillance-Broadcast (ADS-B) technology and the CDTI Minimum Operational Performance Standards (MOPS). The committee served as a forum in which to investigate both near and far-term components of the CDTI in support of operational flexibility, including the Free Flight concept. Early in its deliberations, SC-186 determined that whereas Free Flight was an eventual goal of ADS-B and CDTI capabilities, its accomplishment must consist of many evolutionary steps, each facilitating specific benefits, and each providing full consideration to the realities of existing ATC operations. It developed a two-phase approach, clarifying and separating near-term and farther-term goals for both ADS-B and CDTI technology. For the near-term, emphasis is being placed on developing requirements to promote early ATC applications, including enhanced operations in the oceanic domain and enhancements to visual approaches in the terminal domain.

In support of the near-term goals identified within SC-186, The MITRE Corporation Center for Advanced Aviation System Development (CAASD) conducted several simulation studies investigating pilot's use of a CDTI. In the following sections we provide an overview of this process with a specific emphasis on how the CDTI features were selected for the CAA phase I implementation.

Information Requirements

Since visual approaches are the backbone of operations at major airports in the U.S., the initial simulations focused on the enhanced visual approach application. In their simplest form, visual approaches imply an approach to a runway visually, without the aid of electronic navigational guidance. However, when other traffic is present, their conduct often includes the use of visual separation between aircraft. This separation may be provided by ATC or by pilots, but, by and large, when traffic densities are high, it is the pilots that are responsible for maintaining separation. In these instances, traffic advisories are issued to pilots (e.g., "traffic, 1 o' clock, 4 miles, United 727"), and once visual acquisition of traffic is confirmed, pilots are assigned responsibility for visual separation and a visual approach clearance is issued. The pilot would then be responsible for maintaining visual separation from traffic they are following to their runway or traffic inbound to a closely spaced parallel runway.

Early in the process of determining CDTI requirements, a high-level task analysis was conducted to assess potential information requirements for the visual approach application (Figure 4). Based on this task analysis and discussions within SC-186, an extensive feature list (Table 1) was prototyped at the MITRE Integration and Interaction Laboratory (I-Lab). Recognizing that some features could be superfluous, a preliminary investigation was conducted to establish a core feature set, which would be further evaluated in a subsequent experiment. We will first provide a brief description of the simulation environment.

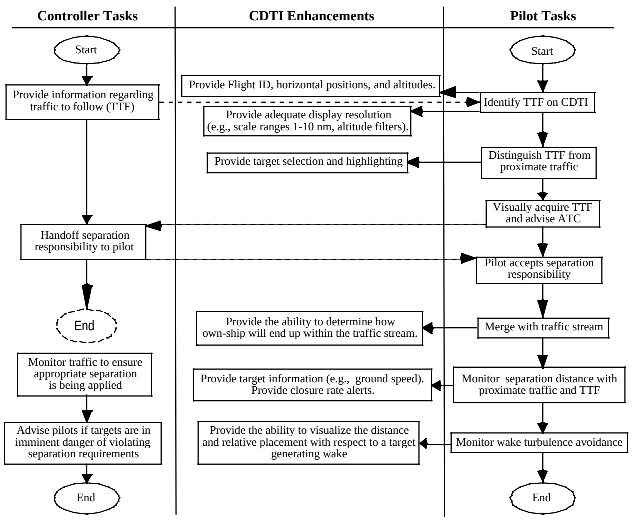

Figure 4. CDTI Information Requirements for the Visual Approach Application

Simulation Environment

The MITRE/CAASD simulation test bed consisted of a generic mid-fidelity transport cockpit with an out-the-window view (120 degrees laterally X 50 degrees vertically), a controller station (composed of a combined TRACON and Tower position), and simulated traffic representing terminal area operations at the Seattle-Tacoma International Airport. Approach operations were modeled to closely match that of the Seattle TRACON employing a southern flow operation. Pilots controlled the lateral and vertical axes of the aircraft via a combination of auto-pilot and auto-throttle controls. Subject pilots always operated as pilot flying and a confederate experimenter performed the duties of pilot-not-flying (e.g., communications, checklists, call-outs, etc.). In the preliminary evaluation, a single controller provided vectors for the subject cockpit only (i.e., communications with other aircraft were not modeled). In the subsequent evaluation, pilots were provided with a voice party line using simulated pseudo-pilots for other aircraft.

The CDTI platform consisted of an integrated EFIS display modeled after a 747-400 "glass cockpit" navigation display. All CDTI enhancements, along with standard TCAS symbology, were overlaid onto the navigation display (Figure 5). Only TCAS traffic and proximate traffic symbology were shown during

Figure 5. TCAS Navigation Display with Overlay of CDTI Enhancements

the simulation. TCAS alerts (i.e., TA's, RA's) were not simulated. Targets appearing on the traffic display were correlated with visible traffic in the out-the-window view. That is, pilots could verify "traffic in sight" using the simulated visual scene and could follow that traffic to a landing on the same or on a parallel runway.

Although Figure 5 shows CDTI features on an EFIS navigation display, they need not appear on such displays. In fact, for the current fleet in the near term, these features are just as likely to appear on many other display types, such as weather radar or dedicated traffic displays.

Preliminary Evaluation & Subsequent Evaluation

In the preliminary evaluation, eight line pilots were trained in the operation of all the CDTI features that were initially identified (Table 1). Pilots then flew six single stream visual approach scenarios with all features available for their use. After completing the

Target Range
Target Bearing
Target Vertical Speed
Target Closure Rate
Target Ground speed
Target Heading
Target Flight ID
Target Highlighting
Relative Track Vectors
Moveable Data blocks
Center Map View[1]
Ground Track Vectors
Predicted Altitude Function[2]
Range Reference

Table 1. List of Candidate CDTI Features for Enhancing Visual Approaches

Target Selection and
Target Flight ID
Target Ground Track Vectors
Target Speed Cues

[1] Although the center map view is available in some EFIS installations today, it is included in this list in order to determine if it may be *required* for some CDTI applications.

[2] This is intended to be a visualization capability to enable a pilot to determine if his projected path will be above or below the current position of the aircraft in front, and is intended to aid in situations where wake vortex may be a concern.

Table 2. Core Feature Set for Visual Approach Simulation

scenarios, pilots were asked to rank the relative utility of the various CDTI augmentations. Results from this ranking identified a core feature set as being potentially useful during the visual approach to landing (Table 2). A follow-on study evaluated this feature set in greater detail.

In the subsequent evaluation, 16 additional line pilots flew eight visual approach scenarios using this core feature set (Table 2). Using data from these approach scenarios, we addressed two issues concerning the visual approach application: 1) how the CDTI can assist pilots in the routine conduct of visual approaches (e.g., enhancing visual acquisition) and 2) how the CDTI can enhance the safety of visual approaches. Performance measures revealed closer spacing was achieved with the CDTI, a reduced acquisition time with the presence of Flight ID's, and subjects recognized a safety benefit with respect to enhanced awareness of proximate traffic speed reductions. Based on these findings and results from an additional oceanic simulation (see Olmos et. al, 1998 for greater detail on both simulations), it was decided that the core feature set (Table 2) could provide significant performance benefits in an operational environment. There is however, extensive work remaining regarding the validation of the current findings.

4. Incremental Applications

While the SC-186 MASPS identified a large number of potential applications, the community has generally agreed with the philosophy of implementing the simplest ones first. This approach simplifies the initial approvals of equipment and promotes more widespread voluntary equipage, since many potential users have no need for complex applications and some cannot afford equipment with high complexity and criticality. As experience is gained with operation of ADS-B, more confidence can be placed in safety projections that will support the more demanding future applications.

The first user group to commit to ADS-B implementation is the Cargo Airline Association (CAA). Its member airlines plan to begin with 12 equipped aircraft and subsequently equip their entire fleet. The initial application will be the relatively modest "Aid to Visual Acquisition", in which ADS-B data will provide information that can assist the crew, but not play any dedicated role. It is intended that these installations would also receive data uplinked from a Traffic Information Service (TIS), fusing the data so as to present a more comprehensive view of traffic to the crews. This application, providing situational awareness of traffic, should appeal to all user groups, particularly those who do not yet have TCAS installations. Even TCAS-equipped users could extend their safety protection to low altitudes and the surface, and could gain benefits from longer-range surveillance and enhanced display features.

Besides their planned in-service use of this application, CAA also hopes to conduct an evaluation of several other applications during a controlled operation at a privately owned and operated airport. The specific applications have not been determined, but are likely to demonstrate the pilots' ability to perform some spacing and sequencing operations with the assistance of CDTI traffic information.

Several air carrier operators have expressed interest in developing applications that would improve airport capacity specifically for parallel runway operations. In one case, aircraft approaching adjacent runways would be paired so as to maintain a prescribed longitudinal offset. In another application, independent streams of traffic would perform approaches to adjacent parallel runways. These operational concepts are still under discussion. The necessary safety evaluations will contribute to the development of any alerting logic and display features that are required for safe operation.

Various organizations have begun investigating concepts for airborne detection of conflicts and their resolution. These range from solutions applicable to the current ATC environment, and thus more near-term in scope, to those aimed at a less structured, "Free Flight" concept of operations. There are many issues, but one of the most important is the need for compatibility among participating aircraft, as well as air-ground compatibility.

The superior content and quality of ADS-B data has inspired visions of an improved collision avoidance system using this data. Such a development appears to be further in the future, as the criticality requirements for a system issuing maneuver advisories would be higher than those for most other applications, and important issues remain regarding the need for independence between any source of navigation and separation, and a collision avoidance system.

5. Steps to Operational Approval

Initial air-to-air applications will require operational authorizations, avionics certifications, and in some cases, new ATM procedures. An effective forum with full participation by all appropriate aviation organizations including government (in the U.S., the FAA Air Traffic Service, Flight Standards offices, and Aircraft Certification offices), airlines and other users, avionics and airframe manufacturers, controller and pilot unions, and research and development organizations is a virtual necessity for the accomplishment of the implementation process. International agreement also is highly desirable, even when an application first may be implemented locally. The following is a discussion of some of the operational, technical, and political considerations that need to be addressed when developing and fielding ADS-B/CDTI procedures.

An early step in the development and implementation of an individual ADS-B/CDTI procedure is the definition of a detailed operational concept. This includes the definition of the proposed basis for the procedure and an initial concept description. The description addresses the operational purpose, targeted airspace domain, applicability to instrument and VFR operational regimes, applicability to radar or non-radar environments, proposed aircraft separation minima, and pilot/controller responsibilities (including any changes in responsibilities for aircraft separation).

Once the concept is defined, the operational procedures can be developed. These must address pilot and controller actions and responsibilities when initiating, authorizing, and terminating the procedure. Any proposed use of ADS-B data for separation between aircraft, proposed new or revised phraseology, limiting factors in applying the procedure (e.g., type of airspace, equipment requirements for other aircraft in the airspace, flight crew consent requirements, flight conditions), any controller responsibility to maintain a monitoring function, and contingency procedures for both the pilot and controller must also be defined. Primary considerations in the development of these procedures are to retain and perhaps increase the level of safety in the airspace system and maintain an acceptable level of workload for controllers and pilots. An effective means of developing the detailed procedures, including an initial assessment of impact on safety and workload, is through simulations.

Human factors issues need to be addressed throughout the development process, from the first steps in concept development to flight trials and implementation. Requirements for cockpit interfaces, for example input devices for such things as selecting a target on the CDTI or inputting own aircraft flight identification for broadcasting, display requirements, aural indications, and failure and mode selection indicators, must be properly understood, integrated, and evaluated. (Section 3, above, describes some of this work for initial applications.) For procedures that involve new controller capabilities or tasks, the requirements for controller interfaces must also be defined. Training requirements for both pilots and controllers and use of appropriate checklists need to be developed. Also, crew resource management and pilot decision making interactions must be considered.

To provide incentives for equipage as well as justification for procedures development, a cost/benefits analysis for each procedure may be necessary, and is best accomplished with direct user involvement. These analyses would estimate effects on the safety, capacity, efficiency, and flexibility of the proposed operation. Any constraints (e.g., pair-wise equipage issues, equipage in affected airspace) to full achievement of benefits must be considered and a sensitivity analysis may be in order. A business case for development must be performed to address affordability (e.g., return on investment), availability, usefulness and usability of those procedures.

Along with the operational concepts and procedures development, the technical requirements for surveillance, aircraft state, and other data (e.g., update rate, accuracy, latency) must be defined, as described more fully in Section 2, above. It may be beneficial to define these in terms of minimum requirements as well as optional, expanded requirements which may afford additional benefits. Interfaces to external systems, such as to the air traffic controller or other ground interfaces (e.g., downlink of data) also need to be defined as appropriate. This document concentrates on air-to-air capabilities and procedures, but it should be noted that when something new is introduced into the cockpit that may affect the way a pilot flies the airplane (e.g., additional traffic situational awareness), the potential impact on ATM must be investigated and considered in the development of procedures.

The safety rationale for each procedure may require specific safety assessments. Each new procedure must be shown to at least maintain the current level of safety; however, the development should strive to increase safety.

Equipment certification and continued airworthiness issues would be addressed throughout the development and implementation process. Equipment certification of ADS-B/CDTI includes hardware and software considerations for cockpit displays (including use with other multi-function display overlay presentations), interfaces, and installations. Continued airworthiness practices (e.g., dispatch/minimum equipment list issues, need for periodic inspections) should be explicit prior to fielding, since this will impact long-term costs and continued applicability of equipment and procedures.

In order to comply with certification standards, manufacturers will be required to demonstrate that 1) CDTI meets its intended functions, and 2) CDTI does not interfere with current critical cockpit functions. As discussed above, SC-186 is developing CDTI MOPS that will define requirements for the first CDTI build. Note, however, that until the CDTI MOPS are approved and appropriate Technical Standard Orders (TSOs) are developed, manufacturers will continue to request certification based on current certification standards (e.g., TCAS TSO) through Supplemental Type Certificates unique to their hardware.

Initial CDTI features may be designed as enhancements to overlay the existing TCAS Traffic Display; therefore, they may be certified as “enhancements” to existing TCAS traffic display functionality under TSO C-119a. This would be accomplished with a supplementary type certificate (STC).

In cooperation with equipment certification authorities, the operational authorization standards for specific procedures that utilize the equipment must be developed by flight standards organizations. This work would involve a determination that any new display features were suitable for their intended purpose, and that the operational use was feasible and non-interfering with other operations. The certification and flight authorization organizations should work together to develop enabling equipment MOPS and TSOs, enabling human factors design criteria and guidelines, operational regulations, proposed Operations Specifications and authorizations, required guidance material (e.g., Advisory Circulars, FAA Handbook Order Changes), and training requirements. Once these tasks are completed, validation tests and evaluations are required.

Overall, a systems approach to developing ADS-B/CDTI procedures should consider the interactions of these procedures with international as well as national airspace interests. Since aviation is a global industry and many of the proposed ADS-B/CDTI procedures may involve use in international airspace (e.g., oceanic), there is a need to strive for international harmonization with organizations such as the International Civil Aviation Organization, Eurocontrol, and international civil aviation authorities. Also, as ADS-B/CDTI may be introduced into an airspace system simultaneously with other initiatives, the inter-relationships with these programs need to be understood and made complementary.

Reference

Olmos et. al. (1998). Evaluation of Near-Term Applications for ADS-B/CDTI Implementation. In *Proceedings of the SAE/AIAA World Aviation Congress*. Warrendale, PA: Society for Automotive Engineering.