Safety Assessments of ADS-B and ASAS

Andrew D. Zeitlin
MITRE/CAASD
7515 Colshire Dr.
McLean VA USA 22102
Azeitlin@mitre.org

Introduction

The International aviation community has taken notice of the opportunities that may be offered by Automatic Dependent Surveillance – Broadcast (ADS-B) technology and Airborne Separation Assurance Systems (ASAS), the equipment and procedures that apply the technology. ADS-B represents a new form of surveillance that can provide accurate information, both air-air and air-ground. ASAS represents a means of realizing new operational applications, including airborne separation assurance. Various benefits for safety, user flexibility and system capacity are envisioned. Both during system design, and ultimately before equipment certification and operational approval of procedures, acceptable results must be developed and agreed, using safety assessments that follow an approved methodology.

Two previous papers [1,2] discussed the application of an Operational Safety Assessment (OSA) process developed by RTCA SC-189 and EUROCAE WG-53 [3]. These papers were focused on ASAS as an ideal candidate for this process, because most ASAS procedures involve air-air and air-ground interactions among participants in ATM.

The development of ADS-B technology and ASAS capabilities is proceeding at a rapid pace. As standards activities progress and prospective implementation grows closer, several safety assessment activities have begun. This paper describes three such activities taking place on considerably different levels of scope, and presents results and conclusions. These illustrate the breadth of perspective that needs to be considered, both early in the technology life-

Summary

Three Safety Assessments conducted at different levels assess various applications of ADS-B and ASAS. They support different purposes: developing surveillance requirements; evaluation of the technology and its applications as a complete entity for an investment decision; and comparing the safety contributions of potentially alternative systems.

The Operational Safety Assessment methodology adopted by RTCA/EUROCAE provides the common framework for these studies. ASAS is a very appropriate candidate for applying this method.

Some aspects of the systems and applications are relatively immature. Nevertheless, early safety assessments are extremely useful in guiding developers to assure robustness where it is needed.

The RTCA work seeks to develop surveillance performance requirements. Its work is still in the early stages.

The other two studies are Comparative Safety Assessments. Both of these were directed by the FAA. One of these studies 25 assorted applications that address various enhancements. The other compares the safety of Airborne Conflict Management to the Traffic Alert and Collision Avoidance System. This paper discusses the application of the safety method and presents the findings of these studies.

cycle, and in an ongoing manner as concepts and systems mature.

Neither the equipment standards nor the application definitions are complete, nor could they be viewed as stable. Nevertheless, the candidate roles for the applications are defined, and can now be evaluated in the context of an operational environment. This can be quite an important input to the debate concerning the desirability of the various levels of ASAS capability and responsibility.

First Study: Requirements Development for Surveillance and Airborne Separation Assurance

RTCA SC186 WG4 is tasked with developing end-to-end technical requirements for Airborne Separation Assurance (ASA), its term corresponding to ASAS. Coordination efforts recently began between this group and EUROCAE WG51 SG3. WG4 also develops technical requirements for airborne surveillance and for the onboard processing function. This function, called ASSAP, could accept input from ADS-B, ground-based Traffic Information Service – Broadcast (TIS-B), or possibly other surveillance sources. The inputs could vary in their quality of surveillance, specifically in their update rates, accuracy, integrity, and data content. Various applications of ASAS are expected to have significantly different requirements for the surveillance performance necessary to achieve their benefits and control their risks. ASSAP in the aircraft receiving the broadcasts could then determine if that data was sufficiently good to be used for the desired application.

However, these required levels need to be determined by analysis. Two goals need to be achieved:
- performing the intended function of the application
- supporting the safety objectives in the operating environment

The analysis work is underway in WG4. The process uses these steps (standard OSA terminology in parentheses):

1. (OSED) Obtain a thorough description of each application, including topics such as:
   a. Its operating environment: airspace, ATC services, traffic density
   b. The functions intended for ASAS airborne equipment (processing, CDTI) and flight crew
   c. Pilot-controller communications
   d. Separation responsibilities envisioned
2. (OHA) Develop a hazard list, including contributing factors
   -This process may use a tool such as a state chart to promote rigor and complete coverage.
3. (OHA, continued) Determine the severity of each hazard, which corresponds to an acceptable level of likelihood
   -Consider two kinds of environmental factors: avoidance factors that make the hazard less likely, and the mitigating factors that alleviate the severity of the hazard when it occurs
4. (ASOR) In concert with this hazard analysis, develop a fault tree that illustrates the logical relationships of these elements.
5. (ASOR, continued) Develop an agreed allocation of performance requirements to all the elements of the fault tree.

These steps provide a derivation of the levels of performance that are assigned to each element analyzed. By comparing the likelihood of the ultimate hazard to the acceptable level for its severity, it can be determined whether the overall safety using these allocations is acceptable. The objectives are to determine the required levels of surveillance quality and of performance of each element in the fault tree. These include human performance, communications, hardware and software reliability. All of these assumed levels of performance must be assured if the operational system is to provide the level of safety that was deemed acceptable.

Since the depth of this analysis requires a high level of detail, it is logical to begin with the applications that are best defined. These happen to be situational awareness applications that are intended for early implementation, and that involve minimum modification to existing pilot-

controller procedures. The study also looks at "probing" applications that are less mature, but are expected to place greater demands on equipment and communications.

It appears that the results produced for many of the hazards and contributory events will be suitable for reuse, possibly with some modification, for many other applications when they are analyzed later. For example, the causes for a "target not displayed" hazard will likely reappear in the analysis of any application. The same is true, to some extent, for the display of erroneous target information, though, of course, the extent of error and the effects may vary greatly among applications.

In performing the allocation of requirements to surveillance and processing system elements, it is important to understand the metrics being applied. WG4 has defined the following list of surveillance parameters:

Parameter	How Used
Required Data Elements	Does the source (e.g., aircraft) provide all the information required to support the application?
Accuracy	In normal operation, is information sufficiently accurate for use?
Integrity	How often does information exceed a conformance limit without warning?
Update Period	How often does the source normally update its data?
Latency	How old is the information when it is received?
Continuity	How reliably will an existing track be updated?
Availability	How often is surveillance available for a target?
Track Purity	How likely is it that track splits or swaps occur?

Second Study: Comparative Safety Assessment of Suite of ADS-B and ASAS Applications

Purpose

As development and demonstration of ADS-B and ASAS capabilities proceed, the FAA faces a key decision as to whether these initiatives should be expected to take on a significant role in the future NAS. One facet of the decision must address the various issues and concerns that bear upon the safety of operations.

Investigators from several organizations, under FAA direction, completed a study this year that assesses the overall safety potential of a full suite of ADS-B and ASAS applications across U.S. airspace. These 25 applications, which include airborne, surface, and some air-ground uses of ADS-B, are listed in the FAA Safe Flight 21 Master Plan, and address 7 of the 9 operational enhancements proposed by the RTCA Free Flight Steering Committee. (Two more applications are treated in the third study, described below.) Some of the applications are air-ground, providing information to the controller, and thus do not fall within the defined scope of ASAS. Although some of the implementation dates are uncertain, the study assumes they would be implemented by 2015, as a target timeframe. The study considers various equipage levels of the fleet, as well as infrastructure improvements that relate to the applications. For example, TIS-B is postulated to support certain applications, and its use would serve to provide airborne surveillance for targets that would not have equipped with ADS-B. However, its surveillance information is not assumed to be at a sufficiently high level for every application.

Although some of the applications are less well defined than others, the operational concepts appear to be sufficiently clear to support the functional analysis and generation of hazards and their effects. The safety analyses will need to be revisited as they mature.

This study illuminates both potential benefits and problems for ASAS and its supporting surveillance sources. For example, safety benefits appear where the provision of airborne surveillance gives flight crews improved abilities to acquire and avoid collision threats, or when controllers are provided with extended or augmented surveillance. Detrimental effects, in

contrast, also are identified. The study considers the relevant communication, processing, equipment and human failures for their contribution to potential hazards. For example, any missing or corrupted ADS-B messages may have consequences that are more or less severe, depending upon their use in a particular application and the effect of any available mitigating elements.

Method
The original charter of the study was to compare the U.S. National Airspace System (NAS) with and without ADS-B and ASAS. To better illustrate the risk reduction potential as well as new hazards introduced, the investigators included a third alternative entitled "ADS-B, Normal Operation." This represents an artificial condition in which all equipment performs properly. It illustrates the intended benefits of the new service and procedures. The other alternative entitled "ADS-B, Abnormal Operation" presents the effects of failures and their associated likelihoods.

Some of the applications are intended to provide a safety increment, while others aim to achieve some new form of operational efficiency or flexibility. For the latter, risks must be judged acceptable. There is not necessarily a comparable operation today.

It is expected that the safety evaluation would be considered together with other factors, such as the intended operational or flexibility benefits, when system-wide investment alternatives are evaluated.

This study is not intended to serve as the basis for equipment certification or for operational approval of procedures, since many of these applications are not well developed. Nonetheless, the work performed here should be useful, and may form much of the basis of that later work.

Results

The alternative "Without ADS-B" shows very few hazards in this study, and all of these are low risk. It is understood that flying in the NAS is safe today. The areas of weather and terrain,

which may contain some of the greatest risks, were not addressed in this study.

The alternative "With ADS-B, Normal Operation" is an artificial alternative that highlights the risk reductions that the subject applications could achieve when all equipment operates as intended, without failures.

- The enhanced situational awareness of traffic, and augmented data items included in ADS-B messages and presented on cockpit or controller displays should improve safety.
- The improvements depend on the extent of traffic equipage with ADS-B. However, where TIS-B is implemented, it should enable the display of all traffic. The data quality of TIS-B may not be adequate for all applications, but should be sufficient for the various situational awareness, and possibly other types of applications.
- All risks within this alternative are ranked Low. In part, this is a result of requiring appropriate levels of information quality and equipment assurance levels for the various applications.
- There should be a considerable reduction of risk on the airport surface, an area of current concern because the complexity of operations or unfamiliarity with a location are causes of human error that could be avoided with better traffic information.
- Human factors always are of some concern, even when equipment operates properly. One notable concern is that pilots using ADS-B cockpit displays, particularly in single-pilot operations, could become distracted to the degree that their see-and-avoid activity is impaired. This is offset to some degree by the assistance they receive in having displayed traffic continuously available and updated.

The alternative "With ADS-B, Abnormal Operation" considers failures of equipment, data link, and human errors. Since most of the applications' procedures and displays have not been defined or demonstrated, the estimates of likelihood will need to be validated before operational approval is given.

- The *availability of ADS-B data*, as it results in an aircraft failing to be displayed to a

pilot or failing to provide augmented data to a controller, proves to be a low risk event. The effect is often simply a missed opportunity to achieve some beneficial risk reduction during an operation already deemed safe. In some cases, the user would need to revert to a conventional procedure instead of using an enhanced procedure based on ADS-B data.

- A corollary to the failure to display traffic, however, is a partial display of traffic. This is an obvious result of partial aircraft equipage. It also can result from an equipment or data link failure in an environment of full equipage or where TIS-B broadcasts data for unequipped aircraft. It is important that training and procedures instill sufficient caution in pilots and controllers that they always remain alert for traffic not shown on their display.
- The *effects of displaying incorrect data* vary according to the usage intended for the application. Where the data is meant only to supplement situational awareness or visual judgment, and where a controller continues to monitor aircraft or VFR users continue to practice see-and-avoid, the risks of erroneous data are low.
- However, risks are rated Medium for reduced separation standards where the data is a primary source that is trusted to enable an operation that cannot be performed today using existing inputs from radar.
- While a similar argument might be made for closely spaced parallel approaches, the study assumes that the data integrity standards for participating aircraft will be strict, and that the algorithms will have been rigorously tested. Accordingly, that application's risk is rated low.
- Risk is also rated Medium in the application for self-separation in one-in-one-out airspace. Here, aircraft with lower levels of broadcast reliability and integrity may participate, and missing or erroneous information can have severe consequences, without ATC radar surveillance as a mitigation. ATC may receive the broadcast information and intervene, when the data is correct and the failure is in an aircraft's receiving or display equipment.

- *Human errors* in interpreting data sometimes can lead to the same risks as for the erroneous display of data. Where an independent source (a controller or a second aircraft) monitors the encounter, however, the correct data would be shown and thus would not provide a common failure comparable to the broadcast of erroneous data.

In summary, the ADS-B applications are low-risk in nearly all cases. Some of the applications should improve the safety of the NAS, while others are intended to enable operational improvements and should not degrade safety in so doing. The medium risk areas concern the possibility of using hazardously misleading information where ADS-B is used for self-separation, or where it could mislead the controller and produce an unsafe clearance. These risks can be controlled by standards, monitoring, or independent validation of broadcast data.

Third Study: Comparative Safety Assessment of Conflict Detection & Resolution versus TCAS

Purpose

A subgroup of RTCA SC-186 WG1 has developed a concept entitled Airborne Conflict Management (ACM)[4]. This is a proposed ASAS application that detects, prevents, and resolves impending conflicts. The proposal envisions a form of alerting that provides flight crews with considerably more information than they have available at present. The goal of this application is to enable flight crews to avoid or resolve conflicts with early, minor maneuvers, and thereby facilitate their use of preferred routes and trajectories concurrent with an increase in safety.

Although the stated purpose of ACM differs from the existing Traffic Alert and Collision Avoidance System (TCAS), it is conceivable that a highly effective ACM could be contemplated as a replacement for TCAS, as well as a

supplement for it. This study, recently performed by investigators from several organizations, under the direction of the FAA, examines the relative safety of this alternative.

If the proposed application always worked as intended, it could be argued that the aircraft in question would never receive a TCAS advisory. This could be achieved in two ways:
• every conflict would need to be safely resolved before TCAS would issue alerts, and aircraft would need to maintain enough separation (in the sense of TCAS's alerting time, not of fixed distance) to avoid TCAS alerts
• Or, ACM could provide its own collision avoidance guidance, replacing that of TCAS

In fact, the ACM document proposes each of these methods to some degree. It seeks to apply the first form of protection to the greatest degree possible, and it can issue collision avoidance guidance when required. Presumably this might happen if a pilot failed to follow the system's earlier guidance, or if a threatening aircraft made a late, adverse maneuver. In recognition of current regulations, the document states that an installed TCAS would be given priority if it alerted. However, there is the implied path of using ACM alone, instead of installing TCAS. Accordingly, that is one of the options evaluated for the comparative study: full fleet equipage with ACM, replacing TCAS for those aircraft where it is now installed.

Method
Four alternatives were compared:
1. TCAS, as currently used
2. ACM, with aircraft fleet partially equipped but some other users retaining TCAS
3. ACM equipped throughout the fleet (including General Aviation)
4. A combination of TCAS and ACM aboard some aircraft

Both technical and human factors issues were analyzed, even though the ACM concept's crucial design directions are not decided. Clearly, ACM can only protect against targets for which airborne surveillance is available – those that are ADS-B equipped, or for which

TIS-B messages of adequate quality are provided.

Next, the issue of maneuver coordination is unclear. The present concept does not require it, and a fundamental question concerns the consequences of a change in strategy, following the perception that one's first maneuver is not working as planned. Both technical and human factors are involved.

The interface with ATC and its own conflict resolution tools also applies to this study. The system may need to work (at least by not degrading safety) in all priority schemes: ground, air, or situational.

This study, like those described earlier, also lists and classifies hazards for each system. For this study, a more detailed evaluation of hazard likelihoods was required, in order to compare the systems. In some respects, this was difficult, since TCAS algorithms are precisely specified [5] and have been extensively evaluated through simulation [6]. In contrast, ACM has several alternative concepts that still are under consideration, and no standard algorithms have been agreed.

Some analysis of traffic and accident statistics was considered in the evaluation of hazard likelihood and potential safety benefits. However, several confounding factors for ACM, beyond the algorithm issue, involve the unknown degree of equipage and the potentially wide variance among ADS-B targets with respect to their surveillance quality (accuracy and integrity).

As development proceeds, tradeoffs may need to be made among the safety and other aspects, such as compatibility. Therefore, the present safety assessment will need to be revisited in light of subsequent developments in system design and the operational use.

Results

In this study, for the timeframe used, ACM is assumed to be used as a backup to ATC for controlled aircraft, and as a backup to see-and-

avoid for VFR aircraft. Free Flight, in the sense of autonomous maneuvering, is not considered. Despite the status of ACM as a backup, it seems realistic that controlled aircraft would perform collision avoidance maneuvers without first coordinating with a controller.

This study examines the functional aspects of each candidate system and ranks potential hazards using a Risk Assessment Code, consisting of a Severity and a Likelihood component. The NAS Modernization System Safety Management Plan specifies the combinations of these components that are termed High, Medium or Low Risk. The Risk Assessment Matrix, Figure 1, shows the ratings of hazards for the four alternatives.

All of the alternative systems display aspects of Medium or High risk. In the case of TCAS, some Medium risks are present:

- Two hazards involving Loss of Separation, for which TCAS is not designed to protect
- Nuisance alerts, which are accepted as an inevitable byproduct of TCAS's limited measurement ability and lack of knowledge of ATC intent
- Two serious but extremely improbable hazards: a coordination failure of RAs, and a pilot not hearing or observing an RA
- An ineffective RA that either fails to resolve a NMAC or helps to induce one through erroneous advice
- A pilot not following an RA, either accurately or at all

For ACM partial equipage, both Medium and High risks are identified:

- A threatening target is not tracked by the system
- Failure to detect a conflict, primarily due to inadequate allowance for low integrity data broadcast by a threat aircraft
- A poor choice by the pilot for conflict resolution, due to the latitude provided by the system and the unknown or varied skill of pilots in utilizing the display for this purpose

- One of the improbable hazards listed for TCAS: pilot failing to hear or observe the equivalent of an RA
- A pilot not following the equivalent of an RA, either accurately or at all
- High Risk: an ineffective collision avoidance resolution that either fails to resolve a NMAC or helps to induce one through erroneous advice. While it is impossible to compare this risk quantitatively to TCAS due to the lack of a standard algorithm, the need to avoid all threats, even those broadcasting low integrity data, raises the likelihood of this risk. While the Protected Airspace Zone (PAZ) alert should reduce collision scenarios to a smaller number than TCAS sees, routine close proximity in altitude provides a vulnerability to induced collisions if erroneous data is used.
- High Risk: uncoordinated resolution advisories between two ACM–equipped aircraft lead to incompatible maneuvers. The ACM system does not perform explicit coordination, and the involvement of ATC (explained below) further complicates the problem.
- High Risk: an aircraft following a resolution maneuver comes into conflict with another aircraft – the greatest risk occurring when the second is not known to the system, principally from partial equipage, and the pilot may not be sufficiently vigilant in this situation.

For ACM full equipage, both Medium and High risks are identified. Note that two medium risks and two high risks that are present for ACM partial equipage are given lesser classifications for ACM full equipage:

- A poor choice by the pilot for conflict resolution, due to the latitude provided by the system and the unknown or varied skill of pilots in utilizing the display for this purpose
- One of the improbable hazards listed for TCAS: pilot failing to hear or observe the equivalent of an RA
- A pilot not following the equivalent of an RA, either accurately or at all

- An ineffective collision avoidance resolution that either fails to resolve a NMAC or helps to induce one through erroneous advice.
- High Risk: uncoordinated resolution advisories between two ACM–equipped aircraft lead to incompatible maneuvers. The ACM system does not perform explicit coordination, and the involvement of ATC (explained below) further complicates the problem.

For the TCAS/ACM combination, only Medium risks are identified. The presence of TCAS avoids some of the ACM risks, while the ACM function supplies the protection for separation that TCAS lacks. There is the concern that pilots may become confused by the display of traffic in which different targets are protected through different capabilities. Another concern is the potential for transitions of resolution between ACM and TCAS (which is given priority) in the midst of an encounter, and whether pilots would achieve safe resolution in such a situation.

An important aspect of the protection afforded to users involves the degree of equipage. TCAS II is installed onboard air carriers, and on a limited number of General Aviation (GA), Regional Carriers and military transport aircraft. It is unlikely, if not impractical, for small GA users to install TCAS. Other regional operators have installed TCAS I, which provides lesser capability without RAs.
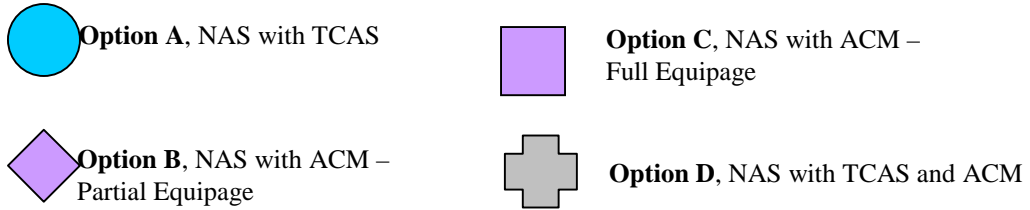
The effectiveness of either system grows with equipage. TCAS equipage is basically stable, though the "full" equipage designated by ICAO would add it for cargo carriers. ACM equipage may need to reach some unknown level before its protection becomes significant. A mixed equipage environment presents some risks of an incomplete traffic display and dangerous secondary encounters after conflict resolution. (TCAS also faces this, to a lesser extent, for non-transponder aircraft.) However, TIS-B may be able to substitute its broadcasts for ADS-B equipage and provide display of all targets. It is not known whether the accuracy limitations of TIS-B would limit its effectiveness.

The ACM concept asserts that it is intended for all categories of users. Despite the disparity of spending capacity, equipment space, and pilot training, among other factors, the concept proposes essentially the same functional capability for all user types, and this study proceeds on this premise. As a consequence, ACM may benefit a far greater number of users than TCAS and thus can address a safety vulnerability (the roughly 18 midair collisions per year between general aviation aircraft) that TCAS cannot. (This represents about 1 percent of GA accidents overall.)

There has been no work done to date on reconciling ACM separation advisories with a controller's conflict detection tools and advice. While this study assumes that a pilot must seek controller direction before responding to a PAZ alert, these potentially conflicting sources of advice could increase the incidence of advisories not followed, or of uncoordinated resolutions (from the various sources) for two aircraft in conflict. As an operational concept matures to integrate the airborne and ground systems, this study again will need to be revisited.

The category of human factors, comprising pilot and controller errors, was carefully considered. Several hazards are identified and should be investigated as development and implementation proceed. This study cannot quantify this type of hazard since the ACM display requirements are quite tentative.

RISK PROFILE OF ALTERNATIVES

Option A, NAS with TCAS

Option C, NAS with ACM – Full Equipage

Option B, NAS with ACM – Partial Equipage

Option D, NAS with TCAS and ACM

Number in shape represents the number of hazards in that category.

Severity / Likelihood	No Safety Effect 5	Minor 4	Major 3	Hazardous 2	Catastrophic 1
Probable A		1, 1			
Remote B		1, 3, 1, 2	2		
Extremely Remote C	5, 3, 5, 3	1, 4, 3, 4	2	3, 1	
Extremely Improbable D	2, 2, 2, 4	2, 3, 5, 3	4, 2, 4, 4	4, 3, 4, 4	

High Risk
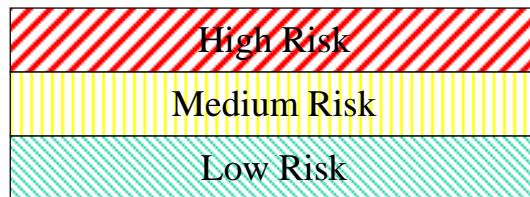
Medium Risk

Low Risk

Figure 1. Risk Assessment Matrix

In summary:

1. The TCAS & ACM alternative could be safer than TCAS alone if the systems can be successfully integrated.
2. ACM appears to carry some higher risk items than TCAS. Several risk drivers should be monitored as the ACM concept matures. Risk would be lowest if:
   - Equipage becomes very widespread
   - All ADS-B aircraft broadcasts conform to integrity limits so that ACM can properly bound the position errors of targets
   - Its algorithms prove to be highly effective and are not handicapped by the lack of coordination between equipped aircraft or between TCAS and ACM.

3. ACM may benefit more users than TCAS and make a notable contribution to the safety of the NAS.
4. The safety of ACM needs to be reassessed as its development proceeds, since many assumptions were needed for this assessment.
5. The safety of ACM is directly related to level of equipage.
6. To assure an acceptable level of safety, the introduction of ACM for conflict detection and resolution may need to be accompanied by either:
   - A mandated level of equipage, or
   - TIS-B of sufficient accuracy and integrity to compensate for low levels of equipage.

Conclusion

There is a great deal of synergy among these three studies, even with the differences in their levels of scope. Many of the hazards and considerations are common among the various applications. ASAS and ADS-B provide good illustrations of the flexibility of the OSA method. We continue to believe in the value of this method and in sharing examples of its utility.

References

1. A. Zeitlin and B. Bonnemaison, "Managing Criticality of ASAS Applications," ATM-2000, Napoli, May 2000.

2. A. Zeitlin, "The Influence of Safety Assessment on Surveillance Performance Requirements", FAA/EUROCONTROL ASAS TIM, Brétigny, November 2000.

3. "Guidelines for Approval of the Provision and Use of Air Traffic Services Supported by Data Communications", DO-264, RTCA, 2000.

4. "Application of Airborne Conflict Management: Detection, Prevention, and Resolution," DO-263, RTCA, 2000.

5. "Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System (TCAS) II Airborne Equipment," DO-185A, RTCA, December 1997.

6. M. McLaughlin, "Safety Study of the Traffic Alert and Collision Avoidance System (TCAS II)," MTR 97W32, MITRE/CAASD, June 1997.

Author Biography

Dr. Andrew D. Zeitlin is Principal Engineer for ATM/Avionics at MITRE/CAASD. He has been a leading developer of cockpit-based traffic warning and display systems since 1975. Before commencing safety assessment work on ADS-B and ASAS, he conducted numerous safety studies for TCAS and related applications. He is a member of SCRSP Working Group A and its ASAS Subgroup, RTCA Committees SC-186 (ADS-B and ASAS), is co-chair of SC-186 WG2 (TIS-B), and previously participated in SC-147 (ACAS), and SC 189/EUROCAE WG-53 (ATS Safety and Interoperability Requirements).