REPORT FROM THE ADS–B AVIATION RULEMAKING COMMITTEE TO THE FEDERAL AVIATION ADMINISTRATION

Recommendations on Federal Aviation Administration Notice No. 7–15, Automatic Dependent Surveillance—Broadcast (ADS–B) Out Performance Requirements to Support Air Traffic Control (ATC) Service; Notice of Proposed Rulemaking

September 26, 2008

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EXECUTIVE SUMMARY

The Federal Aviation Administration (FAA) chartered the Automatic Dependent Surveillance – Broadcast (ADS–B) Aviation Rulemaking Committee (ARC) on July 15, 2007, to—

> Provide a forum for the U.S. aviation community to discuss and review an NPRM [notice of proposed rulemaking] for ADS–B, formulate recommendations on presenting and structuring an ADS–B mandate, and consider additional actions that may be necessary to implement those recommendations.

After the NPRM was published, the ARC was tasked with making specific recommendations to the FAA concerning the proposed rule based on the comments submitted to the docket.

The ARC reviewed 1,423 comments submitted to the docket by 165 entities, categorized the comments for further analysis, and studied the issues underlying 1,101 of the 1,423 comments on the docket. This report presents specific recommendations to the FAA concerning the proposed requirements for ADS–B Out, including recommended dispositions of the public's comments to the NPRM.

The ARC is making 36 summary recommendations regarding the ADS–B link strategy, program, business case, required equipment, security, and privacy. The ARC divided the recommendations into two broad categories: recommendations to be resolved before any rule is adopted and recommendations for future action. The recommendations are discussed in detail in section 4.

The ADS–B program is unique. It requires the concurrent development and implementation of air and ground systems, and revisions to operating procedures. This report makes recommendations for programmatic and regulatory aspects of the rule. The following list summarizes the key elements of this report:

- The aviation community assumes the FAA will meet the planned schedule and required capabilities under a parallel, performance-based contract for the ADS–B ground infrastructure. This report makes a few recommendations regarding that infrastructure, but focuses on the aircraft aspects of ADS–B Out.
- The ARC has validated the proposed ADS–B dual-link strategy assuming that there are no changes to existing collision avoidance and surveillance avionics. However, the FAA has identified the need to reduce congestion on the 1090 MHz frequency, used by ADS–B, ground surveillance systems, and collision avoidance systems. This is needed to ensure successful introduction of ADS–B Out, while supporting current and envisioned ADS–B In applications for the Next Generation Air Transportation System (NextGen). Because reducing frequency congestion may require changing existing collision avoidance and surveillance avionics, the ARC is recommending that the FAA, in evaluating these potential changes, also evaluate the benefits and

additional steps needed to enable a single ADS–B link implementation strategy.

- The ARC could not reach consensus on whether the FAA should mandate equipment meeting interim ADS–B Out standards, 3 years earlier than the NPRM proposed compliance date, to achieve early benefits in certain airspace. The ARC recommends that the FAA retain the 2020 compliance date, but incorporate into the ADS–B Out program additional benefits for all National Airspace System (NAS) users as developed by the ARC.
- The FAA should approve the use of interim ADS–B Out equipage for separation service in the Gulf of Mexico and for non-separation applications in radar airspace well before the 2020 compliance deadline. The FAA also should incentivize operators to voluntarily equip early for the 2020 mandate.
- The ARC has identified additional measures that would benefit the low altitude community, and recommends that the FAA take advantage of this opportunity to provide a positive business case for that large segment of the aviation community.
- The ARC recommends that if the FAA plans to adopt certain significant changes to the NPRM, it should publish a supplemental notice of proposed rulemaking (SNPRM). The ARC recommends that any SNPRM retain ADS–B Out implementation in the NAS by 2020.
- The ARC recommends revisions to some of the performance-based standards proposed in the NPRM to achieve envisioned operational efficiencies at a lower impact to airspace users.

The ARC prepared this report according to a schedule that would support decisions by the FAA's Rulemaking Management Council in January 2009. The ARC emphasizes its support for ADS–B Out implementation in the NAS by 2020.

The community would encourage the FAA to charter future ARCs at the beginning of NPRM development to provide the most complete recommendations possible and assess more potential options.

The ARC sincerely appreciates the opportunity to contribute to this rulemaking, and recognizes the considerable effort the FAA has exerted to advance ADS–B — a first step toward NextGen, with significantly improved capacity and the level of safety the travelling public demands.

1.0 Summary of the Automatic Dependent Surveillance – Broadcast Aviation Rulemaking Committee Recommendations

This section provides an overview of the Automatic Dependent Surveillance – Broadcast (ADS–B) Aviation Rulemaking Committee (ARC)'s recommendations. The ARC studied the topics at length and prepared a thorough explanation behind each recommendation (see section 4.0), along with a summary of the comments submitted on each topic. To best understand the recommendations presented here, please refer to section 4.0, as noted next to each recommendation.

Recommendations that must be incorporated into the final ADS–B Out rule

ADS–B Link Strategy

The ARC has validated the proposed 1090 MHz extended squitter (1090 ES)/universal access transceiver (UAT) dual-link strategy, in the context of 1090 ES being introduced in a manner compatible with existing airborne collision avoidance system (ACAS) and secondary surveillance radar (SSR) systems on 1090 MHz. However, the Federal Aviation Administration (FAA), in assessing the 1090 MHz frequency congestion risk to the Surveillance and Broadcast Services (SBS) Program, has recently highlighted the urgency of mitigating 1090 MHz frequency congestion in high-density airspace to ensure 1090 ES is (1) interoperable with ACAS and SSR and (2) provides sufficient air-to-air range to support Next Generation Air Transportation System (NextGen) ADS–B In applications. These mitigations may include significant changes to ACAS, as well as reductions beyond those currently planned by the FAA in the use of SSR in high-density airspace[1]. Recommendation Nos. 1 through 3 below are designed to ensure the aviation community achieves maximum value from any reengineering of occupancy of the 1090 MHz frequency. The recommendations include a cost-benefit comparison of chosen 1090 MHz frequency congestion mitigations with those further mitigations that would be required to enable a single-link 1090 ES ADS–B implementation.

Recommendation No. 1
(See pages 19 through 22 of this report.)

The FAA should conduct an urgent study on 1090 MHz frequency congestion to be completed by January 2009.

The urgent study should answer the following questions:

- Can the 1090 MHz frequency support 1090 ES, ACAS, and SSR in the National Airspace System (NAS) high-density airspace? If the answer is yes, what are the costs of necessary mitigations? Can the mitigations be limited to ground-based solutions?

[1] Section 5 of this report discusses the proposed changes to ACAS and SSR.

- Can 1090 MHz ADS–B support needed ADS–B In applications in the NextGen timeframe? If so, what mitigations, if any, additional to those above are needed and at what cost?

The urgent study should have the following guidelines:

- The NextGen timeframe extends through 2035 (the 2035 date includes an equipment life cycle after the proposed 2020 rule compliance date).
- Consider the 1090 MHz frequency congestion mitigations that would be required to provide a 45-nautical mile (nm) air-to-air range for ADS–B In applications in future high-density airspace. Provide similar answers for air-to-air ranges of 20 nm, 60 nm, and 90 nm.
- The cost impact and user acceptability of any additional avionics mandates needed to support 1090 ES implementation need to be addressed. Mandating an upgrade from today's Mode C transponder to a mode select (Mode S) transponder in addition to mandating ADS–B Out will not be acceptable to low altitude users.

Recommendation No. 2
(See pages 37 through 42 and pages 113 through 115 of this report.)

In parallel with the urgent study, the FAA should work with the Joint Planning and Development Office to articulate, by January 2009, the changes to ACAS that are expected to enable the planned NextGen operational concepts. The FAA should assess the life cycle costs, timeframe, and benefits of these planned changes, including the projected number of ACAS upgrade cycles. Additionally, the FAA should assess, by January 2009, the feasibility, timeline, and cost of a non-SSR backup to ADS–B.

Recommendation No. 3
(See pages 19 through 22 and 37 through 42 of this report.)

Upon completion of the urgent study and analyses of recommendation Nos. 1 and 2, the FAA should collaborate with industry through the Air Traffic Management Advisory Committee (ATMAC) ADS–B Working Group or ADS–B ARC to—

- Determine which 1090 MHz frequency congestion mitigation strategies will be adopted to make 1090 MHz ADS–B Out compatible with ACAS and SSR.
- Determine which additional 1090 MHz frequency congestion mitigation strategies should be adopted so that ADS–B Out supports NextGen ADS–B In applications in future high-density airspace.
- Decide whether the cost of the additional 1090 MHz frequency congestion mitigations is justified by the benefits of enabling a single-link 1090 ES ADS–B implementation.
- Finalize the ADS–B link implementation strategy.

The ARC strongly recommends that any implementation of a single-link 1090 ES ADS–B strategy proceed in two steps:

- To support ADS–B Out implementation by 2020, and
- To support NextGen ADS–B In applications in high-density airspace, beyond 2020.

ADS–B Program and Business Case

Recommendation No. 4
(See pages 37 through 42 of this report.)

The ARC developed and evaluated potential changes to the current notice of proposed rulemaking (NPRM) that, if adopted, could provide an earlier realization of benefits by high altitude stakeholders. However, the ARC could not reach consensus on whether FAA should mandate DO–260-approved ADS–B Out for operations in class A airspace and at operational evaluation plan[2] (OEP) airports by 2017, three years earlier than proposed[3]. The ARC recommends that the FAA retain the 2020 compliance date, but incorporate into the ADS–B Out program additional benefits for all NAS users as developed by the ARC.

Recommendation No. 5

The ARC considered potential changes to the current NPRM that could be considered significant. To ensure the public has a venue to comment on significant changes, the ARC recommends that if the FAA plans to adopt any of the following changes it should issue a supplemental notice of proposed rulemaking (SNPRM):

- Accelerated compliance date
- A change in the link strategy
- Avionics mandates in addition to the original NPRM

The ARC recommends that any SNPRM retain ADS–B Out implementation in the NAS by 2020.

Recommendation No. 6
(See pages 43 through 46 and 106 through 107 of this report.)

Consistent with the ARC's task 1 report, Optimizing the Benefits of ADS–B, the FAA should enable the use of DO–260-approved equipment for non-separation applications in the NPRM business case such as conflict probe in radar airspace. The FAA should operationally validate these benefits as soon as possible, to give operators confidence in the benefits of ADS–B Out.

[2] Appendix G lists the 35 OEP airports.
[3] The ARC has included an analysis of its 2017 mandate for informational purposes.

Recommendation No. 7
(See pages 48 through 49 of this report.)

The FAA should incentivize operators to voluntarily equip early for the 2020 mandate by providing operational preference for ADS–B equipage. This could include establishing preferred routes and new procedures for ADS–B-equipped aircraft to provide more optimal flight paths and improve system capacity. The FAA should encourage early equipage by establishing agreements with specific operators and accelerating deployment of ADS–B services at designated locations.

Recommendation No. 8
(See pages 37 through 42 of this report.)

The FAA should recalculate its cost-benefit analysis using a range of costs for certain items rather than fixed costs to present the community with a realistic range of potential benefits.

Recommendation No. 9
(See pages 37 through 42.)

The FAA should implement the necessary incentives to create a positive business case for low altitude airspace users. This requires the FAA to make changes that result in lower investment costs and increased benefits, and provide economic incentives to offset costs when benefits are insufficient for a particular operator segment.

If the ADS–B mandate results in the low altitude segment of the aviation community investing more into the system than the benefits enabled, the FAA should not mandate ADS–B Out for that segment of the community.

To increase the overall value of the NPRM and stakeholder buy-in for low altitude operators, the FAA should—

a. Validate ARC calculations of transponder equipage savings for U.S. operators without TCAS if Mode A/C transponders could be removed from those aircraft in the future.

b. Validate ARC calculations of the net benefits for providing surveillance services at non-radar airspace (NRA) airports, then add appropriate service volumes to the SBS Program to provide service at all public use airports that have at least one runway over 3,000 feet and at least one instrument approach procedure.

c. Investigate the value of adding the following services to the SBS Program:

   - Expanded low-altitude NRA surveillance services,
   - Automatic closure of flight plans at NRA airports, and
   - Flight service station (FSS) improvements.

The FAA should establish and introduce in the final ADS–B Out rule a public process for implementing future modifications to the airspace, applications, or airports for which ADS–B equipment is required.

Recommendation No. 10
(See pages 106 through 107 of this report.)

To approve the use of DO–260-like equipage, the FAA should adopt, for 5 nm separations in non-radar airspace to include at least the Gulf of Mexico, European Aviation Safety Agency (EASA) Acceptable Means of Compliance (AMC) 20–24, with appropriate measures to ensure ADS–B integrity.

Recommendation No. 11
(See pages 37 through 42 of this report.)

The ARC recommends that the FAA delay the compliance date of the rule if the following items are not complete by 2013:

- Ground infrastructure coverage needed for the mandated airspace and additional NRA airports,
- Automation systems,
- Equipment certification,
- Performance standards,
- Operational approval,
- Separation standards,
- Operational procedures for ADS–B non-radar airspace, and
- FAA controller training and procedures.

Recommendation No. 12
(See page 103 of this report.)

To align the current ADS–B rule with currently defined transponder airspace, the ARC recommends the FAA revise 14 CFR § 91.225 to say "at and above 10,000 feet mean sea level (m.s.l.), excluding the airspace at and below 2,500 feet above the surface."

Recommendation No. 13
(See page 112 of this report.)

The FAA should include a detailed discussion in the preamble to the final rule of the benefits of Flight Information Service – Broadcast (FIS–B) and Traffic Information Service – Broadcast (TIS–B), including the added investments required to take advantage of these ADS–B In services.

Performance Requirements

The ARC analyzed the performance requirements in the NPRM and recommends the FAA specify the performance requirements by application to expand on the single level proposed in the NPRM.

Recommendation No. 14
(See pages 64 through 66 and 70 through 73 of this report.)

The FAA should specify the following performance requirements for DO–260A and DO–282A according to domain/application as follows[4]:

Table 1 — ADS–B Out Performance Requirements by Application

Domain/Application	NACp and Continuity Greater Than or Equal to—	NIC Greater Than or Equal to—	NACv
For aircraft performing ASSA and FAROA[5] in the terminal area and surface of the 35 OEP airports	9 for 95% per hour (the continuity for NACp≥9 requires future FAA analysis) 8 for 99.9% per hour.	not required	not required
For aircraft performing 3 nm separation in non-radar areas per DO–303	6 for 99.9% per hour	5 for 99.9% per hour	not required
For aircraft performing 5 nm separation in non-radar areas per FAA-approved separation standards in Alaska	6 for 99.9% per hour	5 for 99.9% per hour	not required
For aircraft performing 3 nm separation in radar areas	8 for 99.9% per hour	6 for 99.9% per hour	not required
For aircraft performing 5 nm separation in radar areas	7 for 99.9% per hour	5 for 99.9% per hour	not required
For aircraft performing 2.5 nm in-trail separation on approach in radar areas	8 for 99.9% per hour	7 for 99.9% per hour	not required
For aircraft performing 2 nm dependent parallel approach separation in radar areas	7 for 99.9% per hour	7 for 99.9% per hour	not required
For aircraft performing independent parallel approach separation in radar areas	8 for 99.9% per hour	7 for 99.9% per hour	not required

[4] NACp, NIC, and NACv values based on draft RFG Enhanced ATS in Radar Areas using ADS–B Surveillance (ADS–B–RAD) Application.

[5] Airport Surface Situational Awareness (ASSA) and Final Approach Runway Occupancy Awareness (FAROA) are examples of future applications that will require more stringent performance requirements than separation applications for non-radar airspace and radar airspace. The continuity requirement for situational awareness applications is for the purpose of system design and not for aircraft operational limitations.

The ARC acknowledges that the recommended navigation accuracy category for position (NACp) and navigation integrity category (NIC) requirements for 3 nm and 5 nm separation in radar airspace are more stringent than those for non-radar airspace, because—

1. The reference radar model for radar airspace is monopulse, which is the type of radar most frequently used to support separations in the United States and Europe. The comparative analysis used in non-radar airspace was to sliding window radar, which is significantly less accurate than monopulse. Doing such a comparative analysis was seen as leading to more rapid yet safe implementation of non-radar airspace than doing a "from scratch" target level of safety analysis for the NRA application.
2. The NRA scenario is low density. All radar airspace scenarios are medium-to-high-density scenarios. The manner in which Europe and the United States operate such airspace takes advantage of increasing radar accuracy as one gets closer to the radar. Therefore the "range of applicability" used with the reference radar model (the radar range at which ADS–B and radar are compared) is more stringent for radar airspace than for non-radar airspace.
3. There may be additional indirect factors such as a given hazard having higher severity in high-density radar airspace than in low-density non-radar airspace.

The ARC recommends the FAA validate the ADS–B Out performance parameter values specified in table 1 based on performing the operations identified in table 1 at the earliest possible opportunity (possibly around Philadelphia International Airport (PHL) or Louisville International Standiford Airport (SDF).

Recommendation No. 15
(See pages 77 through 79 of this report.)

The ARC makes the following recommendations on latency:

- The FAA should specify latency requirements at the aircraft level, not the equipment level.
- The FAA should reference latency to the time of applicability of the position provided by the position sensor, for example, time mark for global navigation satellite system (GNSS) sensor position sources.
- The FAA should specify the maximum uncompensated latency, such that it minimizes or eliminates installation wiring changes of existing ADS–B Out implementations, while meeting air traffic control (ATC) surveillance requirements (for example GNSS time mark).
- The FAA should change the proposed requirement for DO–260A and DO–282A to broadcast a change within 10 seconds for NIC, NACp, navigation accuracy category for velocity (NACv), and surveillance integrity level (SIL) to within—
    - 12.1 seconds (95 percent) for changes in NIC and SIL.
    - 3.1 seconds (95 percent) for changes in NACp and NACv.

Recommendation No. 16
(See pages 64 through 66 of this report.)

The ARC recommends that the FAA not apply the vertical position accuracy requirement associated with a NACp=9 for surface applications. The ARC also recommends altering the definition in DO–260A and DO–282A for a NACp=9 to remove a vertical accuracy requirement if the aircraft is on the surface. The ARC acknowledges that altering the definition for NACp=9 for surface applications would require international coordination and harmonization.

Recommendation No. 17
(See page 70 through 73 of this report.)

The FAA should advocate national policies that explicitly allow for the use of non-U.S. positioning resources, like Galileo, as part of the infrastructure to meet aviation performance requirements.

Recommendation No. 18
(See pages 52 through 58 of this report.)

The ARC, based upon analysis it has performed, urges the FAA to allow non-diversity antenna installations for visual flight rules (VFR) aircraft flying through high-density airspace, for example class B and C and below 15,000 feet (1090) or below FL 180 (UAT) but not landing at the primary airports. Additionally, the FAA should continue to resolve the barriers (as identified by the ARC) to permit single-antenna installations on low altitude, slow moving aircraft. The ARC recommends that the FAA conduct the necessary testing to identify appropriate solutions.

Recommendation No. 19
(See pages 64 through 66 of this report.)

The FAA should use the definition in DO–289, Minimum Aviation System Performance Standards (MASPS) for Aircraft Surveillance Applications (ASA), to define SIL. The ARC believes that the definition of SIL in the NPRM was incorrect.

Recommendation No. 20
(See pages 85 through 90 of this report.)

In response to comments, the ARC made a variety of recommendations on the required Broadcast Message Elements for ADS–B Out. Specific recommendations are provided in section 4, pages 85 through 90, of this report.

Recommendation No. 21
(See pages 70 through 73 of this report.)

The FAA should create a function for centralized, expert calculation and reporting of predicted continuity of the required navigation performance (RNP) parameters, assuming a representative set of equipage configurations and the actual GNSS satellite coverage.

Recommendation No. 22
(See pages 70 through 73 of this report.)

The FAA should research and specify a continuity requirement commensurate with allowing selective availability (SA) Off, global positioning system (GPS)-only receivers to meet the performance requirements in the NAS.

Recommendation No. 23
(See pages 70 through 73 of this report.)

The FAA should specify two continuity requirements for the surface situational awareness applications (for example, Airport Surface Situational Awareness (ASSA) and Final Approach Runway Occupancy Awareness (FAROA)[6]). The first requirement is approximately 95 percent per hour (to be verified by FAA analysis) for a horizontal position accuracy of NACp≥9. The second requirement is 99.9 percent per hour for a horizontal position accuracy of NACp≥8.

Required Equipment

Recommendation No. 24
(See page 92 of this report.)

The ARC recommends that the FAA remove the requirement for the pilot to turn off the ADS–B equipment if directed by ATC.

Recommendation No. 25
(See pages 93 through 94 of this report.)

The FAA should explain the following in the final rule preamble:

1. Why transponder carriage is required after the ADS–B Out compliance date.
2. The FAA's commitment and strategy for achieving transponder removal from low-altitude domestic aircraft.

Communication, Navigation, and Surveillance Equipment

Recommendation No. 26
(See pages 113 through 114 of this report.)

The FAA should include an integrated communication, navigation, and surveillance (CNS) roadmap in the preamble to the ADS–B Out final rule that emphasizes the importance of beginning the transition to NextGen as soon as possible.

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[6] ASSA and FAROA are examples of future applications that will require more stringent performance requirements than separation applications for non-radar airspace and radar airspace. The continuity requirement for situational awareness applications is for the purpose of system design and not for aircraft operational limitations.

Other Recommendations for a successful ADS–B Out Program

ADS–B Program and Business Case

Recommendation No. 27
(See pages 111 through 112 of this report.)

The NPRM is focused on ADS–B Out and attempts to establish the requirements of ADS–B Out equipment so that it is compatible with ADS–B In. The FAA, in partnership with industry, should define a strategy for ADS–B In by 2012, ensuring the strategy is compatible with ADS–B Out avionics. The FAA also should ensure this program defines how to proceed with ADS–B In beyond the voluntary equipage concept included in the NPRM.

Recommendation No. 28
(See pages 93 through 94 of this report.)

To support early ADS–B benefits with DO–260-approved equipment, the FAA should further explore opportunities within the ADS–B ground infrastructure/ATC automation to fuse data to accommodate the lack of transmission of the Mode 3/A code.

Recommendation No. 29
(See pages 37 through 42 of this report.)

The FAA should develop and implement the requirements and operational procedures for 3 nm separation in all domestic en route airspace based on ADS–B surveillance, before to the ADS–B Out compliance date.

Required Equipment

Recommendation No. 30
(See pages 93 through 94 and 115 of this report.)

Regardless of the ADS–B link implementation strategy, the FAA should pursue an ADS–B implementation strategy that ultimately results in the removal of transponders from low-altitude stakeholder aircraft that are not equipped with ACAS. The FAA should continue to evolve the collision avoidance systems used by transport category aircraft today. The FAA should conduct an in-depth study to consider modifying ACAS to use ADS–B as the primary surveillance data for collision avoidance. If the FAA is able to eliminate reliance on SSR and make appropriate changes to ACAS, then the FAA should permit U.S. low-altitude operators to remove their transponders[7].

Recommendation No. 31
(See pages 93 through 94 of this report.)

The FAA should explore the opportunity of providing an enhancement to the emergency locator transmitter (ELT)/search and rescue operation by establishing an ADS–B tracking service that could be used to aid in crash locating.

[7] Section 5 of this report discusses the proposed changes to ACAS and SSR.

Recommendation No. 32
(See pages 93 through 94 of this report.)

The FAA should conduct a study that considers an ADS–B-based search and rescue solution that may enable removal of 121.5 MHz ELTs for certain U.S. domestic operations.

Communication, Navigation, and Surveillance Equipment

Recommendation No. 33
(See pages 98 and 99 and 115 of this report.)

The FAA should, in coordination with other Government agencies, develop an integrated CNS strategy to address GNSS interference and outages.

Security, Privacy, and Malicious Use

Recommendation No. 34
(See pages 98 through 99 of this report.)

The FAA should treat 24-bit International Civil Aviation Organization (ICAO) code assignments as information covered under privacy laws, so they are available only to authorized personnel or released by the holder.

Recommendation No. 35
(See pages 98 through 99 of this report.)

The FAA should use the anonymity feature of UAT and develop an equivalent feature for 1090 ES that would apply only to VFR operations not using ATC services, which would be equivalent to a 1200 transponder code.

Recommendation No. 36
(See pages 98 through 99 of this report.)

The FAA should accommodate assignment of 24-bit ICAO codes so that they don't easily correlate to aircraft tail numbers (per ICAO recommendations) and permit aircraft call signs to be something other than the aircraft registration number when receiving ATC services.

2.0 AVIATION RULEMAKING COMMITTEE TASKING

Through the ATMAC, industry and user groups have expressed a desire to be more involved in the FAA's ADS–B rulemaking process. The FAA agreed that a wide scope of input would be beneficial to market and manage both the substantial benefits and significant costs of a nationwide ADS–B system. Therefore, on July 15, 2007, the FAA chartered the ADS–B ARC to—

> Provide a forum for the U.S. aviation community to discuss and review an NPRM for ADS–B, formulate recommendations on presenting and structuring an ADS–B mandate, and consider additional actions that may be necessary to implement those recommendations.

The charter stated that the ADS–B ARC will submit recommendations to the Administrator through the Chief Operating Officer, Air Traffic Organization.

Specifically, the ARC was given the following two tasks:

> *Task 1*: While the NPRM is being finalized and leading up to its publication, the ARC will serve as a platform for developing a report on optimizing the operational benefits of ADS–B before the implementation of a nationwide ADS–B airspace rule.
>
> *Task 2*: After publication of the NPRM, the ARC will make specific recommendations to the FAA concerning the proposed requirements based on the comments submitted to the NPRM docket.

The ARC published the task 1 report on October 3, 2007. Shortly after, on October 5, 2007, the FAA published the ADS–B NPRM for public comment, with comments due on or before January 3, 2008. In response to a number of requests to extend the comment period, on November 19, 2007, the FAA published a notice to extend the comment period until March 3, 2008 (72 FR 64966).

During the comment period, the ARC drafted a series of questions for clarification on the ADS–B NPRM. The questions and FAA responses are available in appendixes E and F to the report.

This report, completed under task 2, explains the ARC's further investigation of issues raised on comments submitted to the docket and the ARC's recommendations to the FAA regarding the ADS–B Out mandate.

3.0 General Analysis of Comments

On October 5, 2007, the FAA published the ADS–B NPRM for public comment with comments due on or before January 3, 2008. In response to a number of requests to extend the comment period, on November 19, 2007, the FAA published a notice to extend the comment period until March 3, 2008 (72 FR 64966).

The FAA received a total of 188 submissions to the docket on its ADS–B NPRM that contained comments. However, of those 188 submissions, 5 were duplicates of other submissions, 5 were requests to extend the comment period, and 1 comment didn't apply to this NPRM. Therefore, the FAA received 177 unique submissions to the docket that contained 1,423 unique comments on the ADS–B NPRM[8].

The following tables provide a breakdown of the number of unique submissions to the docket by type of commenter (Table 2) and the number of comments received by issue (Table 3).

Table 2 — Number of Unique Submissions to the Docket by Type of Commenter

Type of Commenter	Number of Unique Submissions
Air Carrier (Domestic)	7
Air Carrier (Foreign)	1
Aircraft Manufacturer – General Aviation	1
Aircraft Manufacturer – Air Transport	4
Association	22
Aviation Law Student	7
Avionics Manufacturer	10
Department of Defense	1
Individual Aircraft Owner	13
Individual Pilot – ATP	4
Individual Pilot – certificate type unknown	2
Individual Pilot – Commercial Cert.	6
Individual Pilot – Private/Recreational/Sport	25
Other Federal Government Agency	1

[8] Each unique submission of comments to the docket may contain multiple comments on the NPRM. In addition, individual commenters (persons or organizations) may have submitted more than one unique submission to the docket. (There were 165 entities that submitted comments to the docket.) Therefore, there are more comments on the NPRM then there are submissions or commenters.

Type of Commenter	Number of Unique Submissions
Other Government Organization	1
Other Individual	72
Total Number of Unique Submissions	**177**

To conduct its analysis, the ARC reviewed each submission and then categorized the individual issues in the submission. Each of these separate issues is considered a comment. In some instances, the ARC used a different categorization of the comment than that provided by the submitter. The following table provides a breakdown of the total number of comments per issue.

Table 3 — Total Number of Comments by Issue Submitted to the Docket

Issue	Number of Comments
Programmatic Issues	374
Performance Requirements	158
Dual link Requirements	101
Airspace where ADS–B Is Required	95
Other Issues	74
ADS–B In	73
ADS–B Required Equipment	69
Required Broadcast Message Elements	60
Security, Privacy, and Malicious Use	53
Implementation Timetable Program	50
Rulemaking Analysis	49
System Failures/Backups	49
International Compatibility and Harmonization	32
Separation Standards and Operational Procedures	28
Antenna Diversity	25
ADS–B Alternatives	24
Service Volume and Capacity	24
ARC Task 1 Recommendation	16
Rule Section – General	14

Issue	Number of Comments
Potential Disadvantages	11
Cockpit Controls	11
Multilateration	10
Primary Radar	9
Reduction of Secondary Radars	7
Cockpit Management	7
Total Comments	**1,423**

The ARC did not review and provide recommendations regarding all comments submitted to the docket. The ARC focused its analysis on the issues listed in Table 4.

Table 4 — Number of Comments by Issue Reviewed by the ARC

Issue	Number of Comments
Programmatic Issues	374
Performance Requirements	158
Dual link Requirements	101
Airspace where ADS–B Is Required	95
ADS–B In	73
ADS–B Required Equipment	69
Required Broadcast Message Elements	60
Security, Privacy, and the Prevention of Misconduct	53
Implementation Timetable program	50
International Compatibility and Harmonization	32
Antenna Diversity	25
Cockpit Controls	11
Total Number of Comments	**1,101**

The individual comments to docket number FAA–2007–29305 are posted for public viewing at www.regulations.gov.

4.0 Specific Recommendations and Disposition of Comments to the NPRM

This section of the ARC's report provides the ARC's recommendations to the FAA for disposition of the comments on the NPRM, arranged by the particular issue commented on. Under each issue, the ARC—

- Discusses the FAA's original proposal.
- Provides a summary of the comments received on that issue.
- Provides its recommendations, including the disposition of the comments and any proposed changes to the proposed rule language, as necessary.

Dual Link Requirement

Original Proposal

In § 91.225 (a) and (b), the FAA proposed that all aircraft operating in specified airspace, including class A airspace below FL 240, all class B and C airspace, and class E airspace above 10,000 feet m.s.l., be equipped with ADS–B equipment compliant with either Technical Standard Order (TSO)–C166a (1090 ES) or TSO–C154b (UAT). The FAA proposed that all aircraft operating above FL 240 be equipped with 1090 ES. In the preamble, the FAA stated that air carrier aircraft and larger or higher performance general aviation (GA) aircraft would likely install new 1090 ES equipment or upgrade existing Mode S equipment to 1090 ES standards, while most other GA aircraft are expected to equip with UAT-compatible equipment. The FAA explained that, in addition to supporting ADS–B Out functions, UAT equipment would permit GA aircraft to receive ADS–B In services such as TIS–B traffic information and FIS–B weather information. Larger aircraft, which are typically equipped with ACAS, weather radar, and other equipment, would not need these capabilities in ADS–B equipment.

Aircraft equipped with either data link may receive information transmitted from other aircraft on the same link directly, without need for retransmission by ground equipment. The FAA stated that aircraft equipped with either link would receive traffic information on aircraft equipped with the other link through Automatic Dependent Surveillance – Rebroadcast (ADS–R). Under ADS–R, ground-based transmitters receiving ADS–B Out data from 1090 ES-equipped aircraft rebroadcast the information on the UAT data link, and vice versa. Similarly, before fleetwide ADS–B equipage, aircraft equipped with either link would receive information on aircraft not equipped with ADS–B through TIS–B transmissions from ground-based transmitters.

The FAA explained that use of a single data link above FL 240 (1090 ES) could potentially permit applications such as aircraft merging and spacing and self-separation. Because of the latency associated with reception and rebroadcast, ADS–R data could lack the precision necessary for such applications.

The FAA believes that a dual-link system would allow greater capacity and efficiency in the NAS, maintain safety, and provide a flexible, expandable platform to accommodate future traffic growth while avoiding possible system delays and limitations.

Additionally, aircraft would save fuel because of more efficient use of airspace and more precise routing and landing procedures.

Summary of Comments Regarding the Dual Link Requirement

A total of 30 commenters, including 7 associations, 5 aircraft owners, 4 manufacturers, 2 air carriers, and 2 pilots commented on the proposed dual-link requirement.

Most commenters opposed the dual link requirement. Many, including British Airways and the Air Transport Association of America, Inc. (ATA), argue that the dual link system would increase complexity, increase cost, and decrease reliability. The Aircraft Owners and Pilots Association (AOPA) and an individual commenter noted that aircraft on different bandwidths may not be able to see each other using ADS–B, leaving the aircraft vulnerable to mid-air collisions. AOPA suggests that this glitch could be addressed by providing ADS–R at all public airports where a mix of both systems will be encountered.

Several commenters noted problems with ADS–R, including the cost to install and maintain the ground stations. One GA pilot noted that the FAA cannot practically install ADS–R ground stations at every GA airport, even though most GA mid-air collisions occur in the immediate vicinity of airports during day VFR conditions.

Beyond cost, ADS–R presents added risk of faults, failures, and latency in the ground hardware and software required to merge and rebroadcast information from the two links.

Boeing pointed out an inherent latency in the ground rebroadcast which could limit potential separation and efficiency benefits of ADS–B. ATA noted the potential for single point failure causing the degradation or complete loss of surveillance data. An individual pilot mentioned the possibility that ADS–R users could encounter own-ship ghosting, which would present the aircraft with false target indications during critical flight phases. ATA also pointed out that ADS–R may not even be fully feasible, since rebroadcast positions would have no value until ADS–B In is defined and installed in aircraft. Another individual questioned the growth capacity of ADS–R to support future ADS–B air-to-air applications, including collision avoidance.

Due to the various cost and complexity issues, several commenters asked that the FAA choose only one link. British Airways, the Association of European Airlines, International Air Transport Association (IATA), Boeing, and several individuals advocated the use of the 1090 MHz frequency. They assert that the global interoperability and standardization of 1090 ES is important, because UAT is only used in the United States. They also noted that the 1090 MHz frequency could support ACAS/TCAD, allowing transfer of traffic information between aircraft without a ground intermediary. Aircraft currently equipped with 1090 ES would have adequate traffic display and separation with relatively minor upgrades to existing equipment. The commenters also noted that TIS–B data from Mode C aircraft could enhance the existing ACAS/TCAD data, for a complete picture to 1090 ES equipped aircraft during transition to full ADS–B coverage. ADS–B Technologies stated that while such equipment is theoretically possible no one has yet delivered such equipment.

Boeing adds that the NPRM alludes to potential benefits from merging, spacing, and aircraft self separation at higher altitudes, using a single 1090 MHz frequency. Boeing noted that these benefits are valuable for all aircraft and cannot be assured for aircraft operating on separate data links in the same airspace. ATA comments that a single link system using 1090 ES equipment would eliminate the need for ADS–R, and avoid the associated costs, complexities, and vulnerabilities, including ghosting from UAT links. A few commenters, including Boeing, argue that UAT is of questionable utility since there are several commercial weather services, such as XM, that are more cost-effective than UAT installation. Another commenter adds that XM services are priced at two tiers of service, with most GA pilots' needs met by the lower tier service, and also by the seasonal service option.

Several other comments argued that UAT is better suited to be the single link utilized for ADS–B, because of increased bandwidth and better security protection. AOPA notes that the UAT data link can also support the transmission of graphical weather and airspace information into the cockpit, giving pilots with this technology a significant advantage over those using 1090 ES. The UAT data link also can accommodate greater traffic density at a lower cost than 1090 ES. Several commenters, including SANDIA Aerospace (SANDIA), noted that increased production volume would further drive down the cost of UAT equipment. SANDIA argues that UAT should at least be the standardized requirement for aircraft flying in areas with limited ground station coverage, because GA aircraft could equip with small, light-weight, battery powered units. Several commenters pointed out that fleetwide UAT equipage would eliminate dependence on ground stations. Another commenter adds that UAT could use FIS–B to create a single fully-capable data link, without the costs and coverage limitations of ADS–R. This individual also suggests that it would be less costly to equip overseas carriers with UAT equipment than to implement two systems in the United States. Defense Concept Associates advocated the use of UAT, noting the latency of 1090 ES data and that 1090 MHz could not support a full population of aircraft equipage and all other services. Defense Concept Associates also mentioned that UAT was fully tested in Capstone as an unqualified success. Defense Concept Associates noted that because other nations have seen fit to standardize on 1090 MHz, the FAA should consider the unique U.S. aviation system and use UAT.

There are a handful of commenters who favored a dual link system. One individual pilot said that air carrier ACAS would be able to see and receive advisories on GA traffic using UAT in addition to 1090 ES, and would also circumvent the need for ADS–R. Dassault Aviation and the European Business Aviation Association agree that a dual link system will be beneficial; as 1090 ES is not adapted to GA aircraft, UAT will permit these aircraft to equip with ADS–B In and Out, TIS–B, and FIS–B to better navigate in congested airspace. While clearly preferring the single-link UAT option, Defense Concept Associates stated that dual equipage with both links is feasible and would not significantly impact airlines.

Some commenters recommended operators equip with both UAT and 1090 ES. One individual offered that if transport category aircraft equip with UAT in addition to 1090 ES, they would be able to receive regional meteorological information (MET), aeronautical information, and additional ADS–B message elements. Dual equipage

would also allow transport category aircraft to save money by replacing ACARS and digital ATIS message functionality with UAT functionality. If all aircraft were dual equipped, ground stations would only need to use the UAT link. With this simplified ground structure, the FAA could begin deploying ground stations for TIS–B and FIS–B as early as FY 2009 or FY 2010. UAT equipage on all aircraft would also permit air-to-air ADS–B collision avoidance between transport and GA aircraft.
One commenter specifically stated that the NPRM should be amended to require all transport category aircraft to be equipped with both 1090 ES and UAT.

AOPA notes that the NPRM allows GA to equip with either UAT or 1090 ES. AOPA points out that certain flights originating and terminating within the United States may require brief overflight of Canada or Mexico, which have not committed to support UAT. AOPA urges that the FAA to ensure that UAT operations will be supported throughout North America.

A few commenters also sought some clarification and revision in the NPRM.
One individual wonders if UAT equipped aircraft must have a 24 bit ICAO address. Others thought the FAA should clarify that only aircraft on the same link could enjoy direct reception and that 1090 ES will not get FIS–B service. The same commenters also thought the link system needed to be revised in order to extend the potential benefits of merging, spacing, and self-separation to aircraft at all altitudes.

Three commenters mistakenly believe that the FAA barred GA aircraft from using extended squitter functions.

FedEx suggests establishing a formal workgroup with all segments of industry to choose an ADS–B demonstration program including both 1090 ES and UAT.

One individual states that the operational and compatibility issues of dual link raised by the other commenters raises the question of whether ADS–B should be in the deployment phase.

ARC Recommendations Regarding the Dual Link Requirement

The ARC has validated the proposed ADS–B dual-link strategy assuming that there are no changes to existing collision avoidance and surveillance avionics. However, the FAA has identified the need to reduce congestion on the 1090 MHz frequency, used by ADS–B, ground surveillance systems, and collision avoidance systems. This is needed to ensure successful introduction of ADS–B Out, while supporting current and envisioned ADS–B In applications for the NextGen. The ARC recommends that the FAA conduct an urgent study on 1090 MHz frequency congestion to—

1. Identify the extent of the congestion problem from the present to 2035.
2. Analyze the mitigation alternatives from cost, benefit, and schedule perspectives.
3. Evaluate resulting link implementation options.

Because reducing 1090 MHz frequency congestion may require changing ACAS and/or Mode A/C/S equipage, the ARC is recommending that the FAA, in evaluating these potential mitigations, also evaluate the benefits and additional steps needed to enable a single ADS–B link implementation strategy. The ARC recognizes that the conclusions of

this urgent study may dictate modification to the NPRM approach to ADS–B link implementation.

The ARC recommends that the results of the urgent study be coordinated with the industry through the ATMAC ADS–B Working Group or the ARC to—

1. Confirm which 1090 MHz frequency congestion mitigation strategies will be adopted.
2. Finalize the ADS–B link implementation strategy to be implemented.

The ARC has had extensive discussions on the ADS–B link implementation aspects of the NPRM. Appendix H to this report presents the ARC's link implementation vision and explains why the ARC necessarily supports dual link implementation, given the facts available at this time. Appendix I to this report discusses the nature and scope of the 1090 MHz frequency congestion problem to be addressed by the recommended urgent study.

Assuming dual link ADS–B, the ARC evaluated the NPRM and two alternative ways that 1090 ES and UAT might be implemented in the NAS. Appendix J to this report, Link Implementation Alternatives, describes these choices, with pros and cons for each of three link implementation alternatives that remained from a more extensive list of possible implementations. Further, the ARC evaluated costs and quantifiable benefits of the alternatives, as summarized in appendix K to this report, ARC Avionics Cost Subgroup Summary of Findings. Alternative ADS–B dual link implementations to the NPRM were not found to have a better cost-benefit case than the NPRM in light of the benefits that could be quantified. Appendix L to this report presents further elaboration of several aspects of one of the link implementation alternatives. Appendix M to this report discusses potential, but as yet unquantified, benefits to air transport aircraft of receiving the UAT ground uplink service.

The ARC supports AOPA's comment that the FAA ensure that UAT implementation supports GA overflights of Canadian and Mexican airspace as well as routes to Puerto Rico and the U.S. Virgin Islands.

The ARC's recommendation to pursue ADS–R implementation per the NPRM, again caveated by the need for the urgent study, also was formulated after considerable review and discussion. The ARC does not view expanded ADS–R coverage, as recommended by some commenters, to be a significant contributor to 1090 MHz frequency congestion. Appendix N to this report, ADS–R Latency and Reliability Expectations, provides technical information on ADS–R as planned to be implemented in the ADS–B ground infrastructure, establishing that ADS–R latency and the update rate are not expected to provide performance issues to targeted ADS–B In applications. However, the ARC recommends that the as-yet unresolved issue of ADS–R service management messages be addressed by the FAA and RTCA, Inc. (RTCA), with the format and content of such messages finalized in early 2009.

Appendix O to this report provides further detail on the ARC's conclusions that support the above recommendations. In particular, recommendations regarding the urgent study of 1090 MHz frequency congestion are as follows.

The urgent study must answer the following questions:

- Can the 1090 MHz frequency support 1090 ES, ACAS, and SSR in the NAS' high-density airspace? If the answer is yes, what are the costs of necessary mitigations? Can the mitigations be limited to ground-based solutions?
- Can 1090 MHz ADS–B support needed ADS–B In applications in the NextGen timeframe? And if so, what mitigations, if any, additional to those above are needed and at what cost?

The ARC recommends that the urgent study consider the following:

- The NextGen timeframe extends through 2035 (the 2035 date includes an equipment life cycle after the proposed 2020 rule compliance date).
- Consider the 1090 MHz frequency congestion mitigations that would be required to provide a 45 nm air-to-air range for ADS–B In applications in future high-density airspace. Provide similar answers for air-to-air ranges of 20 nm, 60 nm, and 90 nm.
- The cost impact and user acceptability of any additional avionics mandates needed to support 1090 ES implementation need to be addressed. Mandating an upgrade from today's Mode C transponder to a Mode S transponder in addition to mandating ADS–B Out will not be acceptable to low-altitude users. Further, this mitigation is not envisioned to significantly improve the interference situation, unless additional changes are made to optimize the ground Mode S interrogator operation (for example, clustering Mode S interrogators).
- The evaluation should include all effective cost, benefit, and schedule alternatives for air transport and GA use of the 1090 ES and UAT frequencies.
- The cost-benefit analysis for potential mitigations should include the impact on international operators operating in the NAS.
- Any ACAS-related 1090 MHz frequency congestion mitigations proposed for near-term implementation should be bundled with changes needed for ACAS 7.1 to require only one ACAS upgrade cycle.
- The ACAS-related 1090 MHz frequency congestion mitigation of eliminating the dependency of ACAS on the Mode S transponder acquisition squitter should be considered.
- Implementation of passive wide-area multilateration as a potential 1090 MHz frequency congestion mitigation, through removal of SSRs, in high-density airspace.
- Implementation of further alternative methods of removing SSRs in high-density airspace, particularly in the context of surveillance ground systems employing fusion of surveillance data sources.

The ARC recommends that the study be completed by January 2009 (with an interim assessment, if possible, of ACAS-related 1090 MHz frequency congestion mitigations) and coordination of the results with the ATMAC ADS–B Working Group or ADS–B ARC proceed immediately thereafter.

ADS–B Out Business Case

Original Proposal

In § 91.225(a) and (c), the FAA proposed that aircraft to be operated in certain airspace after January 1, 2020, be equipped with ADS–B Out equipment.

In the preamble, the FAA explained that the demand for air travel is growing in the United States and around the world. U.S. airline passenger traffic is forecast to double by 2025, and the active GA fleet is projected to grow from a current level of 230,000 aircraft to 275,000 aircraft in 2020.

The FAA explained that the present ATC system will be unable to handle this level of growth. The FAA stated that its schedule calls for implementation of the ADS–B ground infrastructure to the extent of the current coverage of surveillance radar by 2013. The FAA explained that publishing final requirements as part of the current rulemaking will allow avionics manufacturers time to produce compliant equipment. The FAA added that the compliance date of 2020 would give operators time to schedule equipment installation consistent with the normal maintenance cycle of aircraft.

In the preamble to the NPRM, the FAA stated the estimated cost of this proposed rule ranges from a low of $2.3 billion ($1.6 billion at 7 percent present value) to a high of $8.5 billion dollars ($4.5 billion at 7 percent present value). These costs include costs to the Government, as well as to the aviation industry and other users of the airspace, to deploy ADS–B and represent the incremental increase over the cost of maintaining surveillance using current technology (radar). The aviation industry would begin incurring costs for avionics equipage in 2012 and would incur total costs ranging from $1.27 billion ($670 million at 7 percent present value) to $7.46 billion ($3.6 billion at 7 percent present value), with an estimated midpoint of $4.32 billion ($2.12 billion at 7 percent present value)from 2012 to 2035.

The additional cost of the ADS–B In ground segment is estimated at $533 million ($283 million at 7 percent present value). The FAA did not estimate the cost for aircraft operators to equip with ADS–B In because it concluded the requirements for ADS–B In are insufficient in detail and do not yet support the development of a cost estimate. The FAA will continue to study ADS–B In technology and intends to provide an adoption cost estimate for the final rule. Estimated costs of ADS–B In and Out (excluding ADS–B In avionics costs), relative to the radar baseline, range from $2.8 billion ($1.8 billion at 7 percent present value) to $9.0 billion ($4.8 billion at 7 percent present value).

The FAA stated the estimated quantified potential benefits of the proposed rule are about $10 billion ($2.7 billion at 7 percent present value) and primarily result from fuel, operating cost, and time savings from more efficient flights. The proposed rule would make it more likely the aircraft operators would equip with ADS–B In equipment, which

could result in estimated additional benefits of $3.9 billion ($1.0 billion at 7 percent present value). Benefits of both ADS–B In and Out have been estimated at $13.8 billion ($3.7 billion at 7 percent present value).

While the FAA does not have estimates of ADS–B In avionics costs, the FAA derived an upper bound for what that cost cannot exceed if the ADS–B In and Out scenario is to be cost beneficial relative to radar for each of the two possibilities described below.

Given that the FAA had a range of costs (low to high), it considered the following two possibilities:

> The FAA concluded that ADS–B In and Out would be cost beneficial at a present value of 7 percent if the costs for the ADS–B Out avionics are low ($670 million at 7 percent present value) and the avionics costs for ADS–B In do not exceed $1.85 billion at 7 percent present value.
>
> The FAA also concluded that ADS–B In and Out would be cost beneficial at a 3-percent present value if the costs for the ADS–B Out avionics are low ($950 million at 3 percent present value) and the ADS–B In avionics costs do not exceed $5.3 billion at 3 percent present value or if the costs for the ADS–B Out avionics are high ($5.35 billion at 3 percent present value) and the ADS–B In avionics costs do not exceed $870 million.

Besides the costs savings made possible by this proposed rulemaking, the FAA stated there will be potential environmental benefits. The FAA estimates that between 2017 and 2035, ADS–B technology would allow more efficient handling of potential en route conflicts, which will result in a total of 410 million gallons of fuel savings and 4 million metric tons less carbon dioxide emissions. The increased use of continuous descent approaches that ADS–B would allow would lead to about 10 billion pounds of total fuel savings and about 14 million tons less carbon dioxide emissions between 2017 and 2035. Additionally, optimal routing over the Gulf of Mexico would result in an additional cumulative decrease of 300,000 metric tons of carbon dioxide emissions over the 2012 to 2035 time period.

Summary of Comments Regarding the Implementation Timetable

A total of 32 commenters, including 5 air carriers, 11 associations, 3 avionics manufacturers, and 13 individuals, submitted comments pertaining to the planned implementation timetable.

Three commenters asserted that the planned timetable is too aggressive, given the current unknown concerns. The commenters noted the exact compliance requirements are not currently defined, the timeframe for mandatory equipage is unrealistic, and the airspace capacity and efficiency benefits are not yet validated.

Several commenters expressed concerns about the mandatory compliance date. One aviation law student noted that the pace of implementation will be dependent on the level of Government commitment and participation. The National Air Transportation Association requested publication of a phased plan of equipage addressing all affected sectors of the aviation industry. Similarly, the Cargo Airline Association requested an integrated timeline, including NextGen, which shows all future equipage mandates.

AOPA asserted that the ADS–B infrastructure should be fully deployed and providing weather and traffic information service benefits for 8 to 10 years before ADS–B equipage is mandated for GA. The General Aviation Manufacturers Association (GAMA) recommended including the planned rulemakings for data communications, RNP, and surveillance as part of an integrated plan to ensure operators and manufacturers can optimize investments to access the benefits of the future operational environment.

By contrast, 12 commenters felt that the proposed timetable is not aggressive enough and urged that ADS–B be implemented on an expedited schedule, considering ADS–B has been vetted with Capstone and is already being used overseas. United Airlines, Inc., (United) recommended the FAA mandate ADS–B for flights above flight level 240 (FL 240) beginning in 2015. United further noted the benefits of an early mandate outweigh the cost of early equipage. The Association of European Airlines and the IATA jointly recommended the FAA pursue a program of voluntary equipage worldwide in coordination with international entities, and mandatory equipage by 2015. The Air Line Pilots Association, Int'l (ALPA), pointed out that the safety and capacity benefits of ADS–B cannot be fully realized until a significant percentage of the aviation population is equipped. Aerospace Industries Association (AIA) recommended that all NextGen initiatives be developed and implemented with urgency. IATA supported expeditious implementation of ADS–B Out.

Additionally, one avionics manufacturer recommended that the FAA engage industry in the development of ADS–B applications, including limited-scale capability demonstrations. ATA and Honeywell International (Honeywell) recommended the FAA ensure early user benefits to encourage early equipage. DayJet Corporation, an on-demand air carrier, plans to equip its fleet with ADS–B Out and ADS–B In equipment on an expedited basis.

One individual asserted that ground infrastructure to support a single UAT link could accelerate the implementation timeframe.

Four commenters recommended phasing the mandatory compliance to involve an earlier mandate for new equipment installations and an option for early equipage with DO–260. Delta Air Lines, Inc. (Delta), recommended integrating the initial equipage for air carriers into each air carrier's 5- to 7-year heavy maintenance cycle.

Summary of Comments Regarding the ADS–B Out Equipage Cost

One hundred forty-seven commenters, including 2 aircraft manufacturers, 3 air carriers, 2 avionics manufacturers, 10 associations, and 130 individuals, submitted 161 comments regarding the equipage costs associated with ADS–B.

The majority of commenters were critical of the equipage costs associated with the ADS–B Out rulemaking analysis. Several commenters noted that exact equipage costs are not currently known. Without sufficient data, these commenters question the validity of the FAA's analysis. Furthermore, the commenters asked the FAA to provide tangible, measurable, direct cash flow value to operators.

- British Airways asserted the costs to purchase, upgrade, and maintain equipment are not known at present.

- Boeing noted the NPRM projects the cost of compliance for turbojets to range from $3,862 to $135,736, which conflicts with the 2007 preliminary cost estimate of $16,000 to $510,000. Boeing also questioned the cost of ADS–B In equipment in comparison with ADS–B Out equipment. In addition, Boeing sought clarification on 7 percent present value if ADS–B avionics costs are high.
- Boeing further attests that the more stringent performance requirements in the NPRM will increase the actual equipment cost. Boeing estimates the equipage cost for avionics is three to four times the amounts assumed in the NPRM.
- Delta asserted operators will be slow to equip before they know the actual cost to transition to DO–260A. Delta further asserted that the business case is unfavorable, when multiple retrofits are required.
- ATA asserted the regulatory evaluation placed all large category turbojets in one category, which is not useful to an individual carrier. ATA questions the equipment assumptions in the analysis and estimates the expected cost of retrofitting large turbojet aircraft may be over twice that forecast by the NPRM.
- One commenter questioned how turbojet aircraft equipage costs are significantly less than turboprop aircraft equipage costs. This commenter asked the FAA to provide detailed, independently verifiable cost information.
- Embraer asserted a significant number of older jets and turboprops are not required to have TCAS II and are not equipped with TSO C112 Mode S transponders. Equipping these aircraft for 1090 ES, as required for operations above FL 240 under the proposed rule, would cost about $160,000, which is, in some cases, more than 10 percent of the value of the aircraft.
- The Regional Airline Association (RAA) projects that the regional fleet will be approximately 4,000 aircraft in 2020. If the projected costs of retrofit/forward fit for ADS–B Out are greater than $118,250 per airplane for the regional fleet, then the FAA's benefit analysis becomes negative for regional operators. RAA sought clarification as to whether the benefits described in the FAA's benefit analysis are realistic and whether they can be accomplished only by the ADS–B Out retrofit/forward fit. RAA also sought clarification as to whether the FAA considered the cost incurred by operators at airports without backup radar systems.
- One commenter asserted airlines and GA aircraft owners have been heavily burdened by required equipment for reduced vertical separation minimum (RVSM) and terrain awareness and warning system, making their aircraft cost-prohibitive to operate.
- One commenter asserted ADS–B requires GPS/Wide Area Augmentation System (WAAS) equipment, which does not even meet the velocity or vertical

position requirements. For aircraft not already equipped with GPS/WAAS, this requirement has significant cost implications.

- One commenter asserted the preamble states that "many TSO–C112 Mode S transponders can be modified or are designed to provide 1090 ES functionality under TSO–C166a." The commenter asserted there is much more to this than merely replacing the transponder, for example, getting the appropriate navigation data to the unit. The commenter recommended describing the real costs of upgrading.
- One commenter asserted ADS–B should offer improved capability to the end user with lower implementation and operational costs.

Several commenters specifically contested the equipage cost estimates for GA.

- The Experimental Aircraft Association (EAA) estimates that approximately 200,000 GA aircraft need to equip for the mandate, with an infinite array of avionics and aircraft combinations.
- AOPA asserted the FAA failed to provide an affordable transition from current radar/Mode C transponder-based surveillance to ADS–B. AOPA noted that equipage costs between $6,000 and $8,000 were too expensive for the majority of GA aircraft owners to voluntarily equip or support ADS–B.
- Several commenters asserted that many privately owned aircraft have been in service for 40 years. The commenters estimate the cost of implementation will exceed the value of some aircraft. The commenters agree that the cost for equipage should be low enough to encourage voluntary equipage.
- SANDIA recommended allowing less costly navigation sources and transceivers than the ones required by the NPRM. SANDIA also recommended allowing VFR GPS units to be used as the navigational source for light-sport, experimental, and other low-end aircraft in VFR conditions, which would keep costs low and benefit the entire system by increasing voluntary equipage.
- One commenter asserted the value of avionics is 20 to 50 times the dollars spent when the avionics are not affixed to the airframe. The commenter recommended encouraging the avionics industry to devise what a GA aircraft owner, not an airline, would consider an inexpensive solution before implementing ADS–B. The FAA should pass regulations that foster the development of low price avionics.
- One commenter asserted applications should be designed so that any differences between TSO C129a GPS and a WAAS-based system are taken into account to reduce the cost of installation for GA aircraft. Over time, the benefits of WAAS will induce GA aircraft owners to upgrade so the current rule criteria likely will be met before the mandate date.
- Several commenters asserted the ADS–B equipment and installation cost estimate for GA is too low based on experience installing avionics in older

model aircraft. The commenters noted that some installations will require panel modifications, additional supports, and installation inspections.

- The Soaring Society of America asserted the FAA has developed technology for use by commercial jet aircraft without also developing compatible equipment that is practical for the vast majority of the GA fleet. The only ADS–B equipment available today that is compatible with the proposal is far too costly, consumes too much power, and is difficult to install in gliders. The Soaring Society of America recommended developing Minimum Operational Performance Standards (MOPS) for ADS–B that will allow for reasonably priced units that are practical in aircraft not certified with electrical systems.
- The United States Parachute Association (USPA) asserted that parachute operators are extremely competitive, with slim profit margins and significant weather limitations. The USPA estimates that the low-end equipment possibility poses a tremendous financial burden to parachute operators and the high-end equipment possibility would put most operators out of business.
- Defense Concept Associates asserted the cost in the NPRM appears to be relatively high. It appears that a class A0 UAT could be installed for a total cost of less than $3,000; far less than a 1090 ES S system. Defense Concept Associates asserted A1 equipment might cost twice as much.
- Three commenters asserted the costs for UAT listed in the NPRM do not appear realistic compared with the current prices of TSO 146 equipment.
- One commenter asserted rising fuel costs already cause flight instructors to operate with minimal profit, and asserted that adding a $15,000 piece of equipment that would rarely be used would prevent flight instructors from continuing to train students.
- One commenter asserted requiring multiple equipages for all operators will increase the safety risk for operators that cannot afford the extra costs.
- One commenter asserted while the discontinued use of surveillance radars will reduce the FAA's operational costs, a significant cost equipage will be incurred by individual aircraft owners. The commenter asserts that there is no assurance that costs will decrease if the equipment is required and there are only a few manufacturers.
- One commenter asserted sailplane owners are not required to have a transponder installed; however, many glider pilots are considering installing transponders in their aircraft to take advantage of the benefits of air traffic separation. Implementing ADS–B may cause many small aircraft operators to opt to not install a transponder for fear that the transponder will become obsolete or have limited benefit. Installing ADS–B may not be an option for these operators because it costs three to four times as much as a transponder.
- One commenter asserted that for aircraft not already equipped with a built-in WAAS GPS, the cost of implementation would be much higher that noted in the proposal. Many operators use a handheld GPS, such as the Garmin 496,

- One commenter asserted the FAA should consider experimental aircraft and experimental avionics installation costs. The availability of low cost and high innovation rate equipment in the homebuilt market has greatly enhanced safety with primary flight display and autopilots becoming common. The ability to employ modern technology without paying $20,000 for a single screen is part of why some aircraft are now technically advanced aircraft that have the infrastructure available to support ADS–B. The commenter recommended requiring static system tests and transponder operational checks instead of mandating equipment with a TSO.
- One commenter asserted a 24-month UAT inspection requirement will be more expensive than the current transponder inspection. A 24-month UAT inspection would cost approximately $200 more than a typical transponder inspection.
- One commenter asserted there are low-power, low-cost, small-sized ADS–B units with In and Out capability under development. The commenter hopes the ADS–B unit for airport ground vehicles will be low priced and therefore affordable to GA. The commenter noted that most unmanned aerial vehicles are small and will most likely require battery-powered, low cost, small-sized ADS–B units to be able to operate in airspace with conventional aircraft.
- One commenter recommended placing a size limitation on ADS–B equipment, reflective of expected advances in technology by the mandatory implementation date.

Many commenters were critical of the disproportionate costs versus benefits of ADS–B equipage on GA.

- Thirty-four individual commenters and the EAA asserted that GA is absorbing the cost of ADS–B even though it offers little or no benefit to GA.
- Several commenters asserted the air carriers and the FAA will realize the most benefit from ADS–B, while GA will bear a disproportionate share of the cost. Most of the commenters do not see value for light aircraft owners or VFR operators to equip with ADS–B Out. The commenters quantified their costs in terms of the initial financial burden to equip as well as the annual maintenance for ADS–B in addition to current requirements. The commenters also question the information in the NPRM to make an informed decision about whether to purchase and install ADS–B. Many of the commenters recommend that the GA community not be included in the ADS–B Out mandate.
- Several commenters asserted the NPRM fails to meet any reasonable cost-benefit/return on investment analysis for the GA community. Most of

these commenters considered conventional transponders sufficient for GA operations.

- Several commenters noted the cost of ADS–B equipage, with questionable safety benefits. These commenters noted that the proposal will likely restrict airspace for light GA aircraft.
- AOPA asserted the FAA's contract for ADS–B services with ITT provides little, if any benefit for GA. According to the FAA and ITT, the ADS–B surveillance coverage will replicate existing radar coverage with nothing more, except for the Gulf of Mexico. While the FAA plans to spend $1.8 billion to replicate radar, GA spends nearly the same amount in addition to the costs to maintain the Mode C transponder. Nearly 800 ADS–B ground stations will be installed to provide the ADS–B services. If they are placed on or adjacent to airports, radar-like services could be available where they have not been in the past. However, these 800 ground stations cannot provide low-altitude coverage to even a fraction of the 5,400 public-use GA airports nationwide. If safety services are not expanded, the value of the ITT contract is questionable.
- AOPA asserted the proposal is a costly plan that offers little or no benefit for GA while forcing aircraft owners to retain their existing transponders and spend at least $6,000 to $8,000 to have access to airspace where they already fly. The proposal needs significant modifications to its scope and policy. AOPA recommended the issuance of an SNPRM rather than a final rule, and working with the aviation community through the ARC on ADS–B to develop an alternative proposal.
- One commenter asserted the proposed rule would provide a windfall for equipment manufacturers, while providing no benefit to GA pilots and aircraft owners.
- Three commenters asserted the cost of UAT equipment is not in line with the anticipated benefits to GA.
- A few commenters noted that private owners cannot amortize costs over time and deduct equipage expenses from their taxes or pass the expense on to their passengers.
- One commenter asserted that if the GA community is required to install specialized equipment to use the NAS, the FAA must provide credible evidence that the equipment will benefit those required to bear the costs.
- One commenter asserted mandatory requirements of ADS–B are burdensome to GA. The advantages of ADS–B over current technologies such as TIS and Mode S are not worth the extra cost to the owner/operator.
- Several commenters noted that GPS, Mode S transponders, radar, and anticollision systems are already installed on larger aircraft.

- One commenter asserted the NPRM does little more than require an additional transponder at roughly three or more times the cost of the most expensive existing Air Traffic Control Radar Beacon System (ATCRBS) transponders. The costs are even higher for aircraft not already equipped with GPS/WAAS systems. The limited, cursory cost analysis in the NPRM does not justify mandating equipage.

Many commenters submitted comments regarding the cost of implementing the ground infrastructure necessary for ADS–B.

- Several commenters, including the RAA, noted with ADS–B, the FAA has transferred the cost to install and maintain ground-based equipment to individual aircraft operators who must install and maintain the ADS–B equipment on the aircraft.
- Two commenters asserted that multiple ground based transmitters will require installation and land leasing costs, and frequent maintenance.
- One commenter asserted that ADS–B cost assumptions must include a recapitalization program for the radars that will be retained as backup for ADS–B.
- Three commenters asserted that the fact that the FAA will not decommission any primary radars and half of SSRs diminishes the cost savings of ADS–B.
- Two commenters recommended switching to a 1090 MHz single link to decrease the cost to the FAA for ADS–R, TIS–B, and FIS–B, which would not be necessary in the ADS–B ground stations.
- One commenter recommended a single UAT link, which eliminates the costs associated with developing, certifying, and deploying a dual link infrastructure of more than 750 stations.
- One commenter asserted ADS–R is required to cobble together the two data link systems, which results in higher costs to install the ADS–R translator systems and poorer overall system performance.
- One commenter asserted that if the ground-based ADS–B infrastructure can successfully detect and eliminate false or misleading broadcasts, secondary radars could be eliminated, saving significant costs.
- One commenter asserted the FAA cannot credit ADS–B for decreasing the number of primary and secondary surveillance radars. The FAA could accomplish this decrease by reducing the existing amount of overlapping radar coverage.

Several commenters submitted comments regarding a more uniform cost-benefit scenario between the FAA and each operator.

- One commenter asserted ADS–B should be subsidized by commercial airlines or the Government.
- One commenter recommended lowering the cost impact to GA by applying ground-based control funding to the airborne systems through a grant system.
- Boeing recommended setting a more balanced allocation of expenditures between Government and users.
- One commenter recommended incorporating ADS–B implementation costs in the Federal budget, rather than user fees or public taxes.
- One commenter recommended funding the certification costs to make the skies safer for low-end users who cannot afford equipment costing thousands of dollars.
- One commenter recommended a cap on the out-of-pocket cost for vintage and single-engine GA aircraft.
- One commenter recommended creating a dedicated private sector organization chartered to purchase large quantities of ADS–B systems at significantly reduced costs and resell them to individual aircraft owners without profit.
- One commenter recommended that the FAA ground savings could fund airframe ADS–B installations.

Summary of Comments Regarding the ADS–B Benefits

Eighty commenters, including 6 air carriers, 2 Government agencies, 4 avionics manufacturers, 3 aircraft manufacturers, 18 associations, and 47 individuals, submitted comments regarding the benefits associated with ADS–B.

Many commenters requested more detail regarding the FAA's cost-benefit analysis.

- Boeing asserted the rulemaking analyses quantify ADS–B Out benefits at about $10 billion, and ADS–B In benefits at $3.9 billion, for a total of $13.9 billion. This estimate is inconsistent with an earlier SBS benefits estimate of $18.5 billion. Boeing asked the FAA to provide the affected operators with a detailed analysis to quantify each of the benefits, broken down by location and application.
- Boeing asserted the estimated cost of ADS–B Out implementation is between $2.3 billion and $8.5 billion. However, estimates for the cost of avionics are three to four times the amounts assumed in the NPRM. The benefits of ADS–B Out are estimated to be $9 to $10 billion. If, in fact, the costs are significantly higher than the high end estimate of $8.5 billion, they will outweigh the benefits, and users will not equip.

- Boeing recommended the FAA use the same level of detailed analysis as the report entitled ADS–B Benefits Enabled from Improved En-route Conflict Probe Performance.
- Several commenters noted that cost analysis was limited to ADS–B Out, but the benefit analysis included ADS–B In. The RAA recommended the benefit analysis quantify the benefit that ADS–B Out only would provide, beyond currently available applications (for example, continuous descent approaches). One commenter recommended clearly separating the discussion about possible future applications at the end of the document.
- The Airports Council International-North America (ACI-NA) asserted it is concerned that the NPRM does not adequately identify the specific benefits of ADS–B equipage. Significant benefits, such as reduced separations, enhanced surface situational awareness for runway incursion prevention, and self separation are referenced in general terms and would require future, voluntary equipage with ADS–B In.

Many commenters asserted they found the projected benefits listed in the NPRM to be questionable.

- Boeing asserted that the current 12 second update rate is insufficient to support surveillance accuracy for reduced aircraft separation standards. Boeing estimated that an update no greater than 5 seconds would be required for a reduction to 3 nm en route separation.
- Boeing asserted that additional ground system automation improvements will be necessary to allow suitably equipped aircraft to enjoy the benefits of ADS–B.
- Several commenters, including the RAA, questioned the benefits derived from En route Conflict Probe performance. Specifically, the commenters questioned the FAA's experience validating cost savings and capacity enhancements and whether the cost savings will be lost with other system delays. One commenter asked Congress to validate the benefits and ensure the benefits are not being used to justify multiple programs. One commenter recommended the FAA address capacity issues at airports, instead of en route.
- The USPA asserted that en route efficiency gains promoted in the NPRM would not be realized by a parachute jump operator with ADS–B flying above 10,000 feet m.s.l. USPA recommended noting the financial impact of requiring new avionics on parachute operations.
- Several commenters asserted ADS–B will not improve safety or overall system delays. Specifically, the commenters discussed other factors in traffic delays, including an inadequate number of runways, traditional hub and spoke operations, air carrier scheduling practices, and the trend towards an increased number of small aircraft.
- The RAA asserted the benefits cited for operations within Alaska are not beneficial to regional operators. Furthermore, the RAA expressed difficulty in

defining the benefits for its membership. Specifically, RAA questioned the scope of capacity enhancements and fuel savings when the FAA has not committed to a measureable reduction in aircraft separation standards. The RAA also noted a DOT/FAA policy amendment proposal (Docket No. FAA–2008–0036) that could significantly reduce or eliminate its members' operations at hub airports. RAA recommended addressing how the DOT/FAA policy will impact future traffic projections and how this will impact the benefits stated by this proposal for regional operators.

- The RAA specifically recommended rewriting the benefits analysis to include—

  1. An explanation of how congestion pricing policy could adversely impact FAA traffic forecast projections.
  2. A detailed benefit analysis for surface flow applications for pilot with and without ADS–B In, compared to current alternatives.
  3. A detailed benefit analysis for CONUS terminal and en route flow applications with and without ADS–B In retrofit/forward fit, compared to current alternatives.

- The National Air Carrier Association (NACA) asserted it supports ADS–B as the cornerstone to NextGen but notes no immediate benefit for air carriers in the current ADS–B Out rule.
- ERA Corporation asserted the flying/user community may not immediately recognize the benefits of ADS–B.
- The EAA asserted the mandate require GA to equip with ADS–B Out without situational, fleet, and weather awareness benefits that impact GA accidents.
- The DOD noted that reduced separation standards using ADS–B as described in the NPRM have not been approved. The DOD firmly recommends the FAA approve reduced separation standards before publishing a final rule.
- Several commenters asserted the benefits realized during the Capstone project in Alaska would not be as significant outside Alaska and would not be realized by implementation of ADS–B Out alone.
- Three commenters asserted ADS–B provides no benefit to GA without ADS–B In functionality. One commenter asserted to add the beneficial features of uplink weather and conflicting traffic on a graphical display would double costs.
- Two commenters note alternative sources for weather information. One commenter recommended voluntary equipage for ADS–B.
- One commenter asserted GA will derive little of the calculated benefits of ADS–B Out or In.
- Three commenters asserted there is no data or reliable information justifying the claims of the NPRM that ADS–B is cost justified. The commenter

recommended eliminating the rulemaking analyses until realistic, independently verifiable cost information is available.

- Two commenters questioned the TIS–B benefit. One commenter asserted that TIS–B relies on all aircraft equipping with ADS–B out, which is unrealistic. One commenter noted that current see-and-avoid practices are sufficient, and do not justify mandating ADS–B.

Several commenters submitted comments regarding ADS–B In benefits included in an ADS–B Out rule.

- ATA asserted the NPRM relies on the anticipated benefits of ADS–B In and NextGen to justify ADS–B Out. ATA further notes the ADS–B In benefits are speculative, so the costs to airspace users could outweigh the benefits.
- ACI–NA asserted the proposed ADS–B Out performance requirements fail to identify any specific operational advantage and allude to future benefits from voluntary installation of ADS–B In. ACI–NA recommended improving operational capabilities by integrating both ADS–B Out and ADS–B In and identifying the associated air traffic procedures to accomplish the needed capacity improvement.
- GAMA acknowledges that ADS–B In will provide benefits to GA and the broader GA community. However, GAMA asserted it is difficult to identify direct benefits for business and GA in the ADS–B Out NPRM, which does not consider the future applications and resulting benefits from a fleet equipped with ADS–B Out.

Many commenters submitted comments praising ADS–B benefits.

- Several commenters, including the National Transportation Safety Board (NTSB), the Association of European Airlines, IATA, Delta Airlines and British Airways (BA), the U.S. ADS–B program. These commenters asserted the proposed ADS–B Out performance requirements will have a positive impact on safety, particularly in areas of restricted or nonexistent radar coverage. Most of these commenters recommended transitioning to ADS–B Out surveillance in place of ground radar surveillance, given the better information and lower cost for ADS–B ground equipment.
- ADS–B Technologies asserted ADS–B promises improved routings, greater airspace utilization, and increased safety and efficiency. Based on transmitted aircraft ID, vector state, and intentions, ATC and onboard equipment will be able to track, monitor, and de-conflict aircraft trajectories to maintain safe operations. ADS–B Technologies asserted ADS–B will allow creation of new alerting messages for traffic and weather that can be uplinked to aircraft or cross-linked between aircraft.
- DayJet Corporation asserted the benefits of ADS–B include: 1) energy savings, 2) carbon footprint reduction, 3) noise impact management through departure and arrival procedures that accommodate community interests, 4) fleet departure and arrival management practices allowing greater precision,

safety, capacity, and efficiency, 5) assured regularity of flight operations to meet public expectations regarding the use of emerging on-demand services, 6) transition/evolution to full NAS data and model through trials in non-congested airspace.

- Several commenters asserted ADS–B is a positive tool for the safe and efficient use of airspace. AIA asserted the reduction in delays facilitated by ADS–B will significantly reduce economic costs. British Airways noted that ADS–B will support an increase in air traffic demand and allow for reduced separation standards to safely increase airspace capacity. British Airways asserted ADS–B may enable implementation of constant descent approaches as part of a redesign of airspace route networks and area navigation (RNAV) approaches, leading to fuel savings. The European Business Aviation Association and Dassault Aviation asserted ADS–B will make possible the development and use of satellite-based augmentation systems (SBAS) approaches. Both safety (elimination of non-precision approaches) and environmental impact (procedures to mitigate noise nuisance) will be improved
- ACI–NA, ATA and ALPA noted that ADS–B mitigates the current airspace capacity limits, which cause flight delays, inefficient routings, and increased fuel consumption. ALPA noted the ADS–B benefits were contingent on NAS-wide equipage with ADS–B.
- Two commenters asserted that ADS–B will make flying safer for all aircraft. One commenter specifically noted the ability to see real-time information as provided by ADS–B will provide safety benefits, decreasing the incidence of controlled flight into terrain and runway incursions.

Many commenters discussed the accelerated realization of benefits possible with ADS–B

- DayJet Corporation (DayJet) asserted multilateration combined with TIS–B and other procedural changes at smaller community airports will accelerate adoption of ADS–B. DayJet further noted economic benefits for the smaller communities from the improved efficiencies and emerging on-demand operators.
- Aviation Communication & Surveillance Systems (ACSS) asserted with the ADS–B ground infrastructure deployment already in progress and equipment manufacturers who are or will soon be able to provide required equipment, benefits can begin to be realized much sooner than the proposed 2020 mandatory compliance date.
- National Air Traffic Controllers Association (NATCA) asserted ADS–B benefits will help gain acceptance from the pilot and ATC.
- ATA asserted ADS–B Out has a clear capacity to enhance safety of airport surface operations. ATA recommended evaluating the potential of ADS–B Out to enhance surface management and safety during early demonstrations and evaluations, and accelerate the availability of surface management and safety benefits.

- The Helicopter Association International (HAI) asserted a potential source of early equipage is the emergency medical industry. Users operating below 1,000 feet m.s.l. require close proximity to ground based equipment to receive maximum operational benefit from ADS–B. HAI recommended maximizing the participation of the EMS industry by co-locating ground stations at or near hospitals, trauma centers, and private heliports served by EMS aircraft. HAI also asserted it supports early deployment and implementation of ADS–B in specific areas like the Gulf of Mexico, Alaska, and Hawaii.

Several commenters discussed the benefit of ADS–B in the context of the larger NextGen plan. UPS, United, and ERA Corporation noted that ADS–B is the foundation for many future NextGen applications. UPS noted that NextGen applications needed to start now to progress towards an operational NextGen system in 2025. The Aircraft Electronics Association asserted the ADS–B proposal is only the first element of a broad change in the requirements for flight in the NAS. The Aircraft Electronics Association asserted that the FAA must discuss its entire proposal for NextGen equipment, with a consolidated cost-benefit analysis. Boeing and FedEx noted the reduced separation standards and increased airspace capacity projections require ADS–B, along with other advances, such as RNAV. Boeing further noted that the ADS–B proposal requires a thorough vetting against the NextGen operating concept to enable the projected growth and advances. UPS recommended using the preamble to propose a NextGen roadmap, addressing all of the CNS/air traffic management (ATM) technologies. DayJet asserted ADS–B will succeed in part because of aviation industry leaders and very light jet operators. With new aircraft and new business models, these operators have confidence in the return on investment for NextGen.

Three commenters questioned the anticipated growth in the use of the NAS. One commenter noted that GA may contribute to traffic delays, but considered the analysis incorrect in labeling those aircraft active. Once commenter noted that based on flight activity at certain airports, GA activity is declining.

Three commenters discussed ADS–B as a means to reduce carbon monoxide emissions. One commenter recommended ADS–B should be a priority to assist the implementation of continuous descent arrivals. GAMA recommended including the fuel savings and environmental benefits of ADS–B as part of the cost-benefit analysis in the final rule.

Other commenters submitted various comments concerning the conditions for achieving the reported ADS–B benefits.

- Airbus asserted no aircraft has been certified to the proposed standards. Airbus recommended a program of system demonstrations, inservice evaluations and compliance, and research and development to advanced standards and build confidence in the stated benefits. Airbus recommended the FAA take advantage of the time available to carry out those projects in a collaborative Government-industry effort.
- DayJet asserted development and implementation of RNP procedures would ensure timely dispatch, direct line of flight, and optimum altitudes throughout the NAS, including both large and small airports. DayJet recommended

implementing RNP early and contemporaneously with ADS–B ground system deployment.

- UPS noted several ADS–B In applications that have already received operational approval, such as Cockpit Display of Traffic Information (CDTI) Assisted Visual Separation, Merging & Spacing, and Surface Area Movement Management, as well as prospective applications such as In Trail Procedures. UPS asserted that such applications will provide benefits such as fuel savings, time savings, lower environmental impact, and improvements in safety through better situational awareness and error reduction.
- IATA noted that aircraft equipped today with legacy 1090 ES ADS–B systems will need strong near-term benefits to encourage operators to modify their systems before the 2020 mandate.
- SANDIA recommended the FAA define a standard minimum set of ADS–B services. SANDIA also asked the FAA to clarify the plan to install ADS–B ground stations at public use airports, the coverage around a point in space and relative to the airport surface, the specific weather products to be broadcast, and if ADS–B will reflect the status of military operations areas, warning areas, or other special use airspace.
- AOPA recommended that ADS–B Out must provide, at a minimum, the following safety enhancements and operational improvements: (1) ATC flight following and radar services in the en route phase of flight, at altitudes most commonly used by GA aircraft, usually considered to be below today's radar coverage; (2) terminal ATC services at thousands of GA airports including radar vectoring and flight following; (3) automatic closing of instrument flight plans by ATC after aircraft have landed safely; (4) using ADS–B position reports to re-trace the flight progress of aircraft that have been reported missing thereby accelerating the rescue of pilots and passengers; (5) increasing the availability of low-altitude direct-to-navigation during instrument operations; and (6) enabling an FSS interface for improved weather and flight planning services, including tailored information based on accurate knowledge of the aircraft's position and altitude.
- ATA noted that the initial costs and benefits to the FAA would be relatively low, while the initial costs to users would be high. ATA further noted that the NPRM does not commit the FAA to provide significant benefits before full equipage in 2019.

ARC Recommendations Regarding the ADS–B Out Business Case

The FAA briefed the ARC and reviewed its cost/benefit assumptions, methodology, and calculations. The ARC paid particular attention to understanding the benefit mechanisms from an operational perspective. The ARC notes that in general, the FAA's assumptions were conservative. An example of this is that the FAA used $1.83 per gallon as the assumed fuel cost in their analyses; this is somewhat less than the recent, current or expected price of fuel.

Building on the cost/benefit data provided by the FAA, the ARC used a decision analysis process to identify and choose a strategic alternative that would increase the overall (1) value of the NPRM and (2) stakeholder buy-in. More detail on the analysis described below is contained in appendix P to this report.

The ARC considered multiple strategies and decided initially to analyze two strategies to compare to the NPRM.

NPRM

The NPRM strategy matched the original contents of the rule. The strategy required ADS–B Out for all aircraft flying in transponder airspace, and had a dual 1090 MHz/UAT link, a compliance date of 2020, a NACp≥9 and NIC≥7 for performance requirements, and retired half of the SSRs.

Equipage to Match

The goal of the Equipage to Match strategy was to reduce equipage costs by adjusting performance requirements and the geographical requirements for ADS–B Out equipage to match the ADS–B Out benefits estimated by the FAA and published with the NPRM. The strategy limited the applicability of the mandate to operations in class A airspace and OEP airports, had a 1090 MHz link only, a compliance date of 2015, a NACp≥7 and a NIC≥5 for performance requirements, and most all SSRs were retained.

Expanded Benefits

The goal of the Expanded Benefits strategy was to increase the value of the rule to stakeholders by providing additional ADS–B Out operational applications and benefits. In addition, equipage costs were reduced through performance requirements that matched the applications stated in the rule. This two-phase strategy required equipage for all transponder airspace, and had a phase 1 compliance date of 2015 for operations within Class A airspace and into OEP airports, and a NACp≥7 and NIC≥5. Phase 2 of this strategy had a compliance date of 2020 for all transponder airspace, a NACp≥8 and NIC≥7, assumed elimination of the need for an ELT for GA aircraft[9], retired half of the SSRs, and added ADS–B applications of 3 nm en route separation, radar-like services at NRA airports, and improved search and rescue service via ADS-B.

After the initial analysis, the following three additional hybrid strategies were evaluated. The first two hybrid strategies combined or modified elements from the baseline strategies to improve the overall results.

Phased Expanded Benefits

This strategy adjusted the Phase 1 compliance date to 2017 with the positioning performance requirements from the Equipage to Match strategy above. Additional ADS-B applications of services at NRA airports and improved search

[9] The ELT elimination benefit was ultimately removed from this strategy. For a full explanation, see Appendix P.

and rescue service are implemented in this phase. The Phase 2 compliance date and positioning performance requirements were identical to the Expanded Benefits strategy above. The additional ADS-B application of 3 nm en route separation is implemented in this phase.

Equipage to Match +

The performance requirements were increased to NACp≥8/NIC≥7 to get 70 to 90 percent of the benefit for 3 nm en route separation via ADS-B (benefit reduced since it was calculated for operations above 10,000 ft, but the mandated airspace in this strategy is class A airspace).

Single Link with ACAS Upgrade

This strategy built on the expanded benefits strategy by assuming an ACAS upgrade and the elimination of all SSRs to allow removal of transponders for aircraft not currently equipped with ACAS and by assuming a single link for ADS–B services. This would require an alternate source for FIS–B. The two-phase strategy had a 1090 MHz link only, a Phase 1 compliance deadline of 2017 for operations in class A airspace and into OEP airports, and a Phase 2 compliance date of 2020 for operations in all transponder airspace using the same performance requirements for each phase as for the Phased Expanded Benefits strategy.

Both the Phased Expanded Benefits and the Single Link with ACAS Upgrade options had two identical phases. Phase 1 was designed to make maximum use of current equipage in class A airspace and for aircraft operating into OEP airports, enabling the ADS–B Out benefits estimated by the FAA and published with the NPRM. Phase 1 required ADS–B Out in 2017 with a minimum of a DO–260-approved transponder and positioning performance requirements of NACp≥7 and NIC≥6 (achievable with a TSO–129 GPS receiver that assumes SA On). Phase 2 covered all current transponder airspace and required that in 2020 a minimum of DO–260A (and DO–282A in the Phased Expanded Benefits option) with positioning performance requirements of NACp≥8 and NIC≥7 (achievable with a GPS receiver with SA awareness[10]).

The ARC assumed that any aircraft with a current DO–260-like transponder requiring major upgrade to achieve DO–260-approved status will equip with a DO–260A transponder to meet the 2017 requirement, thus avoiding a second update in 2020. Likewise, the ARC assumed that any aircraft currently without a GPS receiver will install a GPS receiver with performance equal to or better than NACp≥8 and NIC≥7 (achievable with certified SA Off GPS receivers) by 2017, to avoid another upgrade in 2020.

The ARC did a survey of four airlines (Alaska, FedEx, Southwest, and UPS) and all four will have GPS on all their aircraft by 2017 regardless of any ADS–B Out mandate. If the FAA conducts cost-benefit studies of these ARC strategies, the FAA should expand that survey to all operators that fly at OEP airports or in class A airspace.

[10] These receivers are called “SA Off” GPS receivers because SA is deactivated and the U.S. Government plans to keep it this way.

Table 5 — Phases of Phased Expanded Benefits and Single Link with ACAS Upgrade

Phase	Year	Transponder	Positioning Performance (GPS type)
1	2017	DO–260-approved or better	NACp≥7 and NIC≥6 (SA On or better)
2	2020	DO–260A (and DO–282A UAT for Phased Expanded Benefits)	NACp≥8 and NIC≥7 (SA Off or better)

The ARC agrees that the ADS–B Out mandate should be cost-beneficial for all members of the user community. Table 6 summarizes the net present value per-stakeholder for each strategy.

Table 6 — Final Results by Stakeholder for Hybrid Strategies

Stakeholder	NPRM	Phased Expanded Benefits	Equipage to Match +	Single Link with ACAS Upgrade
High Altitude	$1069M	$2098M	$1964M	$2098M
Low Altitude	($541M)	($318M)	$0M	($124M)
FAA	$190M	$190M	$96M	$371M
Total	$718M	$1970M	$2060M	$2345M
GA UAT ADS–B In[11]	$509M	$509M	$0M	$509M[12]

Given the results by stakeholder, the Single Link with ACAS Upgrade option was the most cost-beneficial option that included all stakeholders operating within current transponder airspace. However, these results don't include the equipage and infrastructure costs associated with modifying ACAS to accept ADS–B Out data or mitigations for 1090 MHz frequency congestion. After those costs are included, the strategy may not be the most cost beneficial. The Phased Expanded Benefits and Equipage to Match + strategies are close in terms of net present value; however,

[11] This value is based on the UAT community voluntarily equipping to receive the ADS–B benefits, including TIS and FIS, but does not include cost uncertainty.
[12] The single link alternative assumes FIS on 1090 MHz.

Phased Expanded Benefits strategy provides part of the equipage solution for TIS–B/FIS–B, the Equipage to Match + strategy does not.

After much discussion, the ARC could not reach consensus on whether FAA should mandate DO–260-approved ADS–B Out for operations in class A airspace and at OEP airports by 2017, three years earlier than proposed.

The ARC recommends that the FAA—

1. Retain the 2020 compliance date for the ADS–B Out mandate, but adjust the ADS–B Out program to capture additional benefits for all NAS users as developed by the ARC and described in the Phased Expanded Benefits strategy.
2. Delay the compliance date of the ADS–B Out mandate if the following items are not complete by 2013:
    a. Ground infrastructure coverage needed for the mandated airspace and additional NRA airports,
    b. Automation systems,
    c. Equipment certification,
    d. Performance standards,
    e. Operational approval,
    f. Separation standards,
    g. Operational procedures for ADS–B non-radar airspace, and
    h. FAA controller training and procedures.
3. Implement the necessary incentives to create a positive business case for low altitude airspace users. This requires the FAA to make changes that result in lower investment costs and increased benefits, and provide economic incentives to offset costs when benefits are insufficient. If the ADS–B mandate results in the low altitude segment of the aviation community investing more into the system than the benefits enabled, the FAA should not mandate ADS–B Out for that segment of the community.
4. Increase the overall value of the NPRM and stakeholder buy-in for low altitude operators by—
    a. Validating ARC calculations of transponder equipage savings for U.S. operators without TCAS if Mode A/C transponders could be removed from those aircraft in the future.
    b. Validating ARC calculations of the net benefits for providing surveillance services at NRA airports, then adding appropriate service volumes to the SBS Program to provide service at all public use airports that have at least one runway over 3,000 feet and at least one instrument approach procedure.
    c. Investigating the value of adding the following services to the SBS Program:

i. Expanded low-altitude NRA surveillance services,

ii. Automatic closure of flight plans at NRA airports, and

iii. FSS improvements.

5. Establish and introduce in the final ADS–B Out rule a public process for implementing future modifications to the airspace, applications, or airports for which ADS–B equipment is required.
6. Develop and implement the requirements and operational procedures for ADS–B surveillance based 3 nm separation in all domestic en route airspace, prior to the ADS–B Out compliance date
7. Further investigate the Single Link with ACAS Upgrade strategy to determine if the equipage and modification changes are economically advantageous.
    a. Consider the results of the 1090 MHz Frequency Congestion Urgent Study.
    b. Consider any ACAS changes necessary to support/enable NextGen operations.
    c. Consider implications of moving FIS–B service to 1090 MHz or an alternative source.
8. Recalculate its cost-benefit analysis using a range of costs for certain items rather than fixed costs to present the community with a realistic range of potential benefits. The ARC feels that the FAA used very conservative numbers in their analysis. However, to give the community a more accurate representation of the benefits, the FAA should recalculate their analysis and present the community with a realistic range of potential benefits. Specific examples are the FAA fuel cost estimate ($1.83 per gallon) and the reduction in assumed starting separation at NRA airports (7.5 nm).

Phased Implementation

Original Proposal

In § 91.225 (a)(1) and (2), the FAA proposed that aircraft be equipped with ADS–B Out equipment that meets the performance requirements in TSO–C166a (1090 ES), or later version, or meets the performance requirements in TSO–C145b (UAT), or later version.

In the preamble to the NPRM, the FAA noted that the proposed standards, DO–260A and DO–282A prescribe a NACp≥9. The FAA stated that equipment operating with a NACp≥7 would provide a horizontal position accuracy of approximately 0.1 nm, which is equivalent to the minimum position accuracy provided by existing radar surveillance in terminal area airspace. The FAA explained that it is not engaging in rulemaking simply to meet the existing level of surveillance or to enable separation performance equivalent to that realized today, but to exceed existing standards. The FAA stated that once aircraft using ADS–B equipment with a minimum accuracy value of NACp≥9 or greater have been demonstrated to safely and consistently operate at existing separation standards, reductions in required aircraft separation could be considered.

The FAA noted that the Australian Civil Aviation Authority has been operating an ADS–B system that accepts broadcasts from aircraft equipped to either the DO–260 or DO–260A standard, and applies a 5 nm separation standard. The FAA stated that it intends to use a higher performance standard because it intends to use ADS–B to provide surveillance using the existing separation standards of 3 nm in terminal environments and 5 nm in en route environments. The FAA also noted that DO–260A-compliant equipment will include a means to transmit SSR beacon codes that currently service the NAS and will continue to be required as a backup to ADS–B. The FAA stated that this functionality is not required by RTCA/DO–260.

Summary of Comments Regarding Phased Implementation

Eight commenters, including four associations, Boeing, two air carriers, and the European Organisation for the Safety of Air Navigation (EUROCONTROL) advocated initial implementation and operation of ADS–B with requirements based on existing avionics, which are compliant with a robust subset of the DO–260 standard.

UPS, along with the Aircraft Electronics Association and IATA, recommended an initial implementation based on existing avionics to allow operators to experience early ADS–B benefits without extensive retrofit costs. UPS added that higher performance standards should only be set if and when future ADS–B applications require them.

Boeing noted that DO–260A is still under development and subject to change. Boeing recommended the FAA base the initial implementation of ADS–B on existing DO–260-like equipment and offer financial and procedural incentives for operators to upgrade to DO–260A, when the standard has stabilized.

IATA asserts that, without the benefits offered by ADS–B In, most carriers will defer equipage until the mandatory date of 2020. IATA recommends that equipage for both ADS–B In and Out be mandated with a compliance date of 2020 or possibly later.

ATA asserted that the DO–260A standards appear to support as yet undefined ADS–B In applications. ATA recommended that initial standards be consistent with ADS–B Out only operations and DO–260-like compliant equipage

Rockwell-Collins asserted the industry would be better served with a two-stage ADS–B mandate, rather than a single 2020 mandate. Rockwell-Collins recommended an initial phase in 2013 that would encourage early ADS–B equipage, with lower performance requirements. Specifically, NACp ≥7 (rather than ≥9), NIC ≥6 (rather than ≥7), SIL=2 or 3 (same), and NACv ≥1 (same).

ARC Recommendations Regarding Phased Implementation

The ARC recommends that existing 1090 ES equipage be approved for improved operations until the effective date of the ADS–B Out mandate. It is expected that operators will conduct their own evaluations to determine the proper timing to retrofit their existing fleet from existing 1090 ES to DO–260A Change 3[13] to meet the

[13] The ARC has been informed and assumes that DO–260A Change 3, the next change to the existing 1090 ES MOPS, will not be issued until the FAA has indicated that revision will meet the requirements of the ADS–B Out rule.

compliance deadline. Because of the ARC's recommendations for the FAA to incentives early equipage of DO–260A Change 3, it also is anticipated that operators of aircraft currently not fully qualified for early 1090 ES operations only will undertake one retrofit to meet DO–260A Change 3 as required by the mandate.

To recognize a benefit to early equipage and to learn from several of the initial applications and services identified in the NPRM, the ADS–B ARC recommends implementing a two-phase program. The first phase would take advantage of existing 1090 ES (DO–260-like)-equipped aircraft and allow their operation in the Gulf of Mexico for non-radar airspace.

This proposed recommendation also acknowledges the accommodation of 1090 ES by the global community. Air Services Australia, Transport Canada, and EUROCONTROL all have initiated their ADS–B Out programs using the capabilities of 1090 ES. In AMC 20–24, EASA established certification criteria that were adopted by Transport Canada in its Hudson Bay ADS–B Program. All of these global air navigation service providers also have recognized that DO–260A Change 3 will form the basis for the enhanced operations. This further ensures a consistent investment for future operations.

Note: The FAA sponsored an assessment, based on listening to ADS–B transmissions at single receivers located in Washington, D.C., New York, Los Angeles, and Denver, of available 1090 ES capabilities. These aircraft were equipped with early DO–260-like configurations. The detailed report is included in appendix Q to this report. The results of the analysis are summarized in the three tables below.

Table 7 — Summary of DO–260-like Aircraft with Basic Capabilities from Quick Look Report

Classification	Operations	Airframes with Operations	Percent of Mode S Airframes	Percent of ADS–B Airframes
Total Mode S	9,366,456	41,479	100	
With ADS–B Capability	1,247,887	5,565	13	100
ADS–B that meet basic capabilities requirements	500,720	1,964	5	35

This indicates that a total of 1,964 aircraft are capable of providing some level of ADS–B Out information. However, elements of the information provided may not meet the operational requirements.

Table 8 — Summary of Airframes Reporting Navigation Uncertainty Category (NUC) of 5 or Better

Classification	Airframes with Operations	Percent of ADS–B Airframes	Percent of ADS–B Airframes With Basic Data
ADS–B that meet basic capabilities requirements	1,964	35	100
Always reported an HPL < .5 nm Position (NUC≥5)	1,954	35	99
Always reported an HPL < .2 nm Position (NUC≥6)	1,930	35	98
Always reported an HPL < .1 nm Position (NUC≥7)	1,663	30	85
Always reported an HPL < 25 m Position (NUC≥8)	166	3	8

The distribution of NUC values are summarized below in Table 9. It should be noted that a significant portion of the participating airframes indicate a NUC value of 0. There are multiple reasons for this result, but the implication is that many of the DO–260-like equipped aircraft will still require some level of investment to either their position source or the aircraft wiring, both of which is a significant level of investment.

Table 9 — Weighted NUC Value Distribution Summary

	Weighted NUC Values									
	9	8	7	6	5	4	3	2	1	0
Number of Aircraft with Weighted NUC Value	5	118	532	1087	178	9	5	9	7	1083

Note that DO–282 has not been referenced because all known installations have already transitioned to the proposed DO–282A standard. DO–282A is fully compliant with the proposed NPRM.

The second phase of the program supports the transition to a fully functional ADS–B Out capability enabled by DO–260A Change 3. This would then enable access to the additional applications and services outlined in the NPRM. By stating the intention to transition to DO–260A Change 3, we have enabled airframe manufacturers and airspace users that are planning upgrade programs to specify the more capable functionality as early as possible, thereby avoiding additional upgrade costs.

The benefit of this transition will allow an acceleration of the use of the system during the learning phases of the program and a period where specific, highly detailed procedure development is not required. It further enables early access to the fielding waterfall that would place ADS–B sensor capabilities in the Gulf of Mexico to provide significant benefits in terms of fuel savings by optimizing flight track profiles using continental separation standards while operating in the Gulf of Mexico. This enables more direct trajectories and enhances flows through the airspace.

Equipage Incentives

Original Proposal

In § 91.225, the FAA introduces ADS–B as the preferred mode of surveillance technology to facilitate more accurate and timely aircraft information. The ADS–B system is an advanced surveillance technology that combines a satellite positioning service, aircraft avionics, and ground infrastructure to enable more accurate transmission of information between aircraft and ATC. ADS–B enables equipped aircraft to continually broadcast information, such as identification, current position, altitude, and velocity.

Summary of Comments Regarding Equipage Incentives

A total of 21 commenters, including 8 associations, 4 domestic air carriers, and 3 avionics manufacturers commented on equipage incentives.

The majority of commenters suggest that additional equipage incentives are necessary to accelerate voluntary installation of ADS–B Out equipment before the 2020 mandate. Delta asserts that an equipage incentive program coupled with early user benefits is critical to foster early equipage and maximize ADS–B benefits. The National Business Aviation Association (NBAA) believes the FAA and aviation industry will be able to realize benefits of ADS–B before the 2020 target date if the government develops incentives for early installation of ADS–B equipment. The Airports Council International-North America (ACI–NA) calls for the inclusion of airports and airlines in crafting an incentives program.

Several commenters including AIA suggest that users do not fully recognize the benefits of ADS–B. AIA urges the FAA to provide more support in the proposed rulemaking, confirming that the program includes the necessary planning and execution of a full operational suite. The National Air Transportation Association suggests that the FAA publish financial incentives and operational benefits for operators and equipment owners in all affected sectors. Boeing agrees that clearly understood and published benefits analysis would motivate individuals to equip, as long as the benefits outweigh the costs for users. RAA argues that regional airline operators need a more realistic cost benefit analysis from the FAA so they may seek financial incentives from other government entities as well. Several commenters also recommend education programs, training, and demonstrations to better illustrate the benefits of ADS–B and the procedures for its use.

ATA mentions that some operators had a limited opportunity to provide inputs to the development of the ADS–B Out Economic Decision Tool, which was not released in to time for operators to assess the benefits of the ADS–B Out program before commenting on the NPRM. AIA proposes several benefits to add to the NPRM, such as direct financial incentives (rebates, depreciation rules, research and development, and investment tax credits), direct operational benefits (decreased spacing and more efficient routing), and indirect operational benefits (improved access and early release).

Many commenters believe the FAA needs to provide financial assistance for ADS–B equipment and installation. One aircraft owner proposes that the savings from ADS–B operations should be used to fund tax credits for aircraft owners who purchase and install ADS–B and avionics manufacturers who develop and manufacture the equipment. An individual pilot encourages the United States or Congress to implement ADS–B incentive programs to cover procurement and installation costs. This commenter points out that similar programs in Alaska and Australia have yielded favorable results. A few individuals suggest the government help offset costs by providing free weather and airspace products. AOPA considers that most GA pilots and aircraft owners would be willing to pay about the same amount for ADS–B as they would for a new transponder. AOPA insists that the FAA work with the GA community to ensure that equipping costs are not prohibitive.

One individual strongly advocates single-link UAT equipage, and suggests the dual-link infrastructure savings can be used to fund an equipment loan program. Specifically, the commenter notes that programs could be structured to subsidize development and certification of avionics, and help shelter manufacturers.

Several commenters proposed operational incentives for ADS–B equipage. The Cargo Airline Association, ATA, and ERA Corporation recommend operational preferences, like access to congested airspace over the Gulf of Mexico, for early installers. ATA also suggests committing to continuous availability of radar-like separation standards in expanded coverage areas. DayJet advises selected implementation of multilateration and TIS–B to benefit equipping operators, without requiring equipage by all operators. Delta recommends subsidizing equipage of carriers participating in trials of services, which would show the benefits of more accurate surveillance, and also facilitate buy-in by a potentially skeptical air traffic organization. Delta also noted that early equipage incentives would improve the business case, because it allows more time to take advantage of the proposed benefits of ADS–B. UPS notes the importance of emphasizing that those equipping with ADS–B In will receive priority and benefits, and those who choose not to equip may end up being penalized.

Delta noted that with the currently proposed satellite constellations, operators are forced to augment equipage with WAAS, which worsens the already difficult business case. Delta also asks the government to commit to a greater number of available satellites, which would benefit CNS space-based technologies, GPS based communications, and all ADS–B applications. FedEx requests a fully integrated evaluation of ADS–B Out once the ground infrastructure is in place, to help the industry identify benefits and determine whether supplemental equipment such as WAAS is necessary.

One individual pilot notes that the NPRM does not address those persons who operate in areas where ADS–B will not be required yet voluntarily equip their aircraft.

ARC Recommendations Regarding Equipage Incentives

The following are some mechanisms by which the ARC believes the Government can fund or partially fund ADS–B avionics equipment, some of which are described further. The Government can—

- Reduce the purchase price of ADS–B avionics equipment by subsidizing the nonrecurring manufacturing costs.
- Pay for the certification, purchase, and installation of the equipment.
- Provide a grant for the equipment.
- Provide an investment tax credit.
- Provide adjustments to the existing aviation excise tax rate.
- Encourage market competition through research and development tax credits specifically targeted at ADS–B avionics development.
- Reduce landing/overflight fees for ADS–B-equipped aircraft.
- Reduce or waive registration fees.
- Provide a fuel tax break for equipped aircraft.
- Provide interest-free loans for equipage that are paid back when benefits are accrued.
- Provide a voucher to GA operators for equipment and installation.

Government-purchased Equipment

The Alaska Capstone program relied on Government-purchased avionics equipment as the starting point for operators to equip with ADS–B avionics. This provided a base of airplanes with installed equipment where quantifiable benefits were identified by the FAA. The benefits of equipage, including safety, provided an encouragement for additional operators to invest in ADS–B avionics.

Investment Tax Credits

Investment tax credits have been introduced by Congress to encourage investment in certain property or equipment. This option would require Congress to authorize an investment tax provision specifically for ADS–B avionics. This investment tax provision would involve a basic cost to the Government and would provide an opportunity for a company to offset taxes on profits through the investment tax credit.

Aviation Taxes

Aviation taxes make up the bulk of the money the aviation community pays for the FAA's aviation infrastructure. Congress would have the option of creating an incentive

for equipping with ADS–B by lowering the effective excise tax rate (either fuel or other mechanisms) for operators who elect to equip.

Research and Development Tax Credits

All avionics development involves significant investments by the equipment manufacturer and installer in research, development, engineering, and certification costs. The Government has the option of creating research and development tax credits targeted at the development of ADS–B avionics. Currently, there is a research and development tax credit in place, and several research and development tax credits have existed since introduced in 1981. A targeted research and development tax credit for ADS–B avionics could provide further incentive for companies to develop avionics.

The FAA should coordinate a strategy that includes incentives, service enhancements, and cost reductions to ensure a positive business case and stakeholder buy in. If the ADS–B mandate results in any segment of the aviation community investing more into the system than the benefits enabled, for example low altitude users, the FAA should not mandate ADS–B Out for that segment of the community.

In addition, the FAA should incentivize operators to voluntarily equip early for the 2020 mandate by providing preferred access to additional capacity and efficiencies enabled by ADS–B equipage.

The FAA should establish preferred routes for ADS–B-equipped aircraft. The Gulf of Mexico has been identified as one area where the establishment of preferential routes could provide substantial benefits. The FAA should investigate what other routes, including routes in existing surveillance areas, and new procedures (such as routes with 3 nm en route separation) where they can give preference and other benefits to operators who equip early.

The FAA should encourage early equipage by establishing agreements with specific operators and accelerating deployment of ADS–B services at designated locations. These agreements should include subsidizing equipage of operators participating in trials of new services and procedures. The confidence in the ADS–B benefits could increase by tailoring equipage to the needs of the earliest operators through formal agreements. The FAA should provide accelerated deployment of ADS–B services at air transport hubs in exchange for an agreement to equip. For instance these services could include Surface Management Systems deployment and gate-to-gate priority.

Antenna Diversity and Power

Original Proposal

In § 91.225 (a), the FAA proposed that ADS–B Out equipage meet the performance requirements of either (1) TSO–C166a (1090 ES) or a later version, or (2) TSO–C154b (UAT) or a later version. Both equipment classes include requirements for a top and bottom antenna. The FAA notes that this requirement will support ADS–B Out as well as future air-to-air ADS–B In applications.

Summary of Comments Regarding the Antenna Diversity and Power Requirement

Eighteen commenters, including 3 avionics manufacturers, 3 associations, and 12 individuals, submitted 25 comments regarding the FAA's antenna diversity and power requirements proposal.

The majority of commenters generally oppose the antenna diversity requirements.

- AOPA asserted the performance requirements for ADS–B are excessive for low altitude operations. AOPA also asserted that the FAA has not provided sufficient evidence two antennas are necessary. Decades of operational experience with Mode C transponders and ACAS do not support the dual antenna requirement. For aircraft flying below FL240, AOPA recommended eliminating the requirement for dual antennas.
- Three commenters asserted that given the mass of GA aircraft and the speeds involved, there is no documented evidence that antenna diversity provides better collision awareness or position reporting for those aircraft.
- Four commenters asserted that any gain in performance is not warranted by the inconvenience and cost of the diversity antenna requirement, especially for GA. One commenter recommended either providing a more detailed justification for the antenna diversity requirement, or waiving the requirement for light GA aircraft in most airspace.
- Two commenters noted that in the current environment, Mode C transponder and ACAS operations do not require antenna diversity. One commenter asserted the additional cost will dissuade Mode C users from upgrading to UAT.
- One commenter asserted that placement of a new UAT transmit antenna on the upper surface of a light aircraft will provide unacceptable interference to GPS because cost effective GPS receivers for such aircraft use small active antennas with poor adjacent band rejection. The commenter recommended requiring placement of a single UAT antenna only on the bottom of the aircraft.

Honeywell noted that new GA panel mounted transponders likely will weigh 1 to 2 more pounds than existing transponders because of the diversity antenna requirement, the second antenna, second receiver, and associated interconnect hardware. Honeywell also noted that turbine-class diversity Mode S transponder weight should be unaffected by the requirements of the NPRM.

SANDIA noted the proposal requires UAT transmitters meet TSO-C154b requirements for A1H, A2, A3, or B1. SANDIA asserted this will increase costs unnecessarily because of the diversity antenna requirement. Meeting the A1H power requirements has minimal cost impact on the system, while the antenna diversity requirement will increase system and installation costs and complexity. SANDIA asserted the benefit from the top antenna on GA aircraft is minimal, that is, less than 10 miles separation. The bottom antenna is a better source for signals to and from the ground stations, with the possible exception of

airport operations due to multi-path, obstructions, or distances possible at very large airports. SANDIA recommended placing a second antenna on the airport rather than on 150,000+ aircraft for locations where airport reception is not reliable. SANDIA also recommended adding another equipment class: A0H, that is, A0 with A1H power. This system would have very similar aircraft to ground range (service volume) as an A1H system. SANDIA asserted this may be better aircraft to ground because every other transmission comes from the top antenna in an A1H installation and the top transmission is less likely to reach the ground station at long ranges and on certain headings, for example, when the signal is blanked by the wing.

Trig Avionics stated that 1090 ES equipment should not be required to have B1 transmitters and adds that the lower speed and relative lack of shielding in smaller aircraft permits the use of 70 watt non-diversity transmitters. Trig Avionics recommended the FAA encourage the use of lower power transmitters, to minimize 1090 MHz frequency congestion.

Defense Concept Associates asserted that there is no evidence that a single tail mounted antenna would disadvantage small aircraft.

GAMA asserted the RTCA MOPS allows for low power and single antenna installations with specific airspace and altitude restrictions. GAMA recommended the FAA conduct a cost-benefit analysis of low power and/or single antenna installations per the RTCA MOPS and include it in the final rule. AOPA recommended reducing the minimum requirements for the transmit power, as permitted in RTCA standards.

One commenter asserted that any line of sight issues could be overcome by having the aircraft transmit its complete picture and any gaps would then be filled in with information from other network participants. The commenter noted that data fusion techniques would be required for this to work.

One commenter asserted that there are current installed Mode S transponders that could be upgraded by software to comply with ADS–B, but they cannot be upgraded to meet the proposed diversity requirements. This commenter estimates the mandate could add up to $10,000 to the cost of installation even when the aircraft has a transponder capable of being upgraded to ADS–B. The commenter asserted the use of TSO C-166a class A0 and B0 ADS–B 1090 ES transponders would allow tens of thousands of existing GA aircraft with Mode S transponders installed to meet ADS–B quickly and inexpensively. The commenter also asserted that transponders with diversity capability are twice the price of those with a single antenna. Adding an extra antenna on a non-pressurized aircraft typically adds 4 hours of labor plus the cost of the antenna. Typical installation for GA aircraft would add $500 to the cost of complying with the proposed rule. The commenter recommended pursuing an option that allowed a top antenna on ground mode, which would be much less expensive to implement and could use existing transponders. The commenter also recommended allowing the use of TSO- C-166a class A0 and B0 ADS–B 1090 ES transponders for GA aircraft.

One commenter asserted there is no need for top and bottom antennae on aircraft that have demonstrated spherical single antenna operation when unimpeded by structure. For example, an antenna mounted under Plexiglas or above Fiberglas performs satisfactorily.

One commenter asserted the FAA needs to make a quantitative justification for the proposed top/bottom antenna requirement. The commenter asserted it seems unlikely to be warranted in a system which is proposing to have two incompatible data links. There is little value in having a top mounted antenna transmitting only on UAT to an aircraft above receiving only 1090 ES. In such a situation ADS–R would be necessary and as a ground based system, would be visible to the bottom antenna on both aircraft. If ADS–B is to form the basis of the NAS, then ADS–R will need to be universally deployed and available 24 hours a day, 7 days a week. The commenter recommended considering a performance based specification for antenna systems instead of explicitly requiring a top/bottom installation.

ARC Recommendations Regarding the Antenna Diversity and Power Requirements

Summary

The ARC can confirm that the cost of diversity antenna installation is a significant concern for the GA fleet and other low-altitude, slow moving aircraft. In the time permitted, the ARC has aggressively pursued opportunities to make an allowance for non-diversity (single) antenna installations within an ADS–B Out mandate. The ARC's recommendations related to antenna diversity are included below and summarized in recommendation No. 18. In the limited time available for its analysis, the ARC successfully identified a strategy to allow non-diversity antenna installations for a subset of the low-altitude, slow speed fleet, and the strategy is supported by existing data. The ARC recommends that the FAA make an allowance for non-diversity antenna installations in airspace, which was not originally proposed in the NPRM. In addition, the ARC further recommends the FAA continue to evaluate and address the remaining barriers so that all low-altitude, slow moving aircraft can be approved for non-diversity antenna installations.

Review of Existing Data and Subsequent Recommendations

The ARC has reviewed the existing technical standards, simulations, and models for non-diversity and diversity antenna installations and has discussed ADS–B ground infrastructure issues with the FAA's ADS–B ground infrastructure contractor, ITT. However, no flight test data was available for the ARC review.

The ARC notes that DO–260A allows for non-diversity installations but specifies that the use of such equipage may limit operations by altitude and in congested airspace. The same is true for DO–282A. The ARC also recognized that transmit power and antenna standards were carefully developed in a consensus environment.

Based on the information and analysis in appendixes R, S, T, and U to this report, the ARC agrees with the requirement for antenna diversity and specified power to ensure optimal system link performance in high-altitude and congested airspace as the primary path for an operator to meet the 2020 ADS–B Out rule at this time. As an example, based on currently available data, there are valid concerns about aircraft with a single bottom-mounted antenna with ADS–B installations (for example, line-of-sight, ground reflection, and multipath) not achieving the necessary performance when operating on the

ground because of radiofrequency reflection characteristics. The ARC has identified this reflection as one of several barriers that needs to be and may be possible to mitigate.

The ARC has reviewed ICAO Annex 10, volume IV, requirements for transponder transmit power on the frequency of 1090 MHz. The ICAO requirements specify a minimum transponder transmit power at the antenna of 70 watts for aircraft that operate below 15,000 feet, and a minimum of 125 watts for aircraft that operate at or above 15,000 feet. These requirements are also reflected in the TSO performance standards for both the ATCRBS (TSO–C74c) and Mode S (TSO–C112) transponders. This is important because, unless the FAA pursues a single link 1090ES implementation strategy, a 1090 ES ADS–B Out function very likely will reside in a transponder, where the transponder power is the deciding factor on airspace operations. Without an FAA exception to the ICAO standards for aircraft operating in the United States, a 1090 ES class B0 (70 watt) ADS–B transmitter will, by association, be limited to operations below 15,000 feet. For UAT, DO–282A specifies that low power ADS–B installations are not to operate above 18,000 feet.

Moreover, a low-power, non-diversity antenna installation may introduce limitations in the types of ADS–B In applications an operator can participate in, although the specific applications are unknown at this time. DO–242A, the ADS–B MASPS, which applies to ADS–B implementations using both 1090 ES and UAT, indicates that single-antenna low-power ADS–B installations are intended to support enhanced see-and-avoid applications to a range of at least 10 nm but not to support longer range air-to-air applications such as conflict detection.

Additionally, users equipping with class A0 1090 ES avionics would receive a degraded TIS–B uplink service in light of class A0 receiver sensitivity requirements. However, the MASPS did not directly address higher power, single antenna operations, which the ARC believes should be considered.

Appendix R to this report summarizes aircraft ADS–B antenna diversity and transmit power requirements, as well as the intended scope of ADS–B applications by equipage class for both 1090 ES and UAT.

As previously mentioned, the ARC recognizes that the incremental cost of antenna diversity for GA is substantial, and the added cost of diversity antenna equipment and its installation further erodes the ARC's already negative cost-benefit analysis for the entire low-altitude segment of aviation. For these reasons, the ARC recommends that the FAA undertake further studies to assess/validate the need for antenna diversity in low-altitude airspace. The ARC understands that the ADS–B Out rule may need to specify antenna diversity in some airports or airspace (for example, primary airports in class B and C airspace) to optimize surface performance for ground traffic control, ownship situational awareness, and runway incursion monitoring based on the currently available data, and to meet other safety requirements of the ADS–B program.

Notwithstanding the limitations discussed above for low-power, non-diversity antenna ADS–B installations, it is envisioned that some operators, especially low-altitude, slow moving operators that operate solely in VFR conditions, could benefit from a potentially lower-cost ADS–B Out only installation. These operators would still be able to obtain direct ADS–B benefits from increased situational awareness applications and would be

compliant with the proposed 2020 ADS–B Out rule at a substantially lower cost. Such operators of VFR-only GA aircraft could then operate within class B and C airspace for the sole purpose of airspace transition or to land at the non-primary airport. Therefore, the ARC recommends that low-altitude, slow moving aircraft be allowed to operate within a defined Mode-C veil for the purpose of airspace transition or landing at airports other than the primary airport when operating under VFR.

With the exception of ground infrastructure considerations, the ARC has not identified a problem with the FAA allowing for non-diversity or low-power installations for operation in low-density airspace with altitude restrictions. The ARC discourages the FAA from publishing a final ADS–B Out rule that introduces limitations on permissible ADS–B equipage classes beyond the technical specifications in DO–260A and DO–282A unless specifically warranted by airspace considerations.

The FAA ground infrastructure contractor, ITT, has provided the ARC with the radio link budgets used in developing the placement of ADS–B ground stations. These link budgets presume medium or higher power ADS–B airborne installations with antenna diversity. Therefore, permitting lower power, non-diversity aircraft installations for VFR GA users in low-density airspace with altitude restrictions might have an impact on the number and placement of ADS–B ground stations supporting that airspace. Conversely, increasing the power level, i.e. the creation of a modified A0 (with A1H power), may provide the performance needed to make broader use of non-diversity antenna installations. However, because the ARC is also recommending expansion of the FAA's ADS–B service volumes, the need for ADS–B Out transmitter performance should be verified after any programmatic changes are determined.

With regard to the NPRM comment suggesting transmission by an aircraft of its complete picture, the ARC believes such an approach to be unworkable because of spectrum and potential co-site interference constraints.

Summary of Antenna Diversity Analysis Undertaken by ARC and Recommendations for Additional Analysis by the FAA

The ARC pursued opportunities to make recommendations that would reduce cost and provide for broader use of non-diversity antenna installations beyond what could be justified based on existing data. However, given the time limitations the ARC's analysis and technical review have not identified opportunities to allow for broader use of non-diversity antenna installations beyond what has been discussed above due to several barriers that were identified including concerns about aircraft with a single bottom-mounted antenna not achieving the necessary performance when operating on the ground, lack of definition of radio transparent aircraft, ability to meet required update rates, implications of the ground infrastructure, and lack of real-world flight test of non-diversity antennas Therefore, the ARC recommends that the FAA undertake additional analysis for non-diversity antenna installations which are specifically focused on the barriers identified by the ARC through its review of this issue.

The issue of radio transparent aircraft was raised as a possible solution to the diversity antenna performance versus non-diversity antenna performance. However, the ARC

noted that the concept of radio transparent aircraft (as discussed in the RTCA document) has yet to be defined and therefore cannot be adequately analyzed by the ARC in time for this report. Therefore, the ARC recommends that the FAA define the features of a radio transparent aircraft to allow the community to evaluate whether radio transparency is a possible solution for a non-diversity antenna installation. It should be noted that the ARC members familiar with the development of the term radio transparent as part of the RTCA process does not believe a large portion of the GA fleet will meet this definition. However, because of the added cost of diversity antenna installations, the ARC believes the concept warrants further evaluation.

To evaluate the feasibility of non-diversity antenna installations on slow-moving, low-altitude aircraft, the ARC analyzed three operational scenarios in the context of two selected applications: ASSA and FAROA. While ASSA and FAROA are used as exemplary applications, they were selected only because they are the applications with the tightest performance that have a mature level of definition. And, while they are advisory only in nature, the ARC expects that other applications will be defined in the future that may have similar levels of required performance. The ARC wonders whether these two applications can be defined in such a way that the issues identified by single-antenna installations could be mitigated to the point where the adverse affect is minimal. Furthermore, future definition of ADS–B In applications should also be developed with the low-altitude slow-moving aircraft in mind. The ARC recognizes that the type, size and shape of aircraft in this segment of aviation are growing more diverse.

The results of the modeling and simulation analysis conducted by John Hopkins University Applied Physics Lab (JHUAPL)[14] did not provide results that prove a non-diversity antenna installation could meet the needed performance that have been specified for ASSA and FAROA applications. While the analysis did not indicate opportunities for an allowance for non-diversity antenna installations based on specified update rates for these two applications, the ARC recommends that the FAA conduct additional analysis, specifically in the following four areas to try to address the barriers identified:

1. The ARC recommends that the FAA appropriately apply the ASSA and FAROA analysis results for a low-altitude, slow moving aircraft on approach. The ARC understands that the 2-second update rate requirement is based on faster moving aircraft and that a low-altitude aircraft, at best, would achieve speeds half of what was considered in the scenario that established the 2-second requirement. The ARC also recognizes that the 2-second update rate is related to ADS–B In applications. While, the NPRM only considers ADS–B Out, the ARC has undertaken all its work with consideration of future ADS–B In performance needs.
2. The ARC recommends that, in light of the transmitter performance options and the request for expanding the service volume into non-radar airspace, the FAA review the planned geographic layout of the ITT ground infrastructure to determine whether a non-diversity antenna, modified A0 (with A1H power) could be accommodated with an increase of the number and modification of the location

[14] The results of the JHUAPL antenna diversity analysis are discussed in Appendix Q.

of the ground stations. The ARC notes that comments received by the FAA indicate that single-antenna Mode A/C transponders are permitted throughout the entire NAS today for essentially the same functional purpose. The ARC agrees with these comments that argue the ability of a single-antenna installation to support appropriate air-to-ground surveillance has been demonstrated for decades.

3. The ARC recommends that the FAA evaluate the benefit of some of the applications (for example, ASSA and FAROA) in context of the Airport Surface Detection Equipment, Model X (ASDE–X) deployment and determine whether the specified performance of the ADS–B equipment is needed for these applications. The ARC recognizes that some of these applications consider aircraft-to-aircraft scenarios that ASDE–X may not properly address.
4. The ARC recommends, as another possible mitigation, that the FAA also explore rebroadcasting any ADS–B message received from an aircraft with only one antenna that is on a runway.
5. The ARC recognizes the comments to the NRPM about the added cost of diversity antenna installations as opposed to single-antenna installations. Appendix T to this report contains a high-level review of the additional cost of diversity antenna installations based on broad assumptions related to existing list prices. While the ARC was unable to draw consensus conclusions about the cost of diversity antenna installations, the ARC does believe the cost difference justifies the FAA fully exploring the opportunities for non-diversity antenna installations.

The ARC's analysis does not directly indicate that wider use of non-diversity antenna applications are possible beyond what is recommended below due to the barriers identified. However, the ARC believes that with further analysis, the FAA may permit non-diversity operations in additional segments of airspace provided that the safety case can be made. The ARC recommends that the FAA undertake this analysis with full consideration of acceptable update rates for all planned applications and the effect of the expected time during which non-diversity antenna installation will be blocked by the airframe, that is, persistent null. (Persistent null is the time during which an aircraft, which is maneuvering, blocks its own signal propagating to the ground station.) The ARC recommends that based on this analysis, the FAA should make an allowance for the widest possible use of non-diversity antenna installations for low-altitude, slow moving aircraft.

The ARC further recommends the FAA undertake flight tests comparing single antenna and dual antenna installations, including variations in power, before proceeding with mandating antenna diversity for specific airspace and/or applications in support of the analysis discussed in this paper.

Because of the cost impact of antenna diversity requirements for the GA community, the ARC recommends the analysis outlined above should be part of the critical path toward publication of the final rule and that the FAA, through the appropriate forum, should share the outcome of this analysis with industry.

Finally, the ARC recommends that in the broader context of mandating ADS–B equipment performance for certain airspace, applications, or airports, the FAA establish a public process through which modifications to the airspace, applications, or airports for which ADS–B equipment or specific performance is needed be introduced as part of the final rule.

Summary Recommendation on Antenna Diversity

The ARC, based upon analysis that it has performed, urges the FAA to allow non-diversity antenna installations for VFR aircraft flying through high-density airspace, for example class B and C and below 15,000 feet (1090) or below FL180 (UAT) but not landing at the primary airports. Additionally, the FAA should continue to resolve the barriers (as identified by the ARC) to permit single antenna installations on low altitude, slow moving aircraft. The ARC recommends that the FAA conduct the necessary testing to identify appropriate solutions.

Proposed Changes to Rule Language

The ARC recommends detailed analysis, flight testing and validation of requirements for diversity antenna requirements on low-altitude slow-moving aircraft. Until this activity is complete, the ARC cannot recommend a comprehensive set of changes to the proposed language. Based on existing data, the ARC recommends that the FAA allow a provision in § 91.225(a)(3)) for low-power, single-antenna installations for use in aircraft that are limited to operate under VFR in all airspace at or below 15,000 feet or below 18,000 feet including class B and class C airspace. The ARC understands that this consideration may involve economic tradeoffs between operator and ADS–B ground infrastructure cost.

These recommendations do not imply a change to the current 24,000-foot ceiling for operation of aircraft equipped with UAT.

The purpose of this recommendation is to reduce the cost of ADS–B equipment for pilots who elect to operate only under VFR below 15,000 feet (for 1090 ES) or 18,000 feet (for UAT) in low-density airspace. The FAA should evaluate and consider this potential cost reduction as part of the FAA's economic evaluation of the ADS–B rule.

Should the FAA accept the ARC's recommendation, the following changes should be incorporated in appendix H—Performance Requirements for Automatic Dependence Surveillance–Broadcast (ADS–B) Out, which is invoked in § 91.225(a)(3).

Revise appendix H to part 91 to add new paragraphs (c) and (d) to section 2 as follows:

(c) Aircraft operating below FL 180 under VFR in airspace designated for ADS–B Out may have equipment installed that meets the performance requirements of class A0, A1L or B0 as defined in TSO–C154b or later version.

(d) Aircraft operating below 15,000 feet under VFR in airspace designated for ADS–B Out may have equipment installed that meets performance requirements of class A0 or B0 as defined in TSO–C166a or later version.

Furthermore, based on the analysis and definition of a "radio transparent aircraft," include a new paragraph (e) as follows:

(e) Aircraft meeting the (yet to be defined) requirements for radio transparency and operating below FL 180 in airspace designated for ADS–B Out may have equipment installed that meets the performance requirements of class A0(H) as defined in TSO–C154b or later version.

Finally, but most important, other changes to the rule should be made based on the results of the recommended analysis to address the barriers to non-diversity antenna installations.

Performance Requirements

Original Proposal

In § 91.225(a)(1) and (2), the FAA proposed that aircraft be equipped with ADS–B Out equipment that meets the performance requirements in TSO–C166a (1090 ES) or a later version, or meets the TSO–C145b (UAT) or a later version. In section 3 of appendix H to part 91, the FAA specified the following performance requirements for NAC, NIC, and SIL: (1) NACp≥9 for the positioning source, (2) NACv≥1 for the positioning source, (3) NIC≥7; and (4) SIL of 2 or 3. In addition, the FAA specified that changes in the NIC, NAC, or SIL must be broadcast within 10 seconds.

In the preamble to the NPRM, the FAA stated that the accuracy and integrity of the transmitted aircraft position and velocity are critical for use in surveillance and various airborne and surface applications. The accuracy and integrity of transmitted information expressed by ADS–B avionics is measured by NACp, NACv, NIC, and SIL. An aircraft transmitting its position and velocity with the accuracy and integrity proposed in part 91, appendix H, section 3 (ADS–B Out Performance Requirements for NIC, NAC, and SIL) would be more accurately identified by ATC than it would be in today's radar environment. The confidence with respect to the accuracy of the position and velocity reported by ADS–B Out would enable the future applications discussed in the NPRM that simply could not be provided by existing surveillance systems.

In the preamble to the NPRM, the FAA stated that this proposal specifies performance standards for aircraft avionics equipment for operation to enable ADS–B Out. These performance standards would accommodate and facilitate the use of new technology. Presently, GPS augmented by the WAAS is the only navigation position service that provides the level of accuracy and integrity (NIC, NACp, and NACv) to enable ADS–B Out to be used for NAS-based surveillance operations with sufficient availability.

In the preamble to the NPRM, the FAA explained that the proposal defines latency for the ADS–B message from the time information enters the aircraft through the aircraft antenna(s) until the time it is transmitted from the aircraft. The FAA added that a specific limit between the time the information is received and then processed through onboard avionics is necessary to ensure timely transmission of information and to realize the benefits of the ADS–B system.

In the preamble to the NPRM, the FAA explained that in today's radar surveillance environment, aircraft position accuracy is required to be within 0.3 nm for operations in the en route airspace, and 0.1 nm for operations within terminal area airspace. An aircraft broadcasting its position with a NACp≥7 would provide a horizontal position accuracy of

at least 0.1 nm with no specific requirement for vertical (geometric) position accuracy. Aircraft position reported at a NACp≥7 would meet the minimum radar accuracy requirement for terminal area operations and exceed radar performance for en route operations. Therefore, the FAA believes the minimum accuracy requirement necessary to maintain an equivalent level of surveillance in the terminal airspace area (and provide separation equivalent to today's radar environment) would be a NACp≥7.

The FAA added that it is not engaging in this rulemaking simply to meet the level of surveillance that exists in the current infrastructure, or to establish a new surveillance system that would only enable separation performance equivalent to that realized today. ADS–B performance is intended to go beyond today's standards for accuracy and provide a platform for NextGen.

In addition, the FAA stated that the proposed accuracy requirement could make it possible for future airspace separation to be reduced from today's current separation minima.

The FAA added that the proposed position accuracy requirement also would provide the necessary accuracy to enable certain applications on the surface at the nation's busiest airports. If the aircraft broadcast message element for position has NACp<9, ATC and aircraft equipped with ADS–B In would be automatically notified that the ADS–B Out performance for a particular aircraft is degraded and, therefore, the information is unusable to support either situational awareness on the surface or awareness of runway occupancy on approach to airports.

In addition, the FAA stated that the proposed NIC, NACp, NACv, and SIL requirements would support not only ATC services, but also advisory applications for those who choose to equip aircraft with ADS–B In. The proposed values for accuracy and integrity would meet the needs of all the ADS–B In applications discussed in the proposal. Terminal area and surface applications such as FAROA would not be enabled unless all aircraft in the surface environment report their position accurately on runways and taxiways (NACp≥9). Universal compliance with accuracy and integrity requirements would ensure ADS–B In applications could provide accurate data even in a closely spaced environment such as an airport surface.

The FAA added that to meet the proposed performance requirements using the GPS/WAAS system, aircraft would be required to have equipment installed onboard the aircraft that meets one of the following: (1) TSO–C145b, Airborne Navigation Sensors using GPS augmented by WAAS; or (2) TSO–C146b, Stand-Alone Airborne Navigation Equipment using GPS augmented by WAAS.

Navigational Accuracy and Integrity

Summary of Comments Regarding NACp

Eighteen commenters, including three air carriers, four aircraft manufacturers, three avionics manufacturers, five associations, EUROCONTROL, and two individuals, submitted comments regarding the proposed requirement for broadcast of a NACp≥9.

The majority of commenters were critical of the NACp≥9 requirement. Ten commenters, including United, UPS, Boeing, Airbus, two avionics manufacturers, ATA, AIA, and

two individuals, asserted that the requirement of NACp≥9 is too high. Four of these commenters recommended NACp≥8; two commenters recommended NACp≥7.

Seven commenters recommended the FAA require a lower position accuracy until the applications requiring a higher level are validated. UPS and United Airlines also recommended that the requirement of NACp≥9 be delayed until 27 operational GPS satellites can be consistently maintained.

ATA asserted that the NACp≥9 requirement may be necessary for as yet undefined ADS–B In applications, but that for ADS–B Out applications, a NACp≥7 requirement should be sufficient, and is in line with ADS–B requirements in other countries. ATA noted that this level of accuracy is achievable with existing non-WAAS GPS systems. ATA recommended only requiring the level of accuracy necessary for ADS–B Out applications initially, during the first phase of implementation, and coordinating with industry to validate the performance necessary for defined ADS–B In applications before setting stricter accuracy requirements.

Boeing also pointed out that at NACp≥8, the position accuracy is greater than currently required for RNAV or RNAV (RNP) systems. Boeing further stated that position information more accurate than these limitations is not useful. Boeing noted that, because of latency limitations and other end-to-end system limitations, broadcast of NACp≥9 is impractical and operationally unjustified.

Five commenters disputed the assertion that all aircraft must be equipped and operating with a position accuracy of NACp≥9 to enable terminal area and surface applications such as FAROA. GAMA requested an evaluation of whether the NIC, NACp, and NACv requirements are appropriate to the contemplated applications. One individual aircraft owner noted that the proposed position accuracy is not necessary for GA aircraft not flying closely spaced parallel approaches.

Seven commenters suggested the NACp level be defined by application and location. Boeing requested the FAA document a concept of operations with stated separation goals based on technical analysis to justify the NACp requirement. UPS and United recommended the FAA identify specific areas, such as high-density airports or terminal areas, where applications requiring NACp≥9 will be used.

EUROCONTROL questioned the proposed NACp requirement for surface operations, when there was no NIC requirement. EUROCONTROL also recommended making the NACp≥9 requirement subject to a feasibility check. EUROCONTROL asked how latency is treated in relation to NAC encoding.

UPS and United asserted that the requirement of NACp≥9 exceeds the requirements set by many existing standards, such as MASPS, MOPS, and Surveillance Performance and Interoperability Implement Rule (SPI–IR) documents. They asserted that updated MASPS and MOPS to be published later this year are expected to require NACp≥8. Four commenters noted that the proposed position accuracy requirements would necessitate navigation system upgrades. United Airlines, UPS, and Boeing asserted that lower requirements, such as NACp≥8, can be met by some current systems.

ATA asserted that, by augmenting ADS–B with multilateration, the need for self-reported position accuracy as high as NACp≥9 can be eliminated.

Three commenters, including Dassault Aviation, the European Business Aviation Association, and ALPA, expressed a positive opinion of the NACp≥9 requirements, asserting that stringent position accuracy and integrity requirements will allow for more robust future ADS–B applications and will permit benefits such as reduced separation.

Boeing recommended eliminating the vertical position accuracy requirement. Boeing noted that the operational requirements and applications mentioned in the NPRM do not require vertical position data accuracy. Boeing also noted that the combined NACp encoding requirement penalizes the availability of precise horizontal position accuracy that could support near-term surface applications that don't require vertical data accuracy. Boeing offered that vertical position accuracy data could be encoded as a separate field to avoid impacting the availability of precise horizontal position data.

SANDIA asserted that NIC and NAC are specific to GPS/WAAS, and cannot be obtained from non-WAAS GPS or enhanced long range aid to navigation (eLORAN). SANDIA also noted that existing GPS/WAAS would need to be upgraded to transmit NIC, NAC, and SIL values.

SANDIA also sought clarification regarding how ATC would handle aircraft operating with NACp<9. SANDIA specifically objected to the complete exclusion of such aircraft from ADS–B airspace.

British Airways noted that the NACp requirements include a confidence value in the transmitted vertical geometric altitude. British Airways also asserted that GPS/WAAS equipment is not required to output a vertical protection level (VPL) other than on a localizer performance with vertical guidance (LPV) or lateral navigation (LNAV)/vertical navigation (VNAV) final approach.

Honeywell sought clarification of whether the reported position accuracy is the accuracy of GNSS data at the time of applicability or the time of broadcast. Honeywell sought clarification whether the intent of the proposed rule is to mandate adherence to DO–303, which requires NACp to account for any uncompensated latency.

Rockwell-Collins contested the phrasing in the preamble that stated that information from aircraft transmitting NACp<9 is unusable for ASSA and FAROA. Rockwell-Collins notes that this statement disagrees with DO–289. Rockwell-Collins recommended changing the sentence as follows: "If the aircraft broadcast message element for position has a NACp<9, ATC and aircraft equipped with ADS–B In would be automatically notified that ADS–B Out performance for a particular aircraft is degraded and, therefore, the information does not fully support either situational awareness on the surface or awareness of runway occupancy on approach to airports."

Rockwell-Collins noted the preamble to the NPRM states that "the NACp value must have a small margin of error in position reporting." Rockwell-Collins questions the definition of a small margin, and suggests the goal be no error in our position reporting. Rockwell-Collins recommended deleting the sentence, or changing it to "The NACp parameter must characterize the position accuracy in the ADS–B reported position in order to support evaluating the acceptability of the ADS–B report for supporting the desired application(s)."

Summary of Comments Regarding NACv

Rockwell-Collins asserted NACv may not be determined by the navigation position sensor or system. The commenter further notes that NACv information is not a measured value, but based on its source. Rockwell-Collins asks the FAA to use performance-based descriptions for the parameters. Rockwell-Collins specifically recommends this description, "The NACv is a parameter that is reported as part of ADS–B broadcasts, and it characterizes the 95 percent accuracy in the reported geometric velocity."

Rockwell-Collins recommended the FAA finish the requirements for encoding NACv. Rockwell-Collins noted that the FAA Ad Hoc Velocity Working Group has deemed GPS figures of merit insufficient for encoding NACv. Rockwell-Collins also asserted 14 CFR § 91.225 should be updated to reflect the most recent TSOs for 1090 ES and UAT.

Summary of Comments Regarding NIC

A total of thirteen commenters, including four associations, three aircraft manufacturers, two air carriers, two avionics manufacturers, EUROCONTROL, and an air transport rated pilot, commented on the proposed integrity requirement.

ALPA expressed support for the proposed performance requirements, noting that the higher performance support the development of ADS–B In benefits, including reduced aircraft separation standards.

EUROCONTROL questioned the NACp requirement, without a NIC requirement for surface operations.

Boeing stated that the current industry requirements in the Airborne Surveillance and Separation Assurance Processing (ASSAP)/CDTI MOPS for ASSA and FAROA do not require a NIC or SIL value for target traffic operating on the surface. Boeing recommended the FAA eliminate any requirement for surface traffic and vehicles to transmit NIC and SIL.

The Soaring Society of America, Inc., recommended that the FAA permit operators to use low cost, commercially available GPS equipment with a NIC<7 for VFR only applications. This commenter asserted that these devices could enhance system safety at a lower cost to aircraft owners, not seeking to equip for instrument flight rules operations. One individual air transport-rated pilot asserted that NIC≥7 is not needed for visual acquisition.

UPS and United Airlines asserted that use of SSR, ACAS, and other active interrogation systems in conjunction with ADS–B could increase the accuracy and integrity of vehicles under surveillance in cases of temporary degradation of ADS–B. The commenters recommended that the FAA investigate such augmentation.

GAMA and Rockwell-Collins recommended the NPRM refer to NIC as representing the containment region, because NIC reflects both the horizontal and vertical extent of the containment region.

A number of commenters objected to the proposed performance requirements, as follows:

- Boeing asserted that transitioning from NUC to NIC, NAC and SIL will not increase the accuracy or integrity of received data, as the NPRM suggests. Boeing stated that the data sources themselves will not change; only the receiving entity's knowledge about the accuracy and integrity of the received data.
- SANDIA objected to setting requirements in the form of NIC and NAC values, because they are specific to GPS/WAAS. SANDIA recommended that an RNP value of at least 0.3 addresses most current and future GA needs and is available from existing position sources.
- UPS, United Airlines, IATA, and the Association of European Airlines contested the requirements NIC≥7 and NACp≥9. The commenters asserted that initial ADS–B benefits can be realized with less stringent performance requirements, and recommended that institution of higher requirements be delayed until future surveillance requirements make them necessary. The Association of European Airlines and IATA speculated that, if higher requirements are prescribed, air carriers currently equipped with DO–260-like ADS–B equipment will delay upgrading until a single defined ADS–B package is agreed upon internationally.
- Honeywell asserted that the required accuracy and integrity levels are very high, and recommended that requirements be based on operational applications to align equipage costs with benefits. Honeywell recommended, for example, that requirements based on existing DO–260-like ADS–B equipment be used for en route operations and nonprecision operations in the Gulf of Mexico. Honeywell recommended establishing an integrity requirement high enough to enable use of TIS–B for value-added, near-term applications.
- Airbus asserted that NIC≥7 is possible to achieve, but would require a wiring change in its aircraft. Airbus, like Honeywell, recommended that the accuracy and integrity required be appropriate for use in surveillance and various airborne and surface applications.
- Boeing noted that legacy GPS receivers can meet lower performance requirements, for example NIC≥ 6 and NACp≥8. Boeing pointed out that this would make ADS–B equipage economically feasible for more aircraft operators, particularly operations of older aircraft that would not otherwise equip.
- Boeing also asserted that a NIC≥7 is not necessary to meet existing separation requirements, and recent studies have found it sufficient to support independent parallel approaches with runway spacing greater than 4,300 feet, provided radar monitoring and alerting of excessive position errors are implemented.

Summary of Comments Regarding SIL

EUROCONTROL expressed concern that the SIL focuses on the software assurance level, and not on the actual likelihood of the position source producing an error greater than the integrity containment bound. The commenter asserted that this could cause a problem if position sources other than GNSS sources are used, because they may not have been subject to as extensive a safety assessment. EUROCONTROL recommended a requirement that equipment distinguish between different position sources.

Rockwell-Collins asserted the SIL definition in the NPRM is not consistent with TSO–C166a and TSO–C154b, which point to RTCA documents. Rockwell-Collins specifically explains that SIL characterizes the probability that the geometric position is within the integrity containment region indicated by NIC, considering only the position source. Rockwell-Collins further explains that SIL does not characterize the design assurance level of the transponder. Rockwell-Collins recommended changing the definition of SIL to be consistent with the RTCA-defined standards for ADS–B, which are referred to by the ADS–B TSOs. Rockwell-Collins further recommends the FAA add a requirement that specify the level of criticality needed for the ADS–B avionics, to specify the design assurance level required.

Boeing also questioned the SIL=0 requirement for TIS–B implementation. Boeing asserts that this SIL requirement will limit the surveillance value of TIS–B. Boeing recommends SIL≥2, to be consistent with the ADS–B SIL requirement. Boeing also disagreed with the NPRM definition of SIL and recommended the FAA eliminate any reference to avionics integrity level in the definition of SIL.

ARC Recommendations Regarding Navigation Accuracy and Integrity

The ARC has reviewed the background justification of the NPRM requirement for position accuracy to understand how the NACp≥9 requirement was derived. During the review, the FAA noted that accuracy requirements for ATC separation services, air-to-air applications, and airport surface applications were considered in determining the NACp requirement. Appendix V to this report summarizes the applications and their respective position accuracy performance requirements considered in determining the NPRM NACp requirement.

Also, the ARC reviewed the position performance (NACp/NIC/SIL) requirements specified for ground and airborne ADS–B applications to date as defined by industry committees such as the Requirements Focus Group (RFG), an international effort to join FAA, RTCA, and the European Organization for Civil Aviation Equipment (EUROCAE), to help establish a broader understanding of the position performance requirements for the ATC separation services, air-to-air, and airport surface applications. Appendix W to this report summarizes the performance requirements for these applications, which are also included in Table 1 in section 1 of this report.

The results of these reviews indicate that the most stringent position accuracy requirement is associated with only the airport surface applications (ASSA and FAROA) requiring a NACp≥9. NIC and SIL are not required for the ASSA and FAROA according to the draft MOPS for Aircraft Surveillance Application System (ASAS), because these are situational awareness only applications. All standard ATC surveillance applications

in radar area airspace (3 nm and 5 nm separation, 2½ mile in trail) can be accomplished with a NACp≥8. All currently defined ADS–B applications, other than ASSA and FAROA can be accomplished with a NACp≥8, NIC≥7, and a SIL≥2 (dependent and independent parallel approaches).

The ARC recommends that the use of DO–260-approved equipment for the NRA application require performance parameters consistent with table 1. RTCA/DO–260 does not define a separate accuracy parameter like NACp. Navigation uncertainty category for position (NUCp), which is used in DO–260 to specify position integrity, can be used to estimate position accuracy (RTCA/DO–303, appendix F).

The ARC also considered the practical implications of providing a NACp≥9, as well as less stringent accuracy requirements associated with current position source equipment (see appendix X to this report). It is expected that a high continuity level (for example, 99.9 percent per hour) will be required of the aircraft position equipage to support airborne separation applications and a lesser level for situational awareness applications. This level of continuity to support a NACp≥9 may be difficult to meet because of the performance of the GNSS receiver equipage (for example, SA On and SA Off GPS receivers) and current unaugmented GNSS satellite coverage as identified in appendix Z to this report, assuming a degraded GPS constellation based on the minimum guarantee of satellites. It should be noted that today's GPS constellation is performing at a level better than the assumed minimum guarantee satellite configuration.

The summary findings of the availability/continuity analysis referenced in appendix Z to this report indicate that a NACp≥9 cannot be provided (assuming the minimum satellite guarantee) with today's position equipment with the high degree of continuity defined above (99.9 percent per hour). It is expected that future position sources (for example, tightly coupled GPS/inertial reference system (IRS), dual ranging frequency satellites) will provide the high continuity level required to support the accuracy performance requirement.

The ARC also considered the NACp requirement for airport surface operations. A rudimentary analysis from a visualization perspective of different NACp values and the effects on the position uncertainty with respect to an airport surface is shown in appendix Y to this report. The visualization shows how values of NACp<9 could result in reported positions that would place the aircraft in airport surface non-movement areas.

The ARC considered the vertical accuracy requirement associated with a NACp=9 definition. For the airport surface application, only horizontal accuracy is of interest, and the vertical accuracy has no practical value for aircraft that are known to be on the surface. Also, DO–289 states that the vertical component in the NACp is not required when considering only the horizontal component.

The ARC recommends that the FAA consider specifying the position accuracy requirement by domain/application with lower level of accuracy required for en route, terminal, and advanced operations and a higher accuracy required for the surface applications at the 35 benchmark OEP airports.

The intent of the performance per domain/application recommendation is to provide the operator more flexibility in equipping their aircraft for a specific operation of interest.

The ARC recommends that vertical position accuracy for the surface application is not required.

The ARC also recommends altering the definition for a NACp=9 to remove a vertical accuracy requirement, which would require international coordination and harmonization.

Requiring a vertical position accuracy will result in a more demanding availability requirement (for example, more than the horizontal position accuracy). Also, currently defined situational awareness applications do not require a vertical position accuracy requirement.

To address comments associated with the incorrect definition of SIL in the NPRM, the ARC recommends that the NPRM reference DO–289 for the definition for SIL.

Wide Area Augmentation Systems

Summary of Comments Regarding WAAS

Twenty-two commenters, including four air carriers, three aircraft manufacturers, two avionics manufacturer, seven associations, five individuals, and the DOD submitted comments regarding the effective requirement to use the GPS/WAAS system.

The majority of commenters were critical of the proposed requirement for WAAS to meet the specified position accuracy and integrity performance requirements.

United, Association of European Airlines, IATA, Rockwell-Collins, and the DOD recommended the FAA change the proposal to state that no specific navigation position data source is required, only a performance standard that must be achieved, which would accommodate current and future technologies.

- United asserted the FAA should state the accuracy and integrity of the navigation source, not availability, as implied by the discussion of WAAS in the preamble.
- The Association of European Airlines and IATA asserted that WAAS is not a global solution and does not provide suitable operational benefit to justify its use. The commenters stated that air carriers have and will continue to invest in augmentation systems that are global and offer comparable benefits at a lower cost. The Association of European Airlines sought clarification on the potential use of eLORAN and LORAN C for ADS–B.
- Rockwell-Collins asserted the NPRM does not define a required level of availability. It noted that a statement that GPS/WAAS is required because it is the only position source to have sufficient availability is not a sufficient performance requirement.

Delta recommended determining whether navigation position services other than GPS/WAAS will meet the performance requirements for accuracy and integrity. Delta suggested that a greater number of available satellites in the correct positions could alleviate the need to augment GPS. Boeing noted that the NPRM does not recognize anticipated enhancements to GPS by DOD and planned international GPS systems, which will offer options to meet performance requirements if they prove necessary.

SANDIA stated that the preamble language indicates that other navigational sources may be acceptable, but it does not address how, when, and where they can be used. SANDIA recommended allowing various navigational data sources and tagging them for their accuracy and reliability. SANDIA asserted the range of navigational sources could include VFR (uncertified) GPS, en route GPS, approach GPS, WAAS GPS, eLORAN, and inertial navigation systems (INS).

Dassault Aviation and the European Business Aviation Association expressed appreciation for the recommendation to use GPS/WAAS, while keeping the door open for future technology improvements.

Several commenters, including GAMA, Airbus, and British Airways, noted a future option of GPS coupled with INS as an alternative to WAAS to meet the proposed performance standards. GAMA disputed the NPRM's assertion that WAAS is the only navigation position service that provides the level of accuracy and integrity to enable ADS–B Out to be used for surveillance. GAMA specifically noted that equipment combining GPS with an inertial reference unit has been envisioned but it could not be fully evaluated against the proposed requirements.

Several commenters, including Airbus, FedEx, and the DOD, noted the proposed WAAS requirement adversely affects the international aviation community. FedEx and Airbus asserted WAAS is not globally available or planned to be globally available. FedEx further notes that the NPRM does not promote a harmonized, universal ADS–B Out standard. FedEx recommended using a universal standard of development of ADS–B to promote cost-effective aircraft utilization. The DOD noted a current treaty prohibits European governments from mandating Galileo equipage for access to European airspace. The DOD expressed concern that mandating WAAS equipage for foreign aircraft to access U.S. airspace may nullify the current treaty. The DOD recommended the FAA coordinate with the Department of State regarding treaty implications of mandating foreign equipage with WAAS as part of the ADS–B final rule.

The DOD noted the NPRM prescribes a requirement for WAAS quality GPS positioning and integrity to support ADS–B Out. The DOD intends to use an upgraded Precise Positioning Service (PPS) signal on L–1 and L–2 with M Code to meet the required performance. The DOD anticipates that PPS performance using M Code will be equal to or better than the present PPS signal.

SANDIA asserted the NPRM's requirement to use GPS/WAAS seems to be driven by requirements for parallel approaches and even ground operations at a few airports. SANDIA asserted a WAAS requirement will at least double the minimum price of the UAT transceivers for the foreseeable future. SANDIA pointed out that the WAAS requirement is not only a problem for GA, but for commercial aircraft (1090 ES) as well, because GA is adopting WAAS GPS to benefit from the vertical guidance and low approach minimums. SANDIA noted that the current generation of systems does not output NIC, NAC, or SIL, so a second receiver will be required.

Rockwell-Collins asserted the proposed ADS–B Out performance requirements are achievable with GNSS, which will be the primary source of position to support ADS–B for the foreseeable future. Rockwell-Collins recommended the FAA encourage or

require aircraft installations to include a secondary source of geometric position for ADS–B transmissions, when the primary source of position is unavailable.

Rockwell-Collins and GAMA noted that in appendix H, section 5, paragraph (a), the proposed rule states that "[u]pon receipt of the information by the aircraft antenna(s), the navigation position sensor must process the information in less than .5 seconds." The commenters stated that this latency requirement is written from a GNSS-centric perspective as opposed to being written as a performance requirement for a position source system. Rockwell-Collins recommended the FAA define the primary position source and the secondary position source. Rockwell-Collins also recommended the FAA define latency as a sensor independent performance requirement.

The Cargo Airline Association asserted that omitting the WAAS requirement will reduce initial installation costs and will provide a system that substantially mirrors the requirements already in existence in areas such as Europe, Canada, and Australia. The Cargo Airline Association recommended dropping the WAAS requirement from the initial ADS–B Out implementation.

ACI–NA asserted the proposed ADS–B Out system will not be able to support terminal operations such as instrument approaches to runways separated by less than 4,300 feet, unless the GPS signal availability is improved by additional satellites, ground-based pseudolites such as the Local Area Augmentation System (LAAS), or some other means. ACI–NA asserted that to make significant advances in improving airport capacity, independent instrument approaches to runways spaced as closely as 1,000 feet or 700 feet also are needed. ACI–NA noted that the NPRM solution is for operators to equip with WAAS, but there is no current requirement for WAAS, and major air carriers are not planning on installing WAAS capability. ACI–NA recommended the FAA not promulgate a final rule unless the proposed system can be shown to satisfy the accuracy, integrity, and availability needed to operate in the NAS.

ATA recommended identifying existing position sources and transponders capable of supporting an initial, alternative ADS–B Out system. Appendix A to ATA's comment contains detailed technical information.

Several commenters asserted that the performance requirements appeared to be based on GPS/WAAS as the navigation solution. One commenter speculates that DO–260-like systems may prove usable in en route airspace, and that a DO–260A Change 3 requirement is unjustified. This commenter asserted that the requirement for GPS/WAAS functionality may be too specific. This commenter also noted that the cost of equipping with GPS/WAAS or a tightly coupled inertial positioning source is significant.

One commenter recommended requiring capability for any aircraft manufactured after 2012 or aircraft refit after that time with WAAS capable navigation.

One commenter asserted that an aircraft equipped with GPS for position reporting and a standard instrument landing system/VOR receiver for precision approach capability should be more than adequate for meeting the ADS–B requirements and still have access to class A, class B, and class C airspace in the NAS. The commenter recommended not requiring GPS-enabled aircraft to have WAAS to meet the proposed requirements.

One commenter asserted that if position determination functionality is not built into ADS–B equipment, the GA aircraft would have to install a GPS/WAAS receiver with a TSO, which would substantially increase the cost to each aircraft owner. The commenter recommended that information on additional position determination functionality be included in the NPRM.

ARC Recommendations Regarding WAAS

The ARC recommends that the FAA develop a performance-based rule, which would not specify equipment that can or cannot meet the requirements of an ADS–B equipment mandate.

The ARC understands that the FAA referenced WAAS as a technology that today is known to meet the performance requirements needed to move forward with the NPRM. The ARC understands that the FAA did not intend to limit the positioning source options to WAAS only.

The ARC has reviewed the performance of several positioning sources including WAAS and believes there are opportunities to meet the performance (for example, position accuracy, and availability) of the ADS–B mandate using tightly coupled GPS/IRS and dual GPS frequency positioning sources, assuming the final rule provides a comprehensive definition of the needed performance requirements. Assuming the FAA adopts the multiple continuity requirement for providing a NACp=9 for the surface situational awareness applications (for example, ASSA and FAROA), there are also opportunities to meet the performance of the ADS–B mandate using SA Off GPS receivers alone.

Availability and Continuity

Original Proposal

In § 91.225(a)(1) and (2), the FAA proposed that aircraft be equipped with ADS–B Out equipment that meets the performance requirements in TSO–C166a (1090 ES), or a later version, or meets the TSO–C145b (UAT) or a later version. In section 3 of appendix H to part 91, the FAA specified that to meet the performance requirements, an aircraft's SIL would have to be 2 or 3.

The FAA explained that SIL specifies the ADS–B Out avionics integrity level and the probability that the position error may be larger than the reported NIC. The FAA stated that SIL is typically based on the design assurance level of the ADS–B Out avionics and its navigation position sensor. The FAA noted that while a NIC value varies based on computed navigation sensor position, SIL typically is a static value for ADS–B Out avionics.

The FAA explained that to achieve performance at least equivalent to existing radar systems, a SIL≥2 is proposed. The FAA stated that this value would provide integrity assurance that meets a failure rate probability of 99.999 percent per flight hour.

Summary of Comments Regarding Availability and Continuity

Nine commenters, including two air carriers, two associations, EUROCONTROL, DOD, Boeing, Rockwell-Collins, and an individual commenter, submitted comments relevant to availability.

ALPA expressed support for the proposed performance requirements. ALPA noted that the higher performance requirements are necessary to support the development of ADS–B In benefits such as reduced separation.

UPS and United objected to an availability requirement. The commenters recommended that the rule simply state that if the necessary accuracy and integrity are not achieved, the operator will not be able to fly, so that, rather than incurring the cost of a high availability system, the operator would have the option of not operating if required levels are not available at certain times.

The DOD and an individual commenter noted confusion in the NPRM failure rate probability of 99.999 percent per flight hour. The DOD recommended the FAA specify a maximum allowed failure rate probability of 0.001 per flight hour.

Rockwell-Collins noted the NPRM does not define a required level of availability. Rockwell-Collins asserted that the FAA needs to define "sufficient availability" beyond the requirement for a GPS/WAAS receiver. Rockwell-Collins asserts that availability for a single aircraft is an economic decision that should not be specified. Rockwell-Collins further asserts that because continuity can impact safety, the FAA should specify, in the NPRM, the required continuity of continuing to broadcast ADS–B Out information with sufficient quality.

ARC Recommendations Regarding Availability and Continuity

The ADS–B rule will include minimum requirements for accuracy and integrity performance[15] to support intended operations. It will be expected that at all times during the planned flight the airplane equipage will be able to support the minimum performance requirements with a reasonable availability. For instance, the required minimum NIC, NACp, and NACv values may be required 99.9 percent of the time.

The primary factor affecting the availability of an aircraft to provide ADS–B Out is associated with the external signals used by the aircraft systems to determine relevant ADS–B Out information, including for example the GNSS signal-in-space. A secondary factor affecting the availability of an aircraft providing ADS–B Out at the required performance is all the on-aircraft avionics and systems used to support determining and transmitting the ADS–B Out information (for example, GPS receivers and ADS–B transponders). The ARC is primarily concerned with a continuity requirement to address the signal-in-space availability. The ARC also notes the effect of airplane avionics is expected to be a small component in the overall ADS–B Out continuity.

[15] The performance levels are also referred to as NACp, NACv, and NIC.

Pre-Dispatch Continuity[16] Check

The ARC recommends that the FAA create a function for centralized, expert calculation and reporting of predicted continuity of ADS–B performance parameters for a representative set of receive equipage configurations assuming the actual GNSS satellite coverage required for the operation.

The air navigation service provider would be expected to notify the operators in the same way that they currently notify that a radar station or instrument landing system is inoperable. In this way, the operators can inventory their fleet and ensure their specific equipage configurations can meet the performance requirements during receiver autonomous integrity monitoring outages. In addition, an operator can choose to spend more money on equipage that is more capable and continue to fly during the outage periods. The ARC's recommendation supports the FAA's response to the clarifying question with regard to providing such a dispatch capability (see question 5 in appendix E to this report). It is worth noting that with the best satellite coverage (for example, 24 satellites), 100 percent availability cannot be obtained for NACp≥9; only 98.5 percent (assuming SA Off per analysis in Table 3 of appendix Z to this report) can be obtained.

Availability versus Equipment Performance

The ARC has reviewed the availability of accuracy and integrity for GPS SA On, GPS SA Off, and WAAS, and the ability to meet certain levels of availability (see appendix Z to this report). Current positioning sources such as GPS receivers with SA On cannot meet the NACp≥9 requirement any time, while GPS receivers with SA Off can meet a NACp≥9, but only 98.3 percent of the time based on minimum guarantee satellite constellation performance, which is well below what is currently achievable. GPS receivers with SA Off can provide a NACp≥8 during 99.98 percent of time, at the minimum guaranteed GPS constellation.[17] GPS WAAS (SBAS) can meet NACp≥9 with 99.9 percent availability in SBAS coverage.

The ARC believes that the ADS–B requirement should be performance-based, but does not expect SA On GPS receivers to meet the NACp≥9 at any time, which should be noted by the community. The ARC endorses an explicit statement to the community that beyond a certain date, SA On receivers will not meet needed performance of certain applications that will be introduced in the NAS.

The ARC has not reviewed dual satellite constellations, but expects Galileo to provide enhanced availability. Aircraft operators should be allowed to use Galileo/GPS, GPS/IRS, WAAS, and other satellite augmentation systems to meet the performance requirement. Also, this configuration will require an analysis for reporting its predicted availability (Notices to Airmen) when there is a sufficient user community of installed aircraft equipment. Several members of the ARC are concerned that the U.S. Government has not provided an explicit policy statement that states that operators can use Galileo or other non-U.S. infrastructure to meet the needed performance of the ADS–B rule.

[16] Continuity is defined as the short-term availability, typically in terms of hours or days, required to maintain the minimum performance requirements for NACp, NACv, NIC, and SIL for a given operation. Continuity can take into account the current satellite constellation and power.
[17] Boeing, Rockwell Collins, and MITRE analysis.

The ARC recommends that the U.S. Government make the necessary policy decisions to allow for the use of positional resources like Galileo as part of the infrastructure to meet aviation performance requirements (performance-based airspace).

The ARC also believes that GPS receivers tightly coupled with IRS will provide a solution that meets the needed ADS–B Out performance for the air transport and business jet operators. This is possible with SA Off GPS receivers and also with many SA On GPS receivers. Honeywell has performed an analysis (see appendix EE to this report), which indicates that their tightly coupled GPS/IRS system will improve the availability of meeting NACp≥9 over an unaugmented GPS sensor such that the availability of meeting the NACp≥9 (horizontal only) will exceed 99.9 percent (with a Martinez 24-satellite constellation). Note that the tightly coupled GPS/IRS solution does not apply to the GA community because most do not include inertial systems.

The ARC recommends the FAA consider specifying a continuity of service requirement such that the probability, given that pre-dispatch continuity checks predicted satisfactory performance, that the ADS–B Out required performance will be available 99.9 percent per hour during the time when performing an operation for a given domain or application.

This recommendation is intended to provide some assurances that each aircraft operating in the ADS–B Out mandated airspace be able to continuously meet all of the ADS–B Out performance requirements in that airspace. The ARC provides a detailed overview of the concept of "continuity" in appendix AA, including four possible options for setting a continuity requirement. Consideration should be given for specifying the continuity of external signals-in-space that if lost would potentially affect a large number of ADS–B Out participants (for example, GNSS signal-in-space) as well as specifying the continuity of the aircraft avionics that support the ADS–B Out function on a single aircraft (for example, ADS–B Out transponder).

The ARC has determined through the review of the GPS Signal-in-Space Availability Analysis (appendix Z to this report) that based on the minimum guaranteed satellite assumption and SA Off receivers, a NACp≥9 for horizontal position (as required for the surface applications) is available only 98 percent per hour (averaged for 10 locations identified in the analysis). If worst case satellite constellation assumptions are considered, the availability number could be as low as 90 percent.

The ARC recommends the FAA research and specify a continuity requirement commensurate with allowing SA Off GPS only receivers to meet the performance requirements in the NAS. The ARC recommends that the FAA specify two continuity requirements for the surface situational awareness applications,[18] The first requirement is approximately 95 percent per hour (to be verified by FAA analysis) for a horizontal position accuracy of NACp≥9. The second requirement is 99.9 percent per hour for a horizontal position accuracy of NACp≥8.

[18] Airport Surface Situational Awareness (ASSA) and Final Approach Runway Occupancy Awareness (FAROA) are examples of future applications that will require more stringent performance requirements than separation applications for non-radar airspace and radar airspace. The continuity requirement for situational awareness applications is for the purpose of system design and not for aircraft operational limitations.

By allowing the multiple continuity requirement for the surface situational awareness applications (for example, ASSA and FAROA), meeting the threshold of a NACp≥9 could potentially be obtained with an SA Off GPS receiver. Understanding the fact that the satellite constellation provides better performance than the minimum guarantee (21 satellites 98 percent of the time), the intent is not to drive additional cost to the operator because of a lack of guarantee for a situational awareness surface application. It is interesting to note that DO–289 allows for degraded operations with traffic reporting a NACp=8 and the preferred NACp=9.

Latency

Original Proposal

The FAA proposed adding appendix H to part 91 (Performance Requirements for Automatic Dependent Surveillance-Broadcast (ADS–B Out)). Section 5 of proposed appendix H states

(a) Upon receipt of the information by the aircraft antenna(s), the navigation position sensor must process the information in less than 0.5 seconds.

(b) The processed information from the navigation position sensor must be transmitted in the ADS–B Out message in less than 1.0 second.

(c) The aircraft must transmit its position and velocity at least once per second while airborne or while moving on the airport surface.

In the preamble to the NPRM, the FAA explained that the proposal defines latency for the ADS–B message from the time information enters the aircraft through the aircraft antenna(s) until the time it is transmitted from the aircraft. The FAA added that a specific limit between the time the information is received and then processed through onboard avionics is necessary to ensure timely transmission of information and to realize the benefits of the ADS–B system. ADS–B Out transmits accurate and timely information more frequently than information transmitted under the current radar surveillance system. With ADS–B, information is sent to the aircraft from satellites, processed on the aircraft, and sent to ground stations. The information would enter the aircraft through an antenna(s), be processed by the onboard avionics (for example, navigation sensor, navigation processor, and either 1090 ES or UAT broadcast links), then transmitted to the ground stations through another antenna(s) on either the 1090 MHz frequency or the 978 MHz frequency, depending upon the aircraft's avionics.

Summary of Comments Regarding Latency

Fourteen commenters, including three air carriers, three aircraft manufacturers, four avionics manufacturers, two associations, EUROCONTROL, and one individual, submitted comments regarding the proposed requirements for the latency of ADS–B Out broadcast message elements.

Many commenters criticized the proposed latency requirement for being too strict, or at least asserted that it would be difficult to achieve technologically to meet those

requirements. The following commenters were critical of the proposed latency requirement:

- Lockheed asserted that the proposed latency requirements will not be possible for many military aircraft because military GPS receivers have a processing rate of 1 Hz. Lockheed recommended allowing use of a time tag in the ADS–B message structure as an alternative to the latency requirement. The output of the aircraft state vector at 1 Hz is still possible with the time tag.
- SANDIA noted that GPS systems use filtering to arrive at a location and stated that measuring the latency between the GPS antenna and the output is not exact. SANDIA also noted that some WAAS programs have a latency of 0.7 seconds. SANDIA recommended allowing the navigation sensor 1.0 second latency, as opposed to the requirement of less than 0.5 seconds latency that was proposed by the FAA. SANDIA asserted 1.0 second latency is reasonable and within the design specifications of most navigation sensors.
- Boeing asserted that the maximum allowed latencies specified in the NPRM are not consistent with values allowed under other standards, such as the RTCA Airborne Surveillance Applications MASPS, or the EUROCAE ADS–B NRA Safety, Performance, and Interoperability Requirements. Boeing recommended changing the latency allowances in the NPRM to permit the total airplane system to process GNSS information received by the aircraft antenna(s) and transmit the ADS–B message from the ADS–B Out broadcast link avionics in less than 1.5 seconds with 95 percent probability and less than 3.0 seconds with 99.9 percent probability.
- Eclipse Aviation asserted the requirement that the navigation sensor process information received by the aircraft antenna(s) and forward this information to the ADS–B broadcast link avionics in less than 0.5 seconds seems overly excessive. Eclipse sought clarification as to what analysis or study data the FAA used to derive this figure. Eclipse also sought clarification as to whether the proposed data latency requirements apply to positional (GPS-based) data only, or whether they also apply to non-GPS data such as barometric data and heading data.
- EUROCONTROL asserted that the definition of latency as the time from reception of information to time of broadcast and the statement that the navigation sensor will process information and forward it to ADS–B avionics within 0.5 seconds are inconsistent. EUROCONTROL asserted that this is not helped by the requirement that the ADS–B avionics process and broadcast within 1 second of receiving information from the navigation sensor. EUROCONTROL sought clarification on the requirements for compensated and uncompensated latency, and how they are reflected in the NAC encoding.

UPS and United recommended specifying the accuracy of position information at the time of transmission, rather than setting an allowable latency. This would allow the position to be calculated by extrapolation using aircraft velocity or other tracking techniques. UPS and United asserted that the time of a valid position output from the GNSS receiver should be used as the starting point of the latency time rather than the

receiving of the GNSS signal at the antenna. GNSS signals from multiple satellites are necessary to calculate GNSS position. Position solutions cannot reliably be correlated to a specific time of GNSS antenna signal reception.

Boeing asserted that the notion of information received at the GPS antenna is ambiguous in the sense that the elements of the navigation message come in over a relatively large span of time. Boeing stated that the time that information is received at the antenna is not an appropriate point of reference. Boeing pointed out that a GPS receiver outputs a position message at a specified measurement time of applicability, and that an ADS–B system may further extrapolate the position to a different time of applicability to compensate for the effects of latency. To the extent latency values need to be specified at all, Boeing recommend that they be specified relative to the time of applicability for the reported data.

Honeywell recommended expressing latency from the time of applicability of a reported position output to the time of transmission of the ADS–B state vector message. Honeywell also recommended allowing a maximum latency of 1.5 seconds with a 95 percent probability. In addition, Honeywell asserted that the NPRM implies that position extrapolation cannot be used to meet the overall latency requirement of 1.5 seconds. It recommended revising the NPRM to allow and specify the appropriate use of extrapolation.

Honeywell asserted that it is not clear that the following assumption is correct: if a position source is used that has less than 0.5 seconds of latency then this should imply that the ADS–B Out transmit subsystem can be allocated more than 1 second of latency. Honeywell recommended that the FAA not allocate the latency requirements between the sensor and the ADS–B Out subsystem, but should instead specify the overall performance requirement.

Honeywell asserted that the current 1090 MHz ADS–B Out standardization documents (DO–260A, DO–302) are written so latency of the ADS–B Out subsystem is referenced to the time of applicability of the position report from the GNSS sensor. Honeywell noted the NPRM does not measure latency in the same way. Honeywell recommended the NPRM be modified so that the latency reference is consistent with ADS–B Out standardization documents.

Honeywell asserted that it is unclear if the intent of the NPRM is to mandate the uncompensated latency requirement by requiring adherence to DO–302. Honeywell recommended the NPRM clarify that limiting uncompensated latency to 0.1 seconds is not required to satisfy the NPRM.

Aviation Communication & Surveillance Systems concurred with the NPRM approach of identifying latency requirements for processing and transmittal of position and velocity, but sought clarification regarding how these requirements were established.

The Association of European Airlines and IATA asserted jointly that the 1.5 second maximum allowable latency for the overall ADS–B system may be a significant challenge for retrofitted aircraft. They recommended conducting a study for each aircraft type and avionics equipment combination to determine compliance.

GAMA requested that the FAA differentiate between the latency requirements of a primary source of ADS–B position, such as GNSS, and secondary sources of position, such as distance measuring equipment (DME) through the flight management system (FMS) because the latency will be significantly different. GAMA noted that the NPRM provides no incentive for implementing a secondary position source because these secondary position sources will not meet the "minimum" requirements of the rule. GAMA recommended defining primary position source and secondary position source latency as performance-based requirements. GAMA asserted that latency should be sensor independent.

GAMA also asserted that appendix H to part 91 is not the appropriate place for latency requirements because of the difficulty associated with revising a regulation. GAMA recommended defining latency requirements in an RTCA MOPS, a TSO, or another appropriate document and then incorporating them by reference into appendix H.

Additionally, GAMA asserted that in appendix H, section 5, paragraph (a), the latency requirement is written from a GNSS-centric perspective as opposed to being written as a performance requirement for a position source that is not a GPS-WAAS sensor, such as an INS. GAMA also asserted the proposed latency requirements are unclear as to whether end-to-end- system latency is 1 second or 1.5 seconds. GAMA recommended clarifying the latency requirements so there is no ambiguity as to the end-to-end- system latency.

GAMA asserted that the requirement that allocation to MOPS compliant equipment of the time to indicate changes to NIC, NAC or SIL, as required in proposed section 3, paragraph (b) of appendix H to part 91, is not complete. GAMA recommends that the FAA ensure that RTCA SC–186 has finalized its work before publication of a final rule relying on its standards.

Airbus questioned the wisdom of separating allowable latency for information processing and information transmission as the proposed requirement does. Airbus asserted that the separation into two latency allowances does not match what is required or standardized for non-radar area applications. Airbus also stated that the proposed latency requirement is not compatible with a NACp≥7, referencing DO–302. Airbus asserted that this is inconsistent with the proposed accuracy and integrity requirements in preamble section IV.B.4.

Rockwell-Collins asserted that appendix H, section 5, paragraph (b) refers to a "navigation position sensor," but should use the term "position source" instead. The position source used by ADS–B may not be a "navigation sensor." This proposed change is consistent with DO–302. Rockwell-Collins recommended changing "navigation position sensor" to "position source".

Rockwell-Collins asserted that the definition of latency is not a generic definition and is not consistent with performance-based requirements. The definition does not make sense generically for all possible ADS–B data and even positioning systems other than GNSS or DME usable by ADS–B. ADS–B Out broadcast latency needs to be defined in a different manner to apply to all broadcast elements regardless of their source. Rockwell-Collins recommended defining the latency of the ADS–B Out Broadcast Message elements in a generic sense that applies to all message elements and all types of

possible sources of information. The proposed definition is too limiting to the GNSS position element.

Rockwell-Collins asserted there needs to be a different latency requirement for a "primary" source of ADS–B position (for example, GNSS) and a "secondary" source of position (for example, DME/DME through the FMS). The latency will be significantly different. With the ADS–B Out proposed requirements written as they are, there is no incentive for implementing any secondary position source, as none of them will meet the minimum requirements. Rockwell-Collins recommends defining both primary position source and secondary position source requirements.

Rockwell-Collins asserted that it is impossible to meet the proposed ADS–B Out performance requirements for changes in NIC (that is, "Changes in the NIC, NAC, or SIL must be broadcast within 10 seconds") using any position source that only meets a 10-second time-to-alert integrity requirement, as is required for terminal RNAV systems. Such navigation systems consume the entire 10-second allocation, leaving no budget for the aircraft installation and ADS–B equipment. A minimum of 12.1 seconds is needed for transmitting the NIC, and a minimum of 3.1 seconds is needed to transmit changes in the NACp, NACv, and SIL. See DO–289 for details. Rockwell-Collins recommended changing the requirement to be consistent with the latency allocation in ASA MASPS (D0–289) as follows: "Changes in the NIC must be broadcast within 12.1 seconds and changes in NACp, NACv, and SIL must be broadcast within 3.1 seconds."

One individual commenter asserted the requirement for navigation sensors to process and output information in less than 0.5 seconds is in conflict with DO–229D, which only applies that standard to some data, but permits, for example, horizontal protection limit (HPL) latency to be longer (2.0 seconds for HPL–SBAS and 8.0 seconds for HPL–FD). The commenter stated that HPL is directly linked to the NIC and NAC values required by ADS–B. The commenter recommended resolving the conflict between the NPRM requirements and DO–229D, or explaining why the requirements are not consistent with the standard.

ARC Recommendations Regarding Latency

The ARC has reviewed the NPRM latency requirements and has evaluated and identified several recommendations (appendix DD to this report) for clearly specifying the latency requirements associated with providing ADS–B Out position information.

The ARC believes that the requirement for the navigation position sensor to process information in less than 0.5 seconds upon receipt at the aircraft antenna(s) is written from a GNSS-centric perspective as opposed to a performance requirement for the position source that is not necessarily a GPS-WAAS sensor, but possibly INS.

Furthermore, the latency requirements defined in 14 CFR §91.225 appendix H are ambiguous. It is not clear whether the end-to-end system latency is allowed to be 1 second or 1.5 seconds.

The ARC recommends that latency requirements should be specified at the aircraft level, not the equipment level.

This allows for flexibility in the allocation of latency between avionics equipment.

The NPRM uses time of measurement (TOM) as the reference time for latency measurements. The notion of information received at the GPS antenna is ambiguous in the sense that the elements of the navigation message come in over a relatively large span of time. Even pseudo-range measurements are accomplished by integrating over a period of time. The time that information is received at the antenna is not an appropriate point of reference. A GPS receiver outputs a position message at a specified measurement time of applicability.

The ARC recommends that latency be referenced to the time of applicability of the position provided by the position sensor (for example time mark for GNSS sensor position sources).

This defines a clear reference point for latency considerations.

The ARC considered the impact of meeting ground surveillance (ATC) requirements while minimizing the impact of aircraft wiring for the maximum total latency (time of measurement to time of transmission). By specifying a maximum uncompensated latency and considering this uncompensated latency in the performance of the ground or airborne application can minimize the impact on aircraft installations (eliminate requirement to wire GPS time mark). Note that today's unsynchronized (not synchronized to GPS time mark) avionics equipment can achieve a 95 percent uncompensated latency of ≤ 0.6 seconds and an average total latency of 1.5 seconds. Smaller uncompensated latency can be achieved by existing avionics or by minor updates to existing transponders.

The ARC recommends that maximum uncompensated latency be specified such that it minimizes or eliminates installation wiring changes (for example GPS time mark) of existing ADS–B OUT implementations while meeting ATC surveillance requirements.

Specifying both the total latency and uncompensated latency is strongly recommended.

The ARC reviewed the NPRM performance requirements associated with the broadcast of the NIC, NAC, or SIL parameters within 10 seconds. Industry has evaluated the 10 second requirement and do not believe that it can be practically engineered. The SIS for many of the positioning systems consumes the entire 10 second budget (for example LAAS differential positioning service), which leaves no time for the aircraft installation's time requirements. As an example, there has been no allocation beyond the 10 seconds for actual broadcast which is asynchronous to the position source output.

A minimum of 12.1 seconds under normal conditions[19] is needed for transmitting the NIC, and a minimum of 3.1 seconds under normal conditions is needed to transmit changes in the NACp, NACv, and SIL. These proposed allocations are consistent with the DO–289 and allow a 10 second time-to-alert positioning source, plus 1 second between interfaces A1 and B1 (Table 3-1), and 1.1 seconds between interfaces B1 and D (per section §3.1.1.3 in the ASA MASPS – DO–289) for the transmission of integrity

[19] Does not include the rare condition where a simultaneous change in NIC and NACp along with missed on-aircraft communications between the position source and transponder. In this case the transponder could add an additional 2 seconds. The time-to-alert in the WAAS MOPS is only a 0.999 number and does not account for the missed message. The LAAS MOPS fully accounts for missed messages in it's time-to-alert.

containment bound NIC which is broadcast as part of the state data. The proposed allocation for broadcasting changes in the status data of NACp, NACv, and SIL allow an additional 1 second from the MASPS allocations between interfaces A1 and B1 (1 second) and B1 and D (1.1 second). The rationale is that for 1090 ES transmissions, status data (which includes NACp, NACv, and SIL) is broadcast in lower rate messages than state data.

The ARC recommends the requirement of the equipment to broadcast a change in NIC and SIL within 12.1 seconds (95 percent).

The ARC recommends the requirement of the equipment to broadcast a change in NACp and NACv within 3.1 seconds (95 percent).

The ARC has requested support from RTCA SC–86 to address the latency comments submitted to the NPRM. SC–186 has established an ad hoc group to resolve issues with the Surveillance Transmit Processing (STP) MOPS.

This ad hoc group has agreed to consider the ARC's recommendations on latency and provide standards definitions where applicable, which closes out the ARC's work on latency (reference item 4.3 in the "Minutes of Meeting #02 of RTCA SC–186 Ad Hoc Subgroup for the Review of the STP MOPS").

Proposed Changes to Rule Language for all Performance Parameters

The ARC proposes that appendix H to part 91 (Performance Requirements for Automatic Dependent Surveillance-Broadcast (ADS–B Out) be revised as follows:

Section 3 ADS–B Out Performance Requirements for NIC, NACp and NACv, and SIL of proposed appendix H, some of which are unchanged from the NPRM.

(a) For aircraft broadcasting ADS–B Out as required under §91.225(a), (c), and (d):

1. The aircraft's NACp for the positioning source must meet the following:

i. For aircraft performing ASSA and FAROA in the terminal area and surface of the 35 OEP airports, the horizontal position component of NACp must be greater than or equal to 9 for 95 percent per hour and must be greater than or equal to 8 for 99.9 percent per hour. Based on the current definition of NACp, the vertical position component of NACp is not required for ASSA and FAROA applications. .

ii. For aircraft performing 3 nm separation in non-radar areas, the NACp must be greater than or equal to 6 for 99.9 percent per hour.

iii. For aircraft performing 5 nm separation in non-radar areas, the NACp must be greater than or equal to 5 for 99.9 percent per hour.

iv. For aircraft performing 5 nm separation in radar areas, the NACp must be greater than or equal to 7 for 99.9 percent per hour[20].

[20] NACp, NIC, NACv values based on draft RFG Enhanced ATS in Radar Areas using ADS-B Surveillance (ADS–B–RAD) Application. These values should be reviewed and updated against the final accepted RTCA document for this application.

v. For aircraft performing 3 nm separation in radar areas, the NACp must be greater than or equal to 7 for 99.9 percent per hour[20].

vi. For aircraft performing 2.5 nm in-trail separation on approach in radar areas, the NACp must be greater than or equal to 7 for 99.9 percent per hour[20].

2. The aircraft's NACv for the positioning source must meet the following:

   i. For aircraft performing ASSA and FAROA in the terminal area and surface of the 35 OEP airports, NACv is not required.

   ii. For aircraft performing 3 nm separation in non-radar areas, the NACv is not required.

   iii. For aircraft performing 5 nm separation in non-radar areas, the NACv is not required.

   iv. For aircraft performing 3 nm separation in radar areas, the NACv is not required[20].

   v. For aircraft performing 5 nm separation in radar areas, the NACv is not required[20].

   vi. For aircraft performing 2.5 nm in-trail separation on approach in radar areas, the NACv is not required[20].

3. The aircraft's NIC must meet the following:

   i. For aircraft performing ASSA and FAROA in the terminal area and surface of the 35 OEP airports, NIC is not required.

   ii. For aircraft performing 3 nm separation in non-radar areas, the NIC must be greater than or equal to 5 for 99.9 percent per hour.

   iii. For aircraft performing 5 nm separation in non-radar areas, the NIC must be greater than or equal to 4 for 99.9 percent per hour.

   iv. For aircraft performing 3 nm separation in radar areas, the NIC must be greater than or equal to 6 for 99.9 percent per hour[20].

   v. For aircraft performing 5 nm separation in radar areas, the NIC must be greater than or equal to 5 for 99.9 percent per hour[20].

   vi. For aircraft performing 2.5 nm in-trail separation on approach in radar areas, the NIC must be greater than or equal to 7 for 99.9 percent per hour[20].

4. The aircraft's SIL must meet 2 or 3.

5. Changes in the NIC and SIL must be broadcast within 12.1 seconds (95 percent).

6. Changes in the NACp and NACv must be broadcast within 3.1 seconds (95 percent).

Broadcast Message Elements

Original Proposal

In appendix H to part 91, the FAA proposed performance requirements for ADS–B Out. Section 4 of proposed appendix H states that each aircraft must broadcast the following information, as defined in TSO-C166a or later version, or TSO–C154b or later version. The pilot must enter information for message elements (g) through (k) of this section during the appropriate phase of flight: (a) the length and width of the aircraft; (b) an indication of the aircraft's lateral and longitudinal position; (c) an indication of the aircraft's barometric pressure altitude; (d) an indication of the aircraft's velocity; (e) an indication if ACAS II or ACAS is installed and operating in a mode that can generate resolution advisory alerts; (f) if an operable ACAS II or ACAS is installed, an indication if a resolution advisory is in effect; (g) an indication if the flightcrew has selected to receive ATC services; (h) an indication of the Mode 3/A transponder code specified by ATC; (i) an indication of the aircraft's call sign that is submitted on the flight plan, or the aircraft's registration number; (j) an indication if the flightcrew has identified an emergency and if so, the emergency status being transmitted; (k) an indication of the aircraft's ''IDENT'' to ATC; (l) an indication of the aircraft assigned ICAO 24-bit address; (m) An indication of the aircraft's emitter category; (n) an indication whether a CDTI is installed and operable; and (o) an indication of the aircraft's geometric altitude.

In the preamble to the NPRM, the FAA explained these message elements contain the data necessary for ATC to support aircraft surveillance by ADS–B. The message elements required support future NextGen air-to-air applications such as reduced horizontal separation and self separation. These message elements also support the capability for aircraft avionics to be verified during normal operations for continuing airworthiness in lieu of conducting ground checks of avionics.

Summary of Comments Regarding Broadcast Message Elements

A total of 22 commenters, including 4 avionics manufacturers, 4 air carriers, 4 aircraft manufacturers, 3 associations, EUROCONTROL, the DOD, and 5 individuals, submitted 60 comments relating to the proposed broadcast message element requirements.

The European Business Aviation Association and Dassault Aviation asserted that transmission of an emitter category transmission to quantify the wake vortex signal is an important feature for wake vortex prediction to determine aircraft separations.

Six commenters addressed technical aspects of the barometric and geometric altitude elements, as follows:

- The European Business Aviation Asssociation and Dassault Aviation asserted that the requirement to transmit geometric altitude is an excellent initiative, which will permit monitoring aircraft altitude in RVSM airspace and in the future allow qualification of ”combat aircraft” for operations in such RVSM airspace.
- Three commenters, including Boeing, Airbus, and one individual, commented unfavorably on the requirement for broadcast of aircrafts' geometric altitudes.

The commenters noted that GPS geometric altitude is inaccurate, has no integrity, and is not suitable for verification of barometric altitude.

- The individual commenter asserted that GPS/WAAS has precise altitude output with integrity only on LPV or LNAV/VNAV final approaches.
- The individual commenter also noted that the NPRM discusses a confidence value in the vertical geometric altitude transmitted, and asserted that GPS/WAAS equipment is not required to output a VPL other than on LPV or LNAV/VNAV final approaches.
- Honeywell sought clarification that geometric altitude is height above ellipsoid (HAE) rather than m.s.l.. Honeywell noted that all GPS receivers have a consistent definition of HAE, but not of m.s.l..
- The individual commenter sought clarification of whether reported altitude would be in 25 foot increments, like existing Mode S, or 100 foot increments like Mode C.
- UPS noted that the NPRM requires that the barometric altitude for ADS–B and for Mode C/S transponders must be from the same source, and questioned whether the source must be switched when switching transponders. Similarly, GAMA and Rockwell-Collins noted that the preamble states that the altitude transmitted by both ADS–B and the transponder must be the same. The commenters disputed this characterization, noting that the rule only requires that the source be the same.
- SANDIA sought clarification of whether separate altitude encoders are necessary for ADS–B and for an aircraft's Mode C/S transponder, or whether the same encoder could be used for both.

Seven commenters commented on the technical aspects of the velocity message element, as follows:

- Four commenters, including UPS, United, Rockwell-Collins, and Aviation Communication & Surveillance Systems (ACSS), an avionics manufacturer, noted that aircraft velocity may be calculated by more than one onboard sensor. UPS, United, and ACSS recommended that use of the most accurate sensor available be required.
- Rockwell-Collins, GAMA, and SANDIA asserted that the preamble discussion confuses velocity and airspeed. Airbus recommended that the FAA change the language from “aircraft’s airspeed” to “GPS ground velocity.”
- UPS questioned whether airspeed is an acceptable indication of velocity.

Other than as noted above, twelve commenters questioned the wisdom of or criticized the feasibility of some message element requirements:

- FedEx and Boeing asserted that it is unclear how additional broadcast elements will be utilized by ATC to enhance productivity.

- ATA pointed out that some of the proposed message elements have not been required in other implementations of ADS–B outside the United States, and asserted that they would impede acceleration of an ADS–B Out program.
- British Airways asserted that DO–260-like transponders will not transmit SSR beacon codes, but only the fact that there is an emergency. BA stated that codes will still require a manual IDENT. UPS and Boeing questioned the need for beacon codes, since ground systems should be able to identify specific aircraft by beans such as the ICAO Mode S identification.
- EUROCONTROL asserted that some required message elements are unjustified, including aircraft length/width, indication of requested ATC services, emitter category, CDTI indication, and geometric altitude. EUROCONTROL also requested that the need for elements such as ACAS equipage confirmation and RA in progress indications be confirmed through internationally agreed requirements.
- The DOD emphasized that some of the message items may be necessary only for advanced applications. The DOD recommended that the FAA separate out the elements required for surveillance and the elements required for future applications.
- One individual certificated as a commercial pilot asserted that a message element indicating whether an aircraft is equipped with diversity antennas is unnecessary, because future ground-based applications will be able to determine whether an aircraft has a top antenna and adjust accordingly.
- UPS, United, Airbus, and ACSS questioned the purpose of the element indicating if a flight crew has requested ATC services. UPS asserted that such requests would only apply to aircraft that do not file a flight plan prior to flight, and request services verbally from controllers. UPS argued that this element should be optional for operators that always file a flight plan.
- UPS and United pointed out that IDENT is a concept used in the current system based on lack of aircraft identification except in an aircraft's flight plan. The commenters contended that, because aircraft identification will be part of the ADS–B broadcast message set, an IDENT function is an unnecessary cost to operators, and should not be required.
- Airbus commented that the rule language is misleading, because the pilot does not manually input the aircraft’s identify, but rather activates the IDENT function.
- Boeing, SANDIA, and Airbus questioned the requirement for an element indicating if a CDTI is installed and operable. SANDIA asserted that many displays do not output an indication of whether they are operable. Boeing and Airbus pointed out that proposed rule is not intended to mandate ADS–B In. UPS questioned wither an indication that a CDTI is installed must still be sent if the CDTI is inoperative.

- Airbus questioned the need for an indication if TCAS/ACAS is installed and operating, noting that this is not an existing requirement for radar or non-radar area applications.
- Rockwell-Collins questioned the requirement for transmission of an aircraft's ICAO 24-bit address, noting that this is inconsistent with the anonymous ID concept. Rockwell-Collins recommended broadcast of either the ICAO 24-bit address or an anonymous address assigned by ATC or the operator.

UPS also asserted that many of the message element requirements lack sufficient definition, and noted that, without guidance, an installer or integrator would be left to interpret the meaning of the DO–260A table, which could result in conflicting interpretations.

Other than as already noted above, four commenters commented or sought clarification on specific elements:

- Eclipse Aviation noted that draft AC-20-ADS–B Out states that track angle may be substituted for heading if heading is not available. Eclipse noted that heading is usually available, while track angle is often not available.
- UPS questioned whether an indication that TCAS is installed must be sent if TCAS is in T/A only mode.
- UPS also noted that DO–260A allows for multiple emitter categories, and questioned what emitter category would be appropriate for a give aircraft model.
- Airbus, Rockwell-Collins, and GAMA questioned at what times the length and width of the aircraft must be broadcast. The commenters noted that this element is most important for ground operations, but, for some small aircraft, broadcast of the in air message set at all times is permitted.
- Airbus also sought clarification of the definition of emergency status, for purposes of the element requiring an indication of whether an emergency has been identified.

Five commenters recommended the addition of message elements not addressed in the proposed rule:

- Airbus noted that aircraft length and width are only significant for ground operations, and are beyond the scope of radar and non-radar area ADS–B Out applications, nor are they included in the interoperability requirements of DO–260A. Both Airbus and an individual aircraft owner recommended that, if aircraft length and width elements are to be required, the offset of the aircraft's position from the center of the aircraft should also be a message element, because the difference of half an aircraft length could be significant in ground operations.
- One individual certificated as an air transport pilot noted that the message set defined in the NPRM excludes ASA capability level (ACL), which is part of DO–289. The commenter asserted that this omission would affect

introduction of air-to-air applications such as enhanced visual acquisition, and would prevent flightcrews from knowing if their aircraft is equipped and certified to perform pair-wise ADS–B applications.

- EUROCONTROL asserted that ADS–B should be capable of transmitting Mode S downlinked aircraft parameters (DAP) such as selected altitude, to ensure consistency with core European surveillance requirements.
- Honeywell noted that the NPRM implies that navigation accuracy and integrity parameters must be transmitted, but does not include them as required broadcast message elements.

ARC Recommendations Regarding Broadcast Message Elements

Memo For Record

On February 1, 2008, the FAA posted a Memo for Record to the docket clarifying several of the "Broadcast Message Element" comments. Specifically, the FAA provided the following clarifications in questions 14 through 20 of the memo:

Question 14

Regarding section IV.B.3 "Broadcast Message Elements" (a): Note that the Length and Width Code is only included in the ADS–B surface message formats. Aircraft that are allowed to always transmit the airborne message format will never transmit the Length and Width Code. Please clarify whether the Length and Width Code requirement implies that the surface message format must be supported by all ADS–B equipment installations.

> *Response to ARC:* This question is beyond clarification of the NPRM and may be submitted as a comment to the docket.
>
> The ARC recommends that the FAA address this question as part of the final rule.
>
> The ARC believes that the FAA needs to provide an answer to this question, as submitted by the ARC, as part of the pre-amble to the final rule.

Question 15

Regarding section IV.B.3 "Broadcast Message Elements" (d) Velocity: The text of this section refers to "airspeed". The ADS–B standards only refer to velocity reference to the WGS–84 ellipsoid. Please clarify this discrepancy.

> *Response to ARC:* This was an editorial error and should reference velocity instead of airspeed.

Question 16

Regarding section IV.B.3 "Broadcast Message Elements" (g) "Receiving" vs. "Requesting" ATC Services: The data link MOPS refer to this data element as indicating that the aircraft is receiving ATC services. The NPRM refers to it as requesting services. The distinction is important because it implies a specific order of flight crew interaction with ATC. Please clarify whether the NPRM proposes to re-define how this data element is specified.

Response to ARC: The FAA did not intend to redefine this parameter. Consistent with the MOPS, this data element indicates that the aircraft is receiving ATC services.

While the ARC does not necessarily see a value in this data element, since the broadcast element is already part of the data link, the ARC recommends retaining the parameter.

Question 17

Regarding section IV.B.3 "Broadcast Message Elements" (h) Mode 3/A Code: Practically speaking, the transponder squawk code is also the method that indicates when the aircraft is receiving ATC services. ATC assigns the flight crew a squawk code, and reception of the code by ATC serves to confirm the aircraft's participation within the NAS. A squawk code of "1200" indicates that the aircraft is not being provided ATC services. It is confusing for the FAA to refer to items (g) and (h) as though they were in some way separate entities, requiring separate flight crew entries. This is inconsistent with current aircraft operations. Please clarify whether items (g) and (h) may be considered as one data element.

Response to ARC: Items (g) and (h) are separate parameters. In non radar airspace, such as Alaska or the Gulf of Mexico, ATC will need a way to differentiate between ADS–B transmitting aircraft that are receiving ATC services and those that are not receiving ATC services.

The ARC recommends that the FAA reconsider this part of the rule until the FAA has a comprehensive plan for ATM under NextGen. A key consideration is the duplication of the receiving ATC services and the need for the squawk code. While both of these requirements are needed in the current host system, by 2020 the FAA plans for their automation system to be two generations beyond the host system. For this system beyond 2020, the ARC believes that there should not be a requirement for a 4096 squawk code and an indication of receiving ATC services. The ARC recommends that—

- For installations prior to 2020, before the automation has been modified, installations will require both RATCS and the 4096 squawk code and have single point of entry (see below).
- The FAA should define its plans for ATM as part of this rule. Based on the FAA's evaluation, the FAA should determine if forward and retrofit installations beyond 2020, there should be a requirement for both the 4096 code and "Receiving ATC Services" indication.

The ARC recommends that the FAA clarify the value of the "Receiving ATC Services" provides to the ATC system. The ARC also notes that the NPRM states "it is imperative that the ATC-assigned transponder code be identical to the assigned transponder code in the ADS–B Out message set. If the aircraft's avionics are not capable of allowing a single point of entry for the transponder and ADS–B Out Mode 3/A code, the pilot would have to ensure that conflicting codes are not transmitted to ATC." The ARC recommends that the FAA adopt an approach which supports a single pilot point of entry for the Mode 3/A Code.

The ARC agrees with the commenters who question the usefulness of the "receiving ATC services" broadcast message element. If the FAA were to retain the broadcast message element, the ARC asks the FAA to clarify its usefulness as part of the final rule. In addition, the ARC recommends that the FAA define the usage for "receiving ATC services" and potentially not rely on pilot entry to provide an indication that ATC services are being received.

Question 18

Regarding section IV.B.3 "Broadcast Message Elements" (j) Emergency/Priority codes: There are up to seven emergency/priority codes defined in the ADS–B data link standards. There are only three defined in the ICAO standards that are implemented by the Mode 3/A code. Please clarify whether all of the ADS–B codes must be implemented, or if support for only the existing Mode 3/A codes is sufficient.

> *Response to ARC*: Please see the response to question No. 9. Identify each of the transponder emergency codes listed in the Aeronautical Information Manual (AIM) that are considered "applicable" to the requirement for transmission in ADS–B messages.
>
> *Response to ARC:* The following transponder codes in the AIM are applicable:
>
> - Chapter 4, section 1, 4–1–19 for overall transponder codes and the codes 7500, 7600, 7700 (subparagraph e. discusses 7500 used for hijacking);
> - Chapter 6, section 2, 6–2–2 denotes 7700 for an emergency or distress.
> - Chapter 6, section 4, 6–4–2 denotes 7600 for loss of two-way radio capability.

Question 19

Regarding section IV.B.3 "Broadcast Message Elements" (j): The requirement for ICAO 24-bit addresses implies that other addressing modes (such as the self-assigned temporary address supported under TSO–C154b) may be disallowed under the proposed rules. Please clarify if the proposed rules will modify the existing aircraft address requirements in TSO–C154b.

> *Response to ARC:* This question is beyond clarification of the NPRM and may be submitted as a comment to the docket.

The ARC recommends that the FAA clarify its policy on the use of anonymous addresses in the final rule for both data links. This is important to address operators' privacy and possible security concerns about the ICAO 24-bit aircraft identifier.

Question 20

Regarding section IV.B.3 "Broadcast Message Elements" (n): The "CDTI OK" indication in the ADS–B Out message only indicates that a CDTI is installed and operating on board the aircraft. It does not indicate the specific application capabilities of the CDTI. Paragraph (n) should be updated to reflect the definition of this indication.

> *Response to ARC:* This question is beyond clarification of the NPRM and may be submitted as a comment to the docket.

ARC Comments to Broadcast Element Comments Not Previously Addressed by FAA Memos

In response to the comments on broadcast message elements that the FAA's February 1, 2008, Memo for Record did not address, the ARC recommends that the FAA make the following changes:

- The ARC agrees with the comment that GPS/WAAS equipment is not required to output a vertical protection limit (VPL) other than on LPV or LNAV/VNAV final approaches, but notes that GPS/WAAS equipment also is not precluded from outputting a VPL.
- The ARC agrees with the commenter seeking clarification of whether reported altitude would be in 25 foot increments or 100 foot increments and asks that the FAA clarify the required altitude sensor's resolution in the final rule. It is noted that the data link MOPS requires encoding altitude in 25 foot resolution, but does not set a requirement on the sensor that provides the altitude.
- The ARC notes that achieving agreement of two different encoders for barometric altitude is not possible to guarantee over a reasonable, cost-effective calibration interval. The ARC specifically notes that having the same data source does not result in identical altitude reporting, due to different times of applicability.
- The ARC agrees with the comment by SANDIA seeking clarification of whether separate altitude encoders are necessary for ADS–B and for an aircraft's Mode C/S transponder and recommends that the FAA allow for separate encoder usage between Mode C and Mode S. The ARC believes that allowing for two separate encoders for Mode C and Mode S will be simper from an implementation perspective.
- Several commenters noted that aircraft velocity may be calculated by more than one onboard sensor and one commenter recommended the FAA introduce a requirement to use the most accurate velocity sensor available. The ARC recommends that this issue be deferred to the SC-186 ad hoc working group for resolution, assuming the best available onboard source will be selected.
- The ARC reviewed the UPS about airspeed as an indication of velocity The ARC agrees that airspeed is not an acceptable indication of velocity. The ARC asserts that ADS–B position, velocity and time (PVT) use ground speed and not airspeed.
- Several commenters questioned the need for Mode 3/A codes because the ground system should be able to identify aircraft by other means such as the ICAO Mode S beacon code. The ARC agrees with these commenters and recommends that the FAA justify the use of this data element in the final rule.
- The ARC agrees with the commenters questioning the need for a CDTI installed and operable indication as a required message element. The ARC

notes that CDTI is an air-to-air data element which has questionable operational benefits. The ARC recommends the FAA clarify the use of a CDTI data element in the final rule. The ARC also asks that the FAA clarify how it intends to use this data element in the future ATM system and whether it would be used to restrict operator access or services. Depending on how the FAA plans to use ADS–B in the future ATM system, further clarification on the single bit indication to provide the required ATC information may be necessary. Because the CDTI data element is already in the data link MOPS, the ARC does not see benefit in removing this element, but recommends that the FAA clarify whether new installations need to provide this data.

- The ARC notes EUROCONTROL's comment about the need for ACAS confirmation and resolution advisory (RA) and recognizes that the ADS–B MASPS includes this as a provision for coordinating ACAS RAs with future ADS–B based conflict resolution. The ARC believes that this broadcast element is just one small piece of an application that has not been fully studied. The ARC agrees with the FAA that this data element probably is necessary, but that it may not be sufficient in the long term. The ARC asks the FAA clarify the use of this broadcast message element in the future ATM system. Depending on the FAA's usage decision, the ARC recommends the FAA clarify if this is required in ADS–B installation.
- The ARC disagrees with the commenter who questions the need for the diversity antenna message element stating that future ground based applications will be able to determine whether an aircraft has a top antenna and adjust accordingly. The ARC notes that the antenna diversity message element is a means by which ground-based applications learn whether an aircraft is diversity equipped. The ARC also notes that only 1090 ES has a diversity antenna message element and that UAT does not have a diversity antenna message element. The ARC recommends that the FAA determine whether an antenna diversity data element should be added to the UAT data link.
- One member of the ARC believes that in the spirit of a performance-based system, capability-based broadcast message elements should be favored over equipment-based elements. The member notes that if the intent is to use the antenna diversity message element to restrict access or service, it should be changed to an element that reflects true avionics performance rather than an equipment installation. It is noted that the performance of single-antenna installations may evolve or experience may provide their performance adequate for additional services. The ARC member recommends that the element be replaced with the DO–289 ASA capability level or similar indication of performance capability instead. Also, one ARC member believes that a "radio-transparent" airframe with a single-antenna installation may achieve performance equivalent to other installations with antenna diversity and that those aircraft should have access to airspace and services offer to aircraft with antenna diversity. The term "radio transparent", however, still needs to be defined.

- Comments from UPS and United pointed to the unnecessary cost from the IDENT function in light of the aircraft's identification being part of the broadcast message element set. The ARC recommends that the FAA justify the IDENT requirement by describing how it will be used as part of the final rule. Depending on the FAA's usage in the future ATM system, the FAA may be able to delete this requirement.
- Comments were raised that the message elements lack sufficient definition and that without guidance an installer or integrator would be left to interpret the meaning of the DO–260A table. The ARC recognizes this comment and notes that the FAA is developing an ADS–B installation advisory circular.
- The ARC also asks the FAA to address Airbus's comment about the element requiring an indication of whether an emergency has been identified and addresses this part of the publication of the final rule. The ARC recommends that the FAA justify the emergency status requirement by describing how it will be used in the final rule. Depending on the FAA's usage, the FAA may be able to delete this requirement.
- Several commenters questioned the need for an indication of the aircraft's geometric altitude. The commenter's noted that GPS geometric altitude is inaccurate, has no integrity, and is not suitable for verification of barometric altitude. The ARC recommends that the FAA justify the need for geometric altitude by describing how it will be used in the final rule. Depending on the FAA's usage, the ARC may recommend deletion of this requirement.

Cockpit Controls

Original Proposal

In appendix H, section 4, the FAA proposed broadcast message elements necessary for ADS–B Out. The FAA noted that these elements would be broadcast automatically from the aircraft except where pilot entry is necessary. Among the broadcast message elements requiring flight crew entry are:

- An indication if the flight crew has selected to receive ATC services;
- An indication of the Mode 3/A transponder code specified by ATC;
- An indication of the aircraft's call sign that is submitted on the flight plan, or the aircraft's registration number;
- An indication if the flight crew has identified an emergency and if so, the emergency status being transmitted;
- An indication of the aircraft's "IDENT" to ATC;

In footnote 25 to the preamble, the FAA added that if the air traffic controller identifies that the aircraft avionics is not operating properly (such as providing erroneous or incomplete information), the pilot would be instructed to turn off the avionics. The footnote stated that a simple switch or button in the cockpit to disable ADS–B avionics would provide this feature. Aircraft would then be controlled using the backup

surveillance system or procedurally. The FAA pointed out that this is similar to the methods used today in removing faulty transponder information from a controller's display. Pilots currently have the capability to turn off transponders. Aircraft are then handled procedurally or through primary radar returns.

Summary of Comments Regarding Cockpit Controls

Eight commenters, including 2 air carriers, 2 avionics manufacturers, 2 associations, Boeing, and EUROCONTROL, submitted 11 comments regarding the proposed requirements for cockpit controls.

Several commenters were critical of the proposed provision making it possible for an aircraft to switch off its ADS–B avionics.

- UPS and United asserted there are negative security implications to an aircraft being able to turn off its ADS–B transmissions. They asserted that rather than requiring the ability to turn off ADS–B transmissions, the ground system should address problems with ADS–B broadcasts. If there is a justifiable reason that an unwanted broadcast cannot be handled by ground automation, the existing transponder standby or off switch should be sufficient. UPS and United recommended eliminating the requirement to turn off ADS–B Out transmissions.
- EUROCONTROL asserted that the proposed requirement that pilots have the ability to switch off ADS–B avionics is not clearly justified.
- GAMA sought clarification about the functionality of the "simple switch or button" which would be used disable ADS–B avionics, and whether this function implies an indication in the cockpit that the ADS–B avionics are transmitting, as is provided by traditional transponders.
- The Association of European Airlines and IATA jointly asserted the ADS–B switch-off function is a new pilot procedure, and thus must be justified by a safety case. The Association of European Airlines and IATA asserted that it is important to ensure that TCAS and ADS–B functions can be turned on and off independently.

Boeing noted the required message elements include an indication of whether ATC services are requested, which would require crew entry. Boeing asserted reliance on pilot entry is inadequate, because reliability would be highly suspect, especially in high stress circumstances where the function might prove most useful. Additionally, Boeing noted that such a function would require additional controls or complex logic. Boeing recommended eliminating the requirement for a pilot entered indication if ATC services are requested.

SANDIA noted some users opt to use electronic flight bags (EFB) to minimize costs and optimize benefits. Existing regulations do not permit low cost EFBs to be connected to or transmit information to certified avionics. Therefore, flightcrew entry of requests for ATC services, as well as Mode 3/A code, flight ID, and emergency codes would require a certified display/panel. This precludes use of a remote mounted ADS–B unit coupled with an EFB. SANDIA asserted this is an area where the FAA could remove the

restrictions on use of EFBs with appropriate fusing and other protections. In particular, SANDIA noted that the requirement for transmission of Mode 3/A code is imperative. SANDIA asserted that the ability to set the code form an EFB could benefit equipage by facilitating availability of the lowest possible cost units and installation. SANDIA noted that ATC can readily verify that the information such as the code and Flight ID is entered correctly early in the flight.

Rockwell-Collins asserted that the functional requirements contained in appendix H fail to address items discussed in the preamble, such as a control accessible by the pilot during flight to turn off ADS–B , a means to check that ADS–B Out is turned on, and an interface to permit entry of message elements during the appropriate phase of the flight. Rockwell-Collins recommended adding functional requirements for ADS–B pilot control.

ARC Recommendations Regarding Cockpit Controls

The NPRM requires a switch for ADS–B Out transmissions. The ARC does not see the need for this switch. The ARC believes that any problems with ADS–B broadcast elements can be handled by the ground automation system. Additionally, the ARC believes it would be more cost-effective for the ground system to selectively filter out erroneous or otherwise unwanted surveillance data than to add additional functionality to the aircraft. While ATC may not be able to use degraded data for separation, those data may be suitable for situational awareness on the flight deck of other aircraft (that is, on a CDTI). For equipment malfunctions, a cockpit circuit breaker should suffice to shutoff ADS–B equipment.

Required Equipment

Original Proposal

In the preamble to the NPRM, the FAA explained that equipage to ADS–B requirements will not replace the requirement for transponders because a backup surveillance strategy is necessary in the event of loss or degradation of GPS positioning information. The FAA concluded that maintaining a reduced network of SSR best meets the FAA's backup needs. Legacy transponders (Mode A/C/S) are still necessary to support SSR.

Summary of Comments Regarding Required Equipment

Eighteen commenters, including 1 avionics manufacturer, 1 aircraft manufacturer, three associations, and 13 individuals submitted 28 comments regarding the redundancy of required equipment.

The vast majority of commenters were critical of the fact that the proposed equipment requirements do not replace the requirement for transponders. Four commenters asserted the requirement to have both ADS–B and a conventional transponder imposed an unreasonable expense. Six commenters recommended permitting ADS–B equipped aircraft to immediately operate without a conventional transponder. Five commenters recommended a long term surveillance plan that removes the transponder requirement for ADS–B equipped aircraft in the future.

ATA noted that there is significant overlap between ADS–B capabilities and functions performed by existing required avionics. ATA recommended determining by 2010 what non ADS–B avionics can be replaced by ADS–B equipage. The functions performed by the identified equipment could be integrated with upgraded ADS–B equipment during a second phase of ADS–B implementation.

AOPA stated that the FAA has underestimated the financial impact of requiring aircraft to retain their transponder in addition to ADS–B equipment. AOPA and one individual noted that one stated reason from retaining conventional transponders in addition to ADS–B is to permit continued TCAS functionality. Both commenters recommend that TCAS be upgraded or replaced with a system that recognizes ADS–B transmissions. Another individual recommended that transport category aircraft continue to be equipped with TCAS II as an independent collision avoidance system, but also recommended that GA aircraft owners equipping with UAT ADS–B be permitted to remove their conventional transponders.

In addition to overlap between ADS–B and transponder functionality, three commenters, including two individuals and ATA, asserted that ADS–B equipment could fulfill the function currently performed by ELTs. The two individual commenters recommended that aircraft equipped with ADS–B Out not be required to also have a 121.5 MHz or 406 MHz ELT installed.

ALPA supported retention of existing Mode A/C/S transponder requirements, in addition to the ADS–B Out requirements. ALPA noted that SSR is the chosen backup for ADS–B, and ACAS, which is critical to collision avoidance, relies on transmissions from existing transponders.

ARC Recommendations Regarding Required Equipment

The ARC recommends the retention of legacy transponders to support the FAA's planned backup strategy and current ACAS operations, but suggest that the FAA explore future surveillance architectures that reduce the dependency of a common global position source and expand the use of ADS–B in functions such as ACAS (hybrid surveillance to full ADS–B use). Proposed changes need to be coordinated with the global community.

The FAA should pursue an ADS–B implementation strategy that ultimately results in the removal of transponders from low altitude domestic operators that are not equipped with ACAS. Therefore, the FAA should continue to evolve the collision avoidance systems used by transport category aircraft today and pursue a backup strategy that allows the removal of SSRs[21]. If the FAA is able to remove all the SSRs and make the changes to ACAS, then the FAA can consider removing the GA transponder.

The ARC recommends that the FAA explore opportunities within the ADS–B ground infrastructure/ATC automation to fuse data such that redundant data is not required from multiple systems on the aircraft (for example, no need to transmit Mode 3/A code from both the transponder and ADS–B Out equipment). This is required for entry of Mode 3/A code input to a transponder and ADS–B Out equipment in a non-integrated ADS–B/transponder aircraft architecture (early implementations). Aircraft avionics

[21] See SSR Removal and ACAS Changes in Section 5.

installers can design installations that can provide a single data entry point without requiring two separate inputs. Also, it may be possible for the ADS–B ground infrastructure/ATC automation to correlate transponder and ADS–B data such that data entry on the aircraft is required to only one system.

The ARC recommends that the FAA complete a safety analysis to determine whether the use of ADS–B surveillance in the search and rescue function would result in the same level of safety as the carriage of ELTs by certain GA aircraft that operate solely in the CONUS and in its coastal waters where ADS–B surveillance exists.

Today's ELT systems will not indicate that an aircraft crash occurred in a variety of circumstances: if the crash is into water where the aircraft is submerged, when a crash results in the ELT antenna being shielded by the aircraft or other obstruction, such as the ground when the antenna breaks off in the crash, when the ELT does not activate, or in other ELT failure modes. With an ADS–B based system the actual crash detection and position location can be accomplished remotely from the aircraft and thus is not subject to the above failures.

The ARC further recommends that the FAA explore the opportunity of providing an enhancement to the ELT/ search and rescue operation by establishing an ADS–B tracking service that could be used to aid in crash locating.

With ADS–B surveillance two different services could be offered. First, the ATC automation systems could record aircraft movement, and store the data. If an aircraft is reported missing, the search and rescue official would be able to track the last reported position of the aircraft before it dropped out of ADS–B coverage. Secondly, a function could be added to the ground automation system that would detect whenever an aircraft track ends abnormally. The automation system would take into account the location and the altitude of any track that ends and detect whenever a track ends in a position that would not allow a normal landing at an airport.

The ARC recommends that the FAA perform a study that considers a performance based search and rescue solution. If the current 121.5 MHz ELT equipage requirement for low-altitude stakeholder aircraft could be eliminated, then approximately $78M net present value benefits would accrue to this stakeholder group. Any ADS–B-based search and rescue system should perform as well or better than today's search and rescue system. Any solution must allow for the automatic detection and routing of new distress alerts to the proper search and rescue authorities as specified in the National Search and Rescue Committee (NSARC) Operational Requirements Document (ORD).[22]

[22] More details about Search and Rescue are in appendix A

Security, Privacy, and Malicious Use

Original Proposal

In § 91.225 (b), the FAA specified broadcast message elements necessary for ADS–B Out. These elements contain the data necessary for ATC to support aircraft surveillance by ADS–B. There are 15 informational components that the FAA proposes should be automatically broadcast from the aircraft. The broadcasts would include the aircraft's call sign or registration number, and its ICAO 24-bit address. The ICAO 24-bit address is unique and assigned to each individual aircraft; allowing the FAA to easily identify each aircraft. These codes are necessary for aircraft used in international operations.

Summary of Comments Regarding Security, Privacy, and Malicious Use

A total of 11 commenters, including 5 pilots, AOPA, and the TailLight Consortium commented on the privacy issues stemming from ADS–B broadcast requirements. Several commenters fear that ADS–B will enable the federal government to continuously monitor and police all aviation activity. As the TailLight Consortium points out, ADS–B broadcasts, unlike any predecessor systems, include personal information on the pilot or owner of the aircraft. An aircraft owner notes that mandatory implementation would infringe upon the freedom and privacy currently enjoyed by citizens. He argues that ADS–B broadcast data should be deemed personal and private, should not be available to the public by a freedom of information act (FOIA) request, should not be used for enforcement purposes by the FAA, and should not be disclosed to any person or agency except by court order. An individual ATP pilot also wonders what the nexus will be between national security and privacy. This pilot asks about the circumstances for the government's needs to outweigh personal privacy concerns?

One commenter adds that mandatory implementation of ADS–B should include safeguards to protect citizens from use of flight data for purposes other than safety of flights in progress, search and rescue operations, and NTSB accident analysis.

One individual pilot inquired whether the FAA and DHS will use ADS–B data for accident or enforcement investigations, ensure investigations are fair and equitable; and archive the date. This pilot suggests requiring manufacturers to design ADS–B systems that archive data onboard, and advises pilots to archive data with an independent data source to ensure that government data is corroborated. Another commenter fears that if identification is required as part of aircraft position reports there is a risk of pilots not reporting to avoid enforcement action or fees, creating less safety in NAS. This commenter adds that it is not the Government's duty to track innocent citizens in their travels.

One individual speculates that the real-time position and identification of most ADS–B aircraft, including owner name and address, will eventually be available on the internet, pointing to websites like www.liveatc.net and the availability of hobbyist ACARS receivers to demonstrate the feasibility of this privacy threat.

AOPA asserted that the FAA must allow GA pilots to maintain their privacy while operating under VFR. AOPA further noted that members object to transmitting their N number or ICAO 24-bit address while flying VFR. AOPA recommends that the FAA allow pilots to use the privacy message function on the UAT data link. AOPA offers that the datalink could randomly select an unassigned 24-bit address if the pilot selects the "VFR mode" option on the UAT configuration controls in the cockpit. Each time the UAT would transmit the code it would alert the recipient of the ADS–B message that the operator of that aircraft prefers privacy. Another commenter recommends that ADS–B/NextGen include a system using dynamic host configuration protocol to assign a unique address when the UAT or 1090 ES is turned on, thereby allowing the network to eliminate system duplicity and guarantee anonymity to the pilot of the aircraft.

The TailLight Consortium was specifically apprehensive about the impact on business aircraft. They are concerned that the aircraft identifier data would make it possible for outside entities to monitor the movement of business aircraft, greatly hampering the ability of business to conduct proprietary activities, such as merger discussions, investigation of potential acquisitions, or discreet handling of difficulties. The TailLight Consortium urges the FAA not to include identification based on outwardly identifiable data, arguing that such data is not necessary to effective control of air traffic.

One commenter argued that the privacy concerns are not troubling, saying that if there is nothing to hide, there is nothing to fear.

A total of 17 commenters, including 2 domestic air carriers, an avionics manufacturer, an association, and the DOD commented that the ADS–B system was vulnerable to being used for malicious purposes.

The DOD notes that ADS–B technology makes it possible to receive information without ground station installation, making the position and intent of aircraft in flight available to virtually anyone. The TailLight Consortium adds that any terrorist, criminal, or disgruntled individual could determine the precise location and identity of potential target aircraft, including tail number and operator identity, in real time with readily available knowledge and equipment. Another individual worries that ADS–B would leave passenger aircraft vulnerable to unmanned aircraft designed to target and destroy them.

Several commenters pointed out several possible modes of interfering with transmissions, including failing to broadcast aircraft position, interference with the GPS signal, jamming ADS–B broadcasts, and introducing false targets into the system. Both UPS and United noted the negative security implications of an aircraft being able to turn off its ADS–B transmissions, which could include a hijacker turning off the transmissions hindering pre-emptive action. Beside complete loss of coverage, malicious infiltration into the system is also a risk. One individual asserts that balloons carrying equipment to jam GPS signals could disrupt ADS–B; one balloon could create local disruption, a coordinated deployment of several balloons could create widespread disruption.

According to Defense Concept Associates, the GPS L1 channel is easy to jam, even when the jammer is on the ground and the GPS receiving antenna is on the top of the fuselage. Defense Concept Associates suggests that since redundant GNSS, multiple DNEs, clocked ground stations, SSR, and controller vectoring are all vulnerable to uplink jamming, LORAN should be used as backup for GPS navigation. Defense Concept Associates also points out that both 1090 ES and UAT are susceptible to denial jamming in the vicinity of ground stations. 1090 ES is also vulnerable to deceptive jamming, though due to its superior timing structure UAT is very difficult to infiltrate via deceptive jamming. Another chief concern is terrorists being able to modify ADS–B and transponder equipment to transmit "phantom" aircraft identities, locations, and velocities to ATC. According to one individual commenter spoofing is relatively easy when aircraft positions are readily available.

Several commenters allude to the lack of data encryption as making all categories and classes of aircraft potential targets for terrorism. Even the more secure UAT link is susceptible to interference by basic modifications to test equipment. Advocates stress the need to develop encryption of signals between ground-to-ground, ground-to-air, and air-to-air systems, preventing adversaries from using the ADS–B system to disrupt air traffic or shoot down aircraft equipped with ADS–B. The DOD also recommends a thorough security assessment involving DOD and DHS to determine ADS–B risks and appropriate countermeasures.

Many commenters point out that the NPRM does not at all address national security issues. There is no mention of acquisition and use of ADS–B data for malicious purposes, and no safeguards against unauthorized users accessing the system. RTCA had rejected including security features in ADS–B and TIS–B protocols a few months prior to the 9/11 attacks; though post-fact seeing that these issues needed to be revisited. Yet even the standards currently proposed by RTCA lack security safeguards necessary to protect against terrorist attacks.

Several commenters also had questions left unanswered by the NPRM:

- One individual questioned if the ADS–B system loses the GPS time signal, how long can adequate time synchronization and frequency synchronization be maintained, and what would be the hazards if there is intentional interference with the signal?
- An aircraft owner asked what security issues are addressed within the scope of section 709 of the Century of Aviation Reauthorization act, since physical security of ADS–B equipped aircraft is not addressed in the NPRM.
- Another individual, also noting the lack of security measures addressed in the NPRM, wonders if there will be FAA oversight to ensure that ADS–B Out data is only used for authorized purposes? He also asks what will happen if the FAA deploys ADS–B without a secure link but later decide one is necessary. The commenter questioned who would pay for modification or replacement of thousands of systems.

ARC Recommendations Regarding Security, Privacy, and Malicious Use

Disposition of Security and Privacy Comments

ADS–B provides identification data from the aircraft as a single source, where as today, that data must be assembled through a combination of voice communications, radar data and automation data. However, today for aircraft equipped with Mode S transponders the 24 bit address and 1024 transponder code are available to anyone with a 1090 MHz receiver. Because the 24 bit address for all U.S.-registered aircraft is in the public record, aircraft identification can be easily determined. This feature of ADS–B reduces voice communications as well as pilot and air traffic controller workload thereby adding measurable efficiency in moving traffic. There is some reduction in privacy relative to today's operations; however, that reduction can be controlled to some extent. The question is, "what is the proper balance between aircraft identification and privacy?" The ARC believes that the level of privacy in today's system is adequate and sees no compelling reason to change it.

It is the ARC's opinion that ADS–B aircraft identification information can be controlled in such a way as to provide a comparable level of privacy provided in today's system while satisfying ATM and security requirements.

- The FAA should use the anonymity feature of UAT and develop an equivalent feature for 1090 ES that would apply only to VFR operations not using ATC services, which would be equivalent to a 1200 transponder code.
- The FAA should accommodate assignment of 24 bit ICAO codes so that they don't easily correlate to aircraft tail numbers (per ICAO recommendations) and permit aircraft call signs to be something other than the aircraft registration number when receiving ATC services.
- The FAA should treat 24 bit ICAO code assignments as information covered under privacy laws, so they are only available to authorized personnel or released by the holder.

One area that cannot be mitigated is the immediate reception of ADS–B signals by persons other those that require it for ATM and security. In this case, a key ADS–B strength is also a weakness. However, the ARC notes that it is possible for unauthorized individuals to determine aircraft identification in today's system once the assigned transponder code is known for an aircraft – this information can either be directly determined via VHF voice transmission of the code from a controller to an aircraft, or via interference from monitoring of VHF controller-pilot radio communications. Therefore, the ARC believes the mitigations listed above adequately address this issue.

Disposition of Malicious Use Comments

Contrary to many of the comments, our current transponder and ACAS systems permit any terrorist, criminal, or disgruntled individual to determine the relative location and identity of potential target aircraft, including tail number and operator identity, in real time with readily available knowledge and equipment. Although ADS–B provides more precise location, current weapon systems do not require this information to be effective.

Consequently, there is no greater threat to ADS–B aircraft than those with transponders or ACAS.

The FAA's current implementation calls for using SSR to backup and validate ADS–B surveillance in the busiest U.S. airspace. Other systems such as passive multilateration and non-cooperative surveillance systems have the ability to do the same. Although the ARC agrees that ADS–B spoofing is possible, it believes these alternative surveillance systems are adequate to validate ADS–B reports and defeat spoofing.

The same mitigation applies to the jamming of GNSS signals used for ADS–B position information. In the near-term, SSR could be used to mitigate loss of GNSS signals due to intentional or unintentional interference. However, it should be noted that GNSS jamming also affects aircraft navigation, so the ARC is confident that one or more effective mitigations for GNSS jamming will be required in the future. There are a variety of technical options to support NextGen operations where SSR is inadequate to support closer spacing of aircraft. These options should continue to be studied by the FAA and other appropriate government agencies.

Required Airspace

Original Proposal

In § 91.225(b)(1)(2)(3)(4), (c), (d)(1)(2), the FAA proposed ADS–B Out equipage be required on all aircraft operating in: (b)(1) class A airspace below flight level 240 (FL240), (b)(2) in class B and class C airspace areas, (b)(3) all airspace within 30 nm of an airport listed in appendix D, section 1 of this part from the surface upward to 10,000 feet m.s.l., (b)(4) all airspace above the ceiling within the lateral boundaries of a class B or class C airspace area designated for an airport upward to 10,000' m.s.l., (c) airspace at or above Flight Level 240 (FL240), (d)(1) class E airspace over the Gulf of Mexico from the coastline of the United States out to 12 nm at and above 3,000 feet m.s.l., and (d)(2) class E airspace within the 48 contiguous states and the District of Columbia at and above 10,000 feet m.s.l., except for any aircraft that was not originally certificated with an electrical system, or which has not subsequently been certified with such a system installed, including balloons and gliders.

In the preamble to the NPRM, the FAA explained that the reason the airspace in which ADS–B Out equipage is required is similar to the airspace in which a transponder is required is that ADS–B Out would provide for enhanced surveillance in areas where SSR surveillance currently exists. Accordingly, the FAA stated it is reasonable to require that aircraft meet the performance requirements necessary for ADS–B Out for operation in airspace that currently requires transponders.

The FAA also explained that this area can experience a high volume of aircraft operations and complex transitions from the en route environment to the terminal area around the nation's busiest airports. FAA added that they expect ADS–B to result in better surveillance across a larger area, leading to better ATC situational awareness.

Summary of Comments Regarding Required Airspace

Thirty-Three commenters, including 2 air carriers, 1 manufacturer, the DOD, the USPA, and 27 individuals, submitted 37 comments regarding the airspace in which the FAA is proposing to require ADS–B Out for aircraft operations.

The vast majority of commenters were critical of the proposed airspace requirements, recommending they be reduced so as to cover less airspace.

- Thirteen commenters recommended requiring ADS–B Out equipage only for aircraft operating in class A airspace. One additional commenter recommended raising the requirement for aircraft operating above 10,000 feet to say aircraft in and above class A airspace.
- Three commenters recommended requiring ADS–B Out equipage only for aircraft operating in class A or class B airspace.
- Three commenters expressed concern at the proposed requirement to limit access to certain airspace based on aircraft equipage. One commenter asserted the increasing regulatory demands for expensive avionics turns portions of the public commons into private or exclusionary commons. This is contrary to equitable public access to national airspace which all U.S. citizens have a right to under 49 U.S.C. 40103, Sovereignty and use of airspace. The commenter recommended withdrawing the proposed requirement, or at a minimum not including any portion of class E airspace in the ADS–B Out equipage proposal. One individual commenter asserted the requirement would render the area above 10,000 feet m.s.l.and class C airspace unusable to hundreds of thousands of GA aircraft.
- One commenter recommended exempting aircraft that fly below 18,000 feet m.s.l. and slower than 300 kts from ADS–B Out equipage requirements.
- One commenter recommended limiting the proposed ADS–B Out equipage requirement to all aircraft operating in class A airspace and aircraft over 12,500 pounds in class B and class C airspace.
- One commenter recommended requiring ADS–B Out equipage only for aircraft operating above 25,000 feet.
- One commenter recommended requiring ADS–B Out equipage only for aircraft flying under instrument flight rules using primary airports in class B airspace, with voluntary equipage for all other airspace.
- The DOD does not expect all state aircraft to equip with ADS–B Out and asks the FAA to make accommodations for military, training, and test evaluation requirements for peacetime, contingency, and wartime operations.
- One commenter asserted that the proposed ADS–B Out equipage requirement will severely limit the number of aircraft able to use class B and class C airspace. The commenter noted that the FAA already requires RVSM certification to operate in class A airspace. The commenter recommended

regulating the number of flights and spacing them throughout the day if more density is needed in class B and class C airspace.

- One commenter asserted that altitude and airspace restrictions related to ADS–B Out will reduce flight safety.
- One commenter asserted that the fact that ADS–B Out will only be required in certain airspace decreases its usefulness outside that airspace.
- One individual commenter asserted the requirement was proposed without any evaluation of the negative impact it would have on GA.
- One commenter asserted that requiring GA aircraft to install ADS–B Out equipage would be a considerable financial burden. The commenter recommended raising the floor where ADS–B Out equipage is required to 12,000 feet m.s.l.
- One commenter recommended raising the floor where ADS–B Out equipage is required to above 15,000' m.s.l., which would exclude 90 percent of GA operations outside class B and C airspace from the ADS–B Out equipage requirement.
- One commenter recommended limiting ADS–B Out equipage to aircraft operating in class B or class C airspace or above 18,000' m.s.l. so pilots would have an opportunity to choose whether to subject themselves to government surveillance.

Two commenters, including the DOD, questioned the FAA's plans to decommission TIS–B once ADS–B is functional. One commenter anticipates that significant numbers of GA aircraft will not equip with ADS–B Out. This commenter also notes existing areas of class E airspace under 10,000 feet m.s.l., where ADS–B Out would not be required, that commercial aircraft regularly operate in. The DOD specifically recommended the FAA retain TIS–B after ADS–B is functional.

UPS and United questioned the performance requirement, NACp≥9, for all airspace. UPS and United recommended identifying specific airspace, such as high-density airports or terminal areas, that will utilize applications requiring NACp≥9 or higher.

One commenter noted that GPS sensors would provide horizontal position accuracy within .1 nm. The commenter recommended lowering the horizontal position accuracy for aircraft not landing or operating on the surface of class B or C airports.

ADS–B Technologies, LLC recommended defining ADS–B Out requirements in additional airspace such as air defense identification zones (ADIZ) and offshore control area extensions, consistent with part 99, including the areas contained in subpart B or part 99.

Many commenters, submitted comments regarding specific portions of airspace which are subject to the FAA's proposed ADS–B Out equipage requirement. These comments are outlined below as follows:

- In reference to § 91.225(b)(2), three individual commenters were critical of the proposed requirement to mandate ADS–B Out avionics to operate in

class B and class C airspace. Two of these commenters questioned the economic and safety benefits in class B and C airspace. One commenter specifically noted the financial burden to fly around class B airspace.

- In reference to § 91.225(b)(3), 11 individual commenters submitted 12 comments regarding the proposed requirement to mandate ADS–B Out equipage for all aircraft operating in all airspace within 30 nm of an airport listed in appendix D, section 1 of this part from the surface upward to 10,000 feet m.s.l.
- Six commenters asserted the proposed requirement will have a significant negative economic impact on aircraft owners operating in the aforementioned airspace.
- Two commenters asserted the proposed requirement will have no safety or economic benefit.
- One commenter recommended exempting all aircraft with Mode C transponders flying below 2500 AGL and clear of class B airspace from the ADS–B Out equipage requirement.
- One commenter recommended the FAA further clarify that aircraft operators will be accommodated through or around the periphery of class B and C airports.

In reference to § 91.225 (b)(4), two individual commenters submitted comments regarding the proposed requirement to mandate ADS–B Out equipage for all aircraft operating above class B or C airspace up to 10,000 feet m.s.l. Both commenters asserted the proposed requirement amounted to a disguised increase in the ceilings of class B and C airspace. One commenter asserted there is no economic or safety benefit provided by the proposed requirement. Both commenters recommended eliminating the proposed requirement mandating ADS–B Out equipage to operate above the ceiling of class B or C airspace up to 10,000 feet m.s.l.

In reference to § 91.225(c), two commenters were critical of requiring ADS–B Out equipage on all aircraft operating at or above FL240.

- One commenter asserted that aircraft separation issues are prevalent in terminal areas and lower altitudes, not above FL240. The commenter added that segregating airspace on the basis of an arbitrary altitude is nonsensical since aircraft operating above FL240 eventually have to descend below FL240.
- One commenter asserted that the in-trail spacing standards stated in the NPRM are geared toward air carrier operations. Because even the GA aircraft that are capable of exceeding FL240 will not require the close trail distances regularly encountered in air carrier operations, requiring them to install ADS–B Out equipage offers no benefit. The commenter recommended that ADS–B Out equipage only be required for aircraft operation above FL250.

In reference to § 91.225(d)(1) and (2), seven commenters, including one association (USPA), and six individuals, submitted comments regarding the proposed requirement to set the floor where ADS–B Out equipage is required at 10,000 feet m.s.l. for class E airspace within the 48 contiguous United States and the District of Columbia.

USPA asserted the U.S. parachute jump fleet consists of 296 piston aircraft and 124 turbine aircraft, all of whom fly at or above 10,000 feet m.s.l. for parachute jumps. These aircraft do not cruise at altitude, but rather fly a climb, exit phase, and descent profile from and to the same airport each time. USPA added that nearly all of these flights are conducted under VFR in class E and G airspace. USPA requested FAA note the scope and nature of parachute operations and the financial impact of requiring new avionics on those operations.

Ten commenters, including the DOD, the EAA, and eight individuals, submitted comments regarding the proposed requirement to set the floor where ADS–B Out equipage is required at 10,000' m.s.l. for class E airspace within the 48 contiguous states and the District of Columbia. The commenters were critical of the proposed ceiling of 10,000' m.s.l. for non ADS–B equipped aircraft, arguing that it will be a major hardship and safety issue for aircraft operators that fly in mountainous terrain.

One commenter recommended that implementing ADS–B be a priority in the Gulf of Mexico, high country in Colorado, and the routes over the Atlantic in the Northeastern portion of the United States.

ARC Recommendations Regarding Required Airspace

The intended role of ADS–B in today's radar-referenced airspace needs to be clarified. It is the understanding of the ADS–B ARC that the intention of the NPRM was to require ADS–B capabilities in existing radar airspace with ADS–B providing the equivalent functionality of Mode-A and Mode C transponders. ADS–B Out squitters in both the DO–260A Change 2 and DO–282A will provide enhanced performance to existing radar operations based on the increased precision and frequency of update from the traditional radar systems.

Recognizing this, the FAA should clarify the proposed NPRM requirements in light of § 91.215. The NPRM appears to cover more airspace than the current transponder rule in § 91.215. This increased airspace does not seem consistent with FAA plans for providing ADS–B Service.

Proposed Changes to Rule Language Regarding Required Airspace

The ARC recommends the FAA revise § 91.225(d)(2) to read in pertinent part from "at and above 10,000 feet m.s.l." to "at and above 10,000 feet m.s.l., excluding the airspace at and below 2,500 feet above the surface"

Additionally, the FAA should consider including additional language to clarify why transponder carriage is required after the ADS–B Rule is effective.

International Compatibility and Harmonization

Original Proposal

In § 91.225 (a)(1) and (2), the FAA proposed that, after January 1, 2020, aircraft operating in specified airspace be equipped with ADS–B Out equipment that meets the performance requirements in TSO–C166a (1090 ES), or later version, or meets the TSO–C145b (UAT), or later version. The FAA noted that the two proposed standards apply to the 1090 ES transponders that transport category and high performance aircraft are expected to use, and 978 MHz UAT equipment that GA aircraft are expected to use. The FAA noted that a small number of GA aircraft are already equipped with UAT equipment.

In proposing requirements, the FAA stated that the 1090 ES link is the international agreed upon link for ADS–B. The FAA also noted that ICAO is in the process of updating the 1090 ES Standards and Recommended Practices (SARPs) published in ICAO Annex 10, Amendment 77, to include those requirements identified in the publication of DO–260A, Change 2.

Summary of Comments Regarding International Compatibility and Harmonization

Seventeen commenters, including seven associations, two avionics manufacturers, two air carriers, EUROCONTROL, Airbus, and three individuals, submitted comments relating to international harmonization of ADS–B requirements.

ADS–B, Inc., an avionics manufacturer, stated that ADS–B is already in operation in other countries, and is rapidly maturing and stabilizing, and asserted that the remaining hurdles to global implementation are primarily political in nature.

Five commenters questioned or commented negatively on the global interoperability of the ADS–B system envisioned in the NPRM.

- One individual air transport rated pilot noted a lack of international interoperability for UAT, and stated that this would impact U.S.-registered aircraft flying in Canadian airspace. The commenter inquired what procedures or provisions would be put in place to support U.S.-Canadian operations. Similarly, AOPA asserts that, because Canada and Mexico have not committed to UAT, GA aircraft owners face the dilemma of choosing UAT, which may not be internationally interoperable or 1090 ES, which is more expensive and offers fewer benefits. AOPA recommended that the FAA undertake efforts to ensure that UAT will be supported throughout North America.
- Alternatively, one individual aircraft owner recommended that, because 1090 ES is internationally compatible, it should be the preferred data link for all aircraft.
- NBAA pointed out that the proposed requirements are more stringent than those that have been employed in Canada and Australia, and stated that this raises questions of international interoperability.

- EUROCONTROL commented extensively on international interoperability. EUROCONTROL noted that the preamble states of goal of compliance with ICAO SARPs "to the maximum extent practicable", and questioned how this would impact interoperability. It also questioned why there is no reference to the RFG/RTCA objective of firmly establishing a rulemaking baseline by 2010. EUROCONTROL pointed out that, from an international standpoint, only non-radar coverage area implementations are addressed, and requested coordination with the Single European Sky Safety Performance and Interoperability Implementing Rule. Finally, EUROCONTROL noted that, while DO–260A, Change 2 covers Mode A code for the U.S., it is not clear if the latest change, which removes the geographical filter, will be mandated. If not, and if it is required in Europe, EUROCONTROL pointed out that the U.S. and European requirements would be out of alignment.
- Similarly, the Association of European Airlines and IATA disagreed with setting a specific requirement for DO–260A Change 2, which will not be mandatory until 2020. They pointed out that European rulemakings in the 2015 timeframe are expected to use DO–260A Change "X" as a baseline. The contended that "freezing" the requirement at Change 2 could pose problems for operators equipping aircraft to the standards of the NPRM and subsequently seeking to transfer them to European operations.

Seven commenters, including Honeywell, the European Business Aviation Association, the Association of European Airlines, IATA, GAMA, Delta, Airbus, and the ATA, stressed the importance of global harmonization of requirements.

- Delta asserted that ensuring global harmonization of standards is critical; because operators must be sure their equipment will work worldwide. The European Business Aviation Association recommended that all new air traffic efforts be coordinated between the FAA and authorities in the European Union (EU) to avoiding duplication of equipment costs by operators.
- GAMA urged that the proposed rule adhere to RTCA MOPS. GAMA further recommends that if the FAA proposes more strict requirements, the FAA should forward its recommendations to RTCA to address within its own process.
- The Association of European Airlines and IATA, jointly, as well as Airbus, asserted that ADS–B implementations world-wide must be interoperable both with respect to data link and with respect to ATM applications aligned with regional initiatives such as Single European Sky ATM Research (SESAR) or NextGen.
- ATA noted that, because the ICAO SARPs are not fully developed, the documents relied upon in comparing the proposal with the SARPs may be or may become outdated, and that unresolved conflicts may arise. The ATA recommended a direct dialogue with ICAO to ensure harmonization.
- FedEx noted that, while other areas of the world have permitted use of DO–260-like equipment for ADS–B, the NPRM specifies a requirement for

DO–260A. FedEx also pointed out that the proposal contains an effective requirement for GPS/WAAS, and notes that WAAS is not available worldwide. FedEx recommended that a harmonized, universal standard be adopted to promote effective aircraft utilization.

- Honeywell stated that an operator's assessment of the value of ADS–B equipage will be influenced by whether their investment is globally interoperable.

Three commenters recommended aligning ADS–B standards internationally to enable early ADS–B Out programs to benefit from early operations based on existing equipage. IATA pointed out that radar-like services under ADS–B Out do not require standards more stringent than those in use by some carriers today. IATA and the Association of European Airlines, jointly, noted that Australia and Canada are expected to use compliance with EASA airworthiness approval materials currently under development as an input to early implementation approvals. IATA and the Association of European Airlines recommended alignment with these provisions. Airbus asserted that the proposed requirements and definitions do not take into account, and at times conflict with, existing standards and definitions in other States implementing ADS–B. Airbus recommended harmonizing U.S. standards with the SESAR project.

IATA and the Association of European Airlines pointed out that the FAA's plan to have the ADS–B ground infrastructure in place by 2013 permits harmonization with SESAR in deliver of near-term benefits. The commenters recommended taking European efforts such as SPI–IR into account when setting requirements, and recommended continuing coordination between the FAA and other air traffic organizations, cautioning that significant differences between U.S. requirements and other requirements will discourage early participation. The commenters speculated that carriers currently equipped with DO–260-like equipment will not upgrade to higher standards until there is a single, internationally defined ADS–B package. The commenters recommended that initial implementation standards be based on ADS–B Out requirements, rather than more stringent ADS–B In requirements.

One individual noted that other commenters have urged equipage of all aircraft with UAT, and pointed out that this would require foreign air carriers to equip with it. The commenter recommended addressing the issue of foreign operator equipage from an international perspective, such as via the ICAO SARPS.

Another individual asserted that calls for the FAA to harmonize regulations with European standards should be rejected because the European system is dysfunctional and dependent on the U.S. for its supply of pilots and technological innovation. The commenter also asserted that large airlines exert political pressure to harmonize regulations because the resulting unnecessary regulatory burden suppresses competition from small, low-cost carriers.

ARC Recommendations Regarding International Compatibility and Harmonization

Consistent with the ARC's task 1 report, Optimizing the Benefits of ADS–B, the FAA should enable the use of DO–260-approved equipment to achieve operational benefits in

radar airspace as outlined in the NPRM through, for example improved ATC conflict probes. Additionally, provide for the use of DO–260-approved equipage, the FAA should adopt, for 5 nm separations in non-radar airspace to include the Gulf of Mexico, the same certification basis as used by Europe (CASCADE) and Canada (Hudson Bay) using EASA AMC 20–24, with appropriate measures to ensure ADS–B integrity. The long-term intent is to support operations based on the DO–260A Change 3 standard. To use AMC 20–24, the FAA should determine the equivalent NUCp values to be consistent with the definitions of NIC and NACp.

The FAA needs to identify any performance requirements that need to be specifically called out to allow use of EASA AMC 20–24 in the U.S. NAS. This requirement is critical to ensure that EASA AMC 20–24 can be used as a harmonized global standard. Appendix HH to this report details current manufacturer plans for 1090 ES equipage.

The ARC also recommends that the use of DO–260-approved equipage should transition to DO260A change 3 at the effective date of the ADS–B Out mandate. It is expected that operators will conduct their own evaluations to determine the proper timing to retrofit their existing fleet from existing 1090 ES to DO–260A Change 3 to meet the mandate timing. It is also anticipated that operators of aircraft currently not fully qualified for early 1090 ES operations will conduct their own evaluation to determine the costs and benefits to undertake one retrofit to 1090 ES for early benefits and a second retrofit to meet DO–260A Change 3 as required by the mandate.

ADS–B In

Original Proposal

In § 91.225, the FAA proposes performance requirements for ADS–B avionics to ensure that the aircraft broadcast the requisite information with the degree of accuracy and integrity necessary for ATC to use that information for surveillance. The NPRM mentions ADS–B Out, referring to an appropriately equipped aircraft's broadcasting of various aircraft information, and ADS–B In, referring to an appropriately equipped aircraft's ability to receive another aircraft's ADS–B Out information. The proposal only requires ADS–B Out; the FAA is not proposing to require ADS–B In at this time.

Summary of Comments Regarding ADS–B In

A total of 30 commenters, including five associations, five manufacturers, three air carriers, the NTSB, and the DOD provided feedback on limiting the rule mandate to ADS–B Out.

Most of the commenters, including the NTSB and the DOD, agree that ADS–B In is vital to successful implementation and realization of the full benefits of NextGen. Yet, they note, the proposed rule will not provide many of the claimed benefits to the user community, because the NPRM only mandates ADS–B Out. Most of the commenters noted that mandating ADS–B Out without ADS–B In will increase costs for aircraft owners, without a guarantee for future ADS–B benefits. As one individual pointed out, ADS–B Out only provides for one-way transmission of flight positional data to ATC, therefore it offers pilots none of the potential benefits of full ADS–B, such as traffic and

weather. UPS agrees that the full realization of increased capacity and enhanced safety cannot be realized until ADS–B In equipage is also mandated. As a fundamental component of NextGen and with identified benefits, UPS asserts that ADS–B In needs to be addressed at the same time as ADS–B Out.

Several commenters argue that without ADS–B In, ADS–B provides insufficient benefits. As ERA Corporation points out, the majority of benefits associated with ADS–B are from applications of ADS–B In. NTSB recommends equipage of aircraft with ADS–B In capability, as it will provide an immediate and substantial contribution to safety, especially in terminal operations. Two individual commenters believe that without ADS–B In a suitable traffic information display will not be available and there will not be any projected safety benefits. They also note that any possible improvement to traffic awareness would require GA pilots to contact ATC, and most GA pilots would rather avoid such contact. Three commenters, including ADS–B Technologies, expressed concern that lack of ADS–B In would limit the possibility of self-separation. DayJet and Defense Concept Associates opine that the benefits of ADS–B Out alone will accrue mostly to air traffic service providers, with marginal benefits to aircraft operators and pilots.

SANDIA argues that the limited benefits of ADS–B Out alone are not sufficient to motivate GA operators to equip. Another individual agrees, speculating that the limitation of requirements to ADS–B Out only means many GA aircraft will not equip with ADS–B In.

Airbus asks the FAA to limit the discussion of ADS–B In to the extent necessary to understand the ADS–B Out proposal, since the NPRM is only mandating ADS–B Out.

British Airways is the only commenter that states that no business case can be made for ADS–B In. British Airways claims that retrofit costs would be too high since new flight instrument displays would be required.

Six commenters submitted comments regarding the expected equipage costs associated with ADS–B In.

- DayJet asserted the value of benefits of equipage with ADS–B In will exceed the costs.
- Boeing asserted the NPRM offers no cost estimates for ADS–B In equipage by aircraft owners and operators because requirements for ADS–B In are insufficient in detail and do not yet support the development of a cost estimate. In order to carry out a thorough costs vs. benefits analysis of the proposed rule, users must know the full costs and benefits of both ADS–B Out and In. ADS–B In applications and requirements must be defined so that the avionics costs for ADS–B In can be determined. If a cost estimate for ADS–B In avionics cannot be determined at this time, then neither the benefits nor the costs of ADS–B In should be used for economic analysis.
- Boeing recommended employing a phased approach for the requirements, such that only the costs and benefits of ADS–B Out are considered for Phase I of the deployment. The FAA should consider the benefits and costs of ADS–B In as part of a Phase 2, to be accomplished after an accelerated

industry effort is conducted to develop the standards and performance requirements for ADS–B In applications. User costs for both ADS–B Out and In should be included when evaluating full costs and benefits for ADS–B.

- NACA asserted there are at least five applications for ADS–B In that will provide carriers with information that can improve operational efficiency and safety. NACA recommended that the NPRM should include ADS–B In applications to provide added incentives to carriers if they are expected to expend billions of dollars to make the initial equipage modifications.
- ATA asserted any current estimate for ADS–B In is speculative. However, surveys indicate that retrofitting for ADS–B In could cost three or more times as much as equipping for ADS–B Out, or as much as $1 million per aircraft. Air Transportation Association of America recommended implementing an initial ADS–B system using existing equipment with lower position accuracy as the first phase of a two phase program. Also, suspend maintaining the proposed ADS–B Out system and extensive provisioning for ADS–B In until the benefits of both ADS–B Out and In are better understood.
- GAMA anticipates that ADS–B In display requirements will significantly affect the human factors and cost of display equipment. GAMA encourages the FAA to consider the process by MITRE to develop standards for ACAS traffic and resolution advisories when developing standards for ADS–B In. GAMA also recommends that the FAA allow for ADS–B In display options for EFBs, personal digital assistants, multi-function displays, and other systems.
- One commenter asserted owners and operators of legacy aircraft will evaluate the benefits of ADS–B In equipage versus the direct and indirect costs such as installation downtime. The commenter suggested that use of portable, uncertified display devices such as the Garmin 396/496 or other EFB-type devices may be attractive, if complex and expensive FAA design approval is not required. The commenter recommended specifying what devices will be permitted to support initial ADS–B In applications and provide clear guidance for their installation and operational use.

A total of 19 commenters, including 4 avionics manufacturers, 3 aircraft manufacturers, 3 associations, 2 air carriers, and the DOD commented on ADS–B In functionality. The comments cover a broad range of topics, and there is not a general consensus in regards to any one issue.

- The DOD argues that the NPRM fails to adequately explain the benefits of potential air-to-air ADS–B In requirements.
- A few commenters, including Aviation Communication & Surveillance Systems, state that there are significant benefits available for aircraft operators to equip with ADS–B In capability. SATSair argues that ADS–B In is as important as ADS–B Out. RNP is needed to move traffic away from the congested class B/C airspace that the current proposal addresses. SANDIA

agrees that there are several ADS–B In benefits, and urges the FAA to assure continued ADS–B In capability.

- Honeywell notes that the costs of ADS–B In are not easy to estimate because they are likely to be distributed between additional applications running on the ACAS processor.
- One aircraft owner objects the limitation of ASSA applications to controlled airports, as there have been accidents at non-controlled airports that could be prevented with ASSA technology. Rockwell-Collins argues that air-to-air applications need to extend beyond ASSA, to include closely-spaced parallel runway approach, enhanced visual approach, and approach spacing.
- SANDIA suggests that there should be a provision about the use of non-certified displays of EFBs. Another individual asks what ADS–B In applications can be supported on portable uncertified cockpit displays, or hosted on an installed EFB.
- DayJet recommends instituting widespread implementation of surface surveillance capabilities, including multilateration and virtual/remote tower operations, at smaller airports used by the on-demand industry. DayJet also suggests certification of displays for ADS–B In traffic graphics, which will improve spacing and merging for enhanced safety, capacity and efficiencies.
- Another individual believes the FAA should amend the visibility requirements in part 91 to allow approaches in IMC when using ADS–B augmentation. He also asks why terrain and obstacles were included within the scope of the rulemaking, wondering if significant obstacles could be marked with an ADS–B beacon to assist aircraft in detecting them.
- ACI–NA recommends requiring airport surface vehicles with ADS–B Out to serve as a runway incursion prevention tool.

Several commenters, including Boeing and Airbus commented on FIS–B and TIS–B.

- One pilot believes that offering benefits such as TIS and FIS might spawn the market and lay the groundwork for a mandatory rule in the future.
- One pilot asks how many airports, including GA airports, will be digitally chartered by the FAA, and also wonders when they would be chartered.
- Both Dassault and the European Business Aviation Association believe FIS–B is an important safety feature because it provides high speed access to graphic weather maps.
- Two commenters asked for more comparative data on the FIS–B program, pointing out that they need information to compare the anticipated UAT weather products with existing products currently offered by weather service providers.
- Some, like Airbus, believe that FIS–B is redundant, inferior, and costlier than existing commercial services.

- The DOD, while not wholly adhering to this position, does mention that some functionality, such as terrain map displays, is not unique to ADS–B In and is available in existing technology.
- One ATP pilot questions the value in FIS–B because of other excellent, near-real time solutions such as XM satellite weather.
- Boeing objects to the NPRM's characterization of TIS–B as "comprehensive" because it is not usable on airports surfaces, is not available at all flight levels, and may not support ASSA and FAROA.

ARC Recommendations Regarding ADS–B In

ADS–B (both Out and In) will be a foundational element for the NextGen airspace. Although the ARC believes that there are potentially more benefits from ADS–B In than there are for ADS–B Out only, it also believes that at this point ADS–B In is not well enough defined for the FAA to do its required economic analysis and proceed forward with an ADS–B In rule. While the current NPRM is focused on ADS–B Out, the ARC recommends that the FAA, in partnership with industry, establish a program for ADS–B In by 2012. The ARC further recommends that this program defines how to proceed with ADS–B In beyond the voluntary equipage concept included in the current NPRM.

The ARC recognizes that work is ongoing to categorize the numerous operational improvements based on ADS–B In and to align the U.S. NAS, the Single European Sky, and other global initiatives to ensure a cost effective system implementation is essential. Although the requirements for situational awareness and some spacing applications based on ADS–B In are mature, other spacing applications and all delegated separation and self separation applications need additional work and industry consensus. The ARC urges the FAA to accelerate work on developing ADS–B In applications to a level of maturity where government and industry can understand the overall system performance requirements and estimate the tangible NAS operational benefits.

While the ARC believes that further work needs to be done for ADS–B In, there is no reason to delay the core benefits from implementing ADS–B Out as recommended by the ARC as an initial step in modernizing the U.S. and global airspace systems.

The ARC established a balanced set of skills from all parts of industry in support of the current NPRM. The ARC recommends that the charter for the current ARC be extended to take advantage of this knowledge base to develop the positions that define the ADS–B In applications and services. The ARC believes that it would benefit the community by developing recommendations on how ADS–B In should be implemented in terms of priorities, performance, and sequenced releases. This is to include—

- Defining ADS–B In terms of its response to defined system wide operational improvements.
- Establishing benefits based on flexible performance characteristics that consider both the air and ground contribution.
- Ensuring that the solutions identified are consistent with global perspectives.

- Offering guidance to domestic and global standards bodies to ensure that appropriate performance standards will exist to enable the defined system.
- Ensuring that all aspects of the system (for example, airspace and ground automation, sensors, and operational procedures) have been considered and are in place to enable access to benefits.

The ARC recommends that the preamble be modified to include the intention to move towards and encourage ADS–B In in the future.

FIS–B and TIS–B

The NPRM includes cost and benefits for ADS–B Out only. However, the FAA SBS Program was developed to provide ADS–B In information services that provide operational and safety benefits to incentivize the early voluntary equipage of ADS–B. These services include the broadcast of FIS–B and TIS–B by FAA ground infrastructure, similar to that provided in the FAA Alaskan Capstone program. Weather, traffic, and aviation system status information provided via FIS–B and TIS–B can be combined with GPS navigation and terrain avoidance information on a moving map display to improve pilot decision making, leading to increased safety and operational efficiency. Some operators have already equipped with various combinations of GPS navigation systems, terrain avoidance warning systems, and moving map displays. These operators will be able to realize benefits at a lower cost than currently unequipped operators. The diversity of current aircraft fleet equipage and avionic system options makes computation of accurate equipage costs challenging.

The FAA estimated the total costs and benefits for operator equipage of FIS–B and TIS–B services, on the UAT link, for the 25 year life of the program. These calculations resulted in a net aggregated benefit of $509M[23] and a net GA operator benefit of $2,738, if they are equipped from the beginning of the program. Although this cost-benefit information is not included in the rulemaking cost-benefit analysis, the ARC's decision analysis showed that the potential net benefit is significant and critically important to GA operators who elect to equip with the UAT link. The ARC believes cost-benefit information should be provided by the FAA as part of the rulemaking process so that GA operators can make an informed equipage decision.

The ARC recommends that the FAA include a discussion of the FIS–B and TIS–B benefits in the preamble to the ADS–B Out rule.

[23] From the Joint Resources Council (JRC) SBS Business Case.

5.0 Other ARC Recommendations on the NPRM

Implementation Timetable

NextGen requires the synergies of greatly improved CNS/ATM and cannot be enabled by any single technology. The ARC believes the aviation industry must pursue today the establishment of all CNS/ATM technologies if we expect NextGen by 2025. Although each of the technologies has some benefits when evaluated as a standalone system, those benefits are minimal compared to the benefits of NextGen.

The capabilities of NextGen and more near-term activities shift functions from ground-based equipment to the aircraft. This has the potential of greatly improving flight efficiency; however, it requires upgrades to multiple aircraft systems. Upgrading an aircraft is expensive in and of itself. Taking an aircraft out of service and pilot training can be more expensive than the upgrade. In addition, numerous systems on the aircraft are connected to or dependent on other aircraft systems to function correctly; therefore, touching one system frequently impacts others. For an aircraft operator to effectively manage the asset, changes must be carefully planned and integrated.

Because the CNS/ATM technology impacts numerous systems on the aircraft, upgrades cannot be effectively managed independently. If the NextGen CNS policies and regulations are not integrated as they relate to aircraft systems, the result will be a disaster for the aircraft operator.

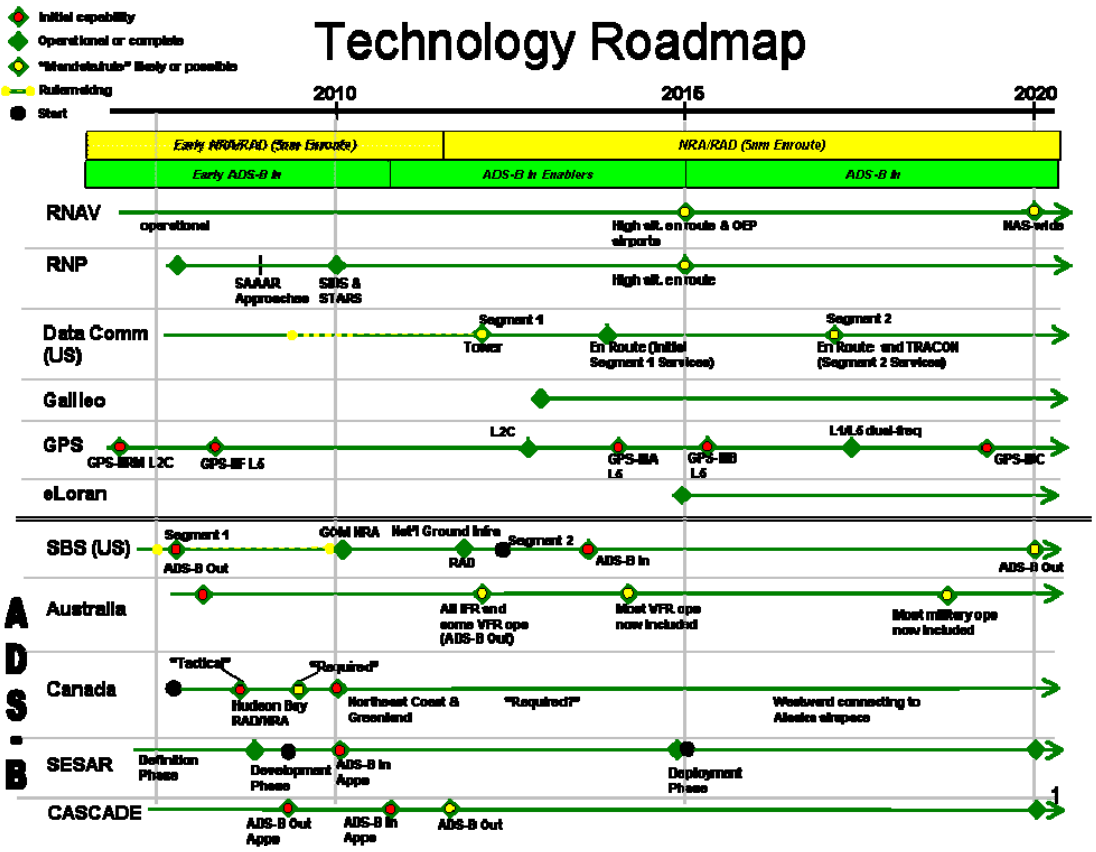
As we move forward, each CNS/ATM technology must be viewed as a mandatory subsystem of NextGen, otherwise they may not be optimized for their role in NextGen. While every opportunity should be taken to maximize benefits during the transition, the FAA needs to emphasize the importance of beginning the transition as soon as possible.

The FAA should include in the preamble of the final rule a roadmap with projected rulemaking dates for all three CNS technologies. The ARC understands that this integration is not easy, but it must be undertaken. The FAA needs to develop an integrated CNS roadmap before issuing the ADS–B final rule. The roadmap needs to include a phased transition path to what we know is going to be available in 18 to 20 years. It should include the avionics integration required onboard the aircraft for the different systems, especially those in common between the technologies. The roadmap should include the plan for mandating the equipment.

This roadmap should have bundled avionics upgrades with the goal that aircraft operators should only have to do upgrades every 5 to 7 years. The upgrades need to be integrated among the NextGen programs, not done individually, and need to reflect evolving international requirements for U.S. operators. All phases need appropriate cost-benefit justification.

In support of an integrated approach to enabling NextGen, the ARC offers the following graphical representation of technology, program, and global interoperability perspectives. While there is some uncertainty in timing identified in this representation, the notional elements have been included for completeness.

Figure 1—Technology Roadmap



Several conclusions can be drawn from this representation. These include the following:

- The use of ADS–B Out will be required in Australia, Canada, and Europe by 2015 or earlier based on the EASA AMC 20–24 for non-radar airspace using 5 nm separation.
- While commitment to rulemaking has yet to be determined for other technology domains, it is clear that an integrated perspective is required to enable NextGen.
- ADS–B In applications and services will require prioritization and investment. This investment must include the development of procedures and other air and ground infrastructural elements to enable the future airspace.

SSR Removal

The FAA should replace the current radar-based backup strategy with an ADS–B backup strategy that does not require the use of SSR. A non-SSR backup strategy is now much more feasible because of the FAA's 2008 policy decision to add fusion to all ATC automation systems. Aircraft identification, velocity vector, and altitude information are still broadcast by the ADS–B systems if there is a GPS service disruption/outage and could be associated with the primary radar track (the ADS–B broadcast serves the same function as Mode C). The FAA also should consider the use of passive multilateration as part of this backup strategy[24]. In addition, aircraft will have some alternative positioning/navigation source that will provide a position estimate with accuracy degraded from nominal GNSS — this information can be used to further aid the track correlation process. Fusion combines everything into one best position estimate. If the FAA is able to remove all SSR, the benefit would be $285M.

ACAS Changes

The FAA should conduct an in-depth study to consider modifying ACAS to use ADS–B as the primary surveillance data for collision avoidance in high-density airspace, while maintaining the current interrogation/reply functionality as a backup in high-density airspace until a suitable alternative is identified. If the FAA is able to eliminate reliance on SSR and make appropriate changes to ACAS, then the FAA should permit low-altitude domestic operators to remove their transponder.

Besides fixing certain safety problems, this modernization would significantly reduce 1090 MHz interference, enable collision avoidance functionality during very high-density NextGen operations, and likely permit many low end GA aircraft to remove their transponder functionality. Adding ADS–B based collision avoidance logic on top of the current CAS logic could significantly reduce the development time and cost of a modernized ACAS while retaining the ACAS functionality in the case of any ADS–B outage.

Since ADS–B based collision logic can increase the effectiveness of collision avoidance by solving certain altimetry problems, certain encounter geometry problems, reduce the false alarm rate, and decrease the missed alarm rate it is highly probable the this new collision avoidance architecture would result in an increase in safety. If the FAA is able to do this, it would also enable certain NextGen operations that would not be possible with the current ACAS system.

[24] Passive multilateration could be used to help associate the primary radar track with the ADS–B data.

APPENDIX A—ARC MEMBERS

Mr. Doug Arbuckle, Joint Planning and Development Office

Mr. Basil Barimo, *Co-Chair,* Air Transport Association of America, Inc.

Mr. Steve Brown, *Co-Chair,* National Business Aviation Association, Inc.

Mr. Jim Byrum, Cessna Aircraft Company

Mr. Vincent Capezzuto, *Designated Federal Official*, FAA, En Route and Oceanic Services

Ms. Sarah Dalton, Alaska Airlines

Mr. Jerry Davis, Airbus

Mr. Bruce DeCleene, FAA, Aircraft Certification Service

Mr. Jim Duke, Air Line Pilots Association

Mr. Ken Dunlap, International Air Transport Association

Mr. Scott Foose, Regional Airline Association

Mr. R. John Hansman, Massachusetts Institute of Technology

Mr. Rick Heinrich, Rockwell Collins

Mr. Jens Hennig, General Aviation Manufacturers Association

Mr. Bob Hilb, NESC

Mr. Randy Kenagy, Aircraft Owners and Pilots Association

Mr. George Ligler, Project Management Enterprises, Inc.

Mr. Chuck Manberg, Aviation Communication and Surveillance Systems

Mr. John McGraw, FAA, Flight Standards Service

Mr. Jeff Mittelman, MITRE/CAASD

Mr. William Richards, Boeing

Mr. Sam Seery, Garmin

Mr. Allan Storm, Department of Defense

Mr. Dale Wright, National Air Traffic Controllers Association

APPENDIX B—LIST OF ACRONYMS

1090 ES	1090 MHz extended squitter
ACAS	Airborne Collision Avoidance System
ADS–B	Automatic Dependent Surveillance – Broadcast
ADS–R	Automatic Dependent Surveillance – Rebroadcast
AIA	Aerospace Industries Association
ALPA	Air Line Pilots Association, Int'l
AMC	acceptable means of compliance
AOPA	Aircraft Owners and Pilots Association
ARC	Aviation Rulemaking Committee
ASDE–X	Airport Surface Detection Equipment, Model X
ASA	Aircraft Surveillance Applications
ASAS	Aircraft Surveillance Application System
ASSA	Airport Surface Situational Awareness
ATA	Air Transport Association of America, Inc.
ATC	air traffic control
ATCRBS	air traffic control radar beacon system
ATM	air traffic management
ATMAC	Air Traffic Management Advisory Committee
ATS	air traffic service
CDTI	cockpit display of traffic information
CNS	communication, navigation, and surveillance
CPR	compact position reporting
EAA	Experimental Aircraft Association
EASA	European Aviation Safety Agency
EFB	electronic flight bag
eLORAN	enhanced long range aid to navigation
ELT	emergency locator transmitter
EUROCAE	European Organization for Civil Aviation Equipment
EUROCONTROL	European Organisation for the Safety of Air Navigation
FAA	Federal Aviation Administration
FAROA	Final Approach Runway Occupancy Awareness
FIS–B	Flight Information Service – Broadcast
FSS	flight service station
GA	general aviation
GAMA	General Aviation Manufacturers Association
GNSS	global navigation satellite system
GPS	global positioning system
HPL	horizontal protection limit
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
INS	inertial navigation system
IRS	inertial reference system
MASPS	Minimum Aviation System Performance Standards
Mode S	mode select

MOPS	Minimum Operational Performance Standards
m.s.l.	mean sea level
NACp	navigation accuracy category for position
NACv	navigation accuracy category for velocity
NAS	National Airspace System
NextGen	Next Generation Air Transportation System
NIC	navigation integrity category
nm	nautical mile
NPRM	notice of proposed rulemaking
NPV	net present value
NRA	non-radar airspace
NUC	navigation uncertainty category
NUCp	navigation uncertainty category for position
OEP	operational evaluation plan
PPS	Precise Positioning Service
RAA	Regional Airline Association
RFG	Requirements Focus Group
RNAV	area navigation
RNP	required navigation performance
RTCA	RTCA, Inc.
RVSM	reduced vertical separation minimum
SA	selective availability
SARP	ICAO Standard and Recommended Practice
SBAS	satellite based augmentation system
SBS	Surveillance and Broadcast Services
SIL	surveillance integrity level
SNPRM	supplemental notice of proposed rulemaking
SPI–IR	surveillance performance and interoperability implementing rule
SSR	secondary surveillance radar
TIS–B	Traffic Information Service – Broadcast
TSO	technical standard order
UAT	universal access transceiver (978 MHz data link)
USPA	United States Parachute Association
VFR	visual flight rules
VOR	VHF omnidirectional range
WAAS	Wide Area Augmentation System

APPENDIX C—TERMINOLOGY

The following terminology applies to this report and the Aviation Rulemaking Committee (ARC)'s recommendations:

1090 ES (1090 MHz extended squitter) **—**An Automatic Dependent Surveillance – Broadcast (ADS–B) data link operating on the 1090 MHz frequency that uses messages conveying ADS–B information that comply with the format for a Mode S extended squitter. Each extended squitter is 112 bits long, of which 56 bits are allocated to ADS–B information. Typical 1090 ES equipment transmits on average of 4 to 5 ADS–B extended squitters per second. 1090 ES is an unsynchronized data link.

1090 MHz frequency congestion mitigation — A change to the operation of one of the three systems broadcasting on the 1090 MHz frequency (1090 ES, airborne collision avoidance system (ACAS), and secondary surveillance radar (SSR)) to reduce the amount of message traffic on the frequency caused by that system and, therefore, reduce the amount of interference on the frequency experienced by all three systems.

ADS–R — Automatic Dependent Surveillance – Rebroadcast — ADS–R is a ground-based component of a dual ADS–B link system. ADS–R consolidates ADS–B messages transmitted on one ADS–B frequency and broadcasts equivalent ADS–B messages on the other ADS–B frequency using the other frequency's link protocol.

Antenna diversity — The notice of proposed rulemaking (NPRM) requires aircraft to be equipped with a top- and bottom-mounted antenna to support ADS–B Out applications as well as future air-to-air ADS–B In applications.

Availability — The long-term performance of a system, typically defined in years. Typical availability analysis for ADS–B Out considers a pessimistic minimum guarantee of a global navigation satellite system (GNSS) constellation performance (currently 21 healthy global positioning system (GPS) satellites in appropriate orbital positions, 98 percent of the time, with minimum satellite power).

Continuity — The short-term availability, typically in terms of hours or days, required to maintain the minimum performance requirements for navigation accuracy category for position (NACp), NAC for velocity (NACv), navigation integrity category (NIC), and surveillance integrity level (SIL) for a given operation. Continuity can take into account the current satellite constellation and power.

DME–DME — Aircraft positioning, using the distance measuring equipment (DME) range from two DME stations to determine the aircraft's horizontal position.

DO–260-approved — A variant of the DO–260 standard (not yet specified by the FAA), based on European Aviation Safety Agency (EASA) Acceptable Means of Compliance (AMC) 20–24, that the ARC expects will be approved for several ADS–B applications in the National Airspace System (NAS). Some DO–260-like equipment is expected to be easily modified to become DO–260-approved. See Appendix Q to this report.

DO–260-like — An early implementation of 1090 MHz extended squitter (1090 ES) developed in accordance with a draft of the DO–260 standard. DO–260-like implementations have not been certified to technical standard order (TSO) C–166 (the Federal Aviation Administration (FAA) TSO implementing DO–260) and vary from the final DO–260 standard in ways that are manufacturer-specific.

DO–260A Change 3 — The planned update to the Radio Technical Commission for Aeronautics (RTCA)/DO–260A that will be used by the FAA in measuring compliance of 1090 ES avionics to the proposed ADS–B Out rule.

DO–282A Change 2 — The planned update to RTCA/DO–282A that will be used by the FAA in measuring compliance of universal access transceiver (UAT) avionics to the proposed ADS–B Out rule.

Dual Link Implementation Strategy — As articulated by the FAA in 2002, ADS–B messages are to be broadcast on two ADS–B links on separate radio frequencies, with ADS–R providing a bridge between the two. The two ADS–B links are 1090 ES operating on 1090 MHz (for high altitude aircraft and international interoperability) and UAT operating on 978 MHz (for low altitude aircraft).

Hybrid surveillance — A technique for airborne collision avoidance systems (ACAS) to use ADS–B data along with transponder interrogation data. This technique would reduce the frequency of transponder interrogations, therefore reducing congestion on the 1090 ES link.

Multilateration, Active — A method of aircraft surveillance using three or more ground receivers using the time difference of arrival (TDOA) of 1090 replies to a 1030 MHz interrogation signal.

Multilateration, Passive — A method of aircraft surveillance using three or more ground receivers using the time difference of arrival (TDOA) of periodic, uniquely identified transmissions, which can include ADS–B transmissions.

NextGen — Next Generation Air Transportation System. See www.jpdo.gov.

Non-radar airspace (NRA) airport — An airport without radar coverage, which receives air traffic control (ATC) procedural separation service.

OEP 35 — (Operational Evolution Partnership 35 Airports) — Commercial Airports with significant activity. The FAA and Congress studied the most congested airports in the U.S. and compiled a list of the 35 OEP Airports. These airports serve major metropolitan areas and also serve as hubs for airline operations. More than 70 percent of passengers move through these airports. Delays at the OEP 35 airports have a ripple effect to other locations. The OEP 35 airports do not change.

Primary surveillance radar (PSR) /secondary surveillance radar (SSR) — Primary radar uses radio frequency energy transmitted from the radar site and reflected back from an aircraft to determine the aircraft's position relative to the radar site. Secondary radar sends an interrogation signal to an aircraft transponder and uses the transponder's reply to determine the aircraft's identity and position relative to the radar site. Mode S and C transponders also transmit altitude information in their replies.

SA On/SA Off — The U.S. Government designed GPS satellites with a selective availability (SA) feature that degrades the accuracy of the GPS signal for civilian purposes. In 2000, President Clinton signed an order to turn off this feature and improve GPS accuracy for all users. Early GPS receivers are referred to as "SA On," because they were necessarily designed based on satellites with SA enabled. SA Off GPS receivers (also called SA-aware receivers) are designed so that no SA-related factors need to be included when estimating the accuracy and/or integrity of the GPS position.

UAT — (Universal Access Tranceiver) **—** An ADS–B data link operating on the 978 MHz frequency.

APPENDIX D — ADS–B BACKGROUND INFORMATION

The U.S. air transportation system serves as a critical engine of economic growth and facilitates the safe and efficient movement of people and goods across the globe. As the demand for air transportation increases, new solutions must be developed to avoid an increase in costly air travel delays and the associated compromise of our ability as a nation to grow our economy. Congress tasked the FAA with creating the Next Generation Air Transportation System (NextGen) to accommodate the projected increase in air traffic volume. NextGen is designed to take advantage of the latest technologies, be flexible enough to accommodate new travel options, and be robust enough to handle a projected increase of up to three times the current level of operations. Recognizing the limits of a radar infrastructure, the FAA proposed a new surveillance system for the national airspace system (NAS). After 4 years of initial operational experience with a first generation system in Alaska, on September 9, 2005, the FAA selected ADS–B as the preferred solution for meeting future U.S. surveillance needs.

The proposed ADS–B Out system will provide controllers with aircraft position and direction information, which is more accurate and real-time than the information available in current radar-based systems. The information will facilitate more efficient traffic control procedures and some increase in capacity, while maintaining the safety of flight. A follow-on ADS–B In system could present the same information to flightcrews through cockpit displays. (See the section, ADS–B System, in this appendix for further detail on ADS–B In and ADS–B Out.)

With future air traffic control (ATC) applications and revised ATC procedures, the ADS–B program could significantly increase airspace capacity and support the goals of NextGen. To achieve these benefits, all the aircraft in a given environment must be equipped with ADS–B avionics that meet stringent requirements for safe operation in dense U.S. airspace.

To develop, implement, and manage an ADS–B system, the FAA created the national Surveillance and Broadcast Services (SBS) Program Office within its Air Traffic Organization (ATO). The objective of the SBS Program Office is to develop a multisegment, life cycle-managed, performance-based strategy that aligns with the NextGen vision and generates value for the NAS. Consistent with this goal and in conjunction with other agencies, the SBS Program Office is developing system requirements that meet the need for increased capacity, a comprehensive implementation plan, and a multifunctional backup strategy. Specifically, the backup strategy will maintain surveillance in the event of any degradation or outage of a fundamental ADS–B component, including the global positioning system (GPS) and ground-based broadcast equipment. The SBS program builds on the research, development, and safety work conducted by the Capstone Program Office in Alaska and by the Safe Flight 21 Office in the continental United States.

The FAA intends to provide surveillance and broadcast services in all areas of the NAS covered by radar today and in non radar airspace (NRA), including the Gulf of Mexico. The ADS–B ground infrastructure acquisition has been structured as a multiyear, performance-based service contract under which the vendor will install, own, and maintain the equipment, and the FAA will purchase services in the same way it purchases telecommunications services today. The FAA will define the services it requires and maintain ultimate control of the data that flows between the vendor's infrastructure, FAA facilities, and aircraft.

The initial scope of the SBS program includes two services (air-to-ground surveillance and traffic/flight information broadcast services) and support of five aircraft applications (enhanced visual acquisition, enhanced visual approaches[1], final approach and runway occupancy awareness, airport surface situational awareness, and conflict detection). The SBS program expects to support additional ADS–B applications in later phases of the program.

The ADS–B program has received approval and funding to provide surveillance and flight information services NAS-wide by 2013. Surveillance services will be available as soon as separation standards have been finalized for 4 widely used automation systems within the NAS. ADS–B surveillance and services are scheduled to be certified for permanent use on these automation platforms by September 2010. Ground infrastructure implementation and integration into the remaining automation systems will occur between 2010 and 2013. The figure below shows key milestones for achieving a NAS-wide surveillance and broadcast services.

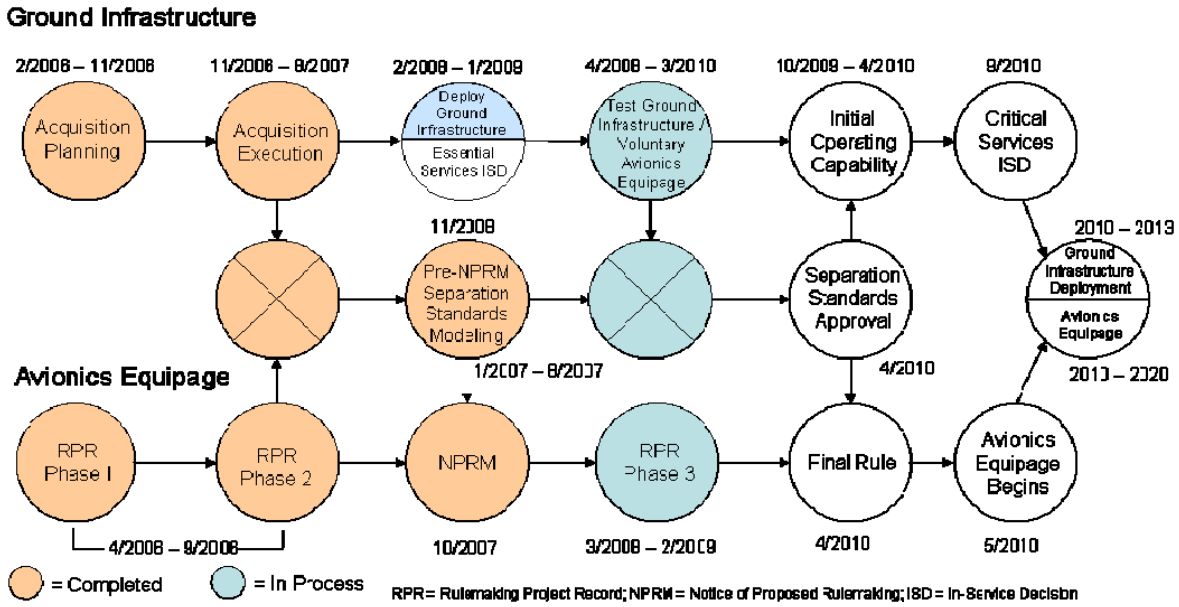


Figure 1—ADS–B Program Milestones

The goal of efforts until 2010 in the program is to prove the concepts of an end-to-end surveillance and broadcast services system. This work already has begun. This effort includes the development of avionics standards for existing and future ADS–B avionics on both the 1090 MHz extended squitter (1090 ES) and universal access transceiver (UAT) datalinks. Development of a ground infrastructure specification, including both the development of ground stations and integration in ATC automation platforms, is also part of early implementation. In addition, before a final rule can be issued there must be approved ADS–B separation standards. Without this approval, aircraft cannot be separated from each other using ADS–B and the system would have limited benefit.

In 2007 the SBS Program Office established a national contract with ITT Corporation to implement a ground infrastructure to support the surveillance and broadcast services

[1] Merging and Spacing and Cockpit Display of Traffic Information (CDTI) Assisted Visual Separation (CAVS) are a part of the Enhanced Visual Approaches Application.

applications. In 2007, the FAA published a notice of proposed rulemaking (NPRM), intended to mandate ADS–B performance in aircraft, and created an ADS–B Aviation Rulemaking Committee (ARC).

Previous prototype equipment deployed along the U.S. east coast will be absorbed and expanded on with new surveillance and broadcast services equipment. The FAA continues to develop future applications of the surveillance and broadcast services infrastructure based on an evaluation of those applications' values to NAS operators. The FAA has already begun developing applications such as a 3 mile en route separation of aircraft.

ADS–B System

ADS–B is a data link system in which aircraft avionics broadcast the position and other information from the aircraft for ground-based receivers and other aircraft with receivers. This data link enables a variety of capabilities on the aircraft and in ATC, as shown in figure 2 below.

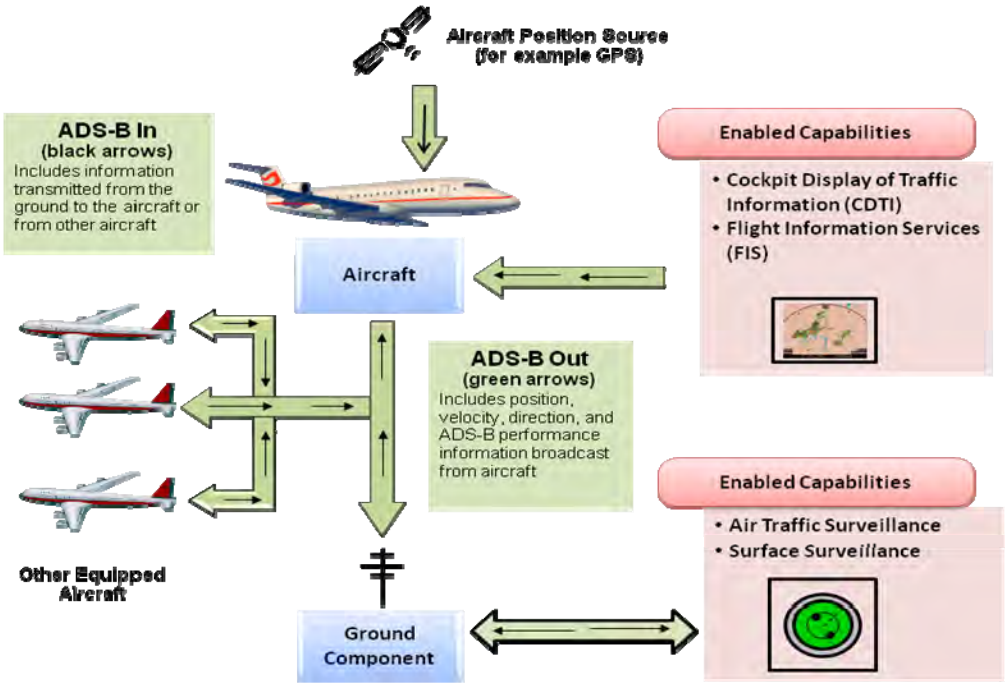


Figure 2—ADS–B System Overview

The ADS–B program consists of two different systems: ADS– B Out and ADS–B In. The ability to transmit ADS–B signals or "messages" is referred to as ADS–B Out. The proposed rule requires most operators to equip with ADS–B Out, which would be a prerequisite for any future option or requirement to install ADS–B In avionics.

ADS–B Out allows for more accurate and timely ATC surveillance data as compared to existing primary and secondary radars, but does not provide flightcrews the ability to receive, display, or interpret ADS–B signals. To realize the many benefits of the ADS–B system, including the ability for a flightcrew to have situational awareness of proximate traffic or to use advanced air-to-air applications, aircraft will need to be equipped with an ADS–B display. Applications enabled by ADS–B depend on whether aircraft are equipped with ADS–B Out or

ADS–B In. ADS–B In capabilities can be divided into the following two categories: capabilities provided by the ground surveillance component and capabilities added by aircraft equipment.

Surveillance and broadcast services are expected to be provided by the FAA on two different broadcast links: 1090 ES and UAT. High altitude users, including larger air transport category operators, are more likely to equip with 1090 ES. Low altitude users, including most general aviation (GA) operators, are more likely to equip with UAT. For future ADS–B In applications, ground-based automatic dependent surveillance–rebroadcast (ADS–R) equipment allows an aircraft in one link to display aircraft on both links. Aircraft equipped with 1090 ES and UAT could display aircraft on both data links, without the ADS–R system. With respect to broadcast information, flight information service–broadcast (FIS–B) is currently available only on UAT.

ADS–B Out

As shown in figure 3, an aircraft using ADS–B Out periodically broadcasts its own position and other information through an onboard transceiver. The ADS–B signal can be received by ground stations providing information to ATC and by other aircraft equipped with ADS–B In. Broadcast signals include the aircraft's flight identification, position (horizontal and vertical), velocity (horizontal and vertical), and various performance parameters. Standards for the information provided by ADS–B Out broadcast messages have evolved over time. Aircraft have been equipping with ADS–B Out according to the standards at the time of equipage. The proposed rule establishes and requires specific performance standards, which are projected to enable ADS–B In applications.

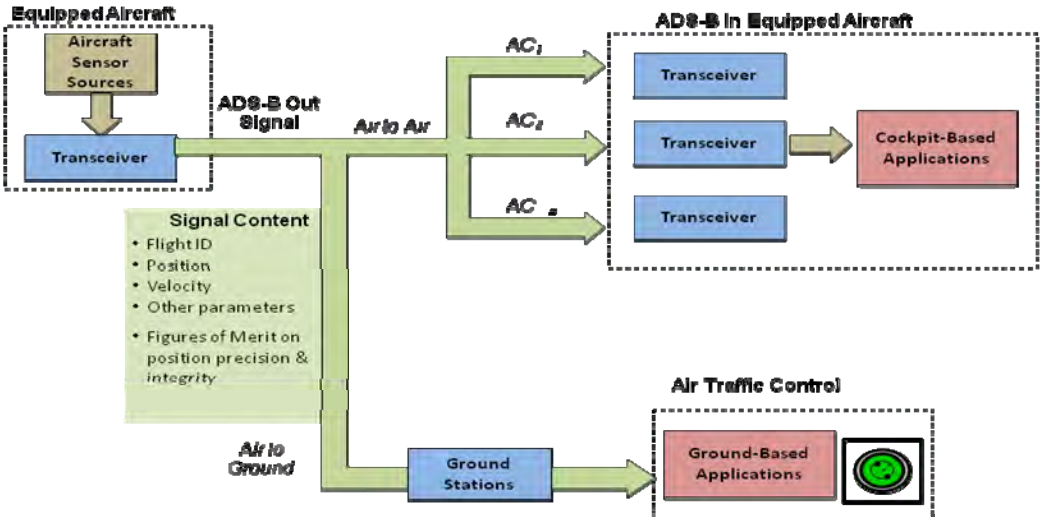


Figure 3—ADS–B Out Signal and Enabled Capabilities

ADS–B Out is automatic in the sense that no pilot action is required for the information to be transmitted. It is dependent surveillance in the sense that the surveillance information depends on the positioning and broadcast capabilities of the source. As shown in figure 3, ADS–B Out could be used by ATC for surveillance and traffic separation, in a manner similar to the current radar usage and radar-based separation standards. The broadcast signal can also be received by other aircraft equipped with ADS–B In avionics (as discussed in the next section) to enable

cockpit-based applications. Aircraft can be equipped with ADS–B Out without having ADS–B In capability.

ADS–B In

The ability to receive ADS–B signals from the ground and other aircraft, process those signals, and display traffic and information to flightcrews is referred to as ADS–B In, as illustrated in figure 4.

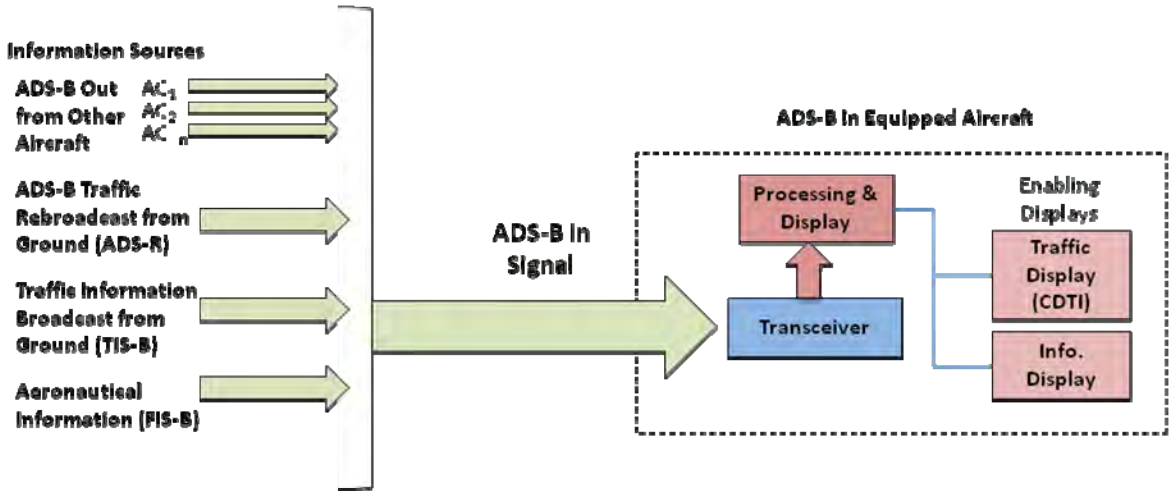


Figure 4—ADS–B In Signal Sources and Enabled Capabilities

As shown in figure 4, an ADS–B In-equipped aircraft can receive information from multiple sources. Achieving benefits from ADS–B In requires onboard processing of the ADS–B signal and integration with aircraft displays. The ADS–B signal processing may be done in terms of a decision logic platform to generate warnings or provide guidance for numerous air-to-air applications, and may be presented on a variety of display platforms. ADS–B In complements ADS–B Out by providing pilots and aircraft navigation systems with highly accurate position and direction information on other aircraft operating nearby.

At the most basic level, ADS–B In enhances the flightcrew's situational awareness of other aircraft operating within their proximity. The full potential of ADS–B In may allow flightcrews to plot the most efficient flight path without ATC instructions. Flightcrews in ADS–B In-equipped aircraft may be able to locate other traffic, identify crossing flight paths, and adjust their flight path to remove any conflicts. ADS–B In also would sustain the level of flight safety provided by radar-based surveillance systems, and may support reduced traffic separation distances and allow for increased traffic volumes.

Before implementing ADS–B In, the FAA needs to establish performance standards for each ADS–B In application, establish standards for the subsystems necessary to support the expanded operations, and certificate ADS–B In cockpit display systems. Additionally, the FAA will need to make decisions about electronic flight bags (EFB), as an alternative to integrated cockpit displays. ADS–B In is a major element of the future surveillance technology mix planned by the International Civil Aviation Organization (ICAO) Global Air Navigation Plan.

Automatic Dependent Surveillance – Rebroadcast

To take advantage of all ADS–B In applications, flightcrews must have situational awareness that includes aircraft not equipped with ADS–B and aircraft equipped with ADS–B but transmitting on a different data link. ADS–R is planned as a component of the ADS–B ground infrastructure, which provides interoperability between UAT and 1090 ES.

ADS–R collects traffic information broadcast on the UAT data link and rebroadcasts the information to 1090 ES users. ADS–R also collects traffic information provided on the 1090 ES datalink and rebroadcasts the information to UAT users. With a dual link system, ADS–R allows any ADS–B In-equipped aircraft to receive messages about aircraft transmitting on either 1090 ES and UAT.

Traffic Information Service – Broadcast

ADS–B is a cooperative surveillance environment that requires all users to participate to maximize operational benefits. During the transition period, when only some users have equipped with ADS–B, other systems will be necessary to provide the best available information to those seeking the total surveillance picture onboard an aircraft. The traffic information service–broadcast (TIS–B) service uses secondary surveillance radars and multilateration systems coupled with other sources to provide proximate traffic situational awareness, including position reports from aircraft not equipped with ADS–B. However, additional ground processing is necessary to create accurate information, and source data may not be equivalent to ADS–B information provided by a participating aircraft. Therefore, the TIS–B signal is planned to be used only as an essential advisory service, not to separate or maneuver aircraft. Figure 5 shows an existing multifunctional aircraft cockpit display that shows both aircraft position reports derived directly from other ADS–B-equipped aircraft and from the TIS–B service (for those aircraft not equipped with ADS–B Out).

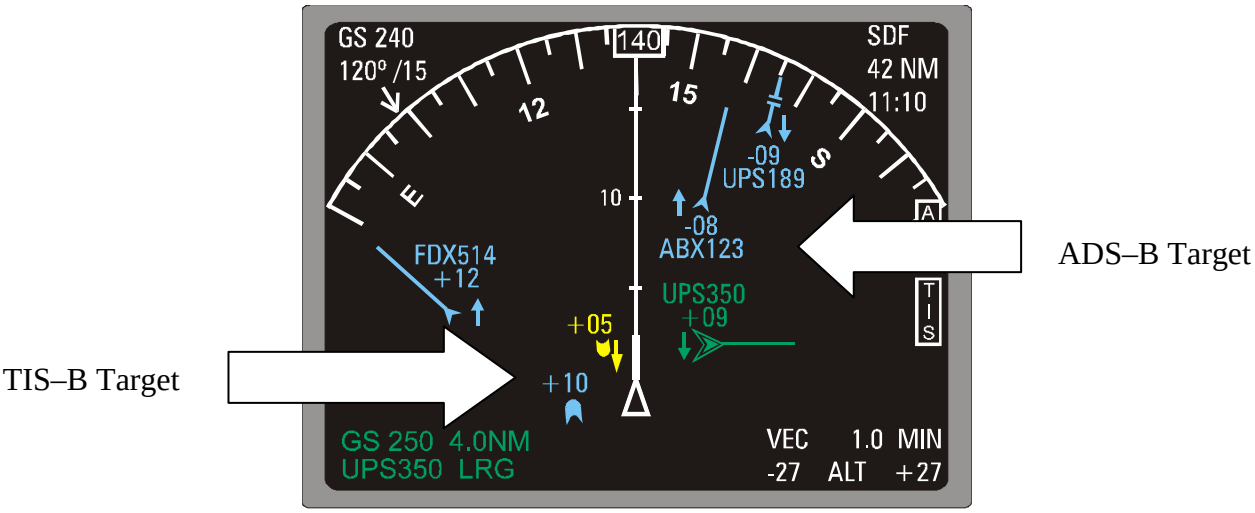


Figure 5—Currently Available Traffic Display

Flight Information Service – Broadcast

The FIS–B service is carried on the UAT data link and provides additional supplementary flight information. FIS–B is intended to provide enhanced weather services, textual and graphic

weather and terrain information, Notices to Airmen (NOTAM), Temporary Flight Restrictions (TFR), and other flight information for processing and display. For the GA user, this provides a single platform that will enhance safety through a broader suite of situational awareness services. Figure 6 shows a prototype FIS–B aircraft cockpit display.

Figure 6—Currently Available FIS–B Display

The air transport community also has expressed interest in using the FIS–B service to increase the real-time availability of weather data in the cockpit on 1090 ES-equipped aircraft — this would require the aircraft to be equipped with a UAT In capability.

ADS–B and Global Harmonization

ADS–B offers aviation the opportunity to create an integrated single sky on a global basis. Through focused global harmonization efforts, aircraft could be enabled to fly the most fuel-efficient routes between the world's airports. However, to fully leverage these benefits, U.S. and international regulators will need to agree to compatible equipment standards, interoperability rules, and comparable flight procedures for ADS–B technology. If done properly, this could result in seamless control of air traffic: a technological leap over today's global patchwork of services and control facilities.

The FAA, Joint Planning and Development Office (JPDO), ICAO, the European Organisation for the Safety of Air Navigation (EUROCONTROL), the European Organization for Civil Aviation Equipment (EUROCAE), Airservices Australia, Japan Civil Aviation Authority, NAV CANADA, and the Radio Technical Commission for Aeronautics (RTCA) are fostering the necessary international cooperation required for ADS–B interoperability through their support of the activities of joint standards workgroups. Additionally, several nations have traded key ADS–B subject matter experts to foster greater dialog and exchange concepts and new ideas for ADS–B planning. Such initiatives are defining and resolving the issues related to aircraft equipment standards and air traffic management procedures for international stakeholders.

The ADS–B Requirements Focus Group (RFG) is a joint RTCA-EUROCAE standards group, strongly supported by the FAA and EUROCONTROL, with further participation from

Airservices Australia, NAV CANDADA, and the Japanese Civil Aviation Board. The RFG has develped RTCA DO–303/ED–126 to provide requirements for the use of ADS–B in NRA and is currently working on further globally harmonized standards for ADS–B Out, in a manner consistent with support for ADS–B In applications.

ICAO standards and recommended practices (SARPs) and manuals have been approved for ADS–B avionics using 1090 ES and UAT.

Australia, Canada, the European Union, and the United States are actively installing ADS–B ground infrastructure and are operationally using ADS–B now or plan to use it in the near future. China, Fiji, Hong Kong, India, Indonesia, Japan, Mongolia, New Zealand, Singapore, and Thailand are planning their own ADS–B trials as well.

Australia currently uses ADS–B to provide radar-like separations in non-radar airspace at en route altitudes over much of the Australian continent. As of June 2008, Australia had 11 commissioned ADS–B ground stations, which provide operational benefits to approximately 660 ADS–B-approved aircraft. Currently, over 50 percent of all international flights in Australian airspace are conducted on ADS–B-approved aircraft. Most recently, Airservices Australia commissioned a ground station at Thursday Island, which provides surveillance across the international boundary with Port Moresby and Indonesia. Australia is currently installing and commissioning an additional 17 ADS–B ground stations to support Australia's Upper Airspace Program. Work is well underway to prepare for the move to use 5 nautical mile (nm) separation standards across the Australian continent in early 2009. Australia has issued mandatory standards, amending Civil Aviation Order 20.18 for ADS–B equipage and transmissions in Australian airspace, with a compliance date of June 28, 2012.

By November 20, 2008, Canada's first ADS–B implementation is scheduled to provide coverage over 250,000 square nautical miles of airspace over Hudson Bay. NAV CANADA has commissioned 15 peripheral air-ground links (PAL) across Canada's northern region, from Whitehorse to Cape Dyer and Pond Inlet. The northern PALs enable controllers to apply reduced aircraft separation, initially for ADS–B equipped aircraft at segregated altitude, which is expected to result in increased airspace capacity and more prompt altitude and routing changes. NAV CANADA projects ADS–B-equipped customers will save $10 million per year in fuel costs.

Step 1 of European ADS–B implementation is voluntary and in "pocket areas," using existing (certified) equipment. In the a recent EUROCONTROL workshop, the participants agreed with requiring operators to carry a transponder and a suitable GPS for ADS–B data, which would support Mode S surveillance, wide area multilateration, and ADS–B. EUROCONTROL expects initial ADS–B operational implementation between 2009 and 2011 in the following areas:

- Greece — to supplement existing radar surveillance.
- Italy and Turkey — to replace procedural control.
- Netherlands — for low altitude offshore helicopter operations.
- Portugal — for traffic surveillance between the Azore islands using a combination of ADS–B wide area multilateration and radar.
- Sweden — for all operations around Kiruna airport.

For Step 2, a European ADS–B surveillance performance and interoperability implementing rule (SPI–IR) is being finalized. The SPI–IR is scheduled to be published near the end of 2009. The SPI–IR is expected to require DO–260A change 3 1090 ES equipment and Global Navigation Satellite Systems (GNSS) engines with Selective Availability awareness. In parallel, EUROCONTROL is planning to introduce ADS–B In for voluntary operations in 2011, starting with in trail procedures. In March 2008, EUROCONTROL conducted the first flight test for in trail procedures, which verified the fuel savings and safety benefits.

APPENDIX E — ADS–B ARC QUESTIONS TO THE NPRM AND FAA RESPONSES DATED DECEMBER 19, 2007

Federal Aviation Administration

Memorandum

Date: December 19, 2007

To: Docket No. FAA-2007-29305

From: Cindy Nordlie, Office of Rulemaking

Prepared by: Cindy Nordlie

Subject: Memo for the record: ADS-B Aviation Rulemaking Committee questions and FAA responses

Under Order 1110.147, effective July 15, 2007, the FAA established the ADS-B Aviation Rulemaking Committee (ARC) pursuant to the Administrator's authority under Title 49 of the United States Code (49 U.S.C.) section 106(p)(5). The ADS-B ARC provides a forum for the U.S. aviation community to discuss and review the ADS-B NPRM after its publication, formulate recommendations on an ADS-B mandate, and consider additional actions that may be necessary to implement those recommendations. The ARC submitted questions to the FAA to clarify the NPRM. The questions and the FAA responses were discussed at an ARC teleconference on December 19, 2007 and are being submitted to the docket so the public will have an opportunity to see the any clarifying information the FAA provided to the ARC.

Questions on the ADS–B NPRM for Clarification—FAA Response

1) Is it the intent of the NPRM to require a Time Mark Synchronized solution (i.e. T=1) in 1090 MHz equipment?

   Although DO-302 is not invoked by the NPRM, in paragraph 2.2.4.1.1.3 of DO-302, it states that NACp should be limited to 7 or below when not in a time synchronized installation. The NPRM requires NACp of 9. Taken together, these statements imply that Time Mark Synchronization may be required.

   Response to ARC: The NPRM is a performance-based rule, and it is up to the applicant to determine the best means to meet the required performance. The NPRM does not specifically require or preclude time mark synchronization for 1090ES.

2) DO-229D paragraph 2.1.2.6.2 allocates 500 ms for a GNSS sensor to compute a solution plus 200 ms to deliver the solution. The NPRM allocates 500 ms for a GNSS to compute AND deliver a solution. Is it the intent of the NPRM to impose a more stringent requirement than DO-229D? Or was the 200 ms transport delay in DO-229D included in the 1 second allocated to the Transmit equipment?

   Response to ARC: The NPRM proposed that, upon receipt of the information by the aircraft antenna(s), the navigation position sensor must process the information in less than 0.5 seconds and the processed information from the navigation position sensor must be transmitted in the ADS-B Out message in less than 1.0 second.

   The NPRM did not propose a more stringent requirement than DO-229D. Further questions regarding latency may be submitted to the docket as a comment.

3) Explain the reason for proposing prescriptive latency limits for certain individual system components rather than one limit for the total aircraft system.

   Response to ARC: This question is beyond clarification of the NPRM. Further questions regarding latency may be submitted to the docket as a comment.

4) Confirm that the proposed requirement for total system latency, from the time the aircraft's antenna(s) receives a GNSS signal until the ABS-B transponder transmits a message, is “no more than 1.5 seconds.”

   Response to ARC: The NPRM did not propose a total latency requirement. The response to question 2 includes proposed allocated latency requirements. Further questions regarding total latency may be submitted to the docket as a comment.

5) The NACp, NIC and SIL performance is highly dependent on the satellite constellation. What is the minimum GPS satellite constellation with which the performance must be achieved (e.g., Martinez 24?).

   Response to ARC: There is no specified minimum constellation. As specified in the NPRM, at time of dispatch, an operator is expected to ensure that they comply with

the ADS-B requirements for their intended flight. From the NPRM: "In accordance with proper preflight actions,[1] each operator would have to verify ADS-B Out availability for the flight planned route through the appropriate flight planning information sources. If the aircraft cannot meet the proposed performance requirements using a given position service, the operator would have to use either a different, available position service, re-route, or reschedule the flight."

We recognize that sometimes ADS-B Out performance is not achievable at certain times due to interference or significant constellation degradation. This is also addressed in the NPRM: "During interference outages of GNSS (scheduled or unscheduled), the FAA expects to revert to the backup ground-based surveillance system and temporarily allow operations without ADS-B Out in required airspace. Pilots would be notified of such action via the Notice to Airmen (NOTAM) system. The FAA also expects to revert to the backup surveillance system during significant degradation in the GPS constellation. When deciding to issue NOTAMs to allow operations by aircraft with inoperable ADS-B Out equipment, the FAA will weigh the impact of denying airspace access to those aircraft that do not comply with the performance requirements against the reduction in operational capability due to the limitations of the backup surveillance system."

6) What is the required availability for meeting the NACp, NACv, NIC and SIL performance?. For example, is this performance required to be met 100% of the time, even while operating with the minimum satellite constellation?

Response to ARC: See response from question 5.

7) What will be the classification of a failure at the aircraft level that leads the transmission of corrupted position data?

Response to ARC: At the aircraft level, the failure classifications are derived from page 3, paragraph 3c, of TSO C166a and TSO C154b .

8) Clarify the objective and intended uses of the proposed 'ATC Service Request Message', and why the message would not duplicate a similar data link message in Part 121 operations.

Response to ARC: This message element would identify to air traffic controllers if services are requested and whether the aircraft is in fact receiving ATC services. The "ATC Services are Requested" indication is used to differentiate aircraft that are receiving ATC services from those that are not receiving ATC services. Currently, aircraft that are not receiving ATC Services are identified by their Mode 3/A code - 1200 codes typically do not receive ATC services. Also, this proposal affects all

[1] See 14 CFR 91.103

operators, not just part 121 operators, and operations in both radar and non-radar airspace.

9) Identify each of the transponder emergency codes listed in the Aeronautical Information Manual (AIM) that are considered "applicable" to the requirement for transmission in ADS-B messages.

Response to ARC: The following transponder codes in the AIM are applicable:

- Chapter 4, section 1, 4–1–19 for overall transponder codes and the codes 7500, 7600, 7700 (subparagraph e. discusses 7500 used for hijacking);
- Chapter 6, section 2, 6–2–2 denotes 7700 for an emergency or distress.
- Chapter 6, section 4, 6–4–2 denotes 7600 for loss of two-way radio capability.

10) Is there a plan to draft an advisory circular for guidance for installing and certificating systems installed by STC rather than service instructions?

Response to ARC: Yes, the FAA is drafting an advisory circular and will make it available for comment.

11) What level of confidence do we have that separation standards will be improved over current standards?

Response to ARC: This question is beyond clarification of the NPRM and may be submitted as a comment to the docket.

12) Is there any credible research that proves that ADSB IN applications such as merging and spacing or self-separation will provide better traffic management or capacity than is currently provided by ATC...(there seem to me to be mainly vague concepts).

Response to ARC: The information the FAA relied on for ADS-B applications is contained in the FAA's Regulatory Evaluation. The supporting documentation and the Regulatory Evaluation are included in the docket.

13) Has there been sufficient research on the 1090 bandwidth issue in high density traffic areas?

Response to ARC: This question is beyond clarification of the NPRM and may be submitted as a comment to the docket.

APPENDIX F — ADS–B ARC QUESTIONS TO THE NPRM AND FAA RESPONSES DATED FEBRUARY 1, 2008

Federal Aviation Administration

Memorandum

Date: February 1, 2008

To: Docket No. FAA-2007-29305

From: Cindy Nordlie, Office of Rulemaking

Prepared by: Cindy Nordlie

Subject: Memo for the record: ADS-B Aviation Rulemaking Committee questions and FAA responses

Under Order 1110.147, effective July 15, 2007, the FAA established the ADS-B Aviation Rulemaking Committee (ARC) pursuant to the Administrator's authority under Title 49 of the United States Code (49 U.S.C.) section 106(p)(5). The ADS-B ARC provides a forum for the U.S. aviation community to discuss and review the ADS-B NPRM after its publication, formulate recommendations on an ADS-B mandate, and consider additional actions that may be necessary to implement those recommendations.

The ARC originally submitted 13 questions to the FAA to clarify the NPRM and then submitted additional questions. Question Nos. 1 through 13 were previously completed and are posted at Docket No. FAA–2007–29305–0046. This document contains Question Nos. 14-45. Question Nos. 14-45 and the associated FAA responses were discussed at an ARC meeting on January 30, 2008, and are being submitted to the docket so the public will have an opportunity to see the clarifying information the FAA provided to the ARC.

Clarifying Questions from the ADS-B ARC
013108 v1

Question Nos. 1 through 13 were previously completed and are posted at docket No. FAA–2007–29305–0046

14. Regarding Section IV.B.3 "Broadcast Message Elements" (a): Note that the Length and Width Code is only included in the ADS-B surface message formats. Aircraft that are allowed to always transmit the Airborne message format will never transmit the Length and Width Code. Please clarify whether the Length and Width Code requirement implies that the surface message format must be supported by all ADS–B equipment installations.

    Response to ARC: This question is beyond clarification of the NPRM and may be submitted as a comment to the docket.

15. Regarding Section IV.B.3 "Broadcast Message Elements" (d) Velocity: The text of this section refers to "airspeed". The ADS-B standards only refer to velocity reference to the WGS-84 ellipsoid. Please clarify this discrepancy.

    Response to ARC: This was an editorial error and should reference velocity instead of airspeed.

16. Regarding Section IV.B.3 "Broadcast Message Elements" (g) "Receiving" vs. "Requesting" ATC Services: The datalink MOPS refer to this data element as indicating that the aircraft is receiving ATC services. The NPRM refers to it as requesting services. The distinction is important because it implies a specific order of flight crew interaction with ATC. Please clarify whether the NPRM proposes to re-define how this data element is specified.

    Response to ARC: The FAA did not intend to redefine this parameter. Consistent with the MOPS, this data element indicates that the aircraft is receiving ATC services.

17. Regarding Section IV.B.3 "Broadcast Message Elements" (h) Mode 3/A Code: Practically speaking, the transponder squawk code is also the method that indicates when the aircraft is receiving ATC services. ATC assigns the flight crew a squawk code, and reception of the code by ATC serves to confirm the aircraft's participation within the NAS. A squawk code of "1200" indicates that the aircraft is not being provided ATC services. It is confusing for the FAA to refer to items (g) and (h) as though they were in some way separate entities, requiring separate flight crew entries. This is inconsistent with current aircraft operations. Please clarify whether items (g) and (h) may be considered as one data element.

    Response to ARC: Items (g) and (h) are separate parameters. In non radar airspace, such as Alaska or the Gulf of Mexico, ATC will need a way to differentiate between ADS–B transmitting aircraft that are receiving ATC services and those that are not receiving ATC services.

18. Regarding Section IV.B.3 "Broadcast Message Elements" (j) Emergency/Priority codes: There are up to seven emergency/priority codes defined in the ADS–B datalink standards. There are only three defined in the ICAO standards that are implemented by the Mode 3/A code. Please clarify whether all of the ADS–B codes must be implemented, or if support for only the existing Mode 3/A codes is sufficient.

    Response to ARC: Please see the response to question No. 9.

19. Regarding Section IV.B.3 "Broadcast Message Elements" (j): The requirement for ICAO 24-bit addresses implies that other addressing modes (such as the self-assigned temporary address supported under TSO-C154b) may be disallowed under the proposed rules. Please clarify if the proposed rules will modify the existing aircraft address requirements in TSO-C154b.

    Response to ARC: This question is beyond clarification of the NPRM and may be submitted as a comment to the docket.

20. Regarding Section IV.B.3 "Broadcast Message Elements" (n): The "CDTI OK" indication in the ADS-B Out message only indicates that a CDTI is installed and operating on board the aircraft. It does not indicate the specific application capabilities of the CDTI. Paragraph (n) should be updated to reflect the definition of this indication.

    Response to ARC: This question is beyond clarification of the NPRM and may be submitted as a comment to the docket.

21. Regarding Section IV.B.4 "Navigation Position Sensor, etc…" NACv: The NPRM gives an incomplete description of NACv. The NACv value indicates the accuracy limits in both horizontal and vertical velocity. The NPRM only mentions the horizontal velocity. Note that the horizontal velocity is based on GPS, but the vertical velocity can be based on either barometric or geometric (GPS) sources. This point should be discussed in more detail due to the impact of this parameter on the equipment implementation.

    Response to ARC: This question is beyond clarification of the NPRM and may be submitted as a comment to the docket.

22. Regarding Section IV.B.4 "Navigation Position Sensor, etc…": The definition of SIL given in the NPRM is not consistent with the current datalink standards. Clarify that the NPRM intends to apply to the current definition.

    Response to ARC: This question does not provide sufficient information regarding the specific inconsistencies between the NPRM definition of SIL and the DO–260A and DO–282A definitions that would warrant clarification.

23. Regarding Section IV.B.4 "Navigation Position Sensor, etc…": NIC and SIL: The NPRM states without justification that only WAAS service can provide the necessary accuracy, integrity, and availability for surveillance in the NAS. It would be helpful to the manufacturers if the NPRM would specifically state the availability requirement, so that alternative implementations may be evaluated.

    Response to ARC: This question is similar to those posed in question Nos. 5 and 6. Please see the response to question No. 5.

24. Regarding Section V.B "Applications and Services": The NPRM states that TIS-B will be phased out when all aircraft are equipped with ADS–B Out. This ignores the fact that the NPRM only applies to aircraft that fly in specific controlled airspaces. A substantial number of aircraft will likely never be equipped with ADS-B Out equipment. The presence of unequipped aircraft presents a significant factor in traffic awareness. Please clarify whether TIS-B service will be decommissioned without regard to the existence of aircraft that lack ADS-B equipment.

    Response to ARC: As stated in the NPRM, TIS–B "is a groundbased uplink report of traffic that is under surveillance by ATC. During implementation of the ADS–B system, TIS–B would provide surveillance information on aircraft that are not yet ADS–B equipped. The ground infrastructure would support air-to-air operations by broadcasting TIS–B messages on both the 978 MHz UAT and 1090 MHz ES broadcast links for targets detected and reported by radar or other surveillance systems. TIS–B would be available during the transition period and until all affected aircraft are equipped for ADS–B Out. Once all aircraft are equipped to meet ADS–B Out performance requirements, TIS–B would be decommissioned as it would no longer be necessary since aircraft would receive traffic information through ADS–B." You may submit this question as a comment to the docket.

25. Regarding the Proposed Amendment: Appendix H: Performance Requirements: Section 3 (NIC, NAC, SIL) The existing text as written requires specific minimum values for NACp, NACv, NIC, and SIL. The rule does not allow for the natural occurrences (during start-up, aircraft maneuvers, etc) when the instantaneous value of these parameters may not meet these required values. Please clarify how the avionics are expected to function when these parameters do not meet the minimum values.

    Response to ARC: This question is beyond clarification of the NPRM and may be submitted as a comment to the docket.

26. Regarding ADS-R:
    a. Will the ADS-B ground system only transmit a limited number of ADS-B targets in the same way that the TIS-B service is limited?
    b. Will ADS-R exist everywhere that both 1090 and UAT aircraft may be operating, which is virtually all airspace and at all airports?

c. If not, how does the FAA envision pilots safely and affordably taking advantage of ADS-B "in" if they cannot receive all ADS-B traffic information?

Response to ARC: This question is beyond clarification of the NPRM and may be submitted as a comment to the docket.

27. Regarding A-zero vs. A-one transmitter question: The NPRM provides minimal justification when proposing to require an intermediate transmit power and dual antenna equipment requirement, instead of the minimum transmit power option as developed in government/industry standards. The NPRM appears to propose an "A1" level of avionics standards. However, an "A0" system standard is provided for in the RTCA MOPS. What is the justification and rational the FAA used to restricts low-altitude aircraft from equipping and operating with an "A0" system for the purposes of compliance with rule?

    Response to ARC: This question is beyond clarification of the NPRM and may be submitted as a comment to the docket.

28. Regarding Non-WAAS positioning sources: Based on the information available today, will dual frequency L1/L5 GPS (non-WAAS) receivers that are capable of receiving the signals currently planned to be available before 2020 by the DOD be another option that would meet the positioning performance requirements articulated in the NPRM?

    Response to ARC: The NPRM sets performance requirements. WAAS is not specifically required. As stated in the NPRM, any position source that meets the performance standards may be utilized.

29. Regarding backup viability analysis: Given the possibility that ADS-B out may enable the FAA to reduce separation standards in the oceanic, en route, or terminal phases of flight, what research has the FAA conducted to validate that the proposed backup strategy is feasible at forecasted traffic levels for the years beyond 2020? What were the results, or when will the analysis be conducted.

    Response to ARC: This question is beyond clarification of the NPRM and may be submitted as a comment to the docket.

30. Regarding 1090 MHz frequency management: What is the approved action plan that the FAA is executing to ensure the 1090 MHz frequency remains viable beyond the 2020 timeframe?

    Response to ARC: This question is beyond clarification of the NPRM and may be submitted as a comment to the docket.

31. Regarding ADS-B data link security risk: Has the FAA assigned a risk level to the issue of ADS-B data link security? If not, when does the FAA plan to assign a risk value? If yes, what mitigations (if necessary) has the FAA identified?

    Response to ARC: This question is beyond clarification of the NPRM and may be submitted as a comment to the docket.

32. IVB3(g) What is the meaning of "An indication if ATC services are requested"? What is meant by "identify to ATC if services are requested and whether the aircraft is in fact receiving ATC services"?

    Response to ARC: Please see the response to question No. 16.

33. IVB1 - "There are some aircraft equipped today with legacy 1090ES ADS-B systems. Operators of these aircraft would need to modify their broadcast link equipment to meet the proposed requirements defined in TSO-C166a." Doesn't the FAA plan on using legacy equipment for early operations?

    Response to ARC: This question is beyond clarification of the NPRM and may be submitted as a comment to the docket.

34. Why did the FAA not provide a schedule of operational approval deadlines for the ADS-B Out and ADS-B In applications listed in the NPRM as an incentive for early adopters? eg; 5 NM separation in NRA by 2015, etc

    Response to ARC: This question is beyond clarification of the NPRM and may be submitted as a comment to the docket.

35. What is the detailed basis for the statement in the NPRM that "Presently GPS augmented by the WAAS is the only navigation position service that provides the level of accuracy and integrity.., with sufficient availability."?

    Response to ARC: This question is beyond clarification of the NPRM and may be submitted as a comment to the docket. As stated in the NPRM, "[t]he FAA is considering whether other navigation position systems such as the Global Navigation Satellite System (GNSS) combined with tightly coupled inertial navigation systems are also capable of meeting the proposed performance standards."

36. Since the required NIC value of 7 cannot be transmitted by DO-260A systems while on the ground due to limits in the encoding tables, what is the FAA's plan for this issue?

    Response to ARC: This question is beyond clarification of the NPRM and may be submitted as a comment to the docket.

37. What is the minimum level of coverage on the airport surface for the TIS-B and ADS-R broadcast services?

    Response to ARC: This question is beyond clarification of the NPRM and may be submitted as a comment to the docket.

38. What is the minimum level of coverage in upper airspace for the TIS-B and ADS-R broadcast services?

    Response to ARC: The system requirements are to provide TIS–B and ADS–R service consistent with the proposal to accommodate UAT or 1090 ES below flight level 240.

39. In the lateral dimension (across the NAS), are there gaps in TIS-B and ADS-R broadcast services?

    Response to ARC: This question is beyond clarification of the NPRM and may be submitted as a comment to the docket.

40. What is the anticipated release date of the Advisory Circular (AC) associated with the new ADS-B rule?

    Response to ARC: There are two ACs anticipated for ADS–B. Draft AC 20–ADS–B Out was released on December 19, 2007, for comment and is available at:

    http://www.faa.gov/aircraft/draft_docs/display_docs/index.cfm?Doc_Type=AC

    This AC intends to provide aircraft equipment certification and installation guidance. The second AC, a 90-series AC, is anticipated to be released for comment with the final AC being published in conjunction with the final rule.

41. An important issue in the NPRM is the requirement that Mode C transponders will continue to be required to support TCAS. What steps does the FAA need to take to prove, or establish the ability to integrate ADS-B and TCAS, and permit aircraft owners to remove Mode C transponders from the aircraft?

    Response to ARC: This question is beyond clarification of the NPRM and may be submitted as a comment to the docket.

42. What is the minimum satellite configuration for normal navigation and surveillance operations?

    Response to ARC: This question is similar to that posed in question No. 5. Please see the response to question No. 5.

43. Has the FAA conducted analyses to validate that the proposed performance levels will enable the operations envisioned to provide the desired safety and efficiency improvements? Has a sensitivity analysis been done? Specifically, could the FAA please supply supporting analysis to show the incremental benefit of NACp $\geq$ 9 vs. NACp $\geq$ 7? It is not clear that NACp of 9 or greater is needed for ATC operations involving aircraft flying (i.e., not on the airport surface).

    Response to ARC: This question is beyond clarification of the NPRM and may be submitted as a comment to the docket.

44. While the ADS-B Out NPRM tries to specify performance-based requirements, there are several instances of implementation specific requirements, including for example, the lack of an availability or continuity specification, but rather a statement that "Presently GPS augmented with WAAS is the only navigation position service that provides the level of accuracy and integrity with sufficient availability." Does the FAA plan to completely write performance-based specifications in the ADS-B Out rule, such that alternative means of compliance can be evaluated against the performance specifications?

    Response to ARC: This question is similar to those posed in question Nos. 5, 6, and 23. Please see the response to question No. 5.

45. As written, the NPRM does not encourage sourcing ADS-B Out with "secondary" sources of position or velocity when the primary source that fully meets the specified performance is not available. Does the FAA believe that the is any benefit from transmitting ADS-B Out based upon non-GNSS position sources that will likely not meet the NACp $\geq$ 9 and NIC $\geq$ 7 levels of performance? If the answer is "yes", does the FAA plan to require or recommend that such "secondary" sources be used when the primary source becomes unavailable?

    Response to ARC: This question is beyond clarification of the NPRM and may be submitted as a comment to the docket.

APPENDIX G—OEP AIRPORTS

Summary

Operational Evolution Partnership (OEP) airports are commercial U.S. airports with significant activity. These airports serve major metropolitan areas and also serve as hubs for airline operations. More than 70 percent of passengers move through these airports.

The OEP 35 airports were compiled in 2000 based on lists from the FAA and Congress, and a study that identified the most congested airports in the U.S. The OEP 35 airports do not change. Key FAA performance measures are based on data from this set of airports. These include: Airport Average Daily Capacity, On-Time Gate Arrivals, and On-Time Gate Departures.

Delays at the OEP 35 airports have a ripple effect on other locations. For example, when delay trends at Miami International Airport (MIA) for the years 2000-2005 were analyzed, it was found that delay increases were not correlated with increases in traffic at MIA or at Miami Center, nor were they related to Florida weather. Rather, they were highly correlated with delays at the other OEP 35 airports. Therefore, improvements at the most congested airports will have a positive impact on other airports as well.

Airports	ID	Region
Atlanta Hartsfield International	ATL	ASO
Baltimore-Washington International	BWI	AEA
Boston Logan International	BOS	ANE
Charlotte/Douglas International	CLT	ASO
Chicago Midway	MDW	AGL
Chicago O'Hare International	ORD	AGL
Cincinnati-Northern Kentucky	CVG	ASO
Cleveland-Hopkins International	CLE	AGL
Dallas-Fort Worth International	DFW	ASW
Denver International	DEN	ANM
Detroit Metro Wayne County	DTW	AGL
Fort Lauderdale-Hollywood International	FLL	ASO
George Bush Intercontinental	IAH	ASW

Airports	ID	Region
Greater Pittsburgh International	PIT	AEA
Honolulu International	HNL	AWP
Lambert St. Louis International	STL	ACE
Las Vegas McCarran International	LAS	AWP
Los Angeles International	LAX	AWP
Memphis International	MEM	ASO
Miami International	MIA	ASO
Minneapolis-St Paul International	MSP	AGL
New York John F. Kennedy International	JFK	AEA
New York LaGuardia	LGA	AEA
Newark International	EWR	AEA
Orlando International	MCO	ASO
Philadelphia International	PHL	AEA
Phoenix Sky Harbor International	PHX	AWP
Portland International	PDX	ANM
Ronald Reagan National	DCA	AEA
Salt Lake City International	SLC	ANM
San Diego International Lindbergh	SAN	AWP
San Francisco International	SFO	AWP
Seattle -Tacoma International	SEA	ANM
Tampa International	TPA	ASO
Washington Dulles International	IAD	AEA


SEA
PDX
SFO
SLC
DEN
LAX
LAS
SAN
PHX
HNL
MSP
ORD
MDW
STL
DTW
CLE
CVG
PIT
LGA
BOS
EWR
JFK
PHL
IAD
BWI
DCA
MEM
CLT
ATL
DFW
IAH
MCO
TPA
FLL
MIA

APPENDIX H—LINK IMPLEMENTATION VISION

The ARC's vision of the Automatic Dependent Surveillance–Broadcast (ADS–B) link implementation, in the context of 1090 ES being introduced in a manner compatible with existing ACAS and SSR systems on 1090 MHz[1], has two major components. First, 1090 Extended Squitter (ES) will be used as the ADS–B link for international interoperability. Second, the universal access transceiver (UAT) will be available to all aircraft operators with near term emphasis on at least general aviation. UAT access will be available to all aircraft operators with long term emphasis on enabling advanced air-to-air ADS–B In applications should 1090 MHz (after planned/potential mitigations to congestion on the 1090 MHz frequency) be unable to support such applications throughout the national airspace; this would allow for potential UAT implementation by air transport class aircraft operating in high density airspace. In implementing this vision, tradeoffs will be required involving costs of (1) avionics; (2) mitigations to1090 MHz frequency congestion; and (3) limitations to ADS–B In functionality in high density airspace.

After analysis of a number of alternative ADS–B link implementation scenarios proposed by its membership, the ARC has concluded that, unless major reengineering of the use of the 1090 MHz frequency by Secondary Surveillance Radar (SSR) and the Traffic Collision Avoidance System (TCAS) is implemented, some variant of the two-link strategy propounded by the Federal Aviation Administration (FAA) in its 2002 ADS–B link decision should be recommended by the ADS–B Aviation Rulemaking Committee (ARC). This recommendation is a response to relevant comments received on the ADS–B notice of proposed rulemaking (NPRM). While formulating this conclusion, the ARC has developed what it considers to be a strategic view of ADS–B link implementation in the 2020–2035 timeframe.

Appendix I summarizes spectrum performance issues on the 1090 MHz frequency, shared by 1090 ES based ADS–B, airborne collision avoidance systems (ACAS), and secondary surveillance radars (SSR). These issues are being treated as a red (high) risk by the FAA's Surveillance and Broadcast Services (SBS) program office. For example, as ADS–B equipage expands, the majority of the technical community believes that the interference environment in the Northeast corridor of the United States in 2020 (even given planned reductions in the number of SSRs), most likely will limit the ADS–B In air-to-air range to less than 40 nautical miles (nm) in that high density airspace. Some experts believe that this range could be as low as 20 nm to 25 nm. Without further mitigations of the use of 1090 MHz by ACAS and/or SSR, the situation will deteriorate further in the 2020–2035 timeframe as air traffic growth continues.

ADS–B In air-to-air applications identified in the RTCA ADS–B minimum aviation system performance standards (MASPS) such as merging, conflict management, and long

[1] Should the use of 1090 MHz by ACAS and SSR be significantly reengineered in the NAS, the feasibility of a single link 1090 ES ADS-B link implementation should be readdressed. If feasible, such a single link approach should be implemented in two phases: (1) to support ADS–B Out implementation by 2020, and (2) to support NextGen ADS–B In applications in high density airspace, beyond 2020. The schedule for major TCAS changes should be decoupled from completion of the 2020 objective.

range conflict management, have been specified as requiring a 40 nm or greater range. These applications would therefore be unavailable to airspace users of 1090 ES ADS–B in future high density airspace without further mitigations of the use of 1090 MHz by ACAS and/or SSR.

Moreover, proposed Next Generation Air Transportation System (NextGen) operating concepts related to use of air-to-air ADS–B In applications should be compared to likely 1090 MHz spectrum realities. This will ensure that anticipated NextGen ADS-B requirements can be met.

The 1090 ES situation is further complicated by desires within the user community to add message elements to the ADS–B data set (for example, intent information) to support more advanced air-to-air ADS–B In applications. Because of international concern about 1090 MHz frequency saturation in high density airspace and the protection of ACAS and SSR, the International Civil Aviation Organization (ICAO) has put a hard limit on the number of ADS–B messages that can be broadcast on 1090 MHz by a single aircraft. Therefore, additional ADS–B In message elements for air-to-air applications will be limited without a fundamental change to the 1090 ES ICAO Standards and Recommended Practices (SARPs) and potential further impact on spectrum congestion.

The ARC has further confirmed the findings of the 2001 FAA/European Organization for the Safety of Air Navigation (EUROCONTROL) Technical Link Assessment Team (TLAT). These findings state that air-to-air ADS–B In performance issues in high density airspace are not an issue for UAT-based ADS–B, at least for the applications identified in the RTCA ADS–B MASPS. Therefore, given the ARC's endorsement of a two-link implementation strategy for ADS–B, the ARC envisages UAT as available in 2020–2035 for any air-to-air ADS–B In applications that cannot be supported in high density airspace by 1090 ES. The ARC further observes that if general aviation aircraft are likely to equip with UAT, any trend to use UAT for high-performance air-to-air ADS–B In in future high density airspace will presage an evolution to all aircraft being equipped with UAT, albeit over an extended period of time.

The ARC notes that current and planned ADS–B implementations outside of the United States make use of 1090 ES. As a de facto matter, 1090 ES has been selected to be the ADS–B link for international interoperability, and international operators will need to be equipped with 1090 ES well past 2020. The ARC further notes that 1090 spectrum congestion issues (apart from the ICAO limit on the number of ADS–B messages that an aircraft can transmit) are not expected through 2035 outside of high density airspace, principally found in portions of the United States and core Europe.

The ARC's link implementation vision is consistent with the rationale provided by the FAA in 2002 for its link decision when it selected 1090 ES for "achieving near-term interoperability among the airspace users." The ARC notes that the FAA further stated in its rationale that "in the longer-term if the international standards and spectrum issues [for UAT and VDL Mode 4] are overcome, these links could play a role in a global ADS–B solution." As of November 2007, UAT has both ICAO SARPs and a worldwide radio frequency allocation to use the 978 MHz frequency.

APPENDIX I—RADIO FREQUENCY SPECTRUM RELATED ISSUES REGARDING FUTURE AIR-TO-AIR PERFORMANCE OF 1090 ES BASED ADS–B

The ARC has reviewed spectrum-related limitations of using 1090 ES for ADS-B and the associated potential alternative mitigations. The ARC, in a companion Link Implementation Vision paper (Appendix H), has recommended Federal Aviation Administration (FAA) implementation of both 1090 extended squitter (1090 ES) and universal access transceiver (UAT), subject to study of alternative mitigations to manage 1090 MHz frequency congestion and in the context that 1090 ES is introduced in a manner compatible with existing ACAS and SSR systems on 1090 MHz. The Link Implementation Vision paper explains that 1090 ES ADS–B is the *de facto* ADS–B link for international interoperability and takes advantage of legacy avionics (although modifications to the avionics may be required) on many aircraft.

UAT, also recommended for implementation in the Link Implementation Vision paper, has international standards and spectrum approval but currently is planned for, at best, highly limited operational implementation outside the United States. Apart from eight distance measuring equipment (DME) stations operating at 978 MHz in Europe, UAT has no identified spectrum-related limitations on a worldwide basis. There are no technical reasons preventing UAT from being implemented internationally.

As an initial matter, 1090 MHz spectrum limitations must not, in the ARC's view, compromise the ability of 1090 ES either to interoperate with other aviation systems that use the frequency, or to support air-ground air traffic control (ATC) surveillance and ADS–B In situational awareness applications. However, the spectrum limitations, unless further mitigated, will affect those more advanced ADS–B In applications that can be supported by 1090 ES in future high density airspace areas[1]. The limitations arise from congestion on the 1090 MHz frequency because of the sharing of that frequency by three major aviation systems: 1090 ES, airborne collision avoidance system (ACAS), and secondary surveillance radar (SSR). Mitigations identified include—

1. Acceptance that 1090 ES will support a reduced set of ADS–B In applications (and/or reduction of supported ranges for certain ADS–B In applications) in future high density airspace areas (with consequent use of UAT to support any ADS–B In applications regarded as necessary that 1090 ES cannot support);
2. Reduction of ACAS-related transmissions on 1090 MHz and/or additional reductions of secondary surveillance radars to those already planned, in order to extend 1090 ES air-to-air range for ADS–B In applications; and

[1] 1090 ES spectrum limitations are not foreseen as impacting ADS–B In operations in future low to medium density airspace, except to the degree that transmission of additional ADS–B data to that specified in DO–260A is not permitted because of spectrum limitations in future high density airspace. UAT does not have spectrum limitations similar to those discussed in this paper.

3. If feasible, development of improved 1090 ES techniques beyond those in current avionics standards such as Radio Technical Commission for Aeronautics (RTCA) DO–260A, to provide extended 1090 ES air-to-air range for ADS–B In applications.

1090 ES Spectrum-Related Limitations in Future High Density Airspace Areas

The 1090 ES based ADS–B system shares the 1090 MHz frequency with two important aviation systems: ACAS and SSR. Aircraft use the 1090 MHz to respond to ACAS and SSR interrogations. Thus, receipt of 1090 ES ADS–B transmissions will be affected by self-interference from 1090 ES ADS–B transmissions (from other aircraft), ACAS, and SSR. Absent changes to ACAS and the number of SSRs, the level of this interference will increase as more aircraft are ADS–B equipped and as the number of aircraft operating in the national airspace (NAS) continues to grow.

Managing the 1090 MHz frequency is being addressed as a red (high) risk by the Surveillance Broadcast Services (SBS) program office. The FAA formed a Spectrum Risk Panel to recommend steps to ensure long-term viability of 1090 ES as an air-to-air ADS–B link. While air-to-ground reception of 1090 ES is also degraded by interference, a number of techniques, such as provision of multi-sector antennas and additional ADS–B 1090 ES ground stations, can be used to ensure adequate air-to-ground reception of 1090 ES.

Particular concern about 1090 ES ADS–B air-to-air performance exists in the NAS' highest density airspaces, such as the Northeast corridor of the United States. In view of projected increases in air traffic in the 2010 to 2035 time frame (the time frame of Segments 1 and 2 of the SBS Program), future predicted interference rates on 1090 MHz are likely to limit the number and nature of air-to-air ADS–B applications that may be performed using 1090 ES (in accordance with DO–260A) in these high density areas. This will be the case unless significant mitigations (beyond those currently planned[2]) of ACAS and SSR use of the 1090 MHz frequency are employed. It should also be recognized that the geographical extent of high density airspace areas is likely to grow as the amount of air traffic grows. Figure 1 depicts high density airspace areas where, in the 2020 time frame, ADS–B In applications are projected to be limited without significant mitigations of ACAS and SSR use of the 1090 MHz frequency.

Recent data on growth of 1090 MHz spectrum congestion in the Northeast corridor (generally, airspace between Washington, D.C. and New York on the Eastern Coast of the United States) is not promising. 2006 and 2007 data collection has indicated that this growth of congestion is occurring at a rate faster than that projected (using 1999/2000 data collected in the Los Angeles Basin) in the 2001–2002 time frame of the FAA's ADS–B link decision and the FAA/European Organization for the Safety of Air Navigation (EUROCONTROL) Technical Link Assessment Team (TLAT).

Using the 2006–2007 measured data as a baseline and projecting worst-case future traffic growth to 2020, even with the planned reduction in civil SSRs and the implementation of several 1090 MHz spectrum congestion mitigations, the majority of the technical

[2] An overall 50 percent reduction in civil SSRs in the NAS (approximately 25 percent in the NAS' highest density airspace).

community is of the view that the interference environment in the Northeast corridor will most likely limit ADS–B air-to-air range for DO-260A-based 1090 ES implementations, expected on air transport category aircraft

Table 1 contains assumptions underlying the projected worst case 2020 Northeast Corridor air traffic scenario. Consistent findings have been published in a 2006 EUROCONTROL study of 1090 MHz spectrum occupancy in Core Europe in 2015.[3] ADS–B air-to-air range is defined as the distance at which an aircraft can receive sufficient ADS–B messages (both in types of messages and frequency of reception) from other aircraft within that range in order to participate in all air-to-air ADS–B applications that require that range.

Table 1—High Density 2020 Northeast Corridor Air Traffic Scenario for 1090 MHz (Both Air Transport and General Aviation)

Number of aircraft	80% above 2006–2007 levels
Percentage of aircraft equipped with Mode S	76%
Percentage of Mode S aircraft equipped with ACAS	88%
Number of SSR interrogators	25% reduction from the current number of civil interrogators; Military interrogators as at present numbers
ADS–B avionics implementation baseline (includes improved 1090 ES reception techniques)	RTCA DO–260A
Predicted high density interference environment[4] (per second, above Class A3 receiver MTL)	45,000 ATCRBS 5,000 "Short" Mode S Replies 3,000 1090 Extended Squitters

The situation in the Northeast corridor will further deteriorate, unless further mitigations on 1090 MHz congestion are employed in the 2020-2035 timeframe as additional air traffic growth occurs. This has the potential of reducing ACAS and SSR performance as well as that of ADS–B. For example, the FAA instrument flight rules (IFR) forecast estimates that commercial traffic in the New York area will grow 26.4 percent between 2020 and 2025. See Figure 1 for a graphical depiction of the 1090 ES hotspots in the 2020 to 2035 timeframe.

[3] The EUROCONTROL study further projects that the 1090 MHz channel occupancy will increase up to 2015, after which it will decrease because of mitigations including decommissioning of Mode A/C radars and improvements to ACAS. The study concludes that 1090 ES system performance will "improve for some period beyond 2015 and then gradually degrade again" as a function of air traffic growth over time.

[4] The predicted high density interference environment assumes TERRA FIX removal and a 40 percent reduction in ACAS 1090 MHz occupancy by voluntary use of hybrid surveillance. The total channel occupancy of the predicted high density interference environment is approximately 150 percent.

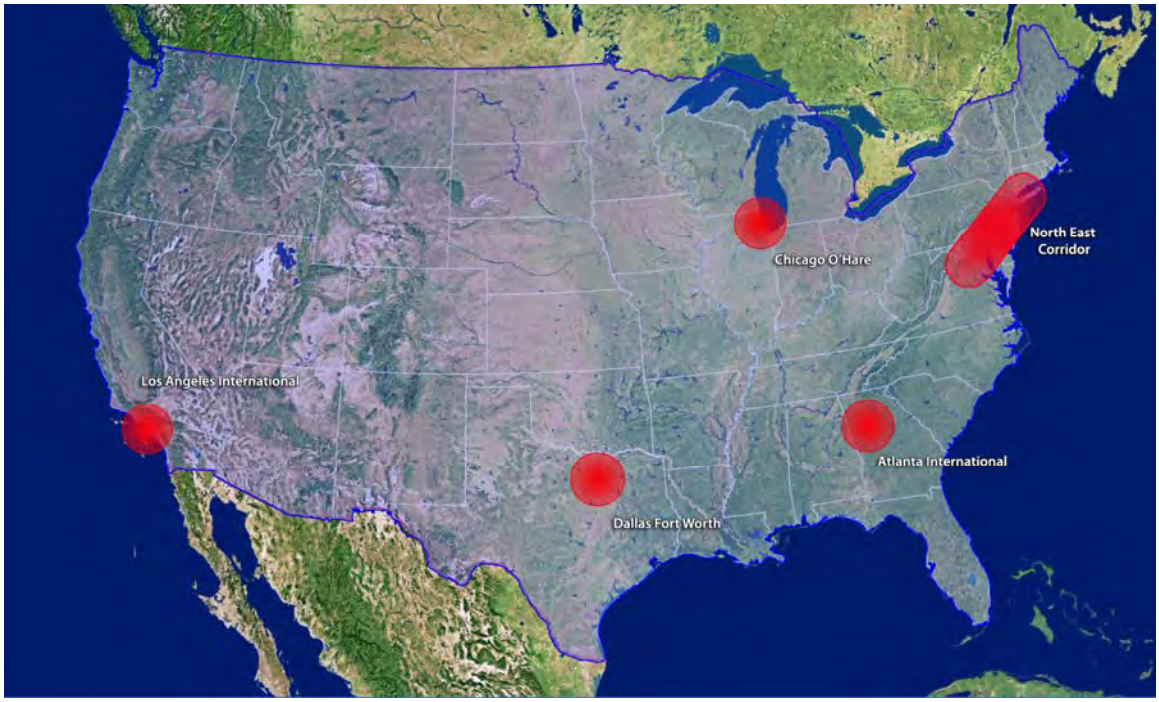


Figure 1—1090 ES Hotspots in the 2020 to 2035 timeframe

Alternative Mitigations to 1090 ES Spectrum Limitations in Future High Density Airspace Areas

Three alternative approaches to dealing with future 1090 ES spectrum limitations have been identified.

(1) Accept limited 1090 ES ADS-B In applications in future high density airspace areas

The practical impact of 1090 ES ADS–B air-to-air range in future high density airspace areas depends on the air-to-air ADS–B applications envisaged. For example, the ADS–B minimum aviation system performance standards (MASPS), RTCA Document 242A, groups applications by required ADS–B air-to-air range as follows:

- Enhanced Visual Acquisition, Conflict Detection 10 nm
- Station Keeping, Airborne Conflict Management 20 nm
- Merging, Conflict Management, In-Trail Climb 40 nm
- Long Range Conflict Management 90 nm (120 nm desirable)

(See DO–242A, Table 3-3a, p.86).

While the required ranges for specific air-to-air ADS–B applications are maturing as those applications are implemented, a number of the above applications are unlikely to be supported by 1090 ES in high density airspace areas in the 2020–2035 time frame without major mitigations of the use of 1090 MHz by ACAS and SSR beyond those currently planned. Moreover, a number of longer range air-to-air ADS–B applications

require additional data (for example, aircraft intent data) to that currently in the ADS–B message set[5].

The current International Civil Aviation Organization (ICAO)-mandated maximum 1090 ES transmission rate per aircraft limits the 1090 ES system's ability to support these additional message elements. The reason for the maximum 1090 ES transmission rate per aircraft in the 1090 ES ICAO Standards and Recommended Practices (SARPs) is to ensure the performance of ACAS (as it exists today) and SSR in high density airspace areas. Increasing the maximum squitter rate per aircraft will likely need to be offset by further mitigations of the use of 1090 MHz by ACAS and SSR.

(2) Substantially reduce ACAS and/or SSR traffic on 1090 MHz

A second alternative mitigation is reduction of ACAS-related interference by adoption of design changes to the ACAS system and/or further reduction in the number of civil and military SSRs covering high density airspace areas. For example, if ACAS were changed to operate without interrogating, but rather used ADS–B transmissions as inputs to perform the ACAS function, the 1090 ES air-to-air range could be extended to beyond 40 nm in 2035 high density airspace areas.

ACAS occupancy of 1090 MHz (approximately 50 percent of current 1090 MHz spectrum occupancy in the Northeast corridor) might alternatively be reduced by use of hybrid surveillance. In this case, ACAS may use 1090 ES ADS–B transmissions, instead of active ACAS interrogations, to track intruders that meet validation criteria and are not projected to be near-term collision threats. The potential reduction of ACAS-related traffic on 1090 MHz with use of hybrid surveillance in future high density airspace areas has not yet been established. Standards for the implementation of hybrid surveillance have been developed by both RTCA (RTCA DO–300 dated December 13, 2006) and ICAO.

Recently, a manufacturer has proposed using an ATC Overlay Data Link on 1090 MHz to significantly increase the amount of information transmitted in each Mode S reply and to provide more robust error detection and correction of Mode S reply messages. This technique, assuming validation through a testing program discussed below, also has the potential to reduce ACAS occupancy on 1090 MHz.

With regard to further reductions than those currently planned in SSR traffic on 1090 MHz, Working Group A recommends that the FAA investigate the benefits of the use of passive wide-area multi-lateration as a phased-in substitute for SSR in areas of high density traffic.

(3) If feasible, use new 1090 ES techniques beyond those in RTCA DO–260A to extend 1090 ES air-to-air range

An additional proposed method to extend 1090 ES air-to-air range in future high density airspace areas is to use 1090 ES receivers that have more aggressive decoding techniques than those standardized in the minimum operational performance standards (MOPS) for 1090 ES, DO–260A. However, (1) testing to date of proposed "advanced decoders" has not shown significant extension of 1090 ES air-to-air range over the decoder specified in

[5] It should be noted that the desirability of intent data is not limited to long-range applications.

the MOPS; and (2) there are practical limits on how these more aggressive 1090 ES decoding techniques can be compared to those in the MOPS without inducing an unacceptably high undetected error rate in 1090 ES receptions.

Several further 1090 MHz interference reduction techniques could be incorporated into the Mode S Transponder MOPS (DO–181D) and the 1090 ES MOPS (DO–260A). These interference reduction techniques could potentially mitigate 1090 ES limitations for ADS–B In applications in future high density airspace areas. The proposed interference reduction techniques include—

- Lower Power 1090 ES ADS–B Out on the Surface for (at least) aircraft with integrated surveillance systems;
- Lower Power Mode S Transponder Replies (for aircraft with integrated surveillance systems) via a command field in ACAS/SSR interrogations; and
- Use, on a voluntary basis by operators implementing more advanced ADS–B In applications, of an ATC Overlay Data Link on 1090 MHz. This would significantly increase the amount of information transmitted in each ES, provide more robust error detection and correction of ADS–B messages, and possibly extend 1090 ES range even within future high density airspace areas.

The ARC recommends that the FAA rigorously evaluate the feasibility and performance of these proposed techniques. The evaluation should include performance and compatibility testing of (prototype) equipment and incorporate the techniques under test inputs representative of a future high density airspace areas environment, as part of its 1090 MHz spectrum risk and management activities.

Conclusion

Because of the sharing of the 1090 MHz frequency between 1090 ES, ACAS, and SSR, 1090 MHz frequency congestion has been recognized as a high risk to the ADS–B program, specifically regarding the support of a number of ADS–B In applications in future high density airspace areas. The ARC urges the FAA to consider the 1090 MHz frequency congestion mitigations that would be required to provide a 45 nm air-to-air range for ADS–B In applications in future high density airspace. Similar answers should be provided for ADS-B In air-to-air ranges of 20 nm, 60 nm, and 90 nm. The aviation community needs to mitigate this risk by agreeing to some combination of the alternative mitigations to 1090 MHz frequency congestion identified in this paper[6]. All of these mitigations have attendant cost, schedule, and performance implications.

It is clear that without significant changes to ACAS, SSR infrastructure, and/or 1090 ES minimum standards, 1090 MHz will not support current NextGen requirements in the context of substantial future traffic growth. The resulting question that must be answered is whether it will be more productive and cost-effective to—

[6] The ICAO Aeronautical Surveillance Panel currently is developing a report on 1030/1090 MHz radiofrequency development. The Draft Report discusses advantages, in mitigating 1090 MHz frequency congestion, of Mode S radar implementation and clustering as well as Mode S transponder implementation, and recommends implementation of ACAS hybrid surveillance. The Draft Report also recommends investigation of several of the potential mitigations discussed in this paper.

1. Implement recommended 1090 MHz frequency congestion mitigations to ensure compatibility of ADS-B, TCAS, and SSR and meet NextGen needs (and necessarily assess the degree to which those mitigations enable a single link 1090 ES ADS-B link implementation);
2. Alter NextGen expectations; or
3. Adopt UAT for ADS–B In applications that 1090 MHz cannot support, keeping standards for the systems using 1090 MHz as they are today.

These alternatives presume that necessary mitigations to ensure basic compatibility of ADS–B Out using 1090 ES, ACAS, and SSR will be identified and implemented.

APPENDIX J—LINK IMPLEMENTATION ALTERNATIVES

Alternatives Under Consideration

NOTE: The pros and cons listed under each alterative are intended to assist in discriminating the three alternatives.

Alternative A: Link implementation per the Notice of Proposed Rulemaking

(Aircraft operating above flight level (FL) 240 must use 1090 extender squitter (1090 ES) and may use either 1090 ES or universal access transceiver (UAT) below FL 240)

Pros

- Requires no Surveillance and Broadcast Services (SBS) programmatic changes with respect to the notice of proposed rulemaking (NPRM).
- Is the least costly alternative for air transport (AT) category aircraft avionics.
- Provides the most harmonization for internationally operated aircraft.
- Provides potential evolutionary path to address 1090 ES saturation.
- There is no added cost for flight information service–broadcast (FIS–B) for UAT-equipped aircraft with automatic dependent surveillance–broadcast (ADS–B) In.
- General aviation (GA) aircraft can use UAT or 1090 ES.

Cons

- Automatic dependent surveillance–rebroadcast (ADS–R) is required on both links.
  - ADS–R will not support as robust a set of ADS–B In applications as those that would direct reception of ADS–B; this is because of ADS–R service status and coverage continuity limitations.
  - ADS–B In equipped aircraft using 1090 ES cannot see ADS–B Out equipped aircraft using UAT, without ADS–R.
  - ADS–B In equipped aircraft using UAT cannot see ADS–B Out equipped aircraft using 1090 ES, without ADS–R.
- The option for GA operators to equip with UAT or 1090 ES creates a potential lack of interoperability between GA aircraft outside of ADS–R coverage areas (for example, at non-towered airports without ADS–B ground infrastructure).
- Permitting GA to equip with either link results in a higher ground infrastructure cost as compared to mandating GA use with one link.
- Does not reduce the risk of 1090 ES saturation.
- May result in limited range for 1090 ES ADS–B In applications (for example 25 to 40 nautical miles (nm)) in high density airspace areas (see Appendix I).
- ADS–R will not provide as much data on 1090 ES as would be received directly on UAT.
- 1090 ES uplink (including traffic information service–broadcast (TIS–B) and ADS–R) puts siting constraints on ground infrastructure, which have been projected to cost between $350 million and $500 million in “then year” funding.
- 1090 ES uplink (TIS–B, ADS–R) adds to 1090 ES congestion problem (approximately 2.5 percent of total 1090 MHz occupancy in future high density airspace areas).

Alternative B: Link implementation per the NPRM, with the addition that dual link ADS–B In capability is required for all aircraft with 1090 ES ADS–B Out choosing to implement ADS–B In. ADS–R from 1090 ES to UAT is required.

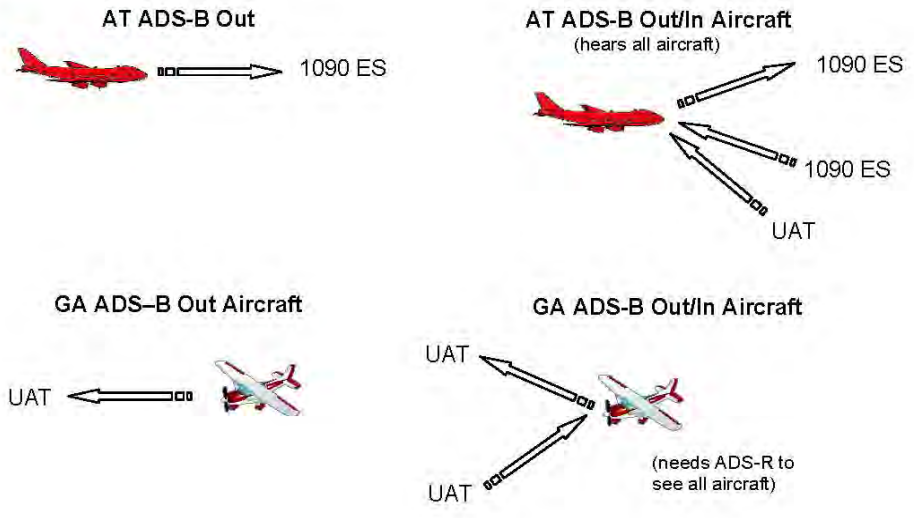


Figure 2—Alternative B

This is a variant of the NPRM. There were comments on the NPRM related to—

- TIS–B and 1090 ES uplink (ADS–R) on UAT (no 1090 ES uplink).
- Concern that ADS–R will not be available in geographical areas of interest.
- Cost of ADS–R to the FAA. ITT Corporation informed the ARC that ADS–R is a small percentage of the ground infrastructure cost for the existing coverage. However, significant cost reductions could be achieved if the ground infrastructure did not need to broadcast on 1090 MHz because of reduced siting constraints with, for example, secondary surveillance radar.

Pros

- Provides additional potential evolutionary path to address 1090 ES saturation.
- There is no added cost for FIS–B for UAT-equipped aircraft with ADS–B In.
- GA aircraft can use UAT or 1090 ES.
- All UAT aircraft can be seen directly using ADS–B; facilitates situational awareness.
- All aircraft implementing ADS–B In will be able to receive communication, navigation, surveillance (CNS) broadcast services (including weather, airspace status, and other to-be-defined data elements) chosen to be delivered on the UAT uplink, without affecting UAT performance for ADS–B.
- There is no need for ground uplink services on 1090 MHz: significant reduction of ground infrastructure siting restrictions and cost as well as some degree of 1090 ES range extension for air-to-air applications.
- Provides improved situational awareness for 1090 ES ADS–B Out aircraft also equipped with ADS–B In outside of the airspace specified in the mandate.
- GA aircraft can use UAT or 1090 ES (but must receive on UAT if does ADS–B In)

Cons

- Does not support direct reception of ADS–B messages for UAT equipped aircraft to see aircraft equipped with 1090 ES ADS–B Out; this is due to ADS–R service status and coverage continuity limitations.
- An aircraft that is appropriately equipped for ADS–B In outside the national airspace system (NAS) would not be so in the NAS unless they add a UAT receive function.
- Does not reduce the risk of 1090 ES saturation.
- May result in limited range for 1090 ES ADS–B In applications (for example 25 to 40 nm) in high density airspace areas (see Appendix I).
- UAT In equipped aircraft can not see 1090 ES Out equipped aircraft without ADS–R.
- The option for GA operators to equip with UAT or 1090 ES creates a potential lack of interoperability between GA aircraft.
- ADS–B In implementation costs would be greater than in the NPRM for AT operators (and other operators equipping with 1090 ES). This is because a UAT ADS–B receive function must be added with additional integration and wiring tasks associated with the merging of ACAS and ADS–B traffic data. Adding this function will ensure that a consistent and consolidated view of ACAS/ADS–B display of traffic is provided. An aircraft that is appropriately equipped for ADS–B In outside the NAS would not be so in the NAS unless they add a UAT receive function.
- Could require switch logic to inhibit UAT receive function when operating outside the NAS.
- ADS–R is still required to retransmit 1090 ES ADS–B on the UAT link (because of ADS–R service status and coverage continuity limitations).

Alternative C: UAT ADS–B Out for all aircraft operating below a given altitude. 1090 ES ADS–B Out for all aircraft above that altitude.

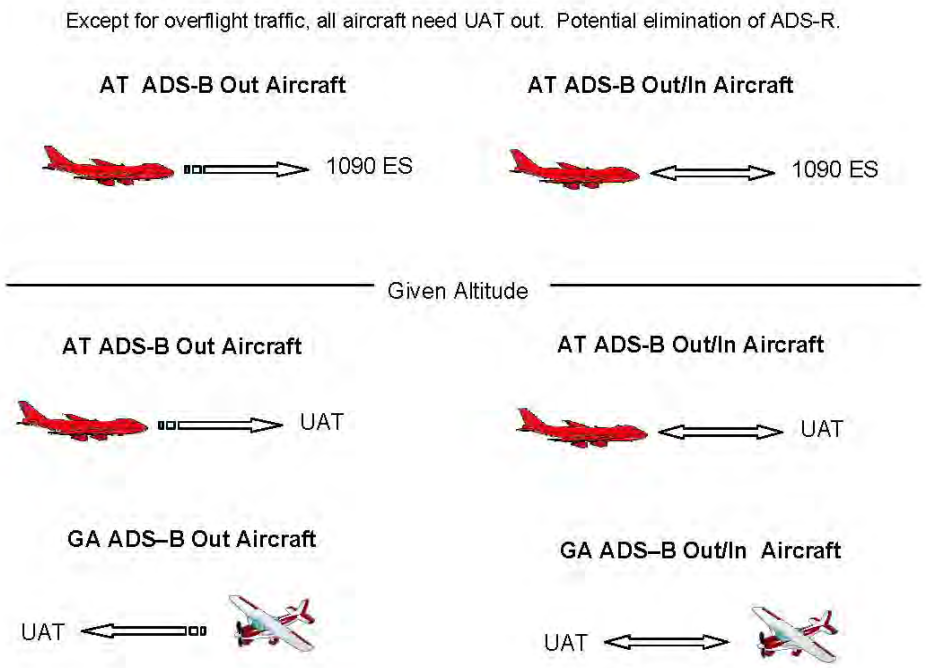


Figure 3—Alternative C

Pros

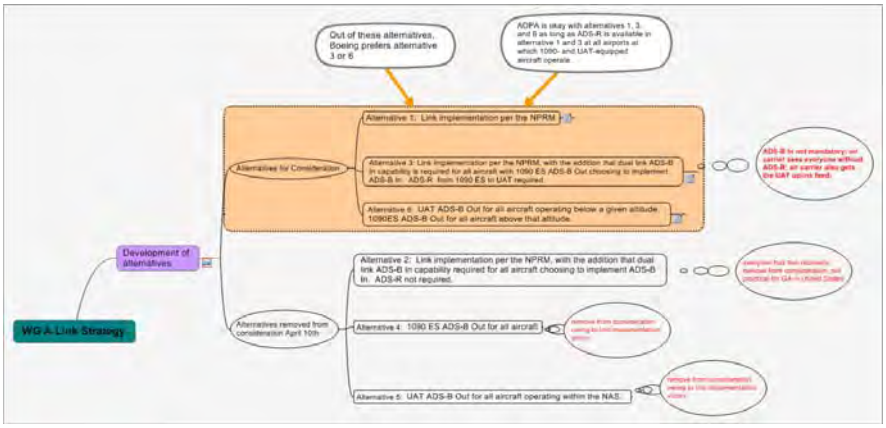
- Provides additional potential evolutionary path to address 1090 ES saturation.
- Provides complete aircraft-to-aircraft interoperability in the NAS.
- Provides for complete elimination of ADS–R. As a result, all UAT aircraft would be seen directly using ADS–B; ADS–B equipped aircraft outside the airspace specified in the mandate would gain improved situational awareness; all UAT ADS–B In aircraft would see all ADS–B equipped aircraft at low altitude and at small airports outside of the mandated airspace.
- All aircraft implementing ADS–B In will be able to receive FIS–B (at no cost) and any other CNS broadcast services chosen to be delivered on the UAT uplink.
- There is no ground uplink services on 1090 MHz. This would result in significant reduction of ground infrastructure siting restrictions and costs as well as some degree of 1090 ES range extension for air-to-air applications.
- All terminal area NextGen ADS–B applications will be capable of being supported at their desired ranges in future high density airspace areas.
- There is a potential switch from 1090 ES to UAT at certain altitude. This would reduce 1090 ES congestion, potentially extending the range of 1090 ES air-to-air applications above the given altitude. This option is estimated to reduce 1090 MHz channel occupancy in future high density airspace areas by 17 percent.

Cons

- Foreign-based aircraft operating in the NAS would have to add UAT equipment for ADS–B Out (and UAT equipment for ADS–B In should they choose to implement ADS–B In).

- Requires the equipment to switch logic from 1090 ES to UAT at certain altitude.
- Requires the equipment to switch logic using a geographical filter to inhibit UAT operations outside the NAS.
- There are costs associated with additional UAT transmitter and airplane integration for those aircraft operating above the given altitude and choosing only to implement ADS–B Out
- There is a cost for an additional UAT receive function for those aircraft operating above the given altitude and choosing to implement ADS–B In.

Figure 1—Link Strategy Development of Alternatives



APPENDIX K—AVIONICS COST SUBGROUP SUMMARY

The Link Alternatives Avionics Cost Subgroup was tasked by the ARC to provide Rough Order of Magnitude (ROM) estimates for the incremental cost of implementing the ARC's Link Alternatives B and C. The subgroup held a number of teleconferences and initially established a list of assumptions to be made in developing the cost estimates and the cost factors to be considered (Appendix K1). Subsequently, the subgroup received ROM estimates at catalog list price from four ADS–B equipment manufacturers: ACSS, Garmin, Honeywell, and Rockwell-Collins (Appendices K2-K5). Boeing provided aircraft integration cost inputs, having considered the inputs of the ADS–B equipment manufacturers (Appendix K6). All companies supplied retrofit cost estimates. Honeywell and Boeing also provided "forward fit" estimates.

The estimates provided by subgroup members are understood to be ROM estimates developed to support the ARC. These estimates do not constitute commitments by these companies to provide UAT equipment, or if such equipment were to be provided, for that equipment to be provided at the ROM costs.

As can be seen from Appendix K1, the initial thrust of the questions addressed by the manufacturers revolved around the incremental cost of providing a universal access transceiver (UAT) receiver (Link Alternative B) or transmitter/transceiver (Link Alternative C) on an aircraft already equipped with both 1090 ES ADS–B Out (per the mandate) and 1090 ES ADS–B In (by aircraft owner's choice). It should be noted that these cost estimates included the cost of functional integration of UAT functionality into the aircraft. For example, for ADS–B In, costs were assessed for integration and correlation of the UAT and 1090 ES ADS–B In data streams for display. The subgroup also discussed the substantially smaller "forward fit" costs of implementing Link Alternatives B and C. They also discussed the potential of a greater portion of the aviation community equipping on a "forward fit" basis, if the details of both short and long-term ADS–B implementation strategy were articulated as early as possible.

The subgroup discussed, at length, the need to adopt either Link Alternatives B or C.in order to have an appropriate strategy for long-term integration of international operators. This need is particularly acute for Link Alternative C, which effectively requires UAT ADS–B Out for all international aircraft operating in the national airspace system (NAS).

Link Alternative B: Addition of a UAT Receive Function

For Link Alternative B (addition of a UAT receive function), the recurring retrofit cost estimates from Boeing and its suppliers varied on a per aircraft basis. These costs assumed federated unit implementation, as opposed to retrofit into an integrated surveillance unit on the aircraft, for example, A380, A350, B787. For non-redundant implementation, estimates ranged between $114,000 and $263,000 plus five hours installation labor. These cost estimates assume overnight accomplishment of the aircraft integration and use of existing antennas and cabling[1]. A dual UAT receive capability for

[1] One manufacturer proposed a configuration for some aircraft in which a stand-alone UAT unit would be supplied with an additional ATC antenna, with an avionics recurring cost of $178K to $213K. The integration and ongoing maintenance costs of this alternative have not been estimated.

federated unit implementation was estimated to cost between $128,000 and $476,000, under these same installation assumptions.

Avionics line replaceable unit (LRU) costs were provided at estimated catalog price. Additionally, an amortization of aircraft certification costs of approximately $200,000 for the initial aircraft type and approximately $100,000 for additional aircraft types would need to be spread over the number of aircraft retrofitted per aircraft type[2].

Recurring retrofit avionics costs for retrofit of an aircraft with an integrated surveillance unit, in which airborne collision avoidance system (ACAS) and the Mode S transponder share the same antenna with integrated avionics were estimated to be between $250,000 and $450,000. It was noted that few aircraft had integrated surveillance systems presently, but that a larger percentage of the fleet would be so equipped in the future.

Forward fit estimates were, as might be expected, substantially lower. Under the cost-related assumption that ADS–B avionics were Buyer Furnished Equipment (BFE), forward fit estimates for Link Alternative B were in the range of $30,000 to $50,000 at list price for avionics involving federated units. Prices were estimated between $40,000 to $60,000 for aircraft with integrated surveillance units. The BFE assumption in the cost ranges means that airframe manufacturer costs of design, integration, and certification are provided by the avionics supplier (and are recovered in the supplier's pricing).

Several alternative implementation strategies were proposed. For example, some cost estimates considered ACAS modifications to receive UAT In one cost estimate, the receipt of UAT was proposed to be via a modified Mode S transponder using a diplexer in order to achieve appropriate isolation of 1030/1090 MHz and UAT transmit/receive.

Garmin's cost estimates were oriented toward integration of the UAT receive function into a business jet/commuter airline platform and did not use the BFE costing model. Estimated costs, using avionics list prices, for Link Alternative B for non-redundant retrofit were $42,000 plus aircraft downtime and an amortized percentage of a single-model supplemental type certificate (STC).

Link Alternative C (Addition of a UAT Transmit/Transceiver Function)

For an aircraft that is not equipped with ADS–B In, Link Alternative C would require the addition of a UAT ADS–B Out function. The costs of adding and integrating a dual UAT transmit function were generally estimated as being the roughly the same or slightly lower than the respective costs of adding and integrating a dual UAT receive function per the discussion of Link Alternative B above.

The addition of a UAT transceiver in Link Alternative C had a higher cost than Link Alternative B. Retrofit costs (recurring) for aircraft with federated units varied from $150,000 to $415,000 at list price plus 15 hours of installation labor per aircraft. This

[2] For example, in its comments on the ADS-B, NPRM the Air Transport Association identified between 35 and 40 aircraft types in discussing retrofit of 4,579 aircraft. Supplemental type certificates (STCs) are often done by aircraft type by airline. Some STCs apply across airlines. Thus one might reasonably assume that the certification costs mentioned above for a single aircraft type might be spread across, at closest order of magnitude, 100 aircraft.

cost is based on similar assumptions/costs to those in Link Alternative B for type certification, the use of existing antennas and cabling, and the accomplishment of the retrofit in an overnight[3].

For integrated surveillance units, the UAT transceiver costs were estimated to be between $250,000 and $450,000 at list price under the same installation assumptions. Forward fit costs of adding a UAT transceiver were estimated to be, again assuming the BFE model, in the range of $50,000-$70,000 for federated units and $40,000-$60,000 for aircraft with integrated surveillance units. They also noted that an appropriate amortization of Boeing engineering design labor for the additional functions would need to be applied.

As with Link Alternative B, Garmin's cost estimates were oriented toward the business jet/commuter airline market and did not use the BFE cost model. Dual equipage of a UAT transmit-only function was estimated to be approximately $71,000 plus aircraft downtime and a pro-rate portion of a single-model STC. Dual equipage of two UAT transceivers was estimated to cost approximately $81,000 plus aircraft downtime and STC costs.

Summary of the Cost/Benefit Profile for Link Alternatives B and C

Using the number of domestic air transport aircraft discussed in Appendix E2 (10,233) and an assumption that equipage of 30% of those aircraft would be on a "forward fit" basis, with an average discount (25%) from catalog price based upon a scale of purchase that includes 15% sparing, the equipage costs for Link Alternative B is estimated to be at least $939M. The equipage costs of Link Alternative C for a UAT Transmit function only would be roughly the same, and the costs of UAT transceiver equipage would be higher. These cost estimates represent a significant percentage of the AT fleet equipage costs for the NPRM estimated in Appendix E2.

Regarding benefits, the ARC has been informed that the potential cost reduction of ADS–B ground infrastructure, through removing the need to uplink on 1090 MHz is on the order of $350M to $500M in then-year dollars, and receiving any potential benefits of future UAT uplink services for air transport class aircraft, have not been quantified at this time. Any other benefits listed in Appendix J (for example, direct receipt of UAT ADS–B transmissions as opposed to reliance on ADS-R) should also be considered.

The ARC concludes that the incremental costs of Link Alternatives B and C over the NPRM baseline are greater than the benefits of those alternatives that the ARC has been able to quantify. Therefore the NPRM baseline is the most cost-effective dual link implementation.

[3] As was the case for Link Alternative B, one manufacturer proposed a configuration for some aircraft in which a stand-alone UAT unit would be supplied with an additional ATC antenna, with an avionics recurring cost of $241.5K to $289K. The integration and ongoing maintenance costs of this alternative have not been estimated.

Appendix K1—Cost Factors/Assumptions Template

Questions to be assessed

1. Assuming that an aircraft is already equipped with 1090 ES for ADS–B Out and In, what is the incremental cost of adding a UAT ADS–B In capability (receive function)?
2. Assuming that an aircraft is already equipped with 1090 ES for ADS–B Out, what is the incremental cost of adding a UAT ADS–B Out capability?
3. Assuming that an aircraft is already equipped with 1090 ES for ADS–B Out and In, what is the incremental cost of adding a UAT ADS–B Out and In capability?

Assumptions:

- Providing a dual-link ADS–B In capability includes the merging/consolidating information from both links onto the ADS–B In display.
- For questions two and three, respectively, costs should include the provision of a switching mechanism to enable transmissions on one ADS–B link or the other, but not both at the same time. This switching mechanism should be based on aircraft altitude. Additionally, a geographical filter will need to be implemented to provide the capability of having the aircraft transmit only on 1090 ES outside of the NAS.
- Non-redundant ADS–B In equipage should be assumed.
- Redundant ADS–B Out equipage should be assumed.
- Costs should reflect catalog pricing.
- Major differences in cost between classes of aircraft should be noted (for example, next generation aircraft vs. the current fleet).

Cost Table template

Cost Factor	Question 1	Question 2	Question 3
Avionics			
Aircraft design and Installation (including cabling)			
Antennas and cabling			
Aircraft downtime			
Certification			
Installation			

Notes on Cost Table

1. Avionics and aircraft design/integration cost factors may be lumped together. If this is done, please provide an explanation of why this is consistent with the protection of proprietary information.
2. Please provide, a block diagram of how the ADS–B capability is realized on the aircraft, reflecting major interactions with other aircraft systems, consistent with the protection of proprietary information.

Appendix K2—ACSS Cost Estimate

Dated May 29, 2008

Question 1. "Assuming that an aircraft is already equipped with 1090 ES for ADS–B Out and In, what is the incremental cost of adding a UAT ADS–B In capability (receive function)?"

Assumptions:

- Providing a dual-link ADS–B In capability includes merging/consolidating information from both links (1090 and UAT) onto the ADS–B In display. (non-recurring engineering cost is not quoted since the customer only will pay recurring engineering cost.)
- Non-redundant ADS–B In equipage is assumed. (Price is for one ADS–B In system—system uses existing antenna.)
- Costs reflect catalog pricing with a range of possible prices.
- A new replacement Surveillance Processor with 1090 and UAT is assumed since new RF and processing is required.
- A new aircraft certification would be required for each type of aircraft.
- Installation costs not included should be quoted by the airlines.

Question 2. "Assuming that an aircraft is already equipped with 1090 ES for ADS–B Out, what is the incremental cost of adding a UAT ADS–B Out capability?"

Assumptions:

- Costs reflect catalog pricing with a range of possible prices.
- A new replacement Mode S transponder with 1090 and UAT is assumed since new RF and processing is required.
- A new aircraft certification would be required for each type of aircraft.
- Installation costs are not included and should be quoted by the airlines.
- Costs include the provision of a switching mechanism to enable transmissions on one ADS–B link or the other, but not both at the same time. This switching mechanism is based on aircraft altitude. Additionally, a geographical filter will be implemented to provide the capability of having the aircraft transmit only on 1090 ES outside of the NAS. (non-recurring engineering cost is not quoted since customer only will pay recurring engineering cost.)
- Redundant ADS–B Out equipage is assumed.

Question 3. "Assuming that an aircraft is already equipped with 1090 ES for ADS–B Out and In, what is the incremental cost of adding a UAT ADS–B Out and In capability?"

Assumptions:

- Providing a dual-link ADS–B In capability includes merging/consolidating information from both links (1090 and UAT) onto the ADS–B In display. (NRE is not quoted since customer will pay RE only.)
- Non-redundant ADS–B In equipage is assumed. (Price is for one ADS–B In system—system uses existing antenna.)
- Costs reflect catalog pricing with a range of possible prices.
- A new replacement Surveillance Processor with 1090 and UAT is assumed since new RF and processing is required.
- A new aircraft certification would be required for each type of aircraft
- Installation costs are not included and should be quoted by the airlines.
- A new replacement Mode S transponder with 1090 and UAT is assumed since new RF and processing is required.
- Costs include the provision of a switching mechanism to enable transmissions on one ADS–B link or the other, but not both at the same time. This switching mechanism is based on aircraft altitude. Additionally, a geographical filter will be implemented to provide the capability of having the aircraft transmit only on 1090 ES outside of the NAS. (NEW is not quoted since customer will pay RE only.)
- Redundant ADS–B Out equipage is assumed.

ACSS Avionics Cost ROM Table

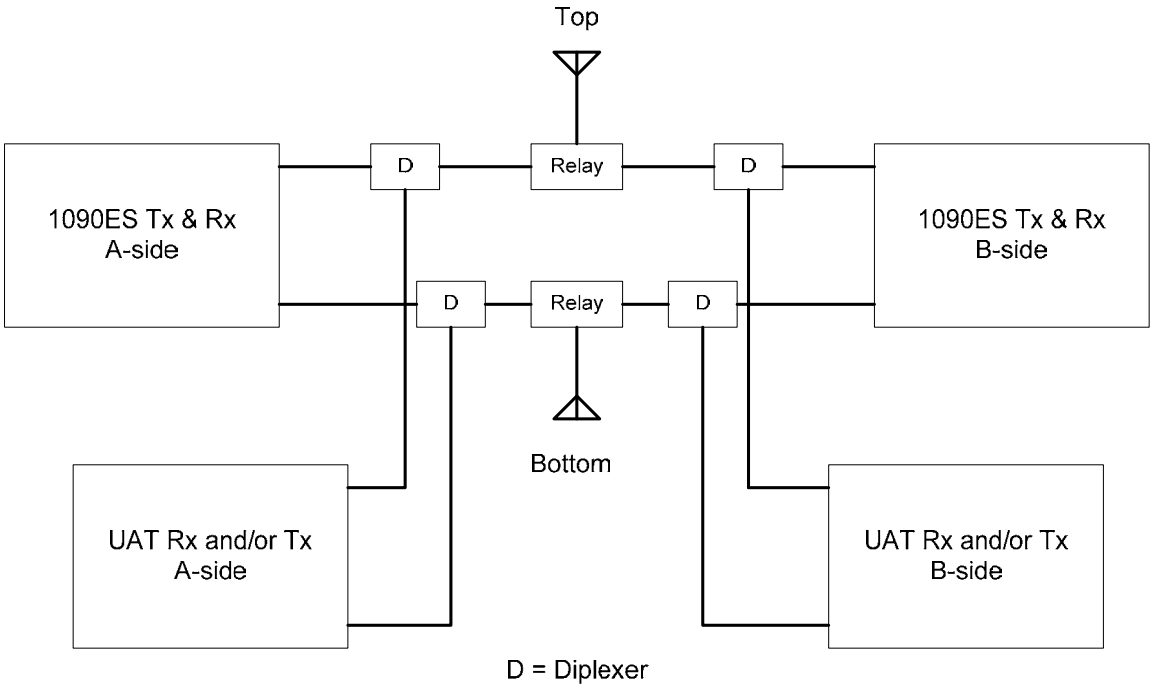
Cost Factor	Question 1	Question 2	Question 3
Avionics: Legacy equipment (ACAS/Mode S units redesigned)	$178K - $213K	$127K - $152K	$305K - $365K
Avionics: T3CAS with offside Mode S (Mode S redesigned and stand-alone UAT IN/OUT unit added to A/C with addl antenna *(T3CAS = ACAS, TAWS, Transponder Integrated unit – On Airbus legacy A/C and some other OEM's newer A/C)*	$178K - $213K Added stand-alone UAT unit with addl ATC antenna	$127K - $152K Mode S redesigned with second Mode S redesigned; reqs addl tray and ATC antenna	$241.5K - $289K Mode S redesigned with UAT stand-alone UAT IN/OUT unit and ATC antenna
Aircraft design and Installation (including cabling)	Airline item	Airline item	Airline item
Antennas and cabling	See above	See above	See above
Aircraft downtime			
Certification First of Type STC Domestic	$85K	$85k	$85k
Certification First of Type STC Foreign	$110K	$110K	$110K
Follow on Cert	40% of First of Type	40% of First of Type	40% of First of Type
Installation	Airline item	Airline item	Airline item

Appendix K3—Garmin Cost Estimate

Cost Table

Cost Factor	Question 1 (Rx-Only)	Question 2 (Tx-Only)	Question 3 (Transceiver)
Avionics	One at $27,000 (non-redundant)	Two at $25,000 each	Two at $30,000 each
Aircraft design and Installation (including cabling)	See Note 1	See Note 2	See Note 2
Antennas and cabling	- 2 diplexer @ $1,000 each - 4 new coax interconnects	4 diplexer @ $1,000 each 8 new coax interconnects	- 4 diplexer @ $1,000 each - 8 new coax interconnects
Aircraft downtime	1 wk	1 wk	1 wk
Certification	Single-model STC $150,000 (one-time charge)	Single-model STC $150,000 (one-time charge)	Single-model STC $150,000 (one-time charge)
Installation	$13,000	$17,000	$17,000

See drawing below for typical installation provisions.
Note 1: UAT Rx-Only equipment connects to the A-side transponder only.
Note 2: Coax relays operated from A/B selector switch in cockpit (not shown).
Note 3: Assumes aircraft has 1090 ES with antenna diversity previously installed.
Note 4: Assumes digital interconnect from existing 1090 ES ADS–B/transponder or transponder control panel for UAT ADS–B control (not shown).



Appendix K4—Honeywell Cost Estimate

Cost Table

Cost Factor	Question 1	Question 2	Question 3
Avionics • Retrofit, • Federated Units	$100 - $150K list (assumes two **new** XPDRS w/ UAT in capability + ACAS upgrade to merge/correlate traffic sources OR UAT integrated into ACAS)	$100K list (2 **new** XPDRS w/ UAT out)	$150K - $250K list (comments from questions 1 and 2 apply)
Avionics • Forward Fit • Federated Units	$30K - $50K	$20K	$50K –– $70K
Avionics • Retrofit • Integrated Surveillance Unit • Dual • (i.e. A380, A350)	$200K - $400K per ship set. (Modification of integrated surveillance system. Additional units and antennas will not be acceptable to the customer. Function performed using combined ACAS/XPDR Antenna).	$100K-$200K per ship set. (Modification of integrated surveillance system. Installation of additional units and antennas will not be acceptable to the customer. Function performed using combined ACAS/XPDR Antenna).	$200K - $400K per ship set. (Answers to Question 1 and Question 2)
Avionics • Forward Fit • Integrated Surveillance Unit • Dual • (i.e. A380, A350)	$40K - $60K per ship set. (same comments as for retrofit)	$20K per ship set. (same comments as for retrofit)	$40K - $60K (Answers to Question 1 and Question 2)
Aircraft design and Installation (including cabling)			
Antennas and cabling			
Aircraft downtime			
Certification			
Installation			

Comments:

1. A standalone UAT transceiver might be less expensive, but the installation and aircraft costs would be higher. The above options do not require new wiring or aircraft down time.

2. Assumes ARINC 600 form factors and ARINC-style connectors and racks.

3. Assumes the system has to meet the current Boeing and Airbus maintenance interference requirements.

4. Current transponder (federated) catalog pricing is approximately $40,000.

5. Current integrated surveillance unit catalog pricing is approximately $200,000.

6. Did not price out separate dedicated UAT avionics as it was assumed that separate units would be offset with aircraft down time and additional integration costs.

Appendix K5—Rockwell Collins Cost Estimate

Rockwell Collins Avionics Cost ROM Table for ADS–B ARC Working Group A Avionics Cost Subgroup (rhs_06/10/2008_rev. A)			
COST FACTOR	**QUESTION #1**		
Method #1: (Legacy Systems) Add UAT Receiver to XPDR Requires Diplexer for each set of antennas and data output to Traffic Function. Also requires Traffic Module Update to process and merge UAT	XPDR Upgrade: $40K per XPDR Diplexer Function: $8K minimum Add. RF Switching: $4K Add Output to Traffic: $6K Update Traffic Merge: $15K Minimum Method Subtotal: **$73K**	**Dual** XPDR Upgrade: $80K Diplexer Function: $16K minimum Add. RF Switching: $8K Add Output to Traffic: $12K Update Traffic Merge: $15K Minimum Method Subtotal: **$131K**	
Method #2: (Legacy Systems) Add UAT Receiver and Diplexer to Transponder plus data output to Traffic function and update to Traffic	XPDR Upgrade: $46K per XPDR Add Output to Traffic: $6K Update Traffic Merge: $15K Minimum Method Subtotal: **$67K**	**Dual** XPDR Upgrade: $92K Add Output to Traffic: $12K Update Traffic Merge: $15K Minimum Method Subtotal: **$119K**	
Method #3: (Legacy Systems) Add Stand Alone UAT Receiver, Diplexer, Output to Traffic Function, and Update of Traffic Function Merge	New UAT RX Unit: $35K per Unit Diplexer Function: $8K minimum Add Output to Traffic: $6K Update Traffic Merge: $15K Minimum Method Subtotal: **$64K**	**Dual** New UAT RX: $35K Diplexer Function: $16K minimum Add Output to Traffic: $12K Update Traffic Merge: $15K Minimum Method Subtotal: **$78K**	
		QUESTION #2	
Method #4: (Legacy Systems) Add UAT Transmitter to XPDR Requires Diplexer for each set of antennas		XPDR/UAT Upgrade: $42K per unit Diplexer Function: $8K minimum Add. RF Switching: $5K Minimum Method Subtotal: **$55K**	**Dual** XPDR/UAT Upgrade: $84K Diplexer Function: $16K min. Add. RF Switching: $10K Minimum Method Subtotal: **$110K**
Method #5: (Legacy Systems) Add UAT Transmitter and Diplexer to XPDR		XPDR/UAT Upgrade: $48K per unit Diplexer Function: $8K minimum Minimum Method Subtotal: **$56K**	**Dual** XPDR/UAT Upgrade: $96K Diplexer Function: $16K min. Minimum Method Subtotal: **$112K**
			QUESTION #3
Method #6: (Legacy Systems) Add UAT Transmitter, Receiver, and Diplexer to XPDR. Add UAT Data Output from XPDR to			Add UAT TX and RX: $50K per unit Add Diplexer Function: $8K minimum Add Traffic Output: $6K Update Traffic Merge: $15K

Rockwell Collins Avionics Cost ROM Table for ADS–B ARC Working Group A Avionics Cost Subgroup (rhs_06/10/2008_rev. A)			
COST FACTOR	**QUESTION #1**		
Traffic Merge Function Update Traffic Merge Function			Minimum Method Subtotal: **$79K per side** **$158K Dual**
Antennas and Cabling	**Highly Dependent on Aircraft Existing Configuration and Desired End Configuration**		
Aircraft Downtime	**Highly Dependent on Aircraft Existing Configuration and Desired End Configuration**		
Certification: First Domestic STC	**$90K**	**$90K**	**$90K**
Certification: First International STC	**$120K**	**$120K**	**$120K**
Follow On Certification	**45% of First of Type**	**45% of First of Type**	**45% of First of Type**
Installation	**Highly Dependent on Aircraft Existing Configuration and Desired End Configuration**		

DEFINITION OF QUESTIONS:

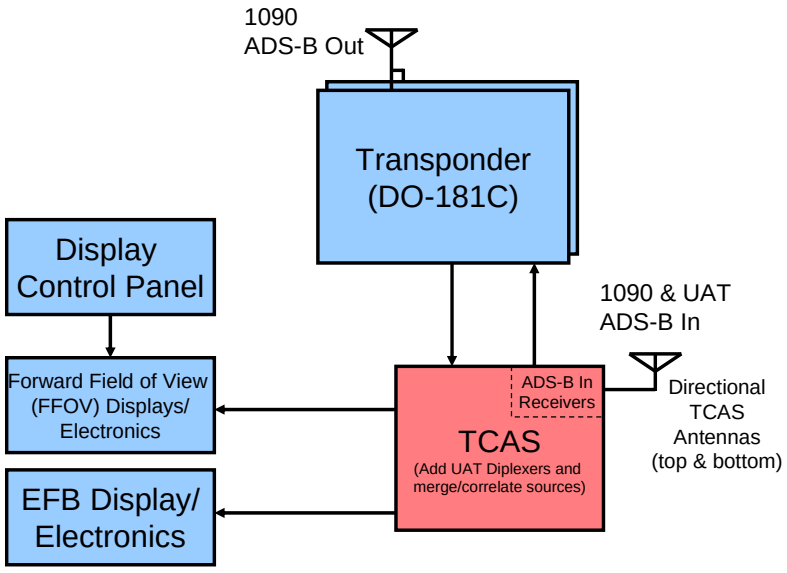
1. Aircraft is already equipped with 1090 ES ADS–B Out and In.
   What is the incremental cost to add UAT ADS–B In with such capability being Non-Redundant?
2. Aircraft is already equipped with 1090 ES ADS–B Out only.
   What is the incremental cost to add UAT ADS–B Out with such capability being Redundant?
3. Aircraft is already equipped with 1090 ES ADS–B Out and In.
   What is the incremental cost to add UAT ADS–B Out and In capability?

Appendix K6—Boeing Cost Estimate

The following does not constitute a commitment on the part of The Boeing Company:

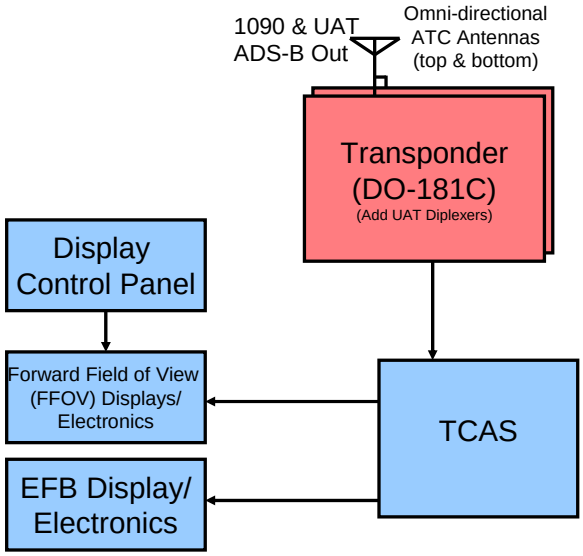
Question 1. Assuming that an aircraft is already equipped with 1090 ES for ADS–B Out and In, what is the incremental cost of adding a UAT ADS–B In capability (receive function)?

- Assuming modification of ACAS unit and use of existing top and bottom ACAS antennas and wiring. (We did not have the benefit of the RCI input which adds a UAT receiver to each of the two ATC transponders).
- T3CAS and Integrated Surveillance System (ISS) architectures are not addressed at this time.



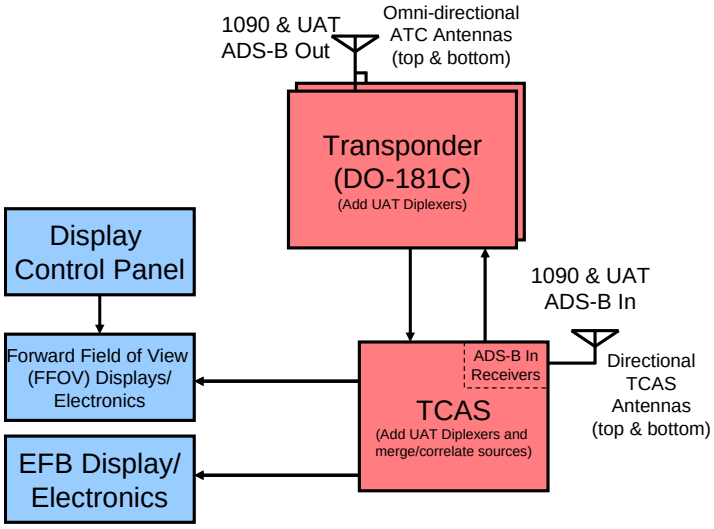
Question 2. Assuming that an aircraft is already equipped with 1090 ES for ADS–B Out, what is the incremental cost of adding a UAT ADS–B Out capability (transmit function)?

- Assuming modification of both ATC transponders for transmit function and use of existing top and bottom omni-directional ATC antennas.
- T3CAS and ISS architectures are not addressed at this time).



Question 3. Assuming that an aircraft is already equipped with 1090 ES for ADS–B Out and In, what is the incremental cost of adding a UAT ADS–B Out and In capability (receive and transmit)?

- Assuming modification of ACAS unit and use of existing top and bottom ACAS directional antennas for UAT ADS–B In, modification of both ATC transponders, and use of existing top and bottom ATC antennas for UAT ADS–B Out.
- T3CAS and ISS architectures are not addressed at this time).



Assumptions:

- Providing a dual-link ADS–B In capability includes merging/consolidating information from both links onto the ADS–B In display.
- For Questions 2 and 3, costs should include the provision of a switching mechanism to enable transmissions on one ADS–B link or the other, but not both at the same time. This switching mechanism should be based on aircraft altitude. Additionally, a geographical filter will need to be implemented to provide the capability of having the aircraft transmit only on 1090 ES outside of the NAS.
- Non-redundant ADS–B In equipage should be assumed.
- Redundant ADS–B Out equipage should be assumed.
- Costs should reflect catalog pricing.
- Major differences in cost between classes of aircraft should be noted (for example, next generation aircraft vs. the current fleet).

Cost Table template

Cost Factor	Question 1	Question 2	Question 3
Avionics			
Production Aircraft design and Installation	• Assume all units are Buyer Furnished Equipment (BFE) • Assume multiple suppliers of BFE • Design/Integrate new controls displays/alerting hardware and software (effort for each production airplane 737NG, 747, 767, 777) • Use existing CDTI design/arch • Verification Testing in Lab and on Airplane - Flight and Ground (no need to instrument airplane, fly against ground test station) • Engineering effort for each supplier unit against each airplane type • Certification • Engineering effort for each supplier unit against each airplane type	• Similar to Question 1	• Adds effort from Question 1 and 2
Retrofit Aircraft design and Installation	• SB design already accomplished in production • Assumes out of production models, 757, MD-11, etc. to be addressed at a later time • SB Parts/Labor - ~$50K per aircraft estimate includes bulletin and attach		

Cost Factor	Question 1	Question 2	Question 3
	parts/connectors but excludes cost of LRUs		
Antennas and cabling	Assumes use of existing antennas and cabling	Assumes use of existing antennas and cabling	Assumes use of existing antennas and cabling
Aircraft downtime (Retrofit)	Can be accomplished in an overnight (no scheduled airplane down time)	Can be accomplished in an overnight (no scheduled airplane down time)	Can be accomplished in an overnight (no scheduled airplane down time)
Certification	Already accomplished in production (out of production to be addressed at a later time)	Already accomplished in production (out of production to be addressed at a later time)	Already accomplished in production (out of production to be addressed at a later time)
Installation (Retrofit)	5 hours/airplane	10 hours/airplane	15 hours/airplane

APPENDIX L—LINK IMPLEMENTATION ALTERNATIVE C WHITE PAPER ON DETAILS OF IMPLEMENTATION

The Aviation Rulemaking Committee (ARC) has proposed, as one of three alternative dual ADS–B link implementations, Alternative C, which reads as follows:

- Mandate universal access transceiver (UAT) ADS–B Out for all aircraft operating below a given altitude (transition altitude)
- Mandate 1090 ES ADS–B Out for all aircraft above the transition altitude.

In this alternative, an aircraft that is equipped for 1090 extended squitter (1090 ES) ADS–B Out and optionally implements ADS–B In is assumed to have implemented an ADS–B receive capability for both 1090 ES and UAT.

The following questions have been raised concerning this link implementation alternative:

1. When, specifically, should an aircraft equipped with both 1090 ES Out and UAT Out transmit on each of these ADS–B links? Should an aircraft ever transmit on both ADS–B links at the same time?
2. Should 1090 ES or UAT reception ever be inhibited by an aircraft equipped with both 1090 ES Out/In and UAT Out/In?

Question 1—When to transmit on each ADS–B link for an aircraft equipped with both 1090 ES Out and UAT Out.

One of the stated advantages of Alternative C is the ability to range-extend 1090 ES for advanced ADS–B In applications in high density airspace areas above the transition altitude. For this advantage to be achieved, 1090 ES transmissions would need to be inhibited below the transition altitude. Given that UAT cannot be assumed to be implemented outside of the national airspace system (NAS), a geographical filter (similar to that initially used in DO–260A for the transmission of the Mode A code in ADS–B transmissions) would need to be provided. This will ensure that 1090 ES transmissions are not inhibited at any altitude outside of the NAS.

The value set for the transition altitude is dependent on a number of factors, including whether UAT transmissions by the dual-link-equipped aircraft are ever inhibited. *An initial consensus has been reached in the Avionics Cost Subgroup that such transmissions need not be inhibited (that is, UAT ADS–B messages are always transmitted by a dual-link-equipped aircraft when over the NAS).*

In reaching this consensus, the Avionics Cost Subgroup has been informed of agreement by appropriate International Civil Aviation Organization (ICAO) panels, based on analysis performed during UAT standard and recommended practices (SARPs) development. The agreement is that UAT operation has no operationally significant impact on other L-Band aircraft systems such as secondary surveillance radar (SSR), airborne collision and avoidance system (ACAS), and distance measuring equipment (DME). Should this approach be adopted, the transition altitude can be set without

concern for aircraft below that altitude receiving ADS–B transmissions from aircraft above the transition altitude that are descending.

A further consequence of this approach is that aircraft dual-link-equipped for ADS–B In and the ADS–B ground infrastructure would receive ADS–B messages on both links from aircraft above the transition altitude. The aircraft ICAO 24–bit designator, used in every ADS–B message on either ADS–B link, would need to be used to at least disambiguate, if not integrate, ADS–B transmissions from such aircraft.

An advantage for advanced ADS–B In applications (for example, spacing and delegated separation) is that both ACAS ranging and the built-in UAT range validation capability (that is, two independent (of ADS–B) validation capabilities that are also independent of each other) could be used to provide higher ADS–B integrity for the ADS–B In application. A disadvantage is that the ADS–B In function (either generically or within each ADS–B In application) would need either to integrate the 1090 ES and UAT data streams or to ignore one of the data streams.

A further question is whether the geographical filter referred to above should also be employed to inhibit UAT transmissions when the aircraft is outside of the NAS. While UAT has a worldwide frequency allocation at 978 MHz, there is no guarantee that all air navigation service providers (ANSP) will permit UAT transmissions on that frequency. This is because UAT compatibility with DME operating at 978 MHz is not assured. (There are seven such DME stations in the world, all of which are in the European Region). It is expected that operation of UAT transmitters outside of the NAS would require ICAO contracting State approvals and is not recommended at this time.

Another question that has been asked is whether, for Alternative C, 1090 ES transmissions are needed at all over the NAS if UAT transmissions are not inhibited. As an initial matter, 1090 ES transmissions will be required within 100 to 200 miles of NAS boundaries for transition (for example, acquisition of 1090 ES ADS–B participants) to support international operations. Second, the development of ADS–B In applications for altitudes above the transition altitude can be developed on a consistent, seamless worldwide basis if 1090 ES ADS–B is transmitted above the transition altitude. Inhibiting 1090ES transmission and relying solely on UAT transmissions at the higher altitudes is not recommended at this time.

Question 2—Inhibiting ADS–B message reception.

The potential disadvantage of the aircraft's ADS–B In function needing to integrate 1090 ES and UAT data streams, or ignoring one of the data streams, could be simplified if not overcome. This could be done by inhibiting reception of, for example, UAT above the transition altitude. However, it may well be better not to inhibit reception for two reasons:

1. The ADS–B In software can be developed to ignore some/all ADS–B receptions from a given ADS–B link in appropriate contexts; and
2. Aircraft at an altitude equipped with dual-link ADS–B In advantageously receive UAT transmissions from aircraft below the transition altitude and ascending. That is, not inhibiting reception simplifies the operational implementation of the transition altitude.

APPENDIX M—POTENTIAL UAT UPLINK BENEFITS TO AIR TRANSPORT CLASS USERS

Summary

The Next Generation Air Transportation System (NextGen) will have new and diverse data communication requirements. The Ground Uplink Segment of the Universal Access Transceiver (UAT) could fill a need in the new system by broadcasting Air Traffic Management state information allowing aircraft to capture latent capacity and improve efficiency, especially when avoiding convective weather. Implementation of ADS–B In using UAT would enable this class of ground-to-air communication.

Example UAT Broadcast Uplink Service

When circumnavigating convective weather, pilots rely on airborne weather radar and the view outside the cockpit window. In the NextGen time frame, uplinked "big picture" weather graphics from ground sensors would give pilots a much better sense of the most efficient path around convective weather. However, graphical weather information does not indicate the demand for the airspace around the convective weather. Traffic density information, combined with graphical weather information, would facilitate aircraft to configure the most efficient routes, especially around convective weather. In the current airspace system, a product with such capabilities could display the current and projected traffic density in a particular airspace sector, and contrast the projected density with the defined capacity of the sector. In NextGen sectors are likely to be dynamic, but a "density of aircraft metric" can still be defined for a particular volume of airspace. This information could be used to define a set of rules for how aircraft are re-routed around convective weather. UAT would be a good choice for such a product, because it is a broadcast link, and thereby could be used by all participating aircraft in the vicinity of the weather event.

APPENDIX N—ADS–R LATENCY AND RELIABILITY EXPECTATIONS

An important aspect of ARC's consideration of dual-link implementation alternatives is the service expectations of ADS–R. The SBS critical specification states: "ADS–B/ADS–R Services will be deployed NAS-wide on the airport surface and in terminal and en route airspace. As these Services will operate, in many cases, in the same airspace as TIS–B/FIS–B Services, the two will be transmitting in the same coverage." (Reference 1, p. 4)

The service expectations of ADS–R can be characterized by the latency and reliability of the system as a function of the service domain (surface, terminal, en route). Several airborne applications detailed in the RTCA Airborne Separation Assurance MASPS, and RTCA DO–289 require a specific ADS–R update interval at the 95 percent confidence level in order to be supported by the ADS–R service, varying from 2 seconds (ASSA and FAROA applications) to 12 seconds (Enhanced Visual Acquisition) for "Basic" ASA Applications. (Reference 2, §2.4.5.2)

Table 1 describes the update interval and reliability requirements of the ground station compared to the capability of the surveillance and broadcast service provider (ITT, Inc.). The service provider reliability is conservatively based on an aircraft receiving at least one message out of multiple messages transmitted during the update interval. The reliability of an aircraft's reception of a single ADS–R message from the ground station is anticipated to be at least 95 percent during the respective update intervals, increasing with proximity to ground stations.

ADS–R Update Interval TPMs	**SBS Specification Requirement**	**ITT Capability**
Surface domain	2 sec (95%)	1090: 2 sec (95%) UAT: 2 sec (95%)
Terminal domain	5 sec (95%)	1090: 5 sec (95%) UAT: 5 sec (99%)
En route domain	10 sec (95%)	1090: 10 sec (95%) UAT: 10 sec (95%)

Table 1: ADS–R Update Interval Technical Performance Metrics (TPMs)

With regard to latency, the service provider ground infrastructure design is such that the time it takes for a received ADS–B message to be processed into ADS–R format and sent to the ADS–R transmission scheduler is 400 milliseconds or less. This latency is less than half of the required maximum of 1 second stated in the critical specifications. (Reference 1, p. 76) Furthermore, to account for the velocity of the target aircraft during the update interval, the ground station will adjust the received position of the target aircraft by linear extrapolation to the expected time of transmission. Thus the total and uncompensated latencies added by ADS–R processing are sufficiently small so that reporting of stringent position quality parameters such as NIC and NAC

need not be degraded from that reported in the original ADS–B message unless NIC>8 and NAC>9 (Reference 1, p. 44).

The ground stations will provide ADS–R service coverage in a service volume equivalent to that of existing radar coverage. Assessments of the existing radar coverage in the NAS can be obtained from the FAA or the 84th Radar Evaluation Squadron. Additionally, the availability of the ADS–R system will exceed the minimum requirement in the critical specifications (Reference 1, p. 78) and is estimated to be greater than .99999.

The anticipated ADS–R service can be described as highly reliable within known service volumes. The definition of ADS–R service availability/management messages to be uplinked is being addressed by RTCA SC–186 in conjunction with the SBS Program Office and ITT. These attributes are particularly useful for analyzing the respective business cases for ADS–R service volume expansion within the aviation community with particular emphasis on general aviation expectations at lower altitudes and non-commercial airports

References

1. **FAA - SBS Program.** *Automatic Dependent Surveillance Broadcast (ADS–B) / ADS–B Rebroadcast (ADS–R) Critical Services Specification.* Washington, DC : USDOT, 2007. v 1.2.

2. **RTCA, Inc.** *Minimum Aviation System Performance Standards for Aircraft Surveillance Applications (ASA).* Washington, DC : RTCA, Inc., 2003. DO–289.

APPENDIX O—CONCLUSIONS/RECOMMENDATIONS ON ADS–B DUAL LINK IMPLEMENTATION

Appendix H details the ARC's vision for a dual link implementation strategy, in the context that 1090 ES is introduced in a manner that is compatible with SSR and ACAS as they presently exist. The additional conclusions listed below are related to recommended actions to make the link implementation vision work.

1. Do we have enough confidence in the ability of 1090 MHz ADS–B, given 1090 MHz spectrum congestion, to support needed ADS–B In applications in the NextGen timeframe (2025 and beyond) to recommend one link (1090 MHz ADS–B) for air transport and general aviation aircraft without mitigations not yet defined?

No, we do not have enough data to convince ourselves that a single 1090 MHz link will support needed ADS–B In applications in the NextGen timeframe. The ADS–B In applications need substantially better definition (air-to-air range, data required for the application, and update requirements). The issue is not NAS-wide but rather is limited to the NAS' highest density airspace such as the Philadelphia-New York corridor.

2. Given No. 1, do we have enough confidence in the ability of 1090 MHz ADS–B to support needed ADS–B In applications in the NextGen timeframe (2025 and beyond) to recommend one link (1090 MHz ADS–B) for air transport aircraft without mitigations not yet defined?

No.

3. a. The ARC recommends an urgent study to answer the following questions:

- Can the 1090 MHz frequency support 1090 ES, ACAS, and SSR in the NAS' high density airspace? If the answer is yes, what are the costs of necessary mitigations? Can the mitigations be limited to ground-based solutions?
- Can 1090 MHz ADS–B support needed ADS–B In applications in the NextGen timeframe? And if so, what mitigations, if any, additional to those above are needed and at what cost?

b. The ARC provides the following recommendations for the study:

- The NextGen timeframe extends through 2035 (the 2035 date includes an equipment life cycle after the proposed 2020 rule compliance date).
- Consider the 1090 MHz frequency congestion mitigations that would be required to provide a 45 nm air-to-air range for ADS–B In applications in future high density airspace. Provide similar answers for air-to-air ranges of 20 nm, 60 nm, and 90 nm.
- The cost impact and user acceptability of any additional avionics mandates needed to support 1090 ES implementation need to be addressed. The ARC is of the view that mandating Mode S transponders will not be a cost effective and/or user acceptable alternative. Further, this mitigation is not envisioned to

significantly improve the interference situation, unless additional changes are made to optimize ground Mode S interrogator operation (for example, clustering Mode S interrogators.)

- Upon completion of the study, Government/industry collaboration through the ADS–B ARC is recommended to determine which 1090 MHz congestion mitigation strategies will be adopted and to finalize what ADS–B implementation strategy will be followed.
- The evaluation should include all effective cost, benefit, and schedule alternatives for air transport and general aviation use of the 1090 ES and UAT frequencies.
- The cost benefit analysis for potential mitigations should include the impact on international operators operating in the NAS.
- Any ACAS-related 1090 MHz frequency congestion mitigations proposed for near term implementation should be bundled with changes needed for ACAS 7.1 to require only one ACAS upgrade cycle
- The ACAS-related 1090 MHz frequency congestion mitigation of eliminating the dependency of ACAS on the Mode S transponder acquisition squitter should be considered.
- Implementation of passive wide-area multilateration as a potential 1090 MHz frequency congestion mitigation, through removal of SSRs, in high density airspace.
- Implementation of further alternative methods of removing SSRs in high density airspace, particularly in the context of surveillance ground systems employing fusion of surveillance data sources.

4. Should the study in No. 3 be completed before issuance of the ADS–B final rule?

Yes.

5. Should ITT continue to develop and implement ADS–R for both links?

Yes. This may preclude achieving ground infrastructure cost benefits but these costs benefits are significantly less than the assessment of avionics equipage costs.

APPENDIX P – PROGRAMMATIC DECISION ANALYSIS

Introduction

The Automatic Dependent Surveillance–Broadcast (ADS–B) Aviation Rulemaking Committee (ARC) used a decision analysis process to identify and choose a strategic alternative that would increase the overall value of the NPRM and stakeholder buy-in.

Stakeholder Issues

General Aviation (GA): We are paying a lot for equipage but getting no benefit.

Airlines and Airframe Manufacturers:

- We would like to get the benefits sooner.
- The performance requirements are too high for the ADS–B Out applications identified, and the performance requirements for ADS–B In applications are still being studied.
- The equipage solution needs to be globally interoperable.
- We need a gated process to reduce risk.

Military:

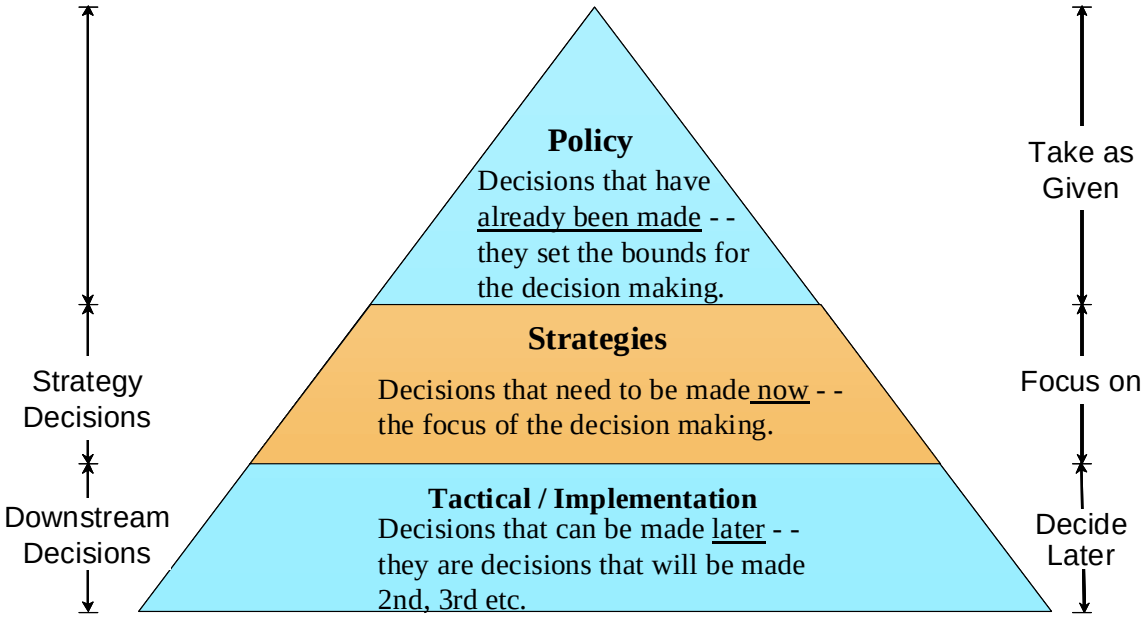
- The current NPRM does not acknowledge that it will affect the U.S. Department of Defense (DOD) and other state aircraft.
- It may be unreasonably expensive to equip some State aircraft with ADS–B Out. Accommodations must be given to ensure DOD needs to access airspace to fulfill military, training, and test evaluation requirements for peacetime, contingency, and wartime operations.

Policies, Strategies and Tactics

To identify strategic alternatives to the NPRM, the team identified the potential decisions that could be made to alter the NPRM and increase stakeholder value. These decisions were then categorized into three categories:

- Policies/Decisions Already Made. When the team unanimously agreed on the preferred course of action regarding a specific decision, that decision was recorded as a policy statement.
- Strategies: Decisions to be Made. When the team identified several strategic options for a given decision and those options would have significant impact on the cost and/or benefit of the NPRM, those decisions were categorized as strategic decisions and included as columns on the strategy table.
- Tactics/Decisions to be Made Later. When the team identified decisions that would either be driven by the strategic decisions above or were of low cost and/or benefit impact, those decisions were categorized as tactics.

Figure 1: Decision Hierarchy



The purpose of this process is to narrow the scope to the viable trade space, while focusing resources on the high value decisions.

Policies: Decisions that have already been made

The team identified and agreed to the following policies regarding the NPRM and the associated ADS–B implementation:

- ADS–B In will not be included in the mandate.
- ADS–B Out will be mandated.
- The mandate is for DO–260A Change 3 for the air carrier segment.
- The retrofit compliance deadline will be tied to FAA readiness and adjusted depending on the availability of services including the following ADS–B components:
    - Ground infrastructure coverage needed for the mandated airspace and additional non-radar airspace (NRA) and airports.
    - Automation systems.
    - Equipment certification.
    - Performance standards.
    - Operational approval.
    - Separation standards.
    - Operational procedures for ADS–B NRA airspace.
    - FAA controller training and procedures.

- Forward fit compliance deadline for air transport will be 2 to 3 years before the phase I compliance deadline.
- A readiness review will be done in 2012.
- FAA will lock down standards for ADS–B out by the time the final rule is published (~2010).
- ADS–B must provide an equivalent or better level of service as the current radar system in terms of coverage, latency, accuracy and integrity.
- Where possible, existing air transport equipage (DO-260-like) will be used for applications such as: Gulf of Mexico (non radar airspace), more efficient metering based on an improved Traffic Management Advisor (TMA), increased ability to perform Continuous Descent Approaches (CDA), and an improved en route conflict probe until the compliance deadline.
- There will be no change to the airborne collision and avoidance system (ACAS) carriage requirements through the mandate period.

Strategic Decisions: Decision that need to be made now

The team identified the following strategic decisions that need to be made:

- Mandated Airspace: In what airspace is ADS–B Out required?
- Link Decision: Is ADS–B a single link (1090 ES) or a dual link (1090 ES/ universal access transceiver (UAT)) system?
- Compliance Deadline: When is the compliance deadline?
- Performance Requirements: What are the performance requirements for the ADS–B Out equipage in terms of Navigation Accuracy Category for position (NACp)/ Navigation Integrity Category (NIC)?
- GA Equipage Elimination: Is there any GA equipment, required today, that can be removed from the aircraft?
- Secondary Surveillance Radar (SSR) Retirement: To what degree will secondary surveillance radars be removed from the system?
- Additional ADS–B Out Applications: What additional applications, beyond those in the current NPRM, will be implemented using ADS–B?

Tactics: Decisions that need to be made later

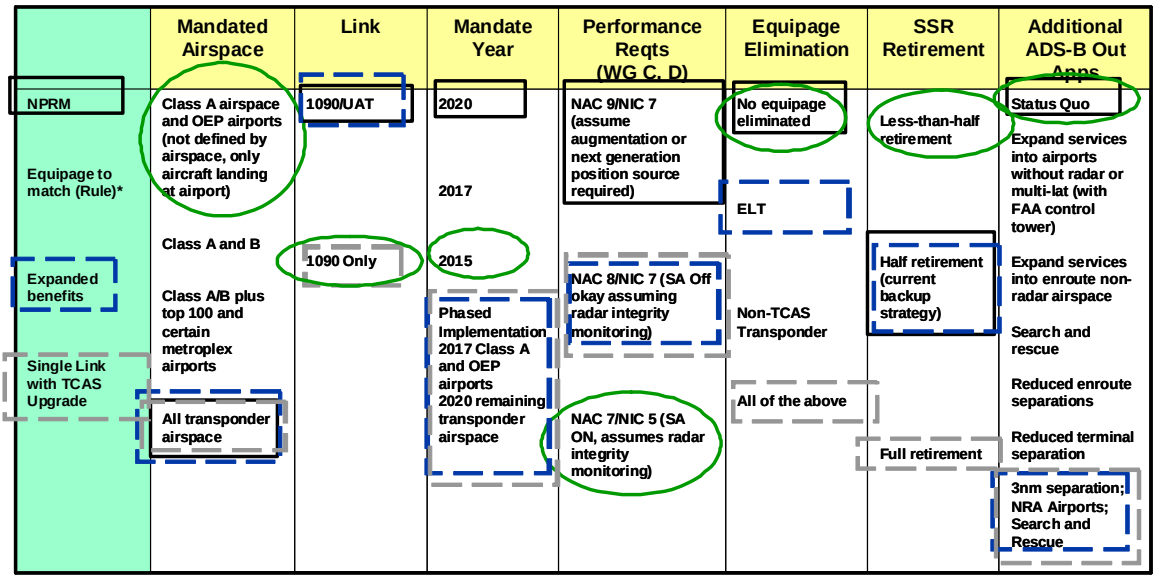
The team identified the following tactical decisions that need to be made once the strategic decisions are made:

- Need demonstration projects and in-service evaluations for ADS–B In applications (gated process).
- Mandate incentives (for example, tax incentives).
- Applications will be accelerated as appropriate based on changes in the compliance deadline.
- ACAS functionality on airplane.

Strategic Alternatives to the NPRM

Options were identified for each of the strategic decisions identified above. Then strategies were defined by identifying a cohesive set of choices among all the strategic decisions. The strategy table below, Figure 2, sums up the four strategies analyzed.

Figure 2: Strategic Options



Mechanisms for Increasing Value of NPRM

In developing the alternative strategies to the NPRM, five mechanisms were identified for increasing stakeholder value:

1. Reduce equipage costs by reducing performance requirements for equipage,
2. Reduce equipage costs by reducing geographical requirements for equipage,
3. Increase the applications taking advantage of ADS–B Out,
4. Reduce requirements for GA equipage (emergency locator transmitter (ELT) and transponder) by taking advantage of ADS–B Out functionality, and
5. Reduce infrastructure costs by moving to a single 1090 ES link.

The ARC determined that, with one exception, all of the major benefits estimated by the FAA and published with the NPRM could be obtained operationally via non-separation applications of ADS-B Out information, using DO-260-approved or UAT equipment with positioning performance of NACp≥7 and NIC>5. The "reduced separation in the Gulf of Mexico" benefit is a non-radar-airspace separation application that the ARC

believes can be safely conducted with the same equipment and performance requirements. This determination was considered in all of the non-NPRM strategies evaluated.

The section below describes the goal and the contents of the NPRM strategy and the two alternative strategies identified.

Strategy Descriptions

- NPRM. The NPRM strategy matched the original contents of the NPRM. The strategy required ADS–B out for all aircraft flying in transponder airspace; had a dual 1090 ES/UAT link; a compliance deadline of 2020; a NACp≥9 and NIC≥7 for performance requirements, which required augmentation or a next generation position source; no equipage eliminated for GA; half of SSRs retired; and no additional ADS–B out applications than those in the original NPRM.
- Equipage to Match. The goal of the Equipage to Match strategy was to reduce equipage costs by adjusting performance requirements and the geographical requirements for ADS–B out equipage to match the ADS–B Out benefits estimated by the FAA and published with the NPRM. The strategy limited equipage requirements to Class A airspace and Operational Evolution Plan (OEP) airports; had a 1090 ES link only; had a compliance date of 2015; a positioning performance requirement of NACp≥7 and NIC≥5; no equipage eliminated for GA; most all SSRs were retained; and added no additional ADS–B Out applications to those in the original NPRM.
- Expanded Benefits. The goal of the Expanded Benefits strategy is to increase the value of the rule to stakeholders by providing additional ADS–B out operational applications and benefits. In addition, equipage costs were reduced through performance requirements that matched the applications stated in the rule. This two-phase strategy required equipage for all transponder airspace, and had a phase 1 compliance date of 2015 for operations within Class A airspace and into OEP airports, and a NACp≥7 and NIC≥5. Phase 1 allowed the early achievement of all major ADS-B Out benefits published with the NPRM. Phase 2 of this strategy had a compliance date of 2020 for all transponder airspace, a NACp≥8 and NIC≥7, assumed elimination of the need for an ELT for GA aircraft, retired half of the SSRs, and added ADS–B applications of 3 nm en route separation, services at non-radar airports, and improved search and rescue service (SAR) via ADS–B.

Influence Diagram

The influence diagram shows how the strategic decisions and the uncertainties influence the overall Net Present Value (NPV) of the decision. Influence is shown when an arrow is drawn between one variable to another variable.

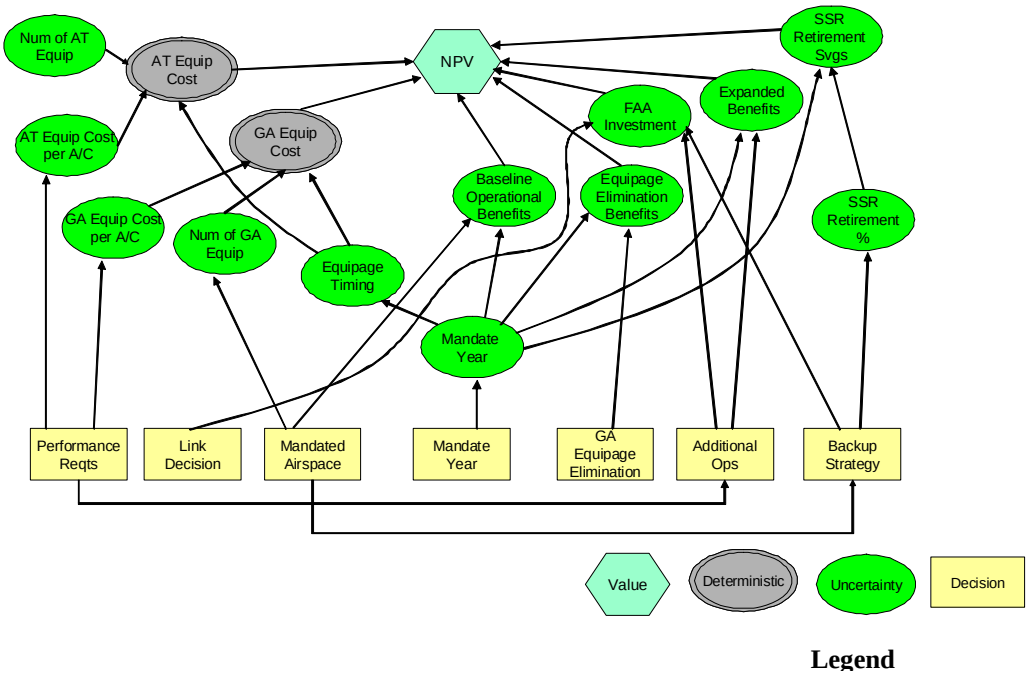
At the top of the diagram is the NPV. The NPV represents the net present value of the cash flows associated with the NPRM. The NPV constitutes the objective to be maximized.

The gray, double-lined ovals, air transport (AT) Equipage Cost and GA Equipage Cost are deterministic variables that influence NPV and are determined by the uncertainties (the green bubbles) with arrows into those bubbles.

The green, single-lined ovals represent the uncertainties important to the decision. Some uncertainties are represented at their most granular level (for example AT Equip Cost), while others are represented at a summary level (for example Expanded Benefits).

The yellow boxes represent the strategic decisions identified and the columns in Figure 2. Decisions influence both uncertainties and other decisions. For instance, performance requirements influence the equipage cost per aircraft and the additional operations that can be implemented.

Figure 3: ADS–B NPRM Influence Diagram



Summary of Results

Strategy Results

Table 1 shows the results for the three initial strategies evaluated[1].

Table 1: Results for Baseline Strategies

Parameter	NPRM	Equipage to Match	Expanded Benefits
Costs			
AT ADS–B Out	$696M	$611M	$741M
1090H Equipage Costs	$407M	$348M	$423M
1090 L/M Equipage Costs	$33M	$27M	$33M
UAT Equipage Costs	$541M	$0M	$541M
Net Benefits			
Baseline Benefits	$2205M	$2654M	$2654M
NRA Airports			$77M
3 nm Separation			$671M
Search and Rescue			$146M
Equipage Elimination			$78M
SSR Cost Avoidance	$190M	$10M	$190M
Single Link Savings	$0M	$0M	$0M
NPV	$718M	$1678M	$2078M
Normalized Results	$0M	$960M	$1360M

In addition to these strategies, three additional "hybrid" strategies were evaluated. Two of the hybrid strategies combined or modified elements from the baseline strategies to improve the overall results.

The third hybrid strategy, called "Single Link with ACAS Upgrade," built on the Expanded Benefits strategy by assuming an ACAS upgrade and an alternative "ADS-B backup" strategy to allow removal of transponders for aircraft not currently equipped with ACAS and by assuming a single link for ADS–B services. The two-phase strategy had a 1090 MHz link only, a Phase 1 compliance deadline of 2017 for operations within class A airspace and into OEP airports, and a Phase 2 mandate for 2020 for all transponder airspace and the same performance requirements for each phase as for the Phased Expanded Benefits strategy. This strategy assumed that "ADS-B backup" functionality could be provided by primary radars, passive wide-area multilateration or other possible sensors or combination of surveillance techniques. Additionally, this strategy assumed that Flight Information Service–Broadcast (FIS–B) service could be moved to 1090 MHz or could be provided via an alternative source (such as satellite radio).

A dual link ACAS upgrade option was also considered but not analyzed, because of the cost implications as shown in Appendix K.

[1] Appendix E1 provides detail to all analyzed strategies.

Table 2 describes the modifications made to the corresponding baseline strategy.

Table 2: Modifications for Hybrid Strategies

	Baseline Alternative	Modifications
1. Phased Expanded Benefits	Expanded Benefits	• Phase 1 Compliance Date = 2017 (was 2015). • Aircraft already equipped with DO–260-approved equipment do not require upgrades until Phase 2 Compliance Date (2020).
2. Equipage to Match +	Equipage to Match	• Performance requirements increased to NACp≥8/NIC≥7 to get 70% to 90% of the 3 nm separation benefit (benefit reduced because of reduced mandated airspace).
3. Single Link with ACAS Mod	Expanded Benefits	• Single link savings results in additional NPV cost avoidance of $86M. • Elimination of all SSRs results in additional NPV cost avoidance of $95M. • Elimination of GA transponders results in additional savings of $194M (enabled by ACAS upgrade and SSR elimination as described below). • FIS–B provided on 1090 Mhz.

A single 1090 ES link solution poses two concerns for the GA community.

1. This option may decrease GA FIS–B benefits, unless a new 1090 MHz design supports full FIS–B services. There is presently no known commercial implementation for this function. The FAA could also investigate an alternate link for FIS–B, but this would increase equipage costs.
2. 1090 MHz equipage with FIS–B capability may cost more than the baseline UAT equipage.

The ARC assumed all FIS–B benefits and no increased equipage cost when analyzing the Single Link with ACAS Upgrade strategy.

GA UAT ADS–B In

The NPRM includes cost and benefits for ADS–B Out only. However, the FAA Surveillance and Broadcast Services (SBS) program was developed to provide ADS–B In information services that provide operational and safety benefits to incentivize the early voluntary equipage of ADS–B. These services include the broadcast of FIS–B and Traffic Information Services (TIS–B) by FAA ground infrastructure, similar to that provided in the FAA Alaskan Capstone program. Weather, traffic, and aviation system status information provided via FIS–B/TIS–B can be combined with global positioning system (GPS) navigation and terrain avoidance information on a moving map display. This will help to improve pilot decision-making, leading to increased safety and operational efficiency.

The FAA estimated, for ADS–B In services via the UAT link, total costs and benefits for operator equipage for the 25 year life of the program. The result was a net benefit NPV of $509M. Although this cost/benefit information is not included in the rulemaking cost/benefit study, the ARC's decision analysis showed that the potential net benefit is significant and critically important to GA operators who elect to equip with the UAT link.

ACAS and FIS Equipage Costs

To allow the removal of transponders from GA aircraft, two changes from the FAA's current plan must occur: (1) the FAA must adopt an "ADS-B backup" strategy that relies on primary radars, passive wide-area multilateration or other possible sensors or combination of surveillance techniques instead of SSRs; and (2) ACAS must be modified to substitute the use of ADS–B Out data for Mode A/C transponder replies. The costs for this ACAS upgrade are unknown since the specific changes are not yet defined.

The costs of providing FIS-B services on 1090 MHz from a user equipage cost is unknown, but these costs may be higher than for current UAT equipage. If full FIS–B services cannot be provided within the 1090 MHz spectrum, then an alternate link for FIS–B could be required. This is an additional cost uncertainty in the analysis.

Parameter	NPRM	Phased Expanded Benefits	Equipage to Match +	Single Link w/ACAS Upgrade
Costs				
AT ADS–B Out	$696M	$658M	$658M	$658M
1090H Equipage Costs	$407M	$391M	$391M	$391M
1090 L/M Equipage Costs	$33M	$31M	$31M	$31M
UAT Equipage Costs	$541M	$541M	$0M	$541M
Net Benefits				
Baseline Benefits	$2205M	$2507M	$2507M	$2507M
NRA Airports		$77M	$0M	$77M
3 nm Separation		$671M	$537M	$671M
Search and Rescue		$146M	$0M	$146M
Equipage Elimination		$78M	$0M	$272M
SSR Cost Avoidance	$190M	$190M	$10M	$285M
Single Link Savings	$0M	$0M	$86M	$86M
Sub-Total NPV	$718M	$2048M	$2060M	$2423M
Sub-Total Normalized Results	$0M	$1330M	$1342M	$1705M
GA UAT ADS–B In[2]	$509M	$509M	$0M	$509M
ACAS & FIS Equipage Costs	NA	NA	NA	?
Total NPV	$1227M	$2557M	$2060M	$2932M - ?
Total Normalized Results	$0M	$1330M	$833M	$1705M - ?

[2] This value is based on the UAT community voluntarily equipping to receive the ADS–B benefits, including TIS and FIS. The "single-link" alternative assumes FIS on 1090 MHz.

Table 3: Results for Hybrid Strategies

Results by Stakeholder

The ARC attempted to identify strategies that would satisfy all stakeholders. The ARC calculated the NPV by stakeholder for ADS–B Out. **Note:** The non-recurring and recurring costs associated with the ground infrastructure for ADS–B are not included in this value. Costs and benefits are allocated to the stakeholders as follows:

Table 4: Allocation of Costs and Benefits to Stakeholder Categories

Parameter	Allocated to
Costs	
AT ADS–B Out	High Altitude
1090H Equipage Costs	High Altitude
1090 L/M Equipage Costs	High Altitude
UAT Equipage Costs	Low Altitude
Net Benefits	
Baseline Benefits	High Altitude
NRA Airports	Low Altitude
3 nm Separation	High Altitude
Search and Rescue	Low Altitude
Equipage Elimination	Low Altitude
SSR Cost Avoidance	FAA/Govt
Single Link Savings	FAA/Govt
Sub-Total NPV	
GA UAT ADS–B In	Not allocated
ACAS & FIS Equipage Costs	Not allocated
Total NPV	

Table 5a: Initial Results by Stakeholder for Hybrid Strategies

Stakeholder	NPRM	Phased Expanded Benefits	Equipage to Match +	Single Link w/ACAS Upgrade
High Altitude	$1069M	$2098M	$1964M	$2098M
Low Altitude	($541)M	($240)M	$0M	($46)M
FAA/Government	$190M	$190M	$96M	$371M
Total	$718M	$2048M	$2060M	$2423M
GA UAT ADS–B In[3]	$509M	$509M	$0M	$509M[4]

After the initial Stakeholder analysis was completed, the ARC independently determined that it did not have an adequate basis for recommending removal of 121.5 MHz ELTs at this time. Therefore, the Stakeholder analysis was revised as shown in Table 5b.

[3] This value is based on the UAT community voluntarily equipping to receive the ADS–B benefits, including TIS and FIS, but does not include cost uncertainty.
[4] The "single link alternative" assumes FIS on 1090 MHz.

Table 5b: Final Results by Stakeholder for Hybrid Strategies

Stakeholder	NPRM	Phased Expanded Benefits	Equipage to Match +	Single Link w/ACAS Upgrade
High Altitude	$1069M	$2098M	$1964M	$2098M
Low Altitude	($541)M	($318)M	$0M	($124)M
FAA Government	$190M	$190M	$96M	$371M
Total	$718M	$1970M	$2060M	$2345M
GA UAT ADS–B In[5]	$509M	$509M	$0M	$509M[6]

Conclusions

Given the results by stakeholder, the Single Link with ACAS Upgrade option was the most cost-beneficial option that included all stakeholders operating within current transponder airspace. However, these results don't include the equipage and infrastructure costs associated with modifying ACAS to accept ADS–B Out data or mitigations for 1090 MHz frequency congestion. After those costs are included, the strategy may not be the most cost beneficial. The Phased Expanded Benefits and Equipage to Match + strategies are close in terms of net present value (NPV); however, the Phased Expanded Benefits strategy provides part of the equipage solution for TIS–B/FIS–B, while the Equipage to Match + strategy does not.

After much discussion, the ARC could not reach consensus on whether FAA should mandate DO–260-approved ADS–B Out for operations in class A airspace and at OEP airports by 2017, three years earlier than proposed.

The ARC recommends that the FAA—

1. Retain the 2020 compliance date for the ADS–B Out mandate, but adjust the ADS–B Out program to capture additional benefits for all NAS users as developed by the ARC and described in the Phased Expanded Benefits strategy.
2. Delay the compliance date of the ADS–B Out mandate if the following items are not complete by 2013:
    a. Ground infrastructure coverage needed for the mandated airspace and additional non-radar airspace (NRA) airports,
    b. Automation systems,
    c. Equipment certification,
    d. Performance standards,
    e. Operational approval,
    f. Separation standards,

[5] This value is based on the UAT community voluntarily equipping to receive the ADS–B benefits, including TIS and FIS, but does not include cost uncertainty.
[6] The "single link alternative" assumes FIS on 1090 MHz.

g. Operational procedures for ADS–B NRA airspace, and

h. FAA controller training and procedures.

3. Implement the necessary incentives to create a positive business case for low altitude airspace users. This requires the FAA to make changes that result in lower investment costs and increased benefits, and provide economic incentives to offset costs when benefits are insufficient. If the ADS–B mandate results in the low altitude segment of the aviation community investing more into the system than the benefits enabled, the FAA should not mandate ADS–B Out for that segment of the community.

4. Increase the overall value of the NPRM and stakeholder buy-in for low altitude operators by—

    a. Validating ARC calculations of transponder equipage savings for U.S. operators without TCAS if Mode A/C transponders could be removed from those aircraft in the future.

    b. Validating ARC calculations of the net benefits for providing surveillance services at non-radar airspace (NRA) airports, then adding appropriate service volumes to the SBS Program to provide service at all public use airports that have at least one runway over 3,000 feet and at least one instrument approach procedure.

    c. Investigating the value of adding the following services to the SBS Program:

        i. Expanded low-altitude NRA surveillance services,

        ii. Automatic closure of flight plans at NRA airports, and

        iii. Flight service station (FSS) improvements.

5. Establish and introduce in the final ADS–B Out rule a public process for implementing future modifications to the airspace, applications, or airports for which ADS–B equipment is required.

6. Develop and implement the requirements and operational procedures for ADS–B surveillance based 3 nm separation in all domestic en route airspace, prior to the ADS–B Out compliance date

7. Further investigate the Single Link with ACAS Upgrade strategy to determine if the equipage and modification changes are economically advantageous.

    a. Consider the results of the 1090 MHz Frequency Congestion Urgent Study.

    b. Consider any ACAS changes necessary to support/enable NextGen operations.

    c. Consider implications of moving FIS–B service to 1090 MHz or an alternative source.

8. Recalculate its cost-benefit analysis using a range of costs for certain items rather than fixed costs to present the community with a realistic range of potential

benefits. The ARC feels that the FAA used very conservative numbers in their analysis. However, to give the community a more accurate representation of the benefits, the FAA should recalculate their analysis and present the community with a realistic range of potential benefits. Specific examples are the FAA fuel cost estimate ($1.83 per gallon) and the reduction in assumed starting separation at NRA airports (7.5 nm).

APPENDIX P1 – ANALYSIS DETAILS

Assumptions

Table 6 lists a set of basic assumptions used in analyzing all the alternatives. These assumptions were used to develop the original SBS business case and the SBS Business Case Analysis Tool. The SBS Business Case Analysis Tool was designed to help AT stakeholders understand the costs and benefits of ADS–B and make desired ADS–B equipage decisions.[7]

Table 6: Overall Business Case Assumptions

Parameter Name	Value	Where Used	Source
Discount Rate	.07	Net Present Value	SBS Business Case Tool
Start Year	2008		SBS Business Case Tool
Final Year	2035		SBS Business Case Tool
Cost per Gallon Fuel	$1.83	Baseline Benefits	SBS Business Case Tool
Beginning Fleet, 2008			
GA UAT	155,624	UAT Equipage Costs	JRC SBS Business Case
GA 1090 Low/Med	5659	1090 L/M Equip Costs	JRC SBS Business Case
GA 1090 High	11959	1090 High Equip Costs	JRC SBS Business Case
Air Transport	7898	Air Transport Equip Costs	SBS Business Case Tool
Average Variable ADOC (Direct Operating Cost) airborne	$2814	Baseline Benefits	SBS Business Case Tool
Average Variable ADOC (Direct Operating Cost) ground	$1411	Baseline Benefits	SBS Business Case Tool
Passenger Value of Time (per hour)	$28.60	Baseline Benefits	SBS Business Case Tool
Average Number of Seats	87.27	Baseline Benefits	SBS Business Case Tool
Average Load Factor	79%	Baseline Benefits	SBS Business Case Tool
Inflation Rate	2.0%	Baseline Benefits	SBS Business Case Tool

Uncertainties

This section includes all the uncertain inputs identified and evaluated during the course of the ARC programmatic evaluation. This section is divided into sub-sections identified in the influence diagram such as equipage costs and baseline benefits.

Equipage Costs

Equipage costs are broken down into four sub-components:

1. AT: Scheduled air carrier and commercial cargo carriers such as UPS and FedEx.
2. 1090 High: Business jets that utilize OEP airports and Class A airspace.
3. 1090 Low/Med: GA aircraft that would equip with 1090 ES. Some of these fly into Class A airspace and OEP airports, some do not.

[7] Surveillance and Broadcast Services Business Case Analysis Tool; FAA document from ATO En Route Services; June 2008, p. 13.

4. UAT: The typical GA aircraft that flies in transponder airspace but typically below FL180. These aircraft do not fly into Class A airspace and OEP airports.

In order to evaluate the impact of different compliance deadlines, a model was created to calculate ADS–B Out equipage costs that differentiates between retrofit and forward fit costs. The model also takes into account aircraft retirements prior to the compliance deadline and new aircraft coming into the system that are forward fit instead of retrofit. Tables 7 and 8 below shows the basic inputs used for the four aircraft types modeled.

Table 7: Equipage Cost Model Parameters for Air Transport[8]

Parameter	Air Transport	Source
Starting Fleet	7898	Sum of Air Transport, Cargo and Regionals from FAA Aerospace Forecast, 2007 – 2020 (Appendix F, Tables 20, 21, and 26).
Ann Net Growth Rate %	2.95%	Derived from JRC SBS Business Case, 2020 – 2035 equipage forecast.
Ann Retirement Rate %	4%	Engineering estimate, based on aircraft life.
Avg Cost per Retrofit	$130000	Derived from ATA analysis. See Appendix P2, Table 22.
Avg Cost per Forward Fit	$30000	Engineering estimate: RF cost assumed to be about 25% of FF costs.

Table 8: Equipage Cost Model Parameter for General Aviation

Parameter	1090 High	1090 Low/Med	UAT	Source
Starting Fleet	11959	5659	155,624	Derived from JRC SBS Business Case.
Ann Net Growth Rate %	3.7%	5.9%	1.47%	Derived from JRC SBS Business Case, 2020 – 2035 equipage forecast.
Ann Retirement Rate %	2.5%	2.5%	2.5%	Engineering estimate, based on aircraft life.
Avg Cost per Retrofit	$41600	$10390	$5200	Derived from SBS Business Case estimates to match SBS costs estimates by stakeholder.
Avg Cost per Forward Fit	$14000	$7250	$2700	Derived from SBS Business Case estimates to match SBS cost estimates by stakeholder.

Note that the annual growth rate is the net growth in the fleet. Also, the Average Costs per Forward Fit and Retrofit are the costs for the NPRM alternative. Table 9 shows the values used for each of the alternatives.

[8] Appendix E2 provides details of the Air Transport equipage costs.

Table 9: Equipage Cost Model Parameter by Strategy

Parameter	Air Transport	1090 High	1090 Low/Med	UAT	Source
Equipage Cost Mult	**Definition: The equipage cost multiplier is the multiplier applied to the NPRM equipage costs for each of the defined strategies to account for lower equipage costs due to lower NIC/NACp values.**				
NPRM	1	1	1	1	By definition
Equipage to Match	.7	.7	.7	1	Analysis of ATA data for Air Transport Category
Expanded Benefits	.85	.85	.85	1	Analysis of ATA data for Air Transport Category
Single Link	.85	.85	.85	1	Analysis of ATA data for Air Transport Category
Percent of GA UAT to Equip	**Definition: The percentage of aircraft that will equip with UAT for the NPRM or the alternative strategies.**				
NPRM	NA	NA	NA	100%	By definition
Equipage to Match	NA	NA	NA	0%	By definition
Expanded Benefits	NA	NA	NA	100%	By definition
Single Link	NA	NA	NA	100%	By definition
GA Low/Med BL to Equip through 2020	**Definition: The number of GA Low/Medium aircraft that will equip with the proposed equipage, depending on the strategy chosen.**				
NPRM	NA	NA	All	NA	By definition
Equipage to Match	NA	NA	2000	NA	3000 estimate from AOPA for 2020. Assumed 1000 forward fit installations.
Expanded Benefits	NA	NA	All	NA	By definition
Single Link	NA	NA	All	NA	By definition

Expanded Benefits

The team identified three additional applications that could be implemented with ADS–B Out. Although the ARC believes that these applications could be implemented in the NPRM alternative, the ARC excluded these applications from the NPRM alternative because they were not included in the NPRM's cost-benefit analysis.

1. Search and Rescue (SAR). Use the increased accuracy and reduced latency to improve the "search" in search and rescue for downed aircraft. When aircraft are missing (usually VFR), it can take hours before it is recognized and SAR operations are initiated. This time can be critical to saving lives. When SAR operations are initiated, it is necessary to go through a time-consuming process of reconstructing surveillance data from radar to determine the last known position. ADS–B surveillance is based on geodetic coordinate system and requires no other correlation. Consequently, terrain, airport, and ADS–B surveillance information, combined with automation logic, is capable of detecting

when an aircraft may have gone down and initiate action much earlier. Additionally, the last known position of missing aircraft can be retrieved more rapidly, especially with greater low altitude ADS–B.

2. 3 nm Separation. Reducing the enroute separation requirement from 5 nm to 3 nm between co-altitude aircraft is possible using ADS–B Out information that meets the positioning requirements described in Section 1, Table 1. The benefit mechanism is in reduced aircraft delays and deviations to avoid "conflicting" traffic in enroute airspace. The FAA commissioned a NAS-wide modeling analysis, based on 2007 traffic levels, to estimate the effects of this separation standard reduction for aircraft operating above 10,000 feet across the NAS.

3. NRA Airports. Provide ADS–B surveillance services at non-radar airports by increasing service volumes beyond current radar coverage. Expanding surveillance services to airports without current radar coverage will (1) serve GA operators and regional airlines by reducing mid-air collisions (using conflict alert); (2) reduce terrain accidents (using Minimum Safe Altitude Warning System (MSAW)), and (3) decrease delays on instrument flight rules (IFR)/ instrument meteorological conditions (IMC) arrivals because of reduced separation.

   The FAA provided cost-benefit information based on 23 regional airports in Minnesota and Wisconsin. In an effort to estimate the approximate magnitude of this benefit NAS-wide, the ARC conservatively estimated that 300 non-radar airports would receive surveillance services. The FAA needs to determine the appropriate number of airports in collaboration with the user community

The team identified the following additional benefits, which have not been quantified:

1. Automatic closure of flight plans at NRA airports. VFR and IFR flight plans must currently be closed by the pilot after landing at non-towered airports. Failure to close the flight plan can initiate unnecessary and costly SAR operations, and delay subsequent operations into that airport. Automation logic can be used where low altitude ADS–B coverage is sufficient to determine when an aircraft has made a full stop landing at a non-towered airport that is its final destination. This will alleviate workload, cost, and operational delays.

   Cost and benefits were not calculated for this enhancement, but the cost savings in SAR costs combined with the life-saving benefits of more expedient recovery are expected to outweigh the costs of adding automation logic and alerting.

2. Expanded low altitude NRA surveillance services. Greater low altitude surveillance coverage combined with 3 nm separation minimums permits GA aircraft to fly lower enroute altitudes on and off airways. This helps to avoid icing, increases low altitude airspace access and capacity, and enhances safety services. Reducing minimum separation minimums to 3 nm allows more aircraft to simultaneously access airspace that previously may have been limited by 5 nm or procedural separation.

3. FSS Improvements. Providing surveillance data to FSS would also help briefers to tailor enroute briefings, locate lost pilots, aid SAR operations, and manage

flight plans. Currently, FSS briefers must rely on pilot position reports to provide such services and use voice communications and homing radios to locate lost aircraft

Table 10 identifies the benefits available for each of the four strategies evaluated.

Table 10: Benefits Model Parameters by Strategy

Parameter	NPRM	Equipage to Match	Expanded Benefits	Single Link
Search and Rescue Benefits	No	No	Yes	Yes
3 nm Separation	No	No	Yes	Yes
NRA Airports	No	No	Yes	Yes

Table 11 shows the cash flows for the 3 nm separation and SAR applications. The assumption is that the 3 nm separation[9] requires everyone to equip with DO–260A Change 3 or DO–282A Change 2 and so it is implemented at the final compliance deadline. In comparison, SAR benefits[10] start as soon as GA starts equipping in 2014 and grows with equipage, reaching full benefit at the final compliance deadline in 2020.

Table 11: Cash Flows associated with 3 nm Enroute Separation and Search and Rescue

Year	2014	2015	2016	2017	2018	2019	2020	2021	And-on
3 nm separation	**-$13**	**-$17**	**-$17**	**-$22**	**-$22**	**$164**	**$164**	**$171**	**$171**
Search and Rescue	**$4.3**	**$5.3**	**$9.6**	**$13.9**	**$18.1**	**$22.1**	**$26.1**	**$26.1**	**$26.1**

The third application identified is NRA airports. Based on an analysis of 12 airports in Minnesota (MN) and 11 airports in Wisconsin (WI), the overall NPV of costs and benefits came to $12.4M or $0.5M per airport. The risk-adjusted costs for both MN and WI were assumed to be 2 ADS–B ground stations (full F&E[11] and O&M[12]).

In the MN analysis, this was a conservative choice because the surveillance maps suggested that one additional ground station would cover 12 additional sites. The WI analysis did not include surveillance maps, so the ARC cannot comment on the validity of our risk-adjusted costs.

The ADS–B Out equipage was assumed to be similar to the projected NAS-wide average (for each user type) used in the Joint Resources Council (JRC) August 2007 SBS Business Case. Therefore, no additional equipage costs were considered. To receive the NRA benefit, ADS–B Out must be installed on the aircraft and be operational.

No controllers were added. The current accident rates are so small (less than 6 per million operations) that the additional conflict alert/MSAW workload was considered minimal. The percent of aircraft at these airports receiving IFR approach services was not assumed to grow beyond what is already provided by the Air Route Traffic Control

[9] November 2007 ADS–B NAS-wide Modeling
[10] June 2006 Surveillance and Broadcast Services (SBS) Basis of Estimate (BOE) Report
[11] Facilities and Equipment
[12] Operations and Maintenance

Center (ARTCC) in today's environment. Therefore no additional workload was considered necessary.

The airport does not require a tower, but the procedures need to be in place so that a pilot can request an IFR approach to the airport from the ARTCC. In the analyses, we assumed all airports that had historic recorded IFR approaches must have had the necessary procedures.

Table 12 summarizes the inputs used to assess NRA airport benefits. Costs and benefits for an increase in low altitude airspace were not available.

Table12: Parameters used to Calculate Benefits of NRA Airports

Parameter	Description	Low	Base	High	Source
Total NRA Airports	The number of airports where the NRA benefit can be had. (There were 23 in Wisconsin and Minnesota). National multiplier assumed to be 13.		300		Eng estimate: 23 in WI and MN, multiple of 13 to extrapolate to US
NRA Airport Duration	Assume that it takes 5 years from the NRA start year to achieve steady state benefits.		5		Engineering Estimate
NRA Start Year	Assume that benefits start accruing in 2015.		2015		Engineering Estimate
NRA Airport NPV	Assume that the NPV of benefits is $0.5M per airport.		$0.5M		SBS Program Office Estimate[13]

SSR Savings

ADS–B will allow a reduction of SSRs. According to the SBS program office, assuming a compliance deadline of 2020 and the timeline in the NPRM, the cost reductions due to eliminating approximately 50 percent of the SSRs are as follows: (Table 13 represents the SSR savings for the NPRM alternative.)[14]

Table 13: Cash Flows associated with SSR Retirements

Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	and-on
Ann Cash Flow	$20.4	$20.4	$20.4	$28.9	$29.3	$29.8	$30.3	$32.4	$34.4	$15.9	$19.5	$19.5	$11.6	$30.3	$30.3

Single Link Alternative: Elimination of the remaining 50 percent of the SSRs, as in the Single Link alternative, will add an additional $93M in NPV.[15]

[13] NPV is based on SBS Program Office estimates based on Radar Establishment Criteria. Analysis based on FAA study: Investment Criteria for Airport Surveillance Radar (ASR/ATCRBS/ARTS); May 1983; FAA-APO-83-5.
[14] SBS Program Business Case
[15] SBS Program Business Case

Compliance Deadline

The compliance deadline determines when all existing aircraft must be retrofitted with ADS–B and all aircraft delivered are equipped with ADS–B. The compliance deadline is an input to the equipage cost model.

Table 14: Compliance Deadline Parameters by Strategy

Parameter	Scope	NPRM	Equipage to Match	Expanded Benefits	Single Link
Phase I Compliance Deadline	Class A airspace and OEP airports	2020	2015	2017	2017
Phase 2 Compliance Deadline	All transponder airspace	2020	Not applicable	2020	2020

GA Equipage Elimination

In the Expanded Benefits and Single Link alternatives, it was assumed that GA would accrue an additional benefit by eliminating the need for installing and maintaining an ELT and a transponder. The tables below show how the equipage elimination benefit applies to the strategic alternatives considered. The assumption was that the transponder cannot be removed unless all of the SSRs are removed. This would require an upgrade to ACAS to accept ADS–B in data. Note that the costs of this update to ACAS have not been included in the model.

Table15: Equipage Elimination Benefits by Strategy

Parameter	NPRM	Equipage to Match	Expanded Benefits	Single Link
ELT Benefit	No	No	Yes	Yes
Transponder Benefit	No	No	No	Yes

Table 16: Parameter Inputs for Equipage Elimination

Parameter	Description	Estimated savings	Source
ELT Annual Svgs	Cost savings from avoiding annual inspection, per aircraft.	$75	AOPA (Kenagy)
ELT Replacement Svgs	Upfront PV of avoiding replacement once every 15 years, assuming ELT is mid-life, per aircraft.	$903	AOPA
Transponder Annual Svgs	Cost savings from avoiding annual inspection, per aircraft	$137	AOPA
Transponder Replacement Svgs	Upfront PV of avoiding replacement once every 15 years, assuming transponder is mid-life, per aircraft.	$1656	AOPA

Single Link Cost Avoidance

The current NPRM assumes a dual link implementation: 1090 ES and UAT. In two of the alternatives, the UAT link is eliminated and 1090 ES is the only link. This approach has the advantage of reducing infrastructure costs to the FAA.

Table 17: Single Link Cost Avoidance Applicability by Strategy

Parameter	NPRM	Equipage to Match	Expanded Benefits	Single Link
Single Link Cost Avoidance	No	Yes	No	Yes

Table 18: Single Link Cost Avoidance NPV

Parameter	Description	Low	Base	High	Source
Single Link Cost Avoidance (NPV)	NPV of the cost avoidance to the FAA from implementing a single 1090 ES link.		$92M		SBS Program Office said $80 - $120M. This amount is discounted by 8% due to contract change.

APPENDIX P2 – AIR TRANSPORT EQUIPAGE COSTS

To estimate AT equipage costs, the Air Transport Association (ATA) estimated the costs for the transponder and the required GPS upgrade for the NPRM alternative and the Equipage to Match alternative. The equipage costs for the Expanded Benefits alternative were then estimated by interpolating between these two costs.

Per the strategy table, the performance requirements for the three alternatives are detailed below:

- NPRM: NACp≥9/NIC≥7 (assume augmentation or next generation position source required).
- Equipage to Match: NACp≥7/NIC≥5 (SA On, assumes radar integrity monitoring).
- Expanded Benefits: NACp≥8/NIC≥7 (SA Off assuming radar integrity monitoring).

Table 19 shows the transponder costs, based on the architecture (Modern, Classic,and Neo-Classic) and the baseline equipage. The population of aircraft by avionics architecture, per MCR Technologies, LLC, is as follows:

- Modern: 931
- Classic: 1212
- Neo-Classic: 4616

Table 19: Transponder Costs

Airplane Baseline Equipage		Upgradeable DO-260	No Xpdr Equipage or Non-Upgradeable DO-260
Equipage Updated		Hardware or Software Upgrade to DO-260A	New DO-260A LRUs
Modern	Average	$25,400	$39,000
	% of Fleet	67%	33%
Classic	Average	$19,100	na
	% of Fleet	100%	0%
Neo-Classic	Average	$19,217	$45,000
	% of Fleet	73%	27%
"Average" costs above do NOT include certification and installation costs, which are addressed in the NPRM tab			

Tables 20 and 21 show the costs for the GPS upgrade for the NPRM alternative and the Equipage to Match alternative.

Table 20: GPS Upgrade Costs for NPRM Alternative

	Equipage Element	Equipage Cost
Modern	Average	60,500
	Cert	27,130
	Install	4,656
	% of Fleet	100%
Classic	Average	68,544
	Cert	54,000
	Install	11,247
	% of Fleet	100%
Neo-Classic	Average	69,600
	Cert	31,500
	Install	8,000
	% of Fleet	85%

Table 21: GPS Upgrade Costs for Reduced Performance Alternative

	Baseline: Most typical of the category	Equipage Element	Equipage Cost
Modern	SA Off GPS	Average	0
		Cert	$27,130
		Install	$4,656
		% of Fleet	100%
Classic	No GPS	Average	$34,083
		Cert	$54,000
		Install	$11,247
		% of Fleet	96%
Neo-Classic	No GPS to GPS upgradeable to SA off	Average	$32,931
		Cert	$31,500
		Install	$8,000
		% of Fleet	85%

Table 22 adds the transponder costs (see Table 19) to the GPS upgrade costs for the NPRM and Equipage to Match strategies (see Tables 20 and 21). The transponder costs are added to calculate the average equipage cost by strategy for the two alternatives.

Table 22: Equipage Costs per AT Aircraft, by Strategy

	NPRM	Equipage to Match
Modern	$122,174	$47,375
Classic	$152,891	$114,546
NeoClassic	$118,494	$87,745
Totals	$846,014,119	$587,965,429
Avg Cost	$125,169	$86,990
% of NPRM	100%	69%

ATA was not able to estimate the costs for the Expanded Benefits strategy. The costs were assumed to be halfway between the NPRM and Equipage to Match strategies.

APPENDIX Q — DO–260 STUDY

DO-260 Study

For ADS-B Aviation Rulemaking Committee (ARC)

Avionics Transition Working Group Delta (WG-D)

Prime Contract No: DTRS57-03-R-20038
L-3 Communications Corporation for
Volpe National Transportation Systems Center
Subcontract Number: 2007-833
Honeywell Technology Solutions Inc. (HTSI)
(A subsidiary of Honeywell International Inc.)
This report generated under:
Task Order: CA8415

July 31, 2008

Prepared by:
Honeywell Technology Solutions Inc.
A wholly owned subsidiary of Honeywell International Inc.
5311 Desert Mountain Court
Boulder, CO 80301

Executive Summary

The ADS-B Aviation Rulemaking Committee (ARC) Avionics Transition Working Group Delta (WG-D) is conducting a study on the feasibility of using DO-260 equipped aircraft for the NRA and RAD applications during a transition period prior to full DO-260A implementation. To support that study, the ARC requested that HTSI perform an analysis of DO-260 data to determine what number and percentage of aircraft appear to meet the data requirements spelled out in DO 303 Safety, Performance, and Interoperability Requirements Document for the ADS-B Non-Radar Airspace Application.

The HTSI ADS-B task team (formerly from Dimensions International, Inc.) has been collecting and analyzing Mode-S and 1090 MHz extended squitter (ES) ADS-B data for the past four years. The primary mission has been to provide counts of ADS-B capable aircraft and to measure the growth of ADS-B capabilities over time. HTSI previously published an analysis of an early and limited set of DO-260A aircraft (26 aircraft) to examine their performance against the requirements of DO-260A, TSO-C166a and the specific requirements outlined in the NPRM entitled: "Automatic Dependent Surveillance – Broadcast (ADS-B) Out performance requirements to support Air Traffic Control (ATC) service." The ARC study requires a detailed examination of a significantly larger data set for DO-260 capable aircraft against a specific set of criteria. HTSI is uniquely positioned to undertake this study because of the massive amounts of data we have collected and retained along with the expertise and tools we have built up to rapidly analyze and make sense of this vast quantity of data.

Due to the need for the ARC to have some visibility into this data in a very quick time frame, the study task was conducted in two parts. In the first part HTSI did a high level assessment of data from a one year period from June of 2007 to May of 2008 to determine how many ADS-B capable aircraft had the data elements present to provide the basic capabilities required:

> ID + Airborne Position Messages +Velocity Messages + Baro Altitude + Position Quality + Emergency Indicators + Special Position Indicator Report.

HTSI did a first level analysis of the NUC values reported by these aircraft and the distribution of NUC values. HTSI also plotted a sample of 24 aircraft to visually assess whether the positions reported appeared reasonable. This analysis, which was published in a Quick Look briefing on July 7, 2008, showed that approximately 2000 aircraft met the basic capability requirements and reported NUC values that were not always zero. This represents 5% of the Mode-S airframes in the data sample and 35% of the ADS-B airframes.

In the second part of the study, HTSI was able to do a more detailed analysis that included assessing data and gathering statistics on an operation by operation basis as well as testing data for anomalies in position, altitude, NUC values, and velocity by processing the binary recorded data that contains all of the messages for each operation for each aircraft. The overall results in terms of percentage of ADS-B aircraft that met the basic criteria did not change substantially. In two different samples of data (a 1-year sample and a 6-month sample) this percentage was 37% and 40% respectively. However, this more in-depth analysis revealed behaviors and anomalies that were not visible in the first pass analysis. These behaviors and anomalies include:

- Aircraft may emit the data necessary to meet the basic capabilities requirements sometimes but not always. That is, on one operation (a flight observed at one of the HTSI ground station locations) the aircraft may meet the criteria and on another operation it may not.

- Some aircraft had significant fluctuations in NUC values during a single operation. Many of the aircraft that exhibited significant fluctuations in NUC values also showed large variations in the altitudes reported.

- Some aircraft had a large percentage of position reports that did not pass a reasonableness test.

- Of the aircraft that passed the check for basic capabilities, 56% had some kind of anomalous behavior (e.g., position changes, altitude changes, or NUC changes) that did not pass a reasonableness test.

At a high level, the analysis shows that approximately 2000 aircraft, or 35% to 40% of the ADS-B equipped aircraft, appear to meet the data requirements spelled out in DO 303 Safety, Performance, and Interoperability Requirements Document for the ADS-B Non-Radar Airspace Application. There are some inconsistencies in the behavior of these aircraft over time but the majority of the time these aircraft appear to provide reasonable output.

The analysis also shows, however, that in the larger data set there are a significant number of exceptions and anomalies in the data currently being broadcast that would almost certainly cause problems for users of this data (e.g., automation systems). Perhaps this is not surprising since there is no certification standard and process in place for DO-260. It is beyond the scope of this report to determine the reasons for the anomalous behavior or why some aircraft pass the basic capabilities test and some don't. However, construction of an effective standard and process for certification will require an understanding of the inherent causes for the problems as well as a robust process for analyzing the performance of aircraft post certification in order to measure the integrity of the overall process.

The analysis also pointed out that there was a large concentration of anomalous behavior in a relatively small number of aircraft types. A study of a small set of these aircraft might yield answers as to how to correct this behavior in a fairly large number of aircraft and therefore increase the opportunity for early benefits from using DO-260 for an interim period.

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1 Introduction

1.1 Purpose

The Purpose of this effort is to provide high level data necessary to support the study on the feasibility of using DO-260 equipped aircraft for the NRA and RAD applications during a transition period prior to full DO-260A implementation.

1.2 Scope

This study is limited in scope to provide an initial analysis to the ADS-B Aviation Rulemaking Committee (ARC) Avionics Transition Working Group Delta (WG-D) in a short period of time. Specifically, this limited scope effort includes the following tasks:

1. Examine data collected during the June 2007 to May 2008 for all aircraft with valid DF 17 (ADS-B) messages.
2. Determine the number and percentage of these aircraft that have:
    a. ID + Airborne Position Messages +Velocity Messages + Baro Altitude + Position Quality + Emergency Indicators + Special Position Indicator Report.
3. For aircraft that reported all the data elements listed above
    a. Determine the number and percentages that had valid CPR data that decoded into nominally valid latitudes and longitudes, i.e., that had reasonably possible latitudes and longitudes around the receiver site.
    b. For those aircraft with reasonable positions, plot at least two dozen tracks with at least 50 position reports to visually check track continuity.
    c. *If possible* for the Quick Look, determine the NUC values. The final analysis report shall include this as well as distribution statistics on NUC variation.
    d. Plot the altitudes versus time for the same aircraft plotted in 3b for the final analysis report.
4. The final analysis report shall state the number aircraft that met all the above criteria and shall document the limitations of the data. The Final Analysis Report shall identify other data elements that should be examined in relation to the possible NRA, possible expansion of the sample size, and other factors impacting the analysis.

1.3 Document Organization

This document is organized to provide a condensed version of the data and findings in Section 3 followed by a more detailed discussion with additional supporting graphics in Section 4. The X/Y and altitude plot data is provided as an Appendix.

2 Applicable Documents

DO-242A	Minimum Aviation System Performance Standards for Automatic Dependent Surveillance Broadcast (ADS-B)
DO-260	Minimum Operational Performance Standards for 1090 MHz Automatic Dependent Surveillance - Broadcast (ADS-B)
Study Objectives	Objectives and Work Plan - DO-260 Study, 26 June 2008

3 Report Summary

3.1 Summary of Analysis Approach

Due to the need for the ARC to have some visibility into this data in a very quick time frame, the study task was conducted in two parts; a quick look analysis and a final analysis.

3.1.1 Quick Look Analysis

To support the need for a quick look report, HTSI did a high level assessment of data from a one year period from June of 2007 to May of 2008 to determine how many ADS-B capable aircraft had the data elements present to provide the basic capabilities required:

ID + Airborne Position Messages +Velocity Messages + Baro Altitude + Position Quality + Emergency Indicators + Special Position Indicator Report.

This analysis was done by developing queries in to a database of operations detail data records to compile contain a count of each of the ME message types received per operation. From this HTSI was able to count how many aircraft had operations that contained the necessary data elements to meet the basic requirements.

HTSI did a first level analysis of the NUC values reported by these aircraft and the distribution of NUC values by compiling a table by AA code of the total counts of ME message types received for that AA code over the course of the year. From this, HTSI was able to calculate the weighted NUC (average of the NUC values reported) by each aircraft over that period and chart that distribution.

In addition, HTSI plotted a sample of 24 aircraft in X/Y positions relative to the receiving station to visually assess whether the positions reported appeared reasonable.

3.1.2 Final Analysis

In the second part of the study, HTSI was able to do a more detailed analysis that included assessing data and gathering statistics on an operation by operation basis as well as testing data for anomalies in position, altitude, NUC values, and velocity. This analysis had the following objectives:

- Assess the consistency of aircraft meeting the basic criteria. While the quick look analysis showed a count of aircraft that had any operations that met the criteria, it did not determine if those aircraft always met the criteria
- Do a more in depth analysis of NUC distribution. The quick look analysis was limited to assessing that distribution based on a total count of ME message types per aircraft for a full year. It did not examine variances within individual operations.
- Do a visual assessment of altitude reasonableness by plotting altitude vs. time for the 24 sampled aircraft.
- Assess the reasonableness of the position data being reported. The quick look analysis was limited to a visual assessment of a sample of 24 plots.
- Detect anomalous behavior within an operation and compile statistics on an operation by operation basis.

To address the first two objectives, HTSI extracted data from our operations detail database and compiled a table which consisted of records for every ADS-B operation over the period of June 2007 to May 2008. These records contained the AA code for the aircraft along with counts of

every DF and ME message type received. This table, which contained 1,076,995 operations and 5468 unique aircraft, was loaded into an MS Access database for further analysis.
We addressed the third objective by plotting the altitude against time for each of the 24 sampled aircraft. Because some of the plots showed anomalous altitude behavior, we expanded the set of plots to look at some other aircraft with the same aircraft type to see if the behavior was unique to the first aircraft examined or whether it was found in other aircraft of the same type.
The last two objectives required processing the binary recorded data that contains all of the messages for each operation for each aircraft. HTSI processed the binary records from December 2007 through May 2008. The binary files recorded prior to December were in a different file format so we were limited at this time to the 6 month period. We wrote software to detect unreasonable position reports (> 250 miles from the receiver site) as well as unreasonable changes in position, altitude, NUC, or velocity from report to report. This software compiled counts of each of these anomalies by operation. This data, which contained 460,145 operations and 4606 ADS-B aircraft, was loaded in to an MS Access database for further analysis.

3.2 Findings

3.2.1 Quick Look Findings Summary

3.2.1.1 Number of Aircraft Meeting Basic Capabilities Requirements

The quick look analysis findings, which were published in a Quick Look briefing on July 7, 2008, showed that approximately 2000 aircraft met the basic capability requirements and reported NUC values that were not always zero. This represents 5% of the Mode-S and 35% of the ADS-B airframes in the sample. **Table 3-1** shows provides a high level summary of the number of operations and aircraft in the data set along with the number and percent of those aircraft that had operations that met the basic capabilities requirements. A more detailed breakdown of this data is provided later in this report in **Table 4-2**.

Table 3-1 Summary of DO-260 Aircraft with Basic Capabilities from Quick Look Report

Total Mode-S	9,366,456	41,479	100%	
With ADS-B Capability	1,247,887	5,565	13%	100%
ADS-B that meet basic capabilities requirements	500,720	1,964	5%	35%

3.2.1.2 NUC Value Distribution

The data was also analyzed to determine what NUC values were being reported. **Table 3-2** shows the number and percent of aircraft that reported only NUC values of 5 or better. To get an idea of what NUC value each aircraft was reporting on average, we calculated a weighted NUC value based on the number of position reports there were for each NUC value. **Table 3-3** shows how many aircraft had weighted NUC values corresponding to NUC values nine through zero. This is a presented graphically later in this report in **Figure 4-4.**

Table 3-2 Summary of Airframes Reporting NUC of 5 or Better

ADS-B that meet basic capabilities requirements	1,964	35%	100%
Always reported an HPL < .5NM Position (NUC>=5)	1,954	35%	99%
Always reported an HPL < .2NM Position (NUC>=6)	1,930	35%	98%
Always reported an HPL < .1NM Position (NUC>=7)	1,663	30%	85%
Always reported an HPL < 25m Position (NUC>=8)	166	3%	8%

Table 3-3 Weighted NUC Value Distribution Summary

	9	8	7	6	5	4	3	2	1	0
Number of Aircraft with Weighted NUC Value	5	118	532	1087	178	9	5	9	7	1083

The data show that the NUC values were clustered around 5, 6 and 7 for aircraft reporting other than NUCs of 0. We noted some significant variations in NUCs for some aircraft (e.g., a max reported NUC of 8 and a min reported NUC of 3). However, since this analysis only had ME message counts for the whole year, we could not determine if this variation happened in a single operation or was a variation from operation to operation over the course of the year.

3.2.1.3 Sample Aircraft Plots

The final component of the quick look analysis was the plotting of a sample of 24 aircraft to visually assess the reasonableness of the positions. All 24 plots appeared to have positions that were reasonable relative to the receiver location and that visually looked like a reasonable aircraft track.

3.2.2 Final Analysis Findings Summary

This analysis provided more in-depth insight in to the capabilities, data quality, and behavior of ADS-B aircraft on an operation by operation basis. The overall results in terms of the percentage of ADS-B aircraft that met the basic criteria did not change substantially from the Quick Look analysis findings.

To assess the consistency of the reported data, we used a data set that contained every ADS-B operation over the period of June 2007 to July 2008. These records contained the AA code for the aircraft along with counts of every DF and ME message type received. This data contained 1,076,995 operations and 5468 unique aircraft.

3.2.2.1 Consistency in Meeting Basic Capabilities Requirements

By examining data on an operation by operation basis, we were able to determine that some aircraft did not meet the basic capabilities requirements for all operations. **Table 3-4** shows the number and percentage of aircraft that met the capabilities for various percentages of the operations in the data set. The data shows that only 477 or 9% met the requirements in every operation. In a cursory examination of this data we noted two categories of behavior:

1. There is a distinct separation in this behavior over time. For example, early in the data set none of the operations meet the requirements but all later samples do.

2. Behavior varies in closely spaced operations. For example, we observed one aircraft that met the criteria on a flight early in the day but later in the day that same aircraft had a flight that did not meet the criteria.

Further analysis of this data is required to determine how many of these aircraft fall in to each of these categories and if there are, in fact, other categories of behavior.

Table 3-4 Summary of Consistency in Meeting Basic Capabilities Requirements

Total ADS-B Capable	5,468	
Meet basic data requirements for any operation	2,012	37%
Meet basic data requirements for > 50% of operations	1,908	35%
Meet basic data requirements for > 90% of operations	1,700	31%
Meet basic data requirements for 100% of operations	477	9%
Meet basic data requirements for <50% of operations	104	2%

3.2.2.2 NUC Distribution Analysis

The quick look analysis of NUC distribution was based on a table that listed the number of ME messages reported by aircraft over the whole year. In this final analysis, we were able to look at the NUCs reported for each operation for each aircraft over the whole year. We could then calculate a weighted NUC, the number of different NUC values reported, and a delta from the maximum reported NUC to the minimum reported NUC for every operation. This provided much better insight into what was going on operation by operation, particularly in terms of the number and deltas in NUC values being reported.

The weighted NUC essentially tells us the average NUC reported by an aircraft in any given operation. By averaging that over all operations for a given aircraft we get an idea of the NUC value predominately reported by that aircraft over the full year. This is basically equivalent to the weighted NUC value we calculated in the quick look analysis looking at the whole year in one record. By looking at the maximum weighted NUC value for each aircraft over the year we get an idea of the best performance we can expect from that aircraft. **Table 3-5** shows the

distribution of the number of aircraft by weighted NUC values using their average and maximum weighted NUC values. As expected, the distribution for the average weighted NUC values is similar to the distribution in the quick look analysis with the majority of the aircraft having an average weighted NUC of 6. The distribution shifts one NUC value higher when looking at the maximum weighted NUC for each aircraft over all of the operations indicating that performance does not vary significantly higher than the norm.

Table 3-5 Average and Maximum Weighted NUC Value Distribution

	Weighted NUC Value									
	9	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
Aircraft With Average Weighted NUC	2	123	529	1141	156	1	2	2	2	54
Aircraft With Max Weighted NUC	60	155	1556	170	14	0	9	8	21	19

Since we noted in the quick look analysis that most aircraft reported more than one NUC value over the course of a year we wanted to get a sense of the variance in reported NUC values over the course of each operation. In this more detailed analysis we were able to calculate the delta between the maximum NUC value reported in each operation and the minimum NUC value reported in each operation. To show what the most common behavior of each aircraft was over all operations we calculated the average delta for each aircraft over all operations. To give an insight into deviations from the norm we calculated the maximum delta for each aircraft over all operations. **Table 3-6** shows the distribution of the number of aircraft by deltas in NUC values reported for both the average and maximum deltas. The average distribution is what we would expect in that most of the aircraft, on average, have only a difference of one between the maximum NUC value reported and the minimum NUC value reported in an operation. What stood out when we graphed this data (see Figure 4-6 later in this report) were the spikes in the distribution for the maximum deltas at the values of 6 and 7. What this indicates is that there are some aircraft with significant anomalous behavior in their NUC reporting. The number of operations involved for those aircraft must be relatively small in order for the average value to be so much lower. As we began to look at this further and coupled it with observations from the altitude plotting and the anomaly detection process, we began to see a pattern emerging of certain aircraft that presented as "bad actors" in each of these analyses. These aircraft also tended to fall in to a relatively small set of aircraft types.

Table 3-6 Average and Maximum of Delta in Reported NUC Values in an Operation

	Delta Between Max NUC Value and Min NUC Value									
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Average of Max to Min NUC Delta	756	1155	64	30	4	2	1	0	0	0
Maximum of Max to Min NUC Delta	101	383	588	130	36	41	157	486	67	23

3.2.2.3 Altitude Plotting

We took each of the aircraft we did X/Y plots for in the quick look analysis and plotted their reported altitudes over time. The aircraft plotted are listed in **Table 4-6** and the plots are provided in **Appendix A.** For the most part, the positions plotted looked like reasonable tracks. We did find one aircraft however where the position reports plotted as parallel bands of points. This aircraft was found while analyzing some of the aircraft flagged in our position anomaly

testing. We also found several aircraft in the set of aircraft we plotted that had large changes in altitude values. Following is a summary of the observations and findings from viewing the altitude plots:

G-Vs

- There were 3 G-Vs in the data set (N313RG ALX, N596GA ALX, N818DA LMT).
- All output NUC 3s intermingled with other NUCs (usually NUC 8).
- NUC 3s are often 20,000 ft or more off of real altitude or an altitude of -2000'
- We looked through their history and found this to be consistent behavior. 3 other flights for each aircraft were examined.
- 3 other G-Vs (N101MH, N526EE, N628BD) were looked at and they all output intermingled NUC 3s with similar altitude jumps.

Falcon 50s

- There was 1 Dassault-Breguet Falcon 50 (N411GC HBC) in the data set and it output some NUC 3s intermingled with other NUC values and there were altitude jumps associated with the NUC 3 values.
- History shows this happened in its other flights
- We examined 3 other F50s not in the original set of plots and they also put out NUC 3s and had altitude jumps.

Other Aircraft

- There were 2 G-IVs (N167AA, N303TP) in the set of plots and they output NUC 3s and had altitude jumps.
- There was 1 Dassault-Breguet Falcon 900 and it output NUC 3s and had altitude jumps.

3.2.2.4 Data Value Anomaly Analysis Findings

In the quick look analysis and the first part of the final analysis, we examined what data elements (ME message types) were being provided by the aircraft. In order to begin to assess the quality of the data contained in those data elements, HTSI processed the binary records from December 2007 through May 2008 to look for anomalies in the data. The processing was set up to detect unreasonable position reports (> 250 miles from the receiver site) as well as unreasonable changes in position, altitude, NUC, or velocity from report to report and to compile counts of these anomalies by operation. This data set contained 460,145 operations and 4606 ADS-B aircraft.

The 4606 ADS-B capable aircraft were first broken down to those that had any operations that met the basic capabilities requirements. That is, they provided the required data elements and had NUC values other than zero. We then analyzed the anomaly data to determine how many of those aircraft had data with limited or zero anomalies. **Table 3-7** summarizes the results of this analysis. The data indicates that the number and percent of ADS-B aircraft that meet the basic capabilities and have reasonable position is 1700 or 37% of the ADS-B aircraft. However, when the other anomalies types are taken in to account, that percentage drops to 34%.

Table 3-7 Summary of Number and Percent of DO-260 Aircraft Data Quality

Total ADS-B Capable	4,606

Meet basic data requirements	1,877	41%
Always have less than 1% position anomalies	1,700	37%
Always have less than 1% position anomalies, NUC anomalies, and altitude anomalies	1,546	34%
Always have NO position anomalies, NUC anomalies, and altitude anomalies	826	18%

3.3 Summary of Observations

Looking at the data for 12 months, 5468 aircraft were noted using ADS-B (DF-17s). Of those, 2012 (37%) meet the basic criteria for effective operations in a NRA environment during at least one operation. 1700 of those met all criteria in at least 90% of all operations examined.
Looking at position reports and NUC, a six month sample was examined in great detail. 4606 ADS-B aircraft were noted. 1877 (41%) aircraft met the basic criteria, and ALL of these had some operations with NO position anomalies noted. 1700 hundred of these had operations that always had less than 1% position anomalies. 1546 always had operations that had fewer than 1% anomalies in position, NUC and altitude. 826 aircraft had no position, NUC or altitude anomalies. NUCs for the aircraft meeting the basic criteria averaged 6.
Essentially every aircraft type had aircraft that performed extremely well, probably meeting the performance requirements for operations in a NRA or RAD environment. The remainder of the 1877 aircraft that met the basic criteria but had greater than 1% anomalies would appear to have the equipment and on-board connectivity to meet all requirements, but further study would be necessary to figure out the difference between those and the aircraft that had the low error percentages.
From fall 2004 through June 2008, 7829 aircraft had been noted emitting DF 17s. About 100 of these are DO-260A, indicating about 7700 have DO-260 ADS-B capable transponders. About 2000 of these meet the basic criteria leaving ~5700 ADS-B capable aircraft not meeting the basic criteria. It's interesting to consider what it would take to make these aircraft operate correctly. As discussed below, a small number of aircraft types account for a disproportionate number of problems. Therefore, a relatively small effort could have a large impact on identifying and fixing the problems and making a much larger percentage of DO-260 capable aircraft meet the basic requirements.
HTSI examined the reasons aircraft failed to meet the basic criteria. The biggest single problems where: complete lack of position and velocity information, NUCs of zero, position errors and altitude errors. The aircraft with no position data may be of little interest to further study, they may not have a GPS source (although it might be worthwhile to do a survey to determine this). Of the remaining aircraft that appear to have all the required data sources, these aircraft types had the most offenders:

- NUCs only Zero:
  - Boeing 767: 163 aircraft
  - Boeing 757: 135 aircraft
  - Boeing 777: 84 aircraft
  - Airbus A300: 70 aircraft
- Serious Position errors:
  - CL 60: 44
  - Gulfstream 5: 64

The CL 60 and GLF5 also have a significant number of serious altitude anomalies. It should be noted that this handful of aircraft types account for a significant percentage of the anomalies seen.

3.4 Conclusions

Given that some anomalies will always be present, somewhere between 1500 and 2500 aircraft in operation today in the US, equipped with DO-260 capable transponders, would seem to meet the basic ADS-B requirements for operations in the NRA or RAD environment.
Some 5500 other aircraft have DO-260 capable transponders but do not meet the basic criteria. The major problems seem to be: lack of position data, NUCs of only zero, a large number of position anomalies, and significant altitude problems. A small percentage of aircraft types account for a much larger percentage of the problems.
From the data transmitted from the aircraft, it is not possible to determine why some aircraft do not operate correctly. Is it the data sources (e.g. GPS unit), a connection issue (i.e. through an FMS), or an issue with the transponder itself? The only way to find out will be to get together with the transponder manufacturers, the aircraft manufacturers and the owner/operators to figure out how this equipment is being installed, connected and set-up. Such an exercise could also identify the rough cost of any required modifications and assist in determining key issues in developing a certification plan.

3.5 Recommendations

The data evaluation conducted found that virtually every aircraft type had examples that worked almost perfectly, and examples that were seriously flawed. While some educated guesses can be made about some of the issues, the ADS-B data transmitted from the aircraft is not adequate to determine what the causes the problems and issues.
What is clear is that there are a handful of aircraft types that have lots of problems. These are major aircraft types with literally hundreds of airframes with problems. These problems are in two major groups (assuming position data is available): NUCs of zero and data anomalies (position, NUC, or altitude anomalies). A detailed examination of just a handful of aircraft types would have a significant payoff in defining exactly what the problems are, what the fixes are, and at least a general idea of the cost to fix the problems. The problems found on this limited survey would probably be applicable to most (if not all) of the other aircraft with NUC, position or altitude problems.
The airframes with significant issues are: Boeing heavy jets, Airbus A300, Gulfstream 5 and Canadair CL 60.
HTSI therefore recommends the following:

1. Determine the primary (largest) operators of the problem aircraft;
    a. Build list of problem airframes by operator
2. Solicit the assistance of the operators in determining the problems/issues:
    a. Possibly with the assistance of the ARC members
    b. Involve AVS
3. Determine the equipage of the aircraft with problems:
    a. Make, model and revision status of transponder/TCAS
    b. GPS equipage
        i. Determine if meets relevant MOPS for ADS-B
    c. Other relevant equipage

   i. FMS
   ii. Altimeter (blind encoder, etc.)
d. Determine connectivity to transponder/TCAS
   i. GPS
   ii. FMS
   iii. Altitude data source

4. Solicit the assistance of the transponder/TCAS manufacturer
5. Determine what is required to make the system components work IAW basic requirements or subsequent requirements documents.
   a. Equipment (e.g. GPS)
   b. Cabling/connectivity
   c. Software/firmware upgrade.
   d. Documentation or documentation modifications.
6. Roughly estimate direct cost to upgrade.
7. Make sure that the certification process addresses the types of anomalies identified in this analysis.
   a. Certification will not be a bench test process. Many of the anomalies seen here may not be testable in a bench or ground test. Specific performance criteria can be developed along with a methodology to collect and analyze the data during normal flight or ground movement and report in a near real-time process on an operation by operation basis.

4 Detailed Report

4.1 Overview of HTSI ADS-B Data

HTSI has been collecting and storing 1090 MHz extended squitter data – both Mode-S and ADS-B data – for over 4 years. That data is stored in several different forms.

4.1.1 Types of Data Stored

Binary Log Data

The HTSI ADS-B receiver sites send binary data to College Station, TX where this data is stored in a set of binary files (typically one file per site per day). These files contain all ADS-B and select Mode-S messages received from DISSRR sites. This data is processed monthly to create what we refer to as operations data. An operation is a flight segment during which an AA Code is actively being reported and which is preceded and followed by a period of not less than 15 minutes of inactivity. Operations do not cross a midnight local boundary.

Operations Summary Data

This data contains information for each "operation" for each discrete airframe. The information includes things like date, start, stop and duration for the operation, AA code, and counts of each of the various DF and ME messages received during that operation. This data is loaded monthly in to a MySQL database for analysis and Web presentation

Operations Detail Data

This data contains detailed records for each operation – there are many records per operation. These records are aggregates of the individual discrete ADS-B messages. For example, position updates are maintained at one second intervals. This data can be loaded in to a MySQL database for analysis and Web presentation. Because of the size of this data, we typically do not keep all of it on-line.

Statistics Data

The above data is processed monthly to produce aggregate statistics that are used for monthly reporting on Mode-S and ADS-B activity. This statistical information is also available on-line.

4.1.2 Real Time Data Available

The HTSI receiver sites also send data in real-time back to College Station, TX. This data is used to provide real time information via the web. The following lists the types of real-time information available and provides a link to the web page:

- Summary of real-time transponder activity by site
  http://www.dissrr.com/1090GS/Activity/

- Data on current aircraft visible by site
  Alexandria, VA
  Huntington Beach, CA
  JFK
  Englewood, CO
  All Sites

- Total ADS-B messages by ME code (DO-260 and DO-260A)

http://www.dissrr.com/1090GS/ADSB/

The real-time data can also be displayed via Google Earth. This requires a KML file from HTSI.

4.2 Analysis Approach

4.2.1 Quick Look Analysis

To support the need for a quick look report, HTSI did a high level assessment of data from a one year period from June of 2007 to May of 2008 to determine how many ADS-B capable aircraft had the data elements present to provide the basic capabilities required:

ID + Airborne Position Messages +Velocity Messages + Baro Altitude + Position Quality + Emergency Indicators + Special Position Indicator Report.

This analysis was done by developing queries in to a database of operations detail data records to compile a count of each of the ME message types received per operation. From this HTSI was able to count how many aircraft had operations that contained the necessary data elements to meet the basic requirements by checking for the presence of the message types listed in **Table 4-1.**

Table 4-1 DO-260 Messages Containing Required Data Elements

Message Types Checked	Required Data Elements
ME1 – ME 4 - Identification	• ID
ME9-ME18 - Airborne Position	• Airborne Position • Barometric Altitude • Position Quality (NUC_P) - determined by ME code • Emergency Indicators • Special Position Indicator Report
ME19 – Airborne Velocity	• Velocity

HTSI did a first level analysis of the NUC values reported by these aircraft and the distribution of NUC values by compiling a table by AA code of the total counts of ME message types received for that AA code over the course of the year. From this, HTSI was able to calculate the weighted NUC (average of the NUC values reported) by each aircraft over that period and chart that distribution. In addition, HTSI plotted a sample of 24 aircraft in X/Y positions relative to the receiving station to visually assess whether the positions reported appeared reasonable.

4.2.2 Final Analysis

In the second part of the study, HTSI was able to do a more detailed analysis that included assessing data and gathering statistics on an operation by operation basis as well as testing data for anomalies in position, altitude, NUC values, and velocity. This analysis had the following objectives:

- Assess the consistency of aircraft meeting the basic criteria. While the quick look analysis showed a count of aircraft that had any operations that met the criteria, it did not determine if those aircraft always met the criteria

- Do a more in depth analysis of NUC distribution. The quick look analysis was limited to assessing that distribution based on a total count of ME message types per aircraft for a full year. It did not examine variances within individual operations.
- Do a visual assessment of altitude reasonableness by plotting altitude vs. time for the 24 sampled aircraft.
- Assess the reasonableness of the position data being reported. The quick look analysis was limited to a visual assessment of a sample of 24 plots.
- Detect anomalous behavior within an operation and compile statistics on an operation by operation basis.

To address the first two objectives, HTSI extracted data from our operations detail database and compiled a table which consisted of records for every ADS-B operation over the period of June 2007 to May 2008. These records contained the AA code for the aircraft along with counts of every DF and ME message type received. This table, which contained 1,076,995 operations and 5468 unique aircraft, was loaded into an MS Access database for further analysis.
We addressed the third objective by plotting the altitude against time for each of the 24 sampled aircraft. Because some of the plots showed anomalous altitude behavior, we expanded the set of plots to look at some other aircraft with the same aircraft type to see if the behavior was unique to the first aircraft examined or whether it was found in other aircraft of the same type.
The last two objectives required processing the binary recorded data that contains all of the messages for each operation for each aircraft. HTSI processed the binary records from December 2007 through May 2008. The binary files recorded prior to December were in a different file format so we were limited at this time to the 6 month period. We wrote software to detect unreasonable position reports (> 250 miles from the receiver site) as well as unreasonable changes in position, altitude, NUC, or velocity from report to report. This software compiled counts of each of these anomalies by operation. This data, which contained 460,145 operations and 4606 ADS-B aircraft, was loaded in to an MS Access database for further analysis.

4.3 Study Data and Results

4.3.1 Number of Aircraft Meeting Basic Capabilities Requirements

The quick look analysis findings, which were published in a Quick Look briefing on July 7, 2008, showed that approximately 2000 aircraft met the basic capability requirements and reported NUC values that were not always zero. This represents 5% of the Mode-S airframes in the data sample and 35% of the ADS-B airframes. **Table 4-2** shows the breakdown of the total numbers of Mode-S and ADS-B operations and aircraft in the data set analyzed. The table then breaks down the ADS-B data to show the number and percent of the aircraft that have the individual data elements required and then the number and percent that have all of the data elements required. The table goes further to show those aircraft that have all the necessary data elements and are transmitting NUC values other than zero. For most applications, NUC values of less than 5 are probably not usable so the table identifies the number and quantity of aircraft the always provide NUC values of 5 or higher, 6 or higher, 7 or higher, and 8 or higher. Based in this analysis the data indicates that there are ***1964*** ADS-B aircraft that have potentially useable data. They all have the required basic set of data and are sending non-zero NUC values. This represents ***~5%*** of all Mode-S aircraft in data set and ***~35%*** of all ADS-B aircraft in data set

Table 4-2 DO-260 Basic Capabilities Analysis Results

Total Mode-S	9,366,456	41,479	100%	-	-
With ADSB Capability	1,247,887	5,565	13%	100%	-
ADSB With ID Capability	960,989	5,352	13%	96%	-
ADSB With Velocity Capability	901,610	3,254	8%	58%	-
ADSB With Position w/Baro Alt Capability	859,463	3,413	8%	61%	-
ADSB With Position w/Baro Alt, & Ident Capability	828,174	3,333	8%	60%	-
ADSB with Position w/Baro Alt, Ident, & Velocity Capability	802,863	3,032	7%	54%	-
ADSB With Baro Alt, Ident, Velocity & ONLY Unknown Position	838	52	0%	1%	-
ADSB With Baro Alt, Ident, Velocity & ONLY NUC 0 Position	280,342	1,267	3%	23%	-
ADSB With Baro Alt, Ident, Velocity & ONLY non-NUC 0 Position	500,720	1,964	5%	35%	100%
ADSB With Baro Alt, Ident, Velocity & ONLY HPL < .5NM Position (NUC>=5)	493,999	1,954	5%	35%	99%
ADSB With Baro Alt, Ident, Velocity & ONLY HPL < .2NM Position (NUC>=6)	408,629	1,930	5%	35%	98%
ADSB With Baro Alt, Ident, Velocity & ONLY HPL < .1NM Position (NUC>=7)	187,725	1,663	4%	30%	85%
ADSB With Baro Alt, Ident, Velocity & ONLY HPL < 25m Position (NUC>=8)	28,849	166	0%	3%	8%

4.3.1.1 Consistency in Meeting Basic Capabilities Requirements

By examining data on an operation by operation basis, we were able to determine that some aircraft did not meet the basic capabilities requirements for all operations. **Table 3-4** showed the number and percentage of aircraft that met the capabilities for various percentages of the operations in the data set. This data is also illustrated in **Figure 4-1**. The data shows that only 477 or 9% met the requirements in every operation.

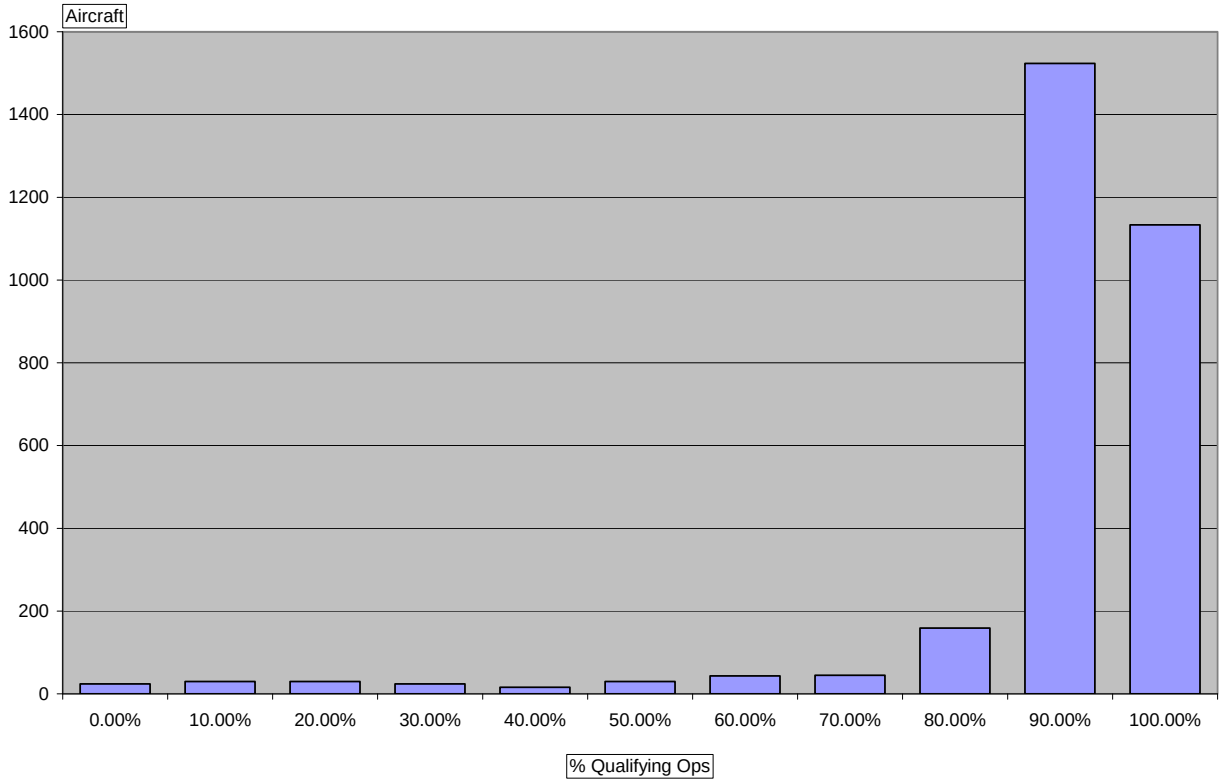


Figure 4-1 Number of Aircraft vs. Percentage of Time Basic Capabilities Requirements are Met

In a cursory examination of this data we noted two categories of behavior:

1. There is a distinct separation in this behavior over time. For example, early in the data set none of the operations meet the requirements but all later samples do.

2. Behavior varies in closely spaced operations. For example, we observed one aircraft that met the criteria on a flight early in the day but later in the day that same aircraft had a flight that did not meet the criteria.

Further analysis of this data is required to determine how many of these aircraft fall in to each of these categories and if there are, in fact, other categories of behavior.

4.3.2 NUC Distribution Analysis

The one-year quick look data set was analyzed to determine what NUC values were being reported. **Figure 4-2** shows the distribution of the NUC values reported over the total number of position reports received. This shows a large number of NUC values of 6 and 7 but also shows a large number of NUC 0 values being reported.

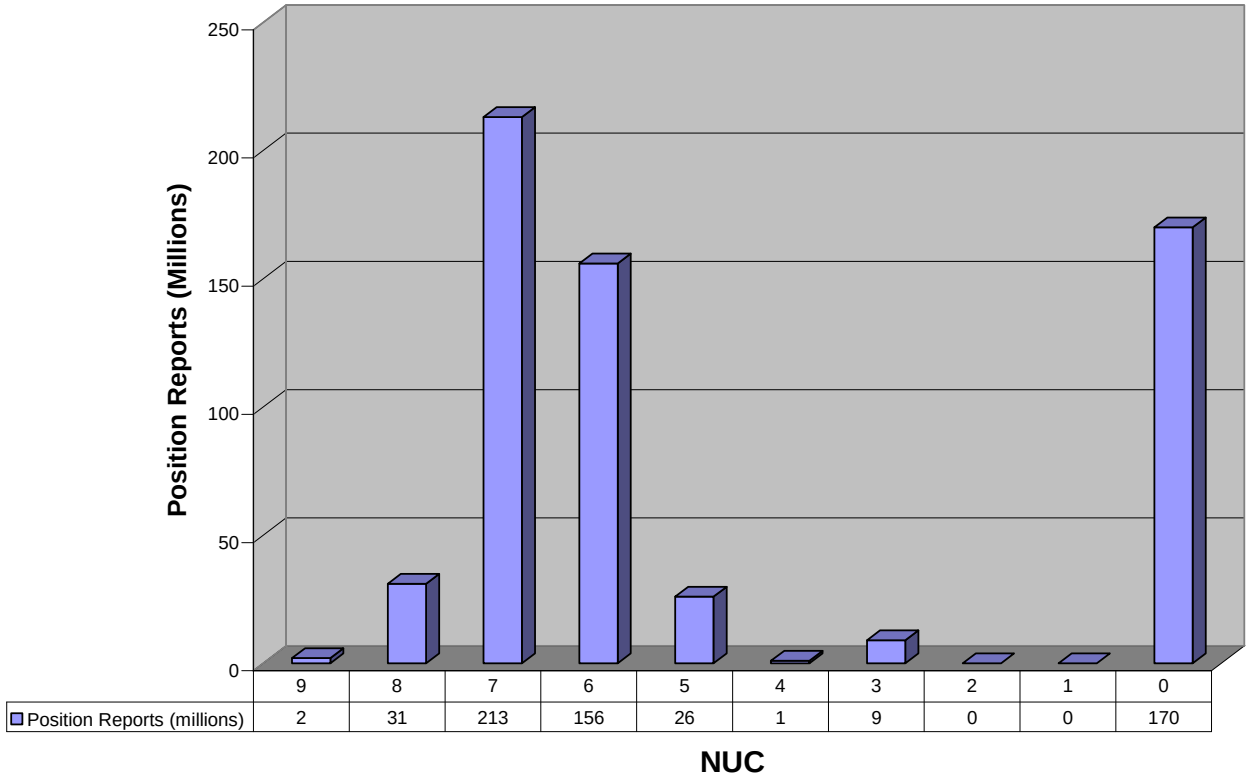


Figure 4-2 NUC Distribution by Position Reports

We next examined the distribution of NUC values reported by aircraft. **Figure 4-3** shows the distribution by aircraft that ever reported a given NUC value. For example, there were 1874 aircraft that ever reported a NUC of 7.

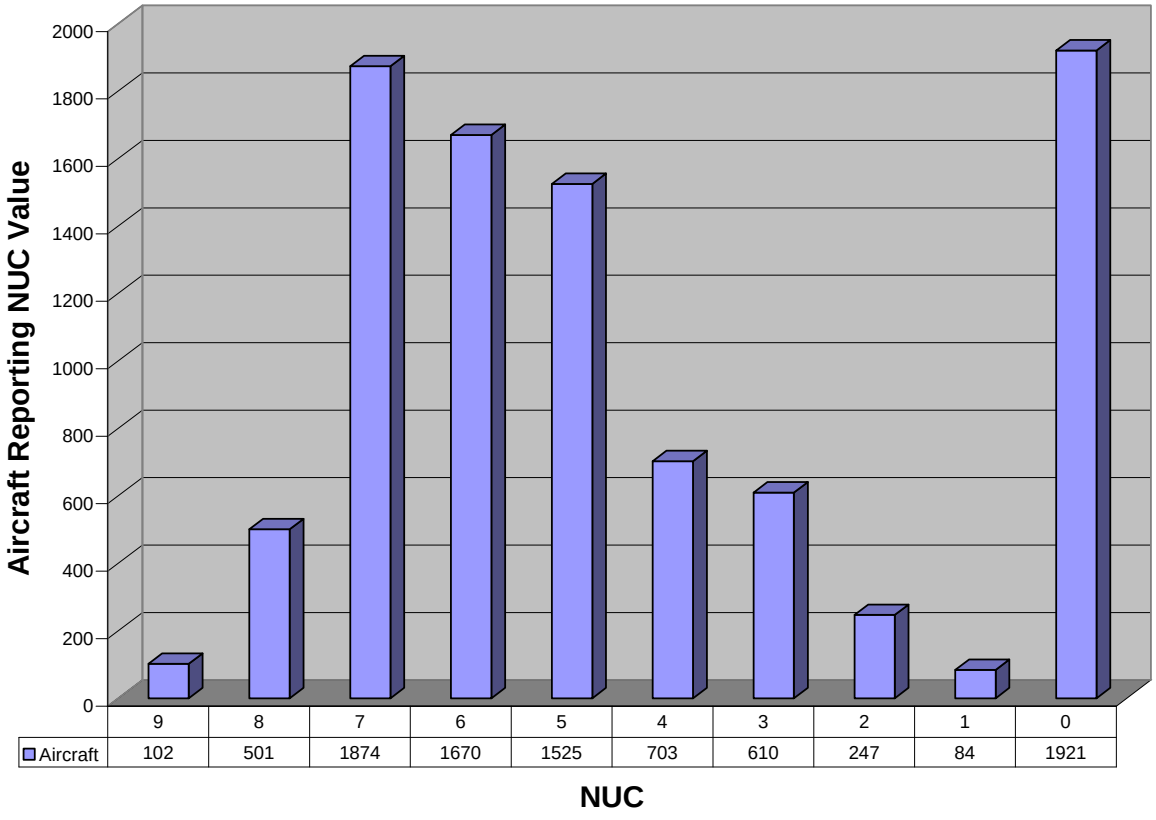


Figure 4-3 NUC Distribution by Aircraft

To get an idea of what NUC value each aircraft was reporting on average, we calculated a weighted NUC value based on the number of position reports there were for each NUC value. **Figure 4-4** illustrates how many aircraft had weighted NUC values corresponding to NUC values nine through zero.

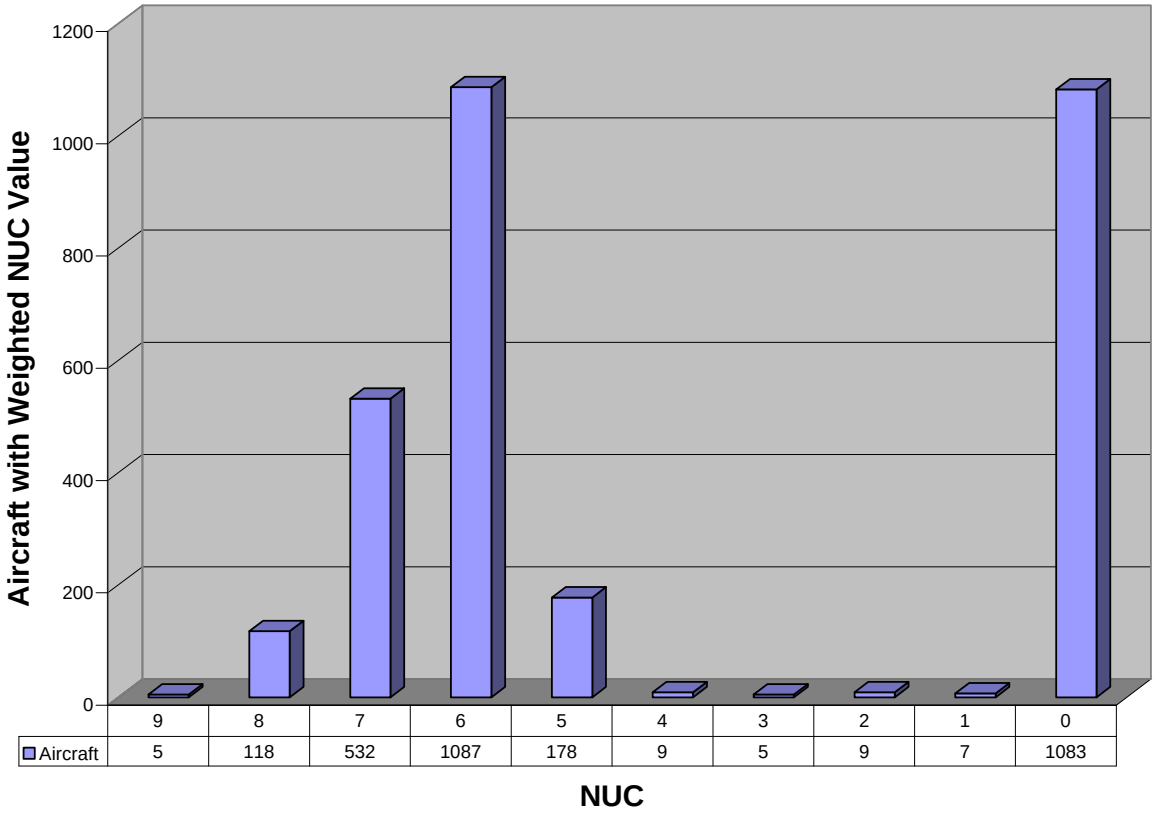


Figure 4-4 Weighted NUC Distribution by Aircraft

The data show that the NUC values were clustered around 5, 6 and 7 for aircraft reporting other than NUCs of 0. In the initial quick look analysis we noted some significant variations in NUCs for some aircraft (e.g., a max reported NUC of 8 and a min reported NUC of 3). However, since this analysis only had ME message counts for the whole year, we could not determine if this variation happened in a single operation or was a variation from operation to operation over the course of the year.

In the final analysis, we were able to look at the NUCs reported for each operation for each aircraft over the whole year. We could then calculate a weighted NUC, the number of different NUC values reported, and a delta from the maximum reported NUC to the minimum reported NUC for every operation. This provided much better insight into what was going on operation by operation, particularly in terms of the number and deltas in NUC values being reported.

The weighted NUC essentially tells us the average NUC reported by an aircraft in any given operation. By averaging that over all operations for a given aircraft we get an idea of the NUC value predominately reported by that aircraft over the full year. This is basically equivalent to the weighted NUC value we calculated in the quick look analysis looking at the whole year in one record. By looking at the maximum weighted NUC value for each aircraft over the year we get an idea of the best performance we can expect from that aircraft. **Figure 4-5** shows the distribution of the number of aircraft by weighted NUC values using their average and maximum weighted NUC values. As expected, the distribution for the average weighted NUC values is similar to the distribution in the quick look analysis with the majority of the aircraft having an average weighted NUC of 6. The distribution shifts one NUC value higher when looking at the

maximum weighted NUC for each aircraft over all of the operations indicating that performance does not vary significantly higher than the norm.

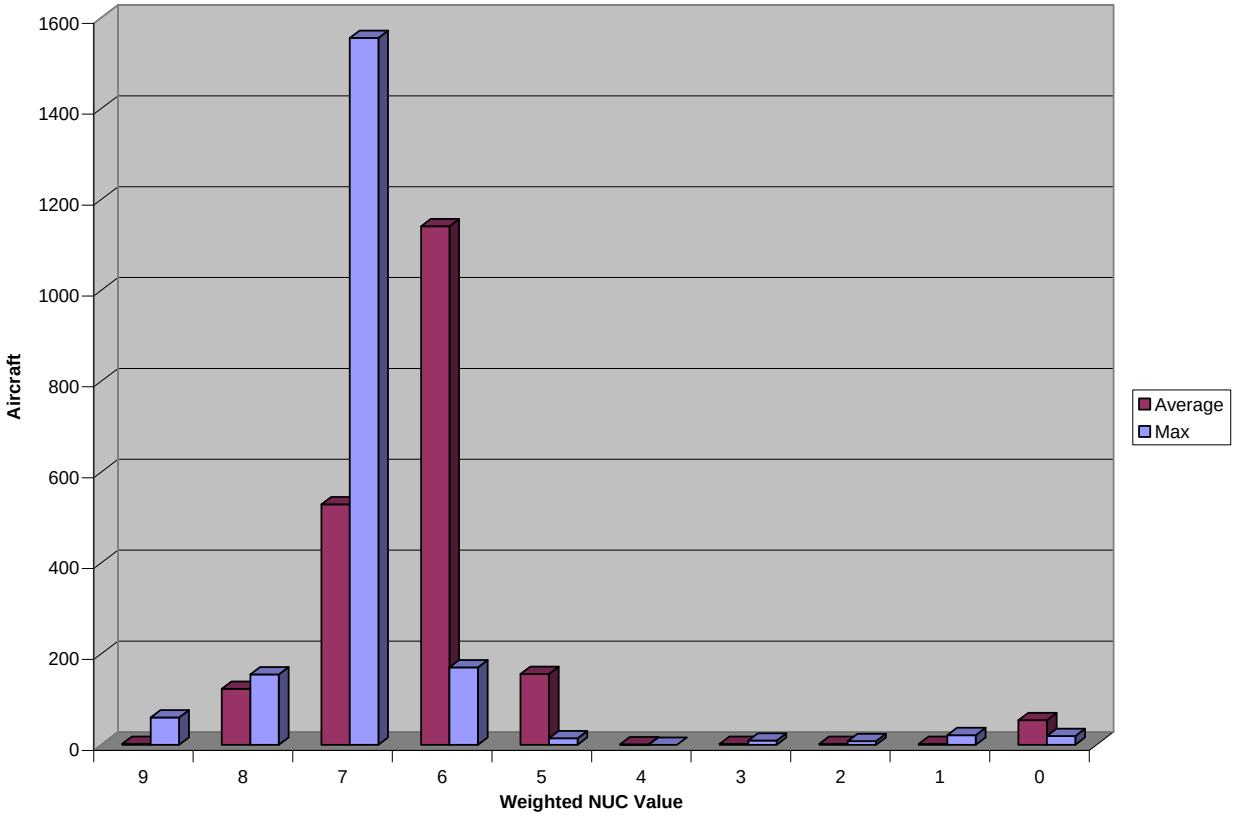


Figure 4-5 Average and Maximum Weighted NUC Distribution by Aircraft

Since we noted in the quick look analysis that most aircraft reported more than one NUC value over the course of a year we wanted to get a sense of the variance in reported NUC values over the course of each operation. In this more detailed analysis we were able to calculate the delta between the maximum NUC value reported in each operation and the minimum NUC value reported in each operation. To show what the most common behavior of each aircraft was over all operations we calculated the average delta for each aircraft over all operations. To give an insight into deviations from the norm we calculated the maximum delta for each aircraft over all operations. **Figure 4-6** shows the distribution of the number of aircraft by deltas in NUC values reported for both the average and maximum deltas. The average distribution is what we would expect in that most of the aircraft, on average, have only a difference of one between the maximum NUC value reported and the minimum NUC value reported in an operation.

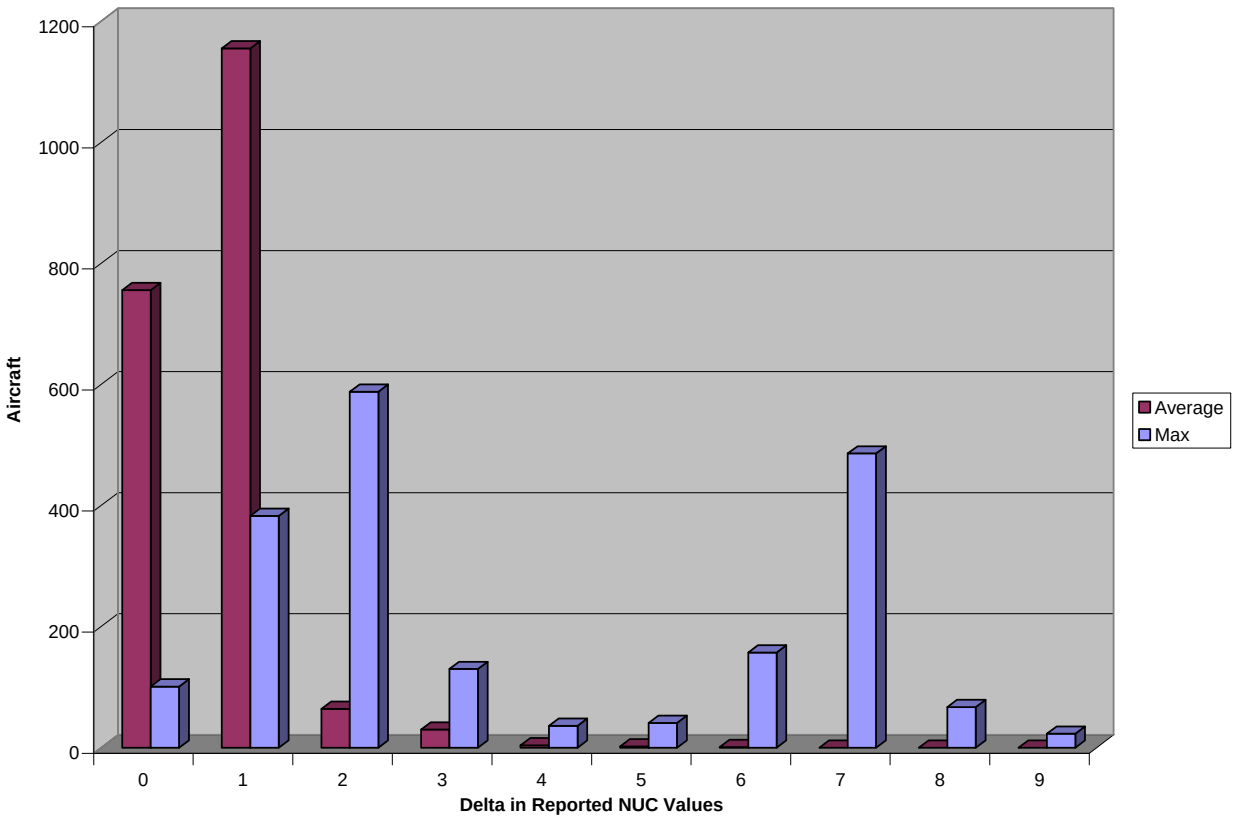


Figure 4-6 Average and Maximum Delta in Reported NUC Values

What stood out when we graphed this data were the spikes in the distribution for the maximum deltas at the values of 6 and 7. This indicates that there are some aircraft with significant anomalous behavior in their NUC reporting. The number of operations involved for those aircraft must be relatively small in order for the average value to be so much lower. As we began to look at this further and coupled it with observations from the altitude plotting and the anomaly detection process, we began to see a pattern emerging of certain aircraft that presented as "bad actors" in each of these analyses. These aircraft also tended to fall in to a relatively small set of aircraft types.

To gain further insight in to the position quality being reported by various aircraft types and configurations, we broke the weighted NUC data down by aircraft type and by owner. This data is presented in **Table 4-3** and **Table 4-4**.

Table 4-3 Weighted NUC Distribution by AC Type

	Weighted NUC					
-	161	780	327			1268
B752		11	4	70		85
B737		74	7			81
A319		44	24			68
A320		52	10			62
B772	1	45	7			53
A306		3	38			41
B738		28	11			39
MD11	4	6	27			37
B763		4	2	28		34
A333		2	28			30
DC87			3	19	4	26
B744	8	12	5			25
A332		1	10			11
B739			10			10
A321		7				7
B742	2		5			7
A318			5			5
B741			5			5
B753		4				4
CL60		4				4
DC8				1	1	2
F900		2				2
MD10		2				2
A312	1					1
AS35			1			1
B734	1					1
B74R			1			1
B762		1				1
C150		1				1
C172			1			1
CL30			1			1
GLF4		1				1
H800		1				1
L13		1				1
SBR1		1				1
Grand Total	**178**	**1087**	**532**	**118**	**5**	**1920**

Table 4-4 Weighted NUC Distribution by Owner

-	161	780	327		1268

UNITED PARCEL SERVICE CO	3	8	78	100	5	194
WELLS FARGO BANK NORTHWEST NA TRUSTEE	3	39	14			56
AMERICAN AIRLINES INC	1	41	5			47
INTERNATIONAL LEASE FINANCE CORP		37	5			42
JETBLUE AIRWAYS CORP		32	3			35
AIRTRAN AIRWAYS INC		32				32
NORTHWEST AIRLINES INC		3	29			32
CONTINENTAL AIRLINES INC		10	18			28
UNITED AIR LINES INC	6	9	2			17
AFS INVESTMENTS 58 LLC			9			9
C C & E I LLC		1	1	7		9
AFS INVESTMENTS 55 LLC		6	2			8
FRONTIER AIRLINES INC			8			8
AFS INVESTMENTS 54 LLC		6	1			7
US AIRWAYS INC		3	4			7
WILMINGTON TRUST CO TRUSTEE	1	5		1		7
AFS INVESTMENTS 56 LLC		5				5
AFS INVESTMENTS 57 LLC		5				5
AFS INVESTMENTS 67 LLC		5				5
UNITED PARCEL SERVICE			2	2		4
AFS INVESTMENTS 48 LLC		3				3
FEDERAL EXPRESS CORP		2	1			3
KALITTA AIR LLC			3			3
WILMINGTON TRUST CO OWNER TRUSTEE				3		3
WILMINGTON TRUST COMPANY TRUSTEE	1	1		1		3
AFS INVESTMENTS 52 LLC			2			2
AFS INVESTMENTS X LLC			2			2
BOEING AIRCRAFT HOLDING CO	1	1				2
DELTA AIR LINES INC		2				2
INTERNATIONAL LEASE FINANCE CORPORATION		2				2
JETBLUE AIRWAYS CORPORATION		2				2
NAS INVESTMENTS 1 INC		2				2
NAS INVESTMENTS 7 INC		2				2
PETTERS AIRCRAFT LEASING LLC			2			2
WILMINGTON TRUST COMPANY OWNER TRUSTEE				2		2
21110 LLC	1					1
737 LEASING COMPANY I LLC			1			1
AAI AVIATION INC		1				1
AEJ SERVICES LLC		1				1
AFS INVESTMENT 48 LLC		1				1
AFS INVESTMENTS 56LLC			1			1
ALTA ENTERPRISES INC		1				1
AMERICAN INTERNATIONAL GROUP		1				1

INC				
ARAMARK SERVICES INC	1			1
ARAMCO ASSOCIATED CO	1			1
AVN AIR LLC		1		1
B & B AIR ACQUISITION 3417 STATUTORY TRU	1			1
BANK OF UTAH TRUSTEE		1		1
BOMBARDIER AEROSPACE CORP	1			1
CAIQUEN LEASING LLC	1			1
CASTLE 2003-2A LLC	1			1
CC & EI LLC			1	1
CERNICALO LEASING LLC	1			1
CHARTWELL PARTNERS LLC	1			1
CIT GROUP/EQUIPMENT FINANCING INC	1			1
DS 128 FLUGZEUGFONDS III TRUST	1			1
DS 128 FLUGZEUGFONDS III TRUST A STATUTO	1			1
EMERSON CLIMATE TECHNOLOGIES INC	1			1
FEDERAL EXPRESS CORPORATION	1			1
FUNAIR CORP		1		1
GROUP HOLDINGS E G INC	1			1
HTSI INTERNATIONAL INC		1		1
JETBLUE AIRWAYS	1			1
JET-I 2616 OWNER TRUST	1			1
KENDRICK H JOE JR	1			1
MGM MIRAGE AIRCRAFT HOLDINGS LLC		1		1
MLW AVIATION LLC	1			1
MSN 2893 LEASING LLC	1			1
MSN 2898 LEASING LLC	1			1
N524VA TRUST	1			1
N633VA TRUST	1			1
N634VA TRUST		1		1
N720CH INC	1			1
PEGASUS AVIATION IV INC		1		1
PHARMAIR CORP	1			1
PUCKETT JEFFREY F		1		1
ROCKWELL COLLINS INC	1			1
SAS INSTITUTE INC	1			1
SHANGRI LA ENTERTAINMENT LLC	1			1
SWIFLITE AIRCRAFT CORP	1			1
TOP FLIGHT 3445 OWNER STATUTORY TRUST		1		1
TOWN AND COUNTRY FOOD MARKETS INC	1			1
TSI LEASING CO	1			1
TURFDELL TRUST	1			1

TUTOR-SALIBA CORP		1				1
TY AIR INC		1				1
U S BANK NA TRUSTEE		1				1
UNITED AIR LINE INC		1				1
UNITED PARCEL SERVICE OC				1		1
UNITED PARCEL SERVICES CO			1			1
VENSKE WILBUR F		1				1
WACHOVIA BANK NA			1			1
WHITE SAPPHIRE LLC		1				1
WORLD WRESTLING ENTERTAINMENT INC		1				1
YONA AVIATION II LLC			1			1
Grand Total	**178**	**1087**	**532**	**118**	**5**	**1920**

4.3.3 Data Anomaly and Position Validity Analysis

In the quick look analysis we examined what data elements (ME message types) were being provided by the aircraft. In order to begin to assess the quality of the data contained in those data elements, HTSI processed the binary records from December 2007 through May 2008 to look for anomalies in the data. The processing was set up to detect unreasonable position reports (> 250 miles from the receiver site) as well as unreasonable changes in position, altitude, NUC, or velocity from report to report and to compile counts of these anomalies by operation. This data set contained 460,145 operations and 4606 ADS-B aircraft.

For the purpose of this study, data anomaly observations were determined via the reprocessing of 112-bit ADS-B messages that had been previously recorded during the time periods of interest. All DF17, DF18 and DF19 messages that passed the ADS-B CRC check mechanism where grouped into flight segments by aircraft "AA Code". Flight segments include the period during which an AA Code is actively being reported and are preceded and followed by a period of not less than 15 minutes of inactivity. Flight segments do not cross a midnight local boundary. Flight segments that resulted from less than 30 ADS-B messages and flight segments that included ME31 messages with a non-zero version number (i.e. DO-260A) were excluded from further processing.

Flight segments were processed for detection of the following anomalies:

Altitude Inconsistencies:

ME0 and ME9-ME18s messages were included for the determination of aircraft barometric altitude. Change in altitude of greater than 500 feet that were detected between two successive altitude updates that were not separated by more than 5 seconds, were flagged as an altitude anomaly.

NUC Inconsistencies:

ME0 and ME9-ME18 messages were included for the determination of aircraft Navigational Uncertainty Category (NUC). Changes in reported NUCs of greater than two NUC levels between successive NUC updates that were not separated by more than 15 seconds were flagged as a NUC anomaly.

Velocity Inconsistencies:

ME19 messages Sub Type 0, 1, and 2 were included for the determination of aircraft velocity over ground. Changes in the magnitude of the velocity (i.e. speed) of greater than 20 knots

between successive updates not separated by more than 5 seconds, were flagged as velocity inconsistencies.

Position Inconsistencies:

ME9-18 messages were included for the determination of aircraft position. Odd and Even CPR pairs not separated by more than 10 second were used to compute aircraft position updates using global unambiguous CPR decoding. Locally unambiguous CPR decoding was not used in order to prevent the possibility of carrying over incorrect position information. Flight segments were processed for both absolute position and relative positions anomalies. Position anomalies were logged for updates that were determined to be in excess of 250 nautical miles from the site that initially received the message. Changes in aircraft location in excess of 3 nautical miles between successive position updates not separated by more than 10 seconds were flagged as position deviation anomalies.

The 4606 ADS-B capable aircraft in the data set were first broken down to those that had any operations that met the basic capabilities requirements. That is, they provided the required data elements and had NUC values other than zero. We then analyzed the anomaly data to determine how many of those aircraft had data with limited or zero anomalies. **Table 3-7** summarized the results of this analysis. The data indicates that the number and percent of ADS-B aircraft that meet the basic capabilities and have reasonable position is 1700 or 37% of the ADS-B aircraft. However, when the other anomalies types are taken in to account, that percentage drops to 34%.

We also examined the other aircraft in the data set to see what percentages of various anomaly types were present for those aircraft and to see if there was any pattern or concentration in the distribution of those anomalies. This was triggered in part when we noticed when we were plotting altitudes that there were certain aircraft types, such as the GLF5, that seemed to exhibit consistent anomalies. We calculated the percentage of position, altitude, and NUC anomalies by operation and then aggregated that day in several ways to look for any groupings or patterns. What we found is that when we looked at operations that had >1% of any error type and grouped that by aircraft type; we found that these operations fell in to a limited set of aircraft types. **Table 4-5** illustrates this for position anomalies and shows the number of aircraft that had position anomalies in each of the 10% ranges. Looking at the CL60 AC Type you can see that there are 44 out of the 100 aircraft of that type in the data set that fall into the 60% range. When we looked at these same aircraft type for altitude and NUC anomaly types we found similar distributions. The GLF5 AC Type also had a high number of aircraft with large percentages of position anomalies. Understanding the cause behind these large numbers of anomalies might give insight in to how to modify these aircraft configurations to make them useful on an interim basis. Given the large concentration in a small number of aircraft types, there may be a large return in terms of the number of DO-260 aircraft that could gain early benefits for a relatively small effort to investigate the root cause of this problem and determine the corrective action(s) required.

Table 4-5 Summary of Anomalies Detected by AC Type

Aircraft	Position Anomaly Percentage Range											
AC Type	0 %	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	Grand Total
B300	1						4					5
B744	82	2									1	85
BE20	1						1					2

BE55							1					1
CL60	50				2	1	44	1	1	1		100
F900	12					1	8	1				22
FA50	25		1	1			13	1	1			42
GLF3	26			1	2	1	6					36
GLF4	74		1		1	2	43	9	2			132
GLF5	50					3	64	14	3			134
H25B	17					1	1	1				20
S315									1			1
UH1							1					1
Grand Total	338	2	2	2	5	9	186	27	8	1	1	581

4.3.4 Aircraft X/Y and Altitude Plotting

In the quick look analysis we plotted a sample of 24 aircraft to visually assess the reasonableness of the positions. All 24 plots appeared to have positions that were reasonable relative to the receiver location and that visually looked like an aircraft track.

In the final analysis we then took each of those aircraft and plotted their reported altitudes over time. The aircraft plotted are listed in **Table 4-6** and the plots are provided in **Appendix A.** For the most part, the positions plotted looked like reasonable tracks. We did find one aircraft (N37273) however where the position reports plotted as parallel bands of points. This aircraft was found while analyzing some of the aircraft flagged in our position anomaly testing. We also found several aircraft in the set of aircraft we plotted that had large changes in altitude values. Following is a summary of the observations and findings from viewing the altitude plots:

<u>G-Vs</u>

- There were 3 G-Vs in the data set (N313RG ALX, N596GA ALX, N818DA LMT).
- All output NUC 3s intermingled with other NUCs (usually NUC 8).
- NUC 3s are often 20,000 ft or more off of real altitude or an altitude of -2000’
- We looked through their history and found this to be consistent behavior. 3 other flights for each aircraft were examined.
- 3 other G-Vs (N101MH, N526EE, N628BD) were looked at and they all output intermingled NUC 3s with similar altitude jumps.

<u>Falcon 50s</u>

- There was 1 Dassault-Breguet Falcon 50 (N411GC HBC) in the data set and it output some NUC 3s intermingled with other NUC values and there were altitude jumps associated with the NUC 3 values.
- History shows this happened in its other flights
- We examined 3 other F50s not in the original set of plots and they also put out NUC 3s and had altitude jumps.

<u>Other Aircraft</u>

- There were 2 G-IVs (N167AA, N303TP) in the set of plots and they output NUC 3s and had altitude jumps.
- There was 1 Dassault-Breguet Falcon 900 and it output NUC 3s and had altitude jumps.

Table 4-6 Summary of Aircraft Plotted

Date	Tail/Flight	Make	Model	Site	Altitude Reasonable	Position Reasonable	Notes
5/15/2008	AFR031	Airbus	A330-203	ALX	√	√	
5/15/2008	DLH414	Airbus	A340-313	ALX	√	√	
5/15/2008	N313RG	Gulfstream	G-V	ALX		√	Large jumps in altitude correlated with large drop in NUC value to NUC of 3.
5/28/2008	N449UP	Boeing	757-24APF	ALX	√	√	
5/28/2008	N505NK	Airbus	A319-132	ALX	√	√	
5/28/2008	N526VA	Airbus	A319-112	ALX	√	√	
5/28/2008	N596GA	Gulfstream	G-V	ALX		√	Large jumps in altitude correlated with large drop in NUC value to NUC of 3.
5/5/2008	ANA6	Boeing	777	HBC	√	√	
5/20/2008	N358FE	McDonnell Douglas	MD-10	HBC	√	√	
5/5/2008	N411GC	Dassault-Breguet	Falcon 50	HBC		√	Large jumps in altitude correlated with large drop in NUC value to NUC of 3.
5/20/2008	N420LA	Boeing	767-316F	HBC	√	√	
5/5/2008	N493TA	Airbus	320-233	HBC	√	√	
5/5/2008	N590NW	Boeing	757-351	HBC	√	√	
5/5/2008	SIA38	Airbus	A345	HBC	√	√	
5/31/2008	N57016/COA49	Boeing	777-224	JFK	√	√	
5/31/2008	N862DA/DAL152	Boeing	777-232	JFK	√	√	
5/11/2008	KAL258			JFK	√	√	
5/31/2008	N436UP	Boeing	757-24APF	JFK	√	√	
5/31/2008	N637JB	Airbus	A320-232	JFK	√	√	
5/1/2008	N650FE	Airbus	A300	JFK	√	√	
5/31/2008	N920DS	Boeing	757-75V	JFK	√	√	
5/1/2008	N37277	Boeing	737-824	JFK	√	√	
5/1/2008	QTR051			JFK	√	√	
5/1/2008	THY2			JFK	√	√	
5/11/2008	BAW28A			LMT	√	√	
5/23/2008	N338AT	Boeing	737-7BD	LMT	√	√	
5/23/2008	N639JB	Airbus	A320-232	LMT	√	√	
5/11/2008	N818DA	Gulfstream	G-V	LMT		√	Large jumps in altitude correlated with

Date	Tail/Flight	Make	Model	Site	Altitude Reasonable	Position Reasonable	Notes
							large drop in NUC value to NUC of 3.
5/23/2008	N662UA	Boeing	767-322	LMT	√	√	
5/23/2008	N37274	Boeing	737-824	LMT	√	√	
5/1/2008	N37273	Boeing	737-824	CLL	√		Position plot shows progression of parallel “stripes”.

5 Summary of Observations

Looking at the data for 12 months, 5468 aircraft were noted using ADS-B (DF-17s). Of those, 2012 (37%) meet the basic criteria for effective operations in a NRA environment during at least one operation. 1700 of those met all criteria in at least 90% of all operations examined.

Looking at position reports and NUC, a six month sample was examined in great detail. 4606 ADS-B aircraft were noted. 1877 (41%) aircraft met the basic criteria, and ALL of these had some operations with NO position anomalies noted. 1700 hundred of these had operations that always had less than 1% position anomalies. 1546 always had operations that had fewer than 1% anomalies in position, NUC and altitude. 826 aircraft had no position, NUC or altitude anomalies. NUCs for the aircraft meeting the basic criteria averaged 6.

Essentially every aircraft type had aircraft that performed extremely well, probably meeting the performance requirements for operations in a NRA or RAD environment. The remainder of the 1877 aircraft that met the basic criteria but had greater than 1% anomalies would appear to have the equipment and on-board connectivity to meet all requirements, but further study would be necessary to figure out the difference between those and the aircraft that had the low error percentages.

From fall 2004 through June 2008, 7829 aircraft had been noted emitting DF 17s. About 100 of these are DO-260A, indicating about 7700 have DO-260 ADS-B capable transponders. About 2000 of these meet the basic criteria leaving ~5700 ADS-B capable aircraft not meeting the basic criteria. It's interesting to consider what it would take to make these aircraft operate correctly. As discussed below, a small number of aircraft types account for a disproportionate number of problems. Therefore, a relatively small effort could have a large impact on identifying and fixing the problems and making a much larger percentage of DO-260 capable aircraft meet the basic requirements.

HTSI examined the reasons aircraft failed to meet the basic criteria. The biggest single problems where: complete lack of position and velocity information, NUCs of zero, position errors and altitude errors. The aircraft with no position data may be of little interest to further study, they may not have a GPS source (although it might be worthwhile to do a survey to determine this).

Of the remaining aircraft that appear to have all the required data sources, these aircraft types had the most offenders:

- NUCs only Zero:
  - Boeing 767: 163 aircraft
  - Boeing 757: 135 aircraft
  - Boeing 777: 84 aircraft
  - Airbus A300: 70 aircraft
- Serious Position errors:
  - CL 60: 44
  - Gulfstream 5: 64

The CL 60 and GLF5 also have a significant number of serious altitude anomalies. It should be noted that this handful of aircraft types account for a significant percentage of the anomalies seen.

6 Conclusions

Given that some anomalies will always be present, somewhere between 1500 and 2500 aircraft in operation today in the US, equipped with DO-260 capable transponders, would seem to meet the basic ADS-B requirements for operations in the NRA or RAD environment.

Some 5500 other aircraft have DO-260 capable transponders but do not meet the basic criteria. The major problems seem to be: lack of position data, NUCs of only zero, a large number of position anomalies, and significant altitude problems. A small percentage of aircraft types account for a much larger percentage of the problems.

From the data transmitted from the aircraft, it is not possible to determine why some aircraft do not operate correctly. Is it the data sources (e.g. GPS unit), a connection issue (i.e. through an FMS), or an issue with the transponder itself? The only way to find out will be to get together with the transponder manufacturers, the aircraft manufacturers and the owner/operators to figure out how this equipment is being installed, connected and set-up. Such an exercise could also identify the rough cost of any required modifications and assist in determining key issues in developing a certification plan.

7 Recommendations

The data evaluation conducted found that virtually every aircraft type had examples that worked almost perfectly, and examples that were seriously flawed. While some educated guesses can be made about some of the issues, the ADS-B data transmitted from the aircraft is not adequate to determine what the causes the problems and issues.

What is clear is that there are a handful of aircraft types that have lots of problems. These are major aircraft types with literally hundreds of airframes with problems. These problems are in two major groups (assuming position data is available): NUCs of zero and data anomalies (position, NUC, or altitude anomalies). A detailed examination of just a handful of aircraft types would have a significant payoff in defining exactly what the problems are, what the fixes are, and at least a general idea of the cost to fix the problems. The problems found on this limited survey would probably be applicable to most (if not all) of the other aircraft with NUC, position or altitude problems.

The airframes with significant issues are: Boeing heavy jets, Airbus A300, Gulfstream 5 and Canadair CL 60.

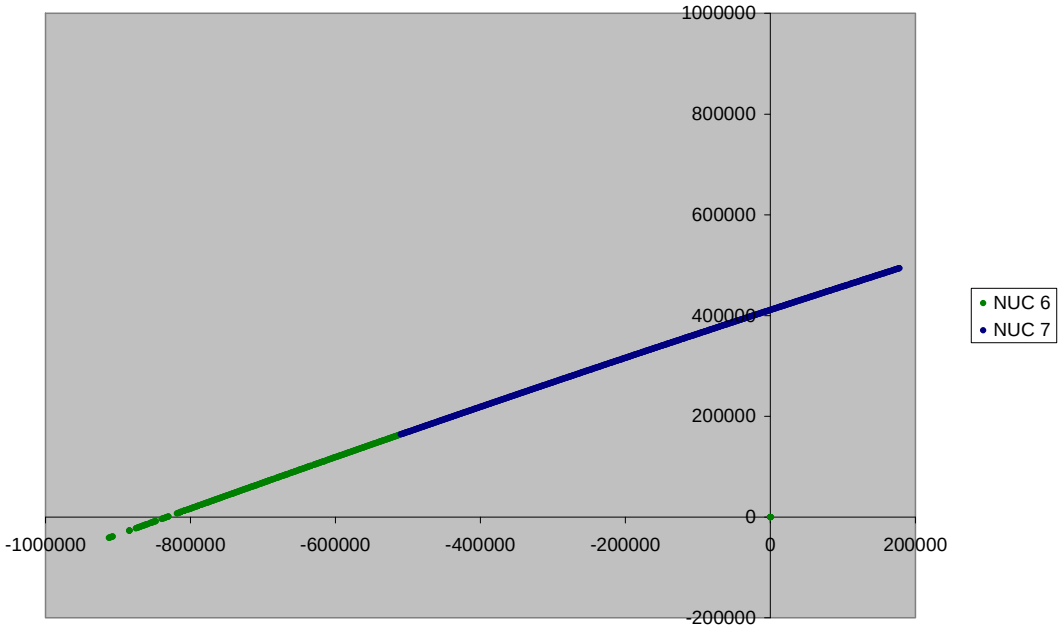
HTSI therefore recommends the following:

8. Determine the primary (largest) operators of the problem aircraft;
    a. Build list of problem airframes by operator
9. Solicit the assistance of the operators in determining the problems/issues:
    a. Possibly with the assistance of the ARC members
    b. Involve AVS
10. Determine the equipage of the aircraft with problems:
    a. Make, model and revision status of transponder/TCAS
    b. GPS equipage
        i. Determine if meets relevant MOPS for ADS-B
    c. Other relevant equipage
        i. FMS
        ii. Altimeter (blind encoder, etc.)

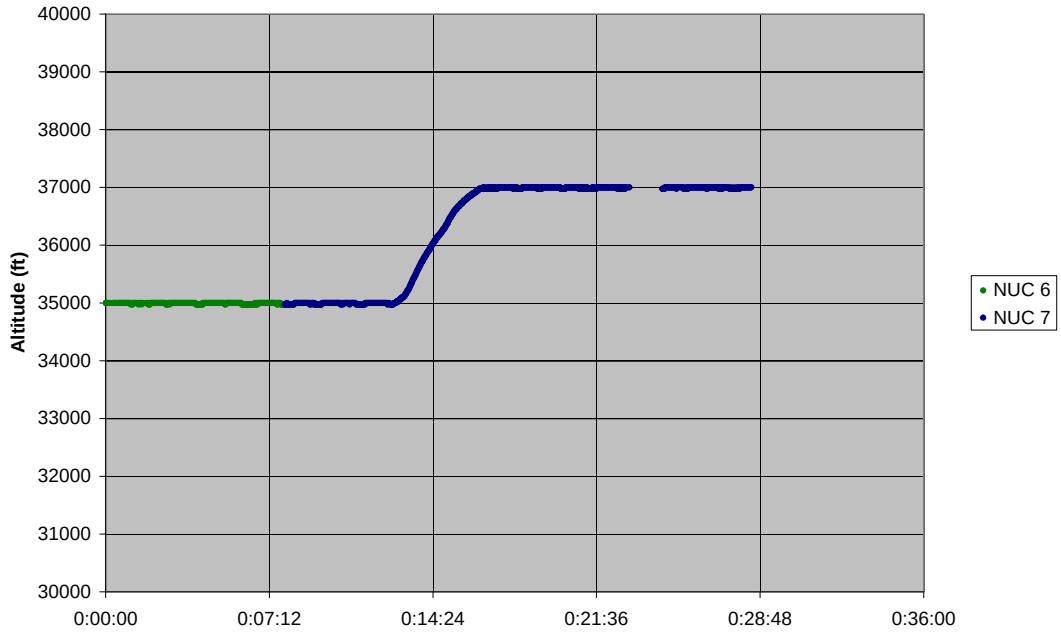
    d. Determine connectivity to transponder/TCAS
        i. GPS
        ii. FMS
        iii. Altitude data source
11. Solicit the assistance of the transponder/TCAS manufacturer
12. Determine what is required to make the system components work IAW basic requirements or subsequent requirements documents.
    a. Equipment (e.g. GPS)
    b. Cabling/connectivity
    c. Software/firmware upgrade.
    d. Documentation or documentation modifications.
13. Roughly estimate direct cost to upgrade.
14. Make sure that the certification process addresses the types of anomalies identified in this analysis.
    a. Certification will not be a bench test process. Many of the anomalies seen here may not be testable in a bench or ground test. Specific performance criteria can be developed along with a methodology to collect and analyze the data during normal flight or ground movement and report in a near real-time process on an operation by operation basis.

Appendix A – Aircraft Plots

ALX - AFR031

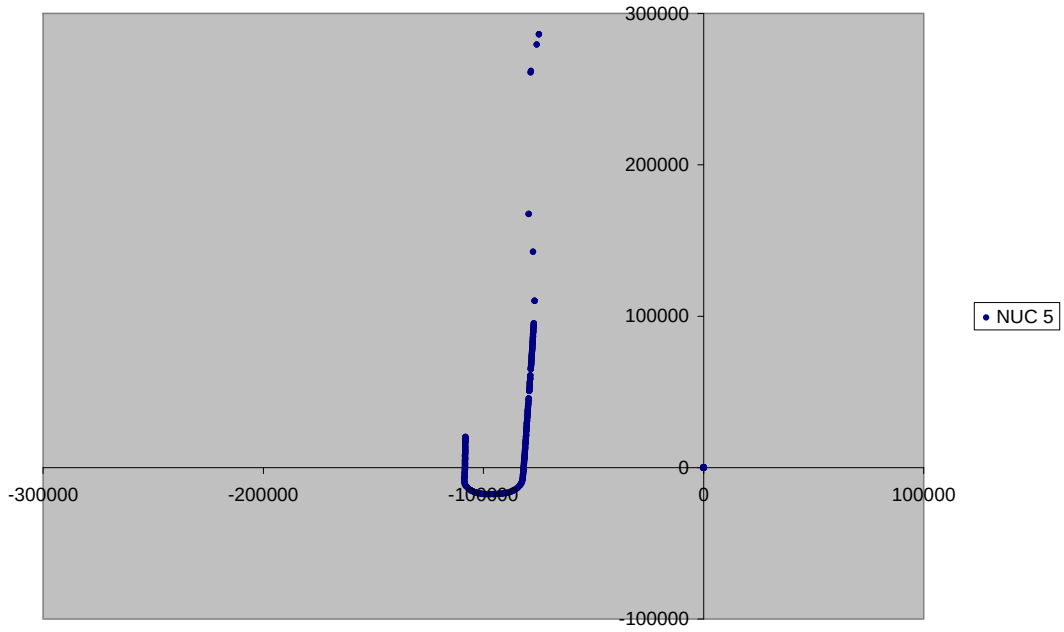


ALX - AFR031



- ❑ X/Y data appears to form a reasonable track
- ❑ Altitudes appear to be reasonable

ALX - DLH414



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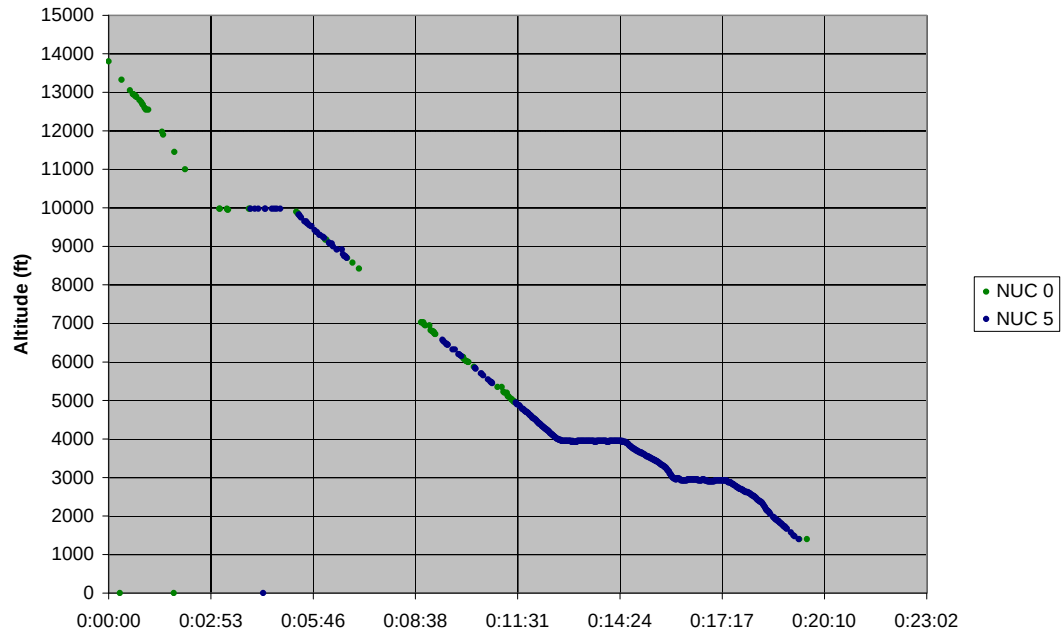
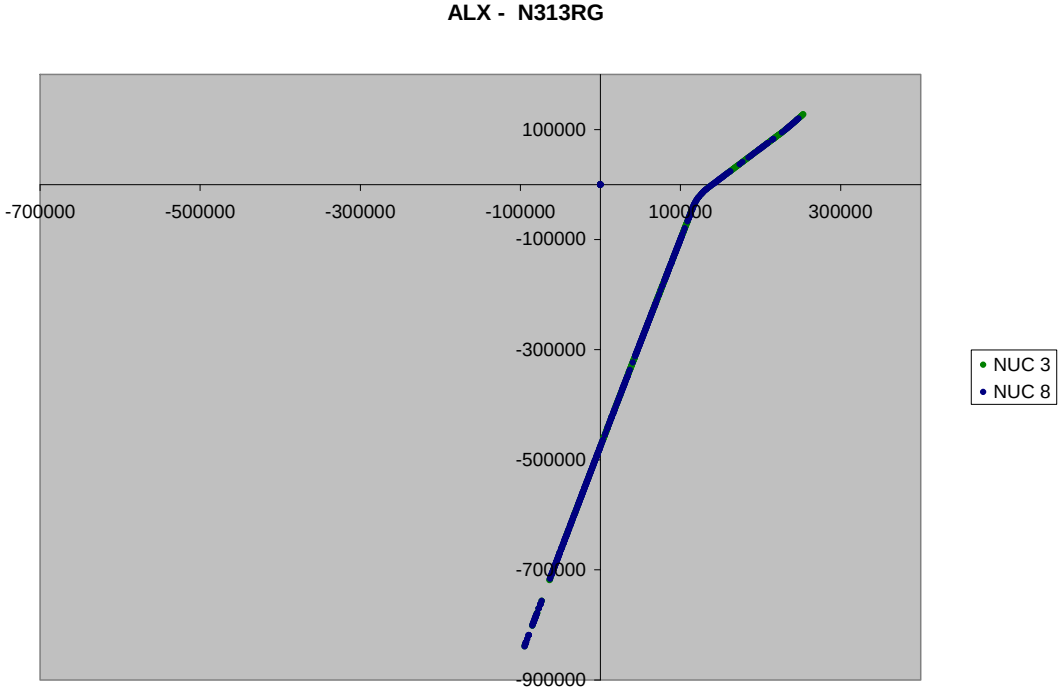
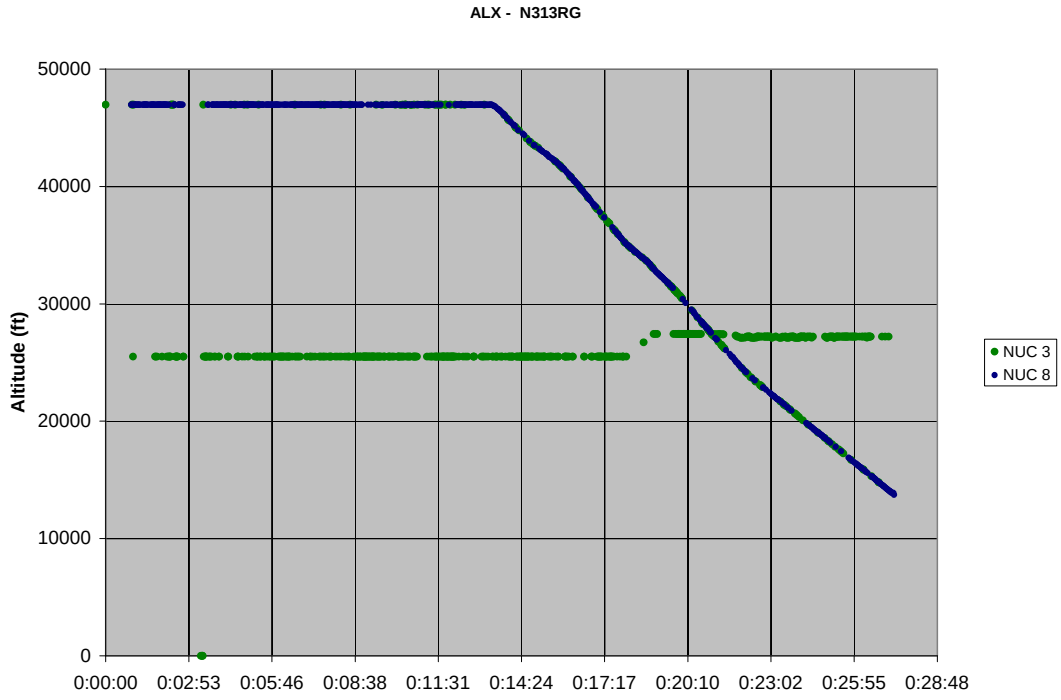


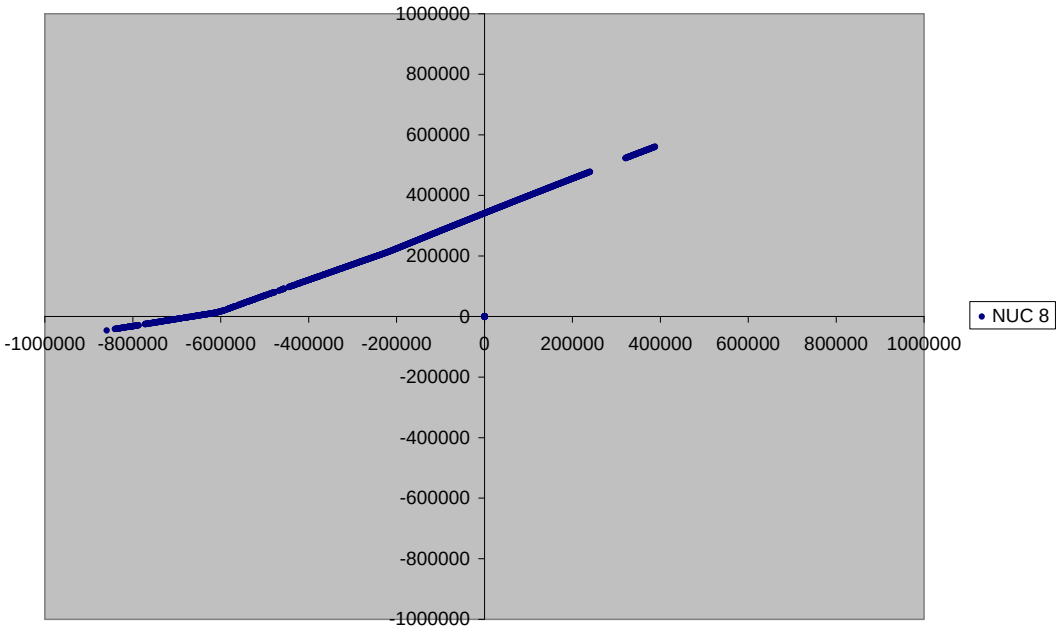
- ❑ X/Y data appears to form a reasonable track
- ❑ Altitudes appear to be reasonable



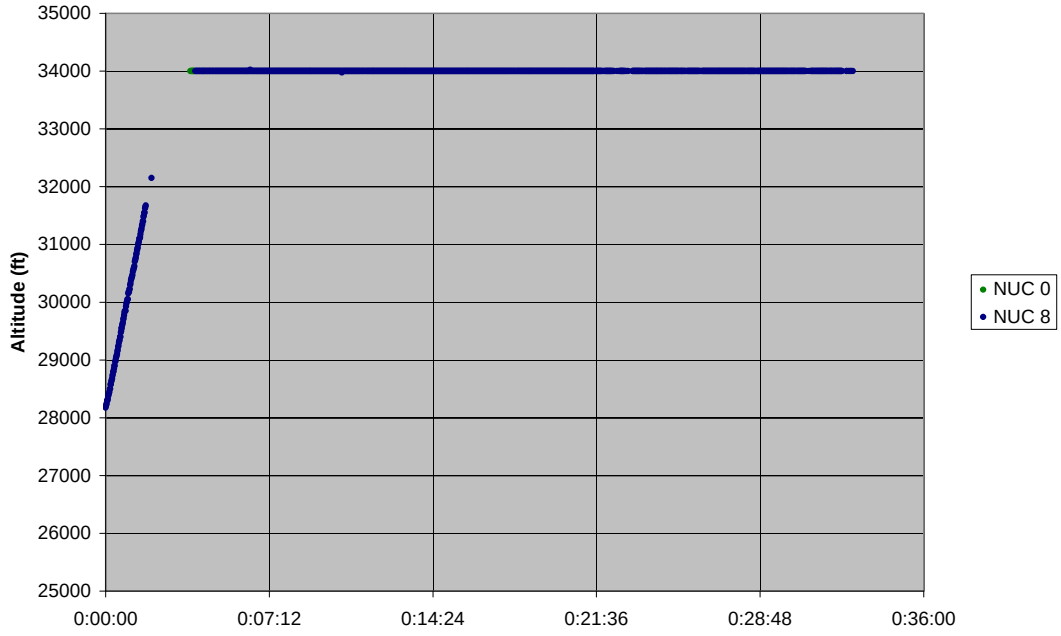


- ❑ X/Y data appears to form a reasonable track
- ❑ Altitudes shows significant errors that correlate to low NUC values

ALX - N449UP

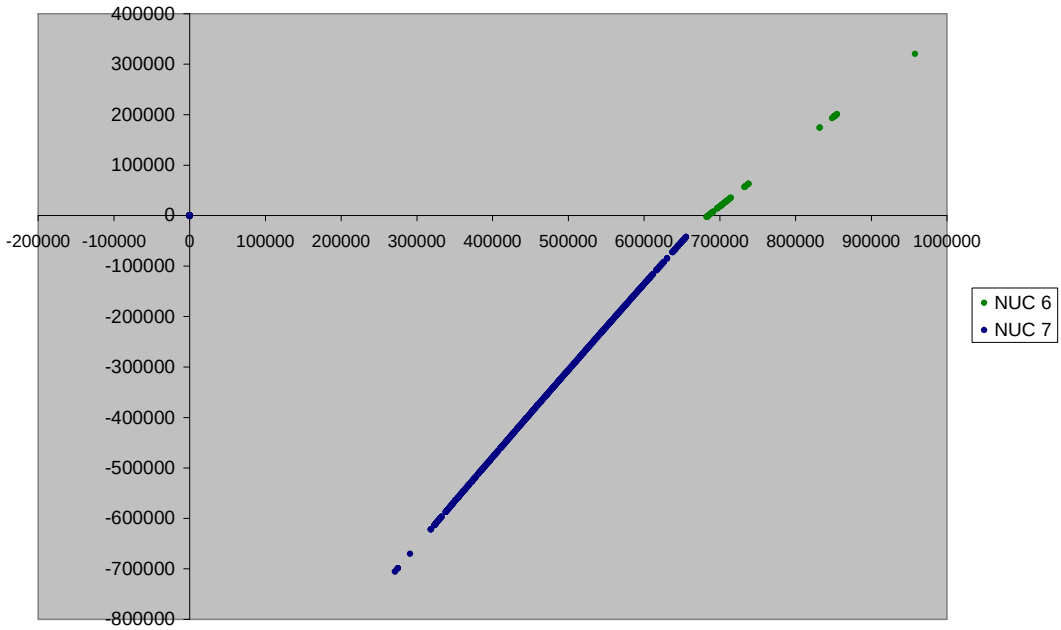


ALX - N449UP



- ❑ X/Y data appears to form a reasonable track
- ❑ Altitudes appear to be reasonable

ALX - N505NK



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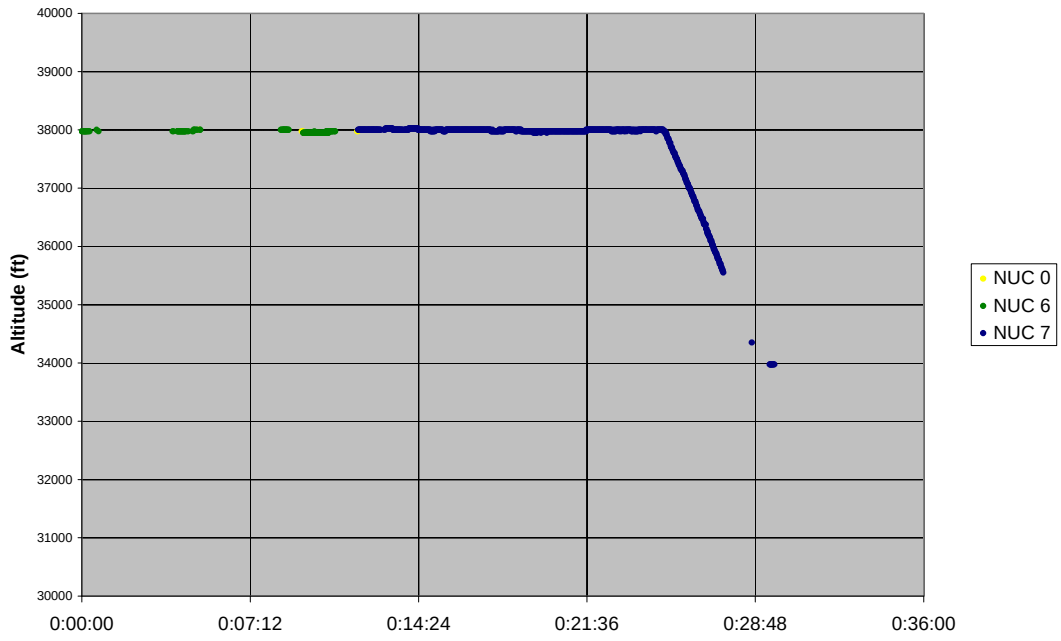

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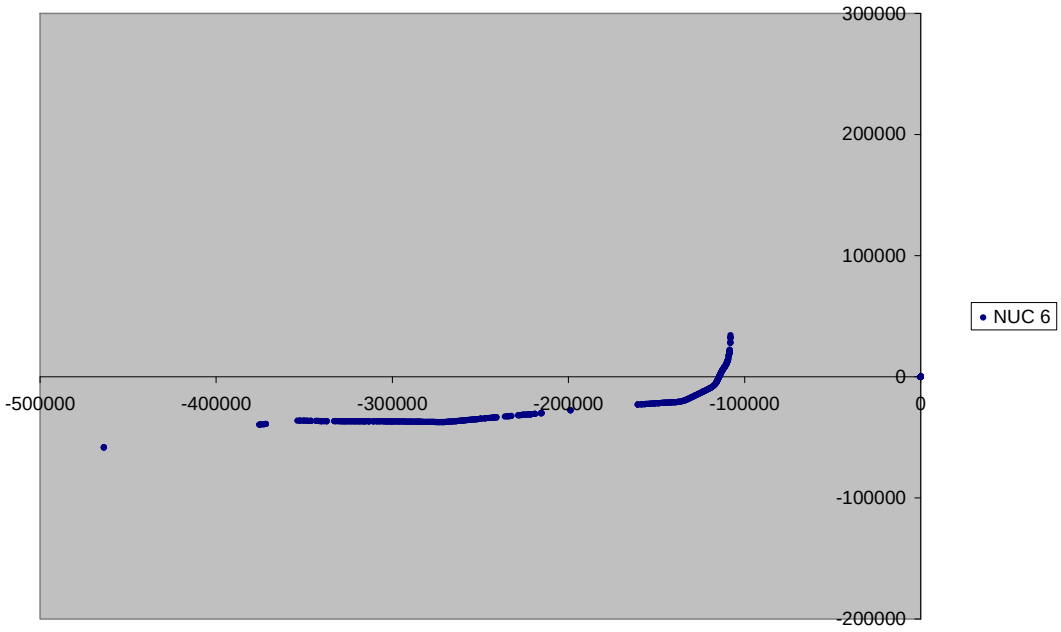
- ❑ Altitudes appear to be reasonable

ALX - N526VA



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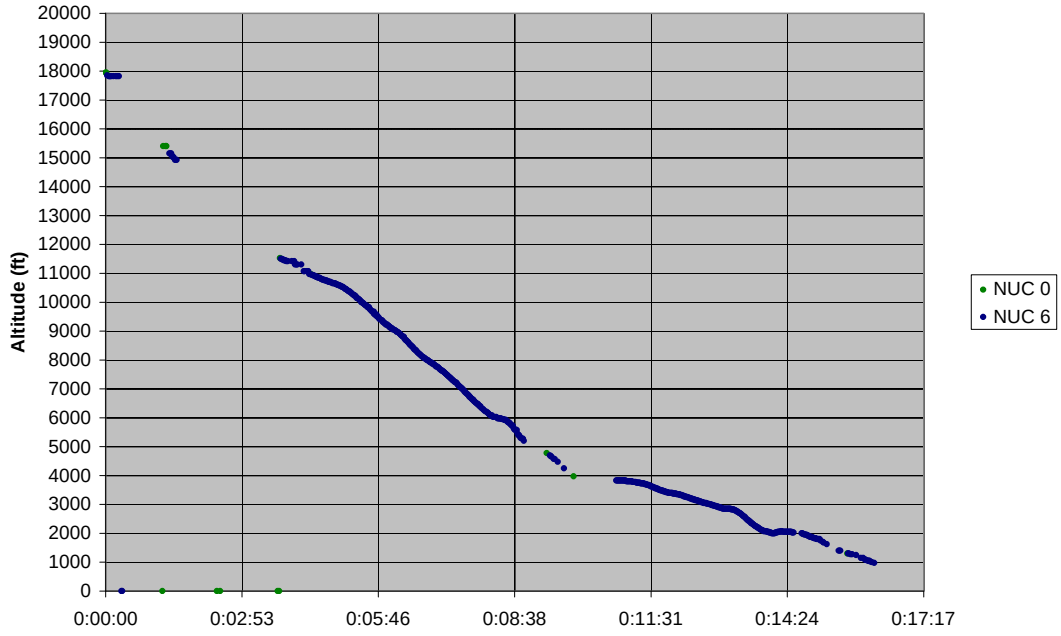

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- ❑ Altitudes appear to be reasonable

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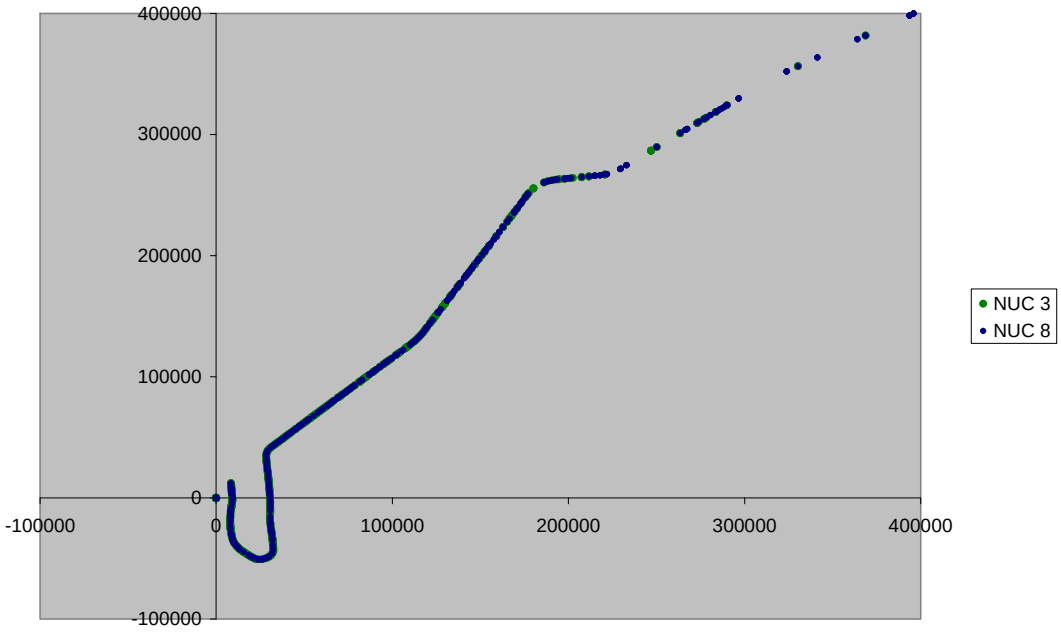

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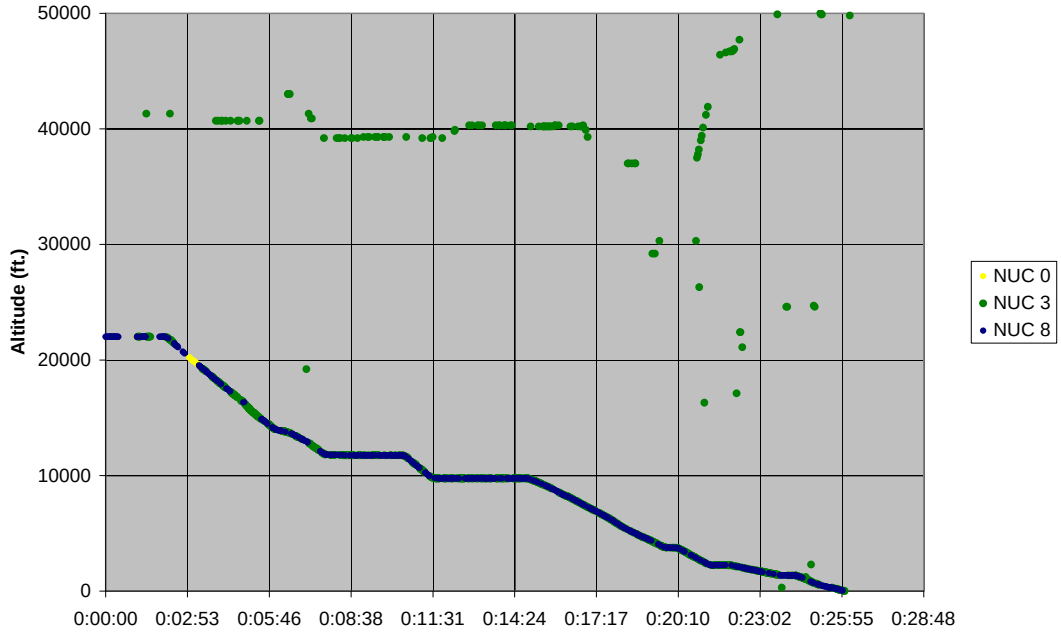
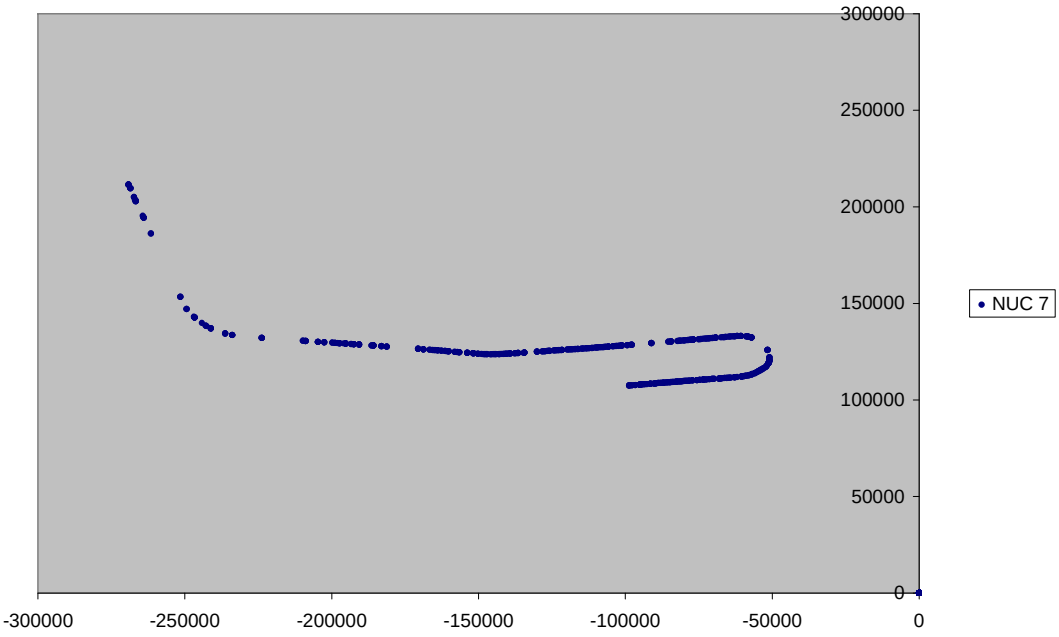


- ❑ X/Y data appears to form a reasonable track
- ❑ Altitudes shows significant errors that correlate to low NUC values

HBC - ANA6



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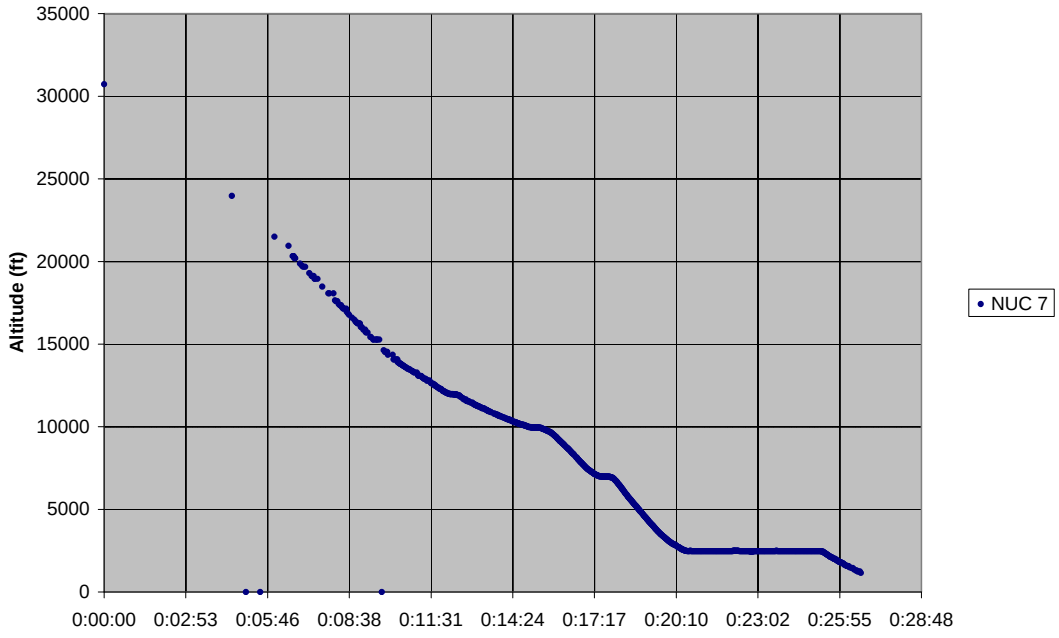

- ❑ X/Y data appears to form a reasonable track
- ❑ Altitudes appear to be reasonable

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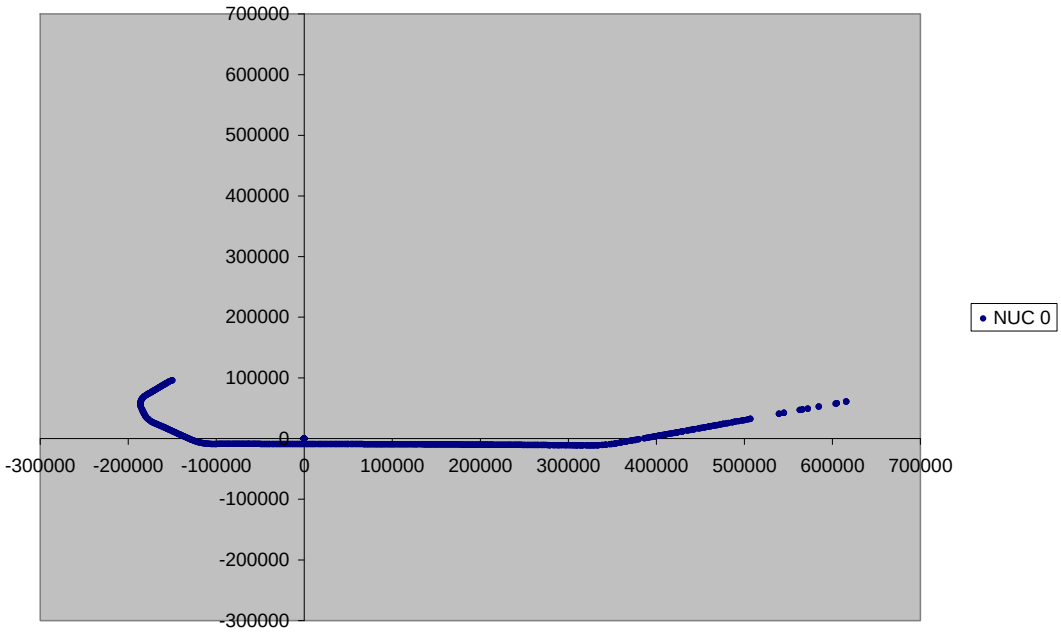

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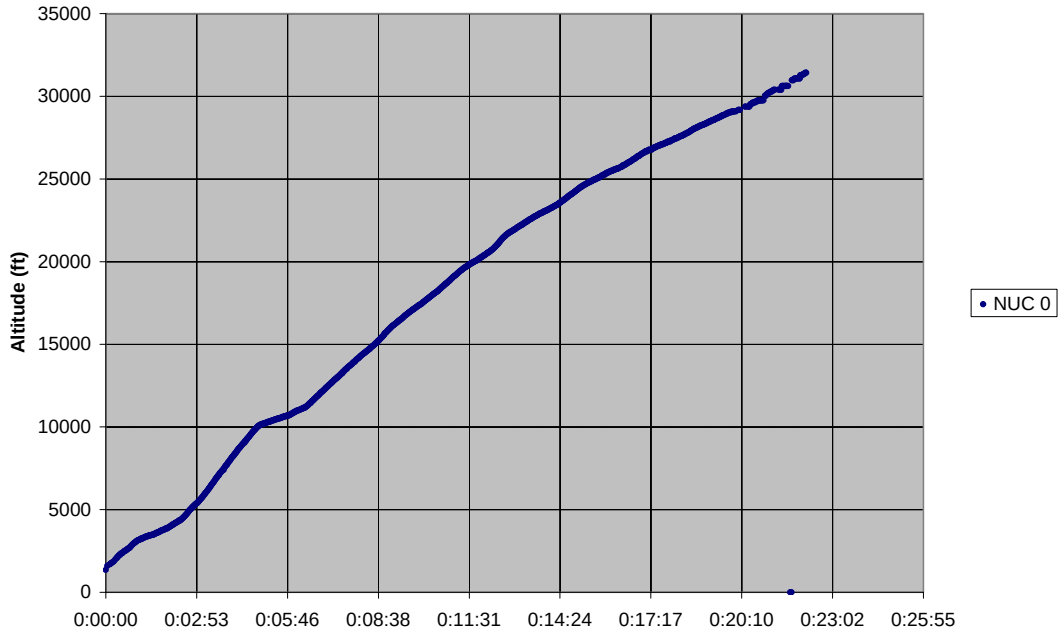
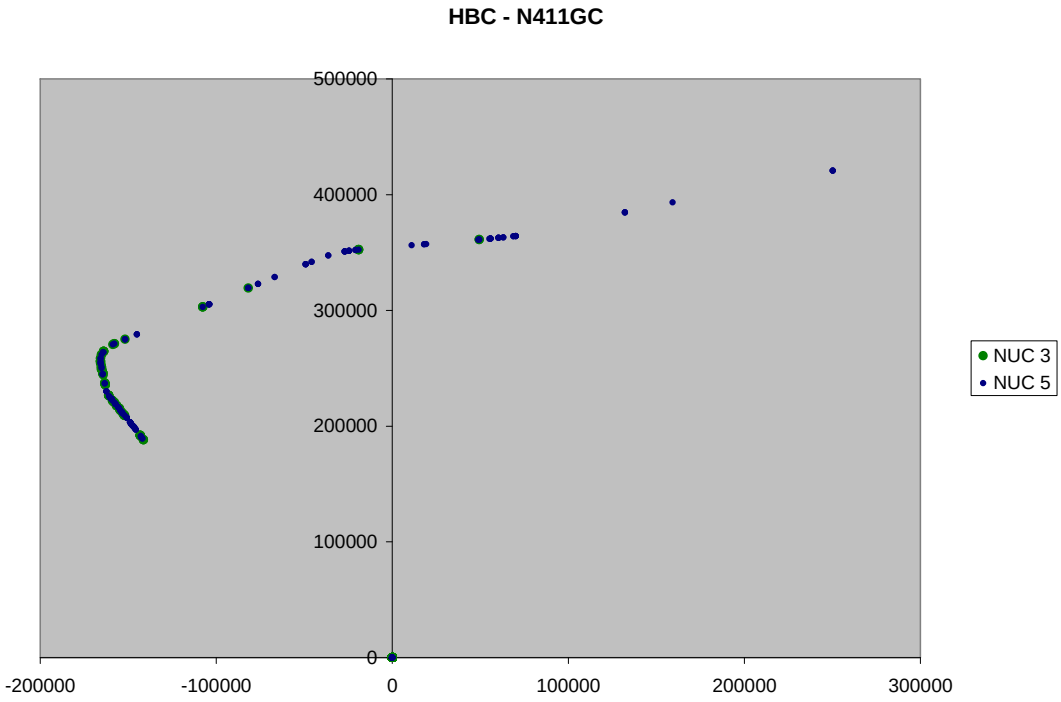
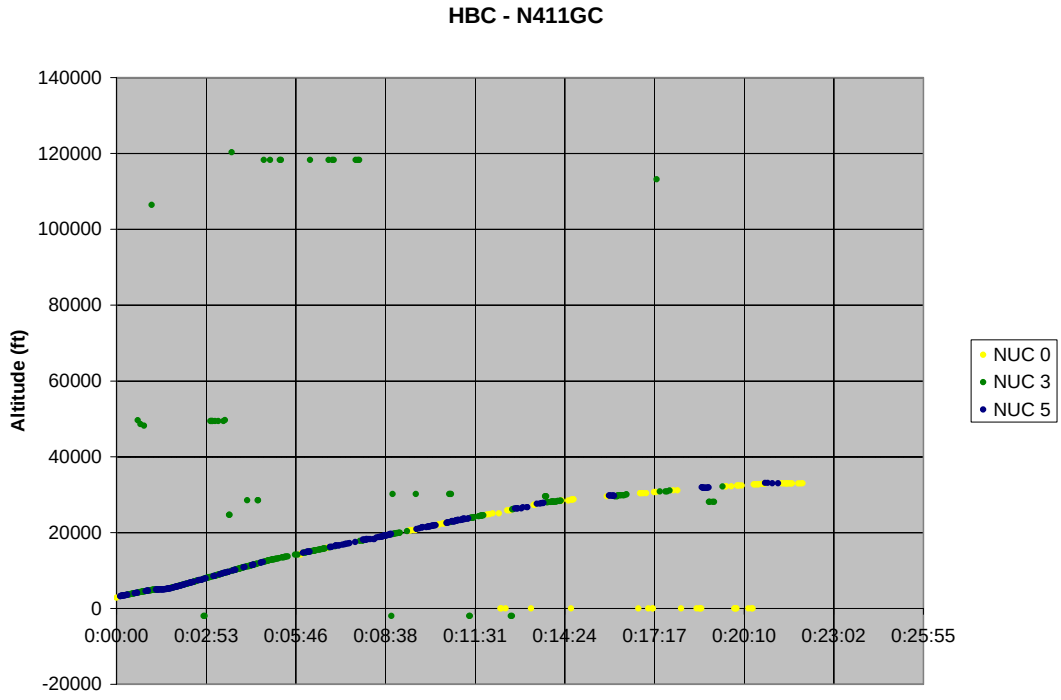
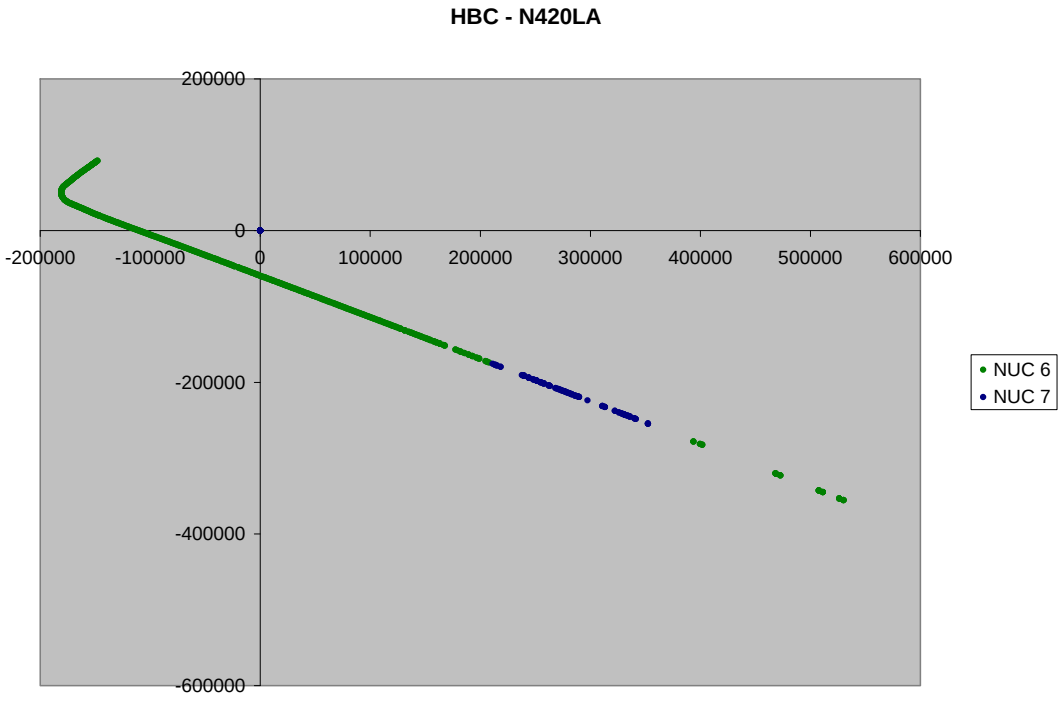


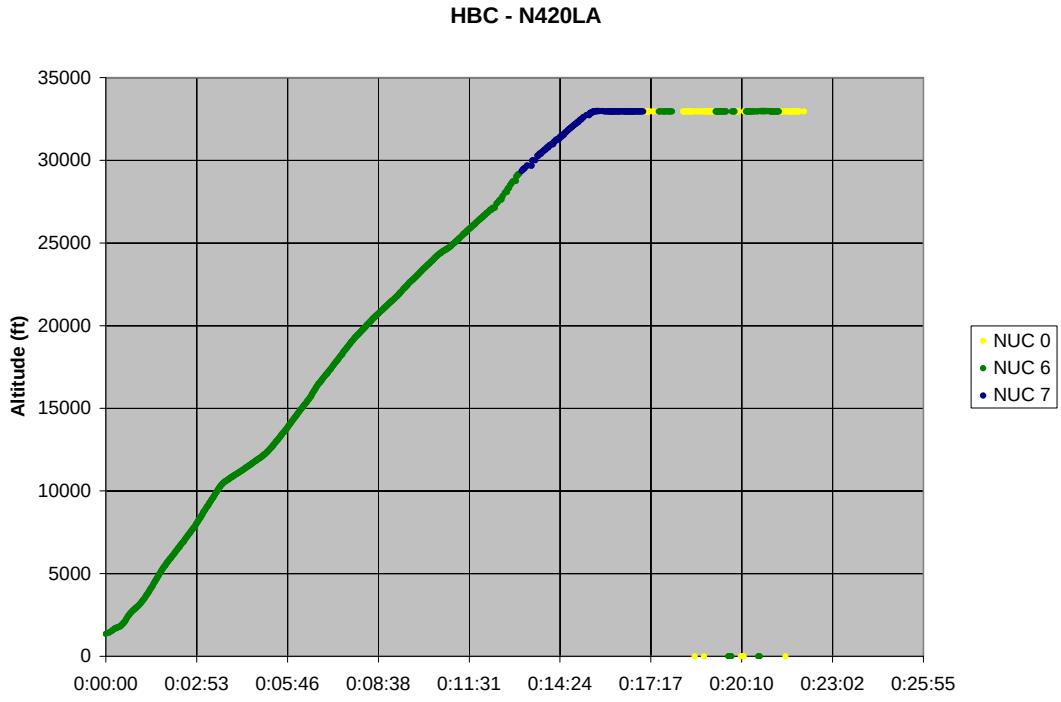
- ❑ X/Y data appears to form a reasonable track
- ❑ Altitudes appear to be reasonable



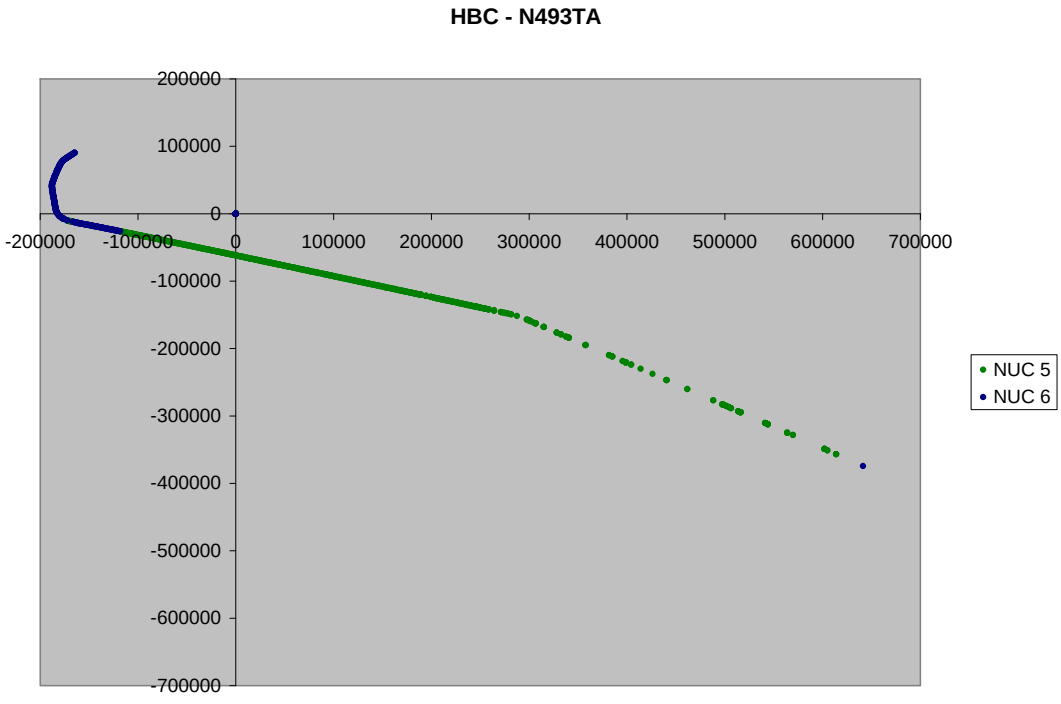


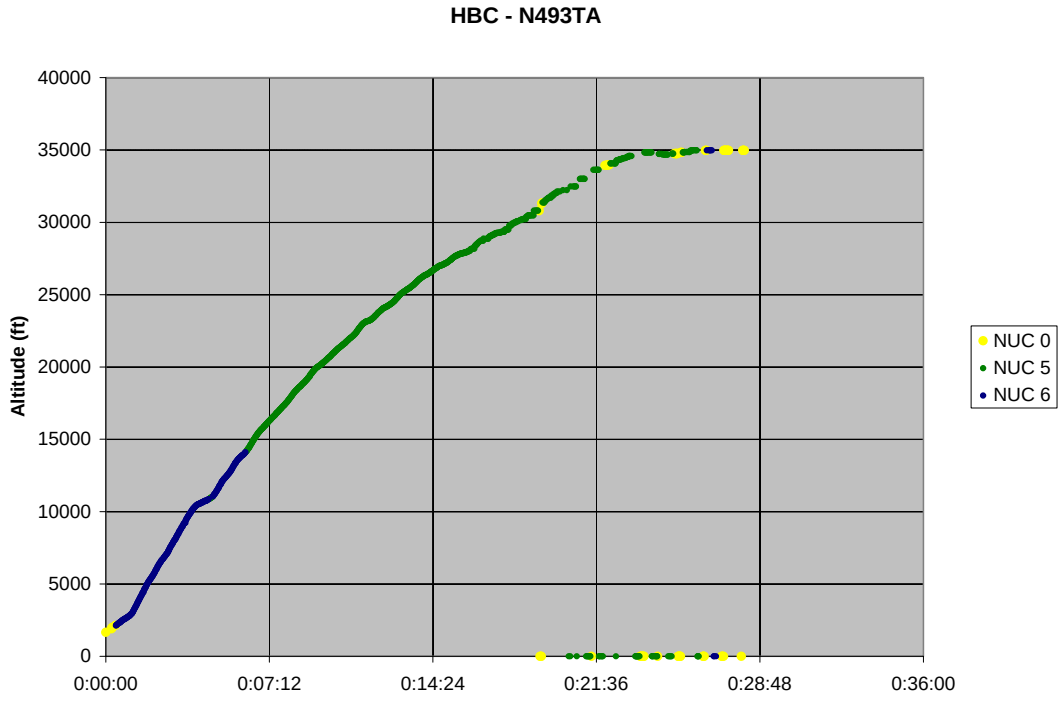
- ❑ X/Y data appears to form a reasonable track
- ❑ Altitudes shows significant errors that correlate to low NUC values



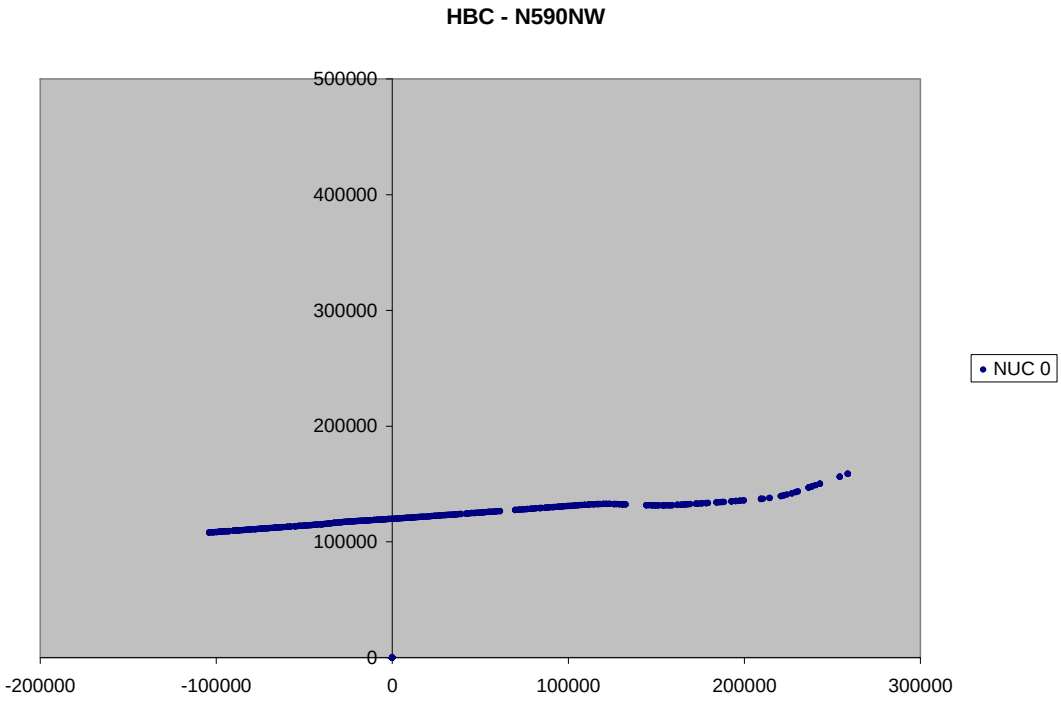


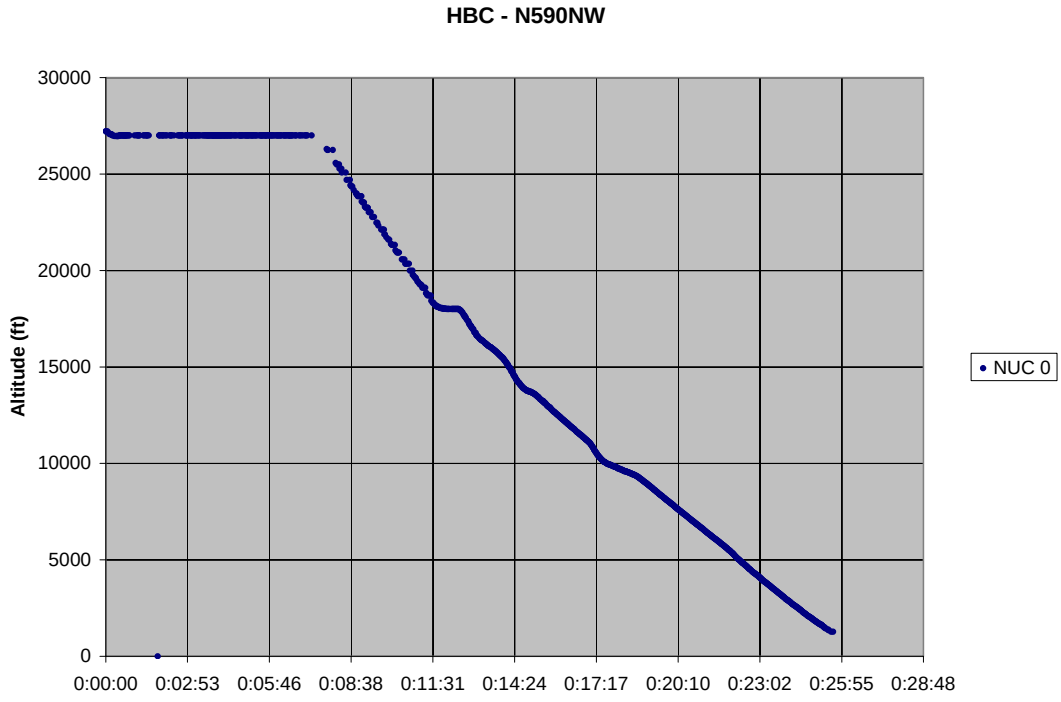
- ❑ X/Y data appears to form a reasonable track
- ❑ Altitudes appear to be reasonable



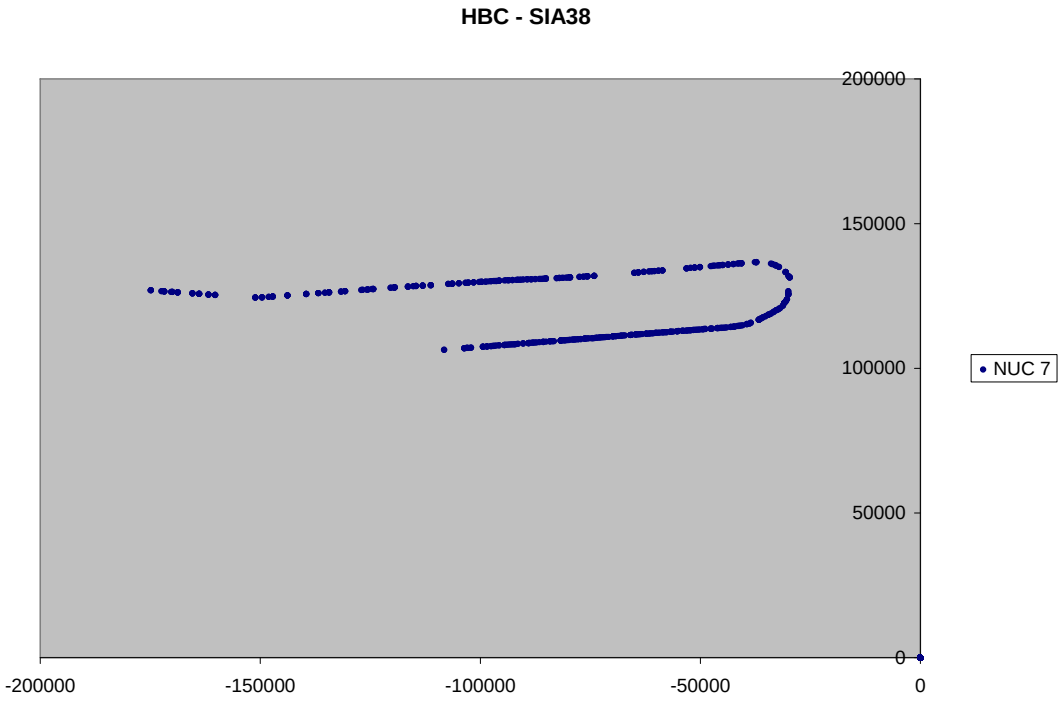


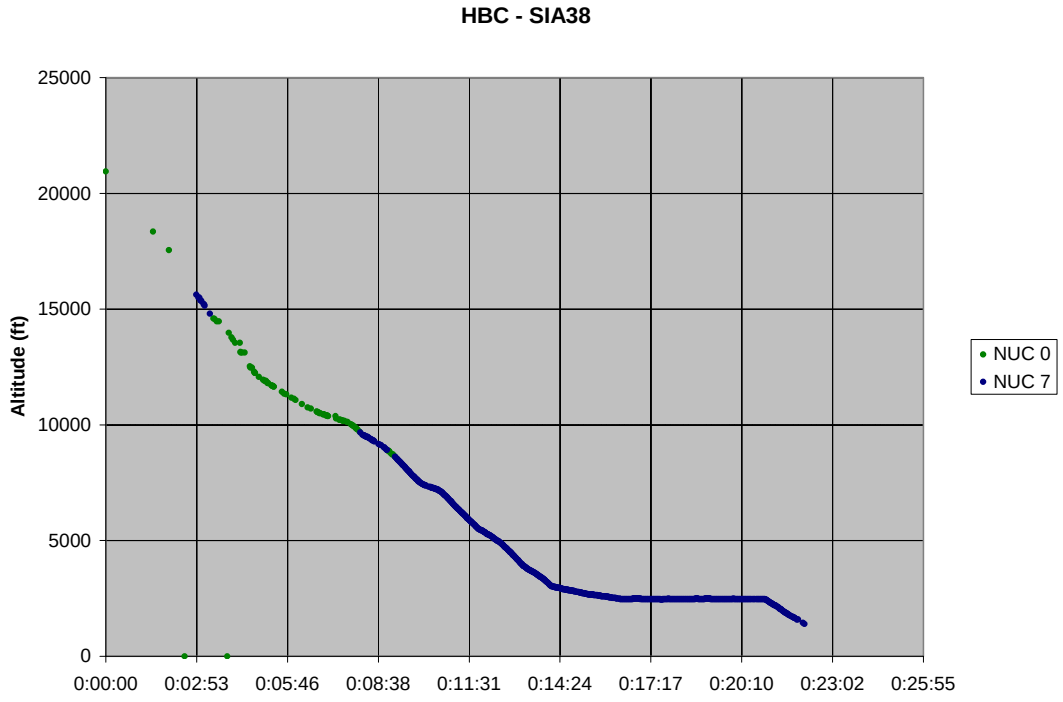
- ❑ X/Y data appears to form a reasonable track
- ❑ Altitudes appear to be reasonable – some zero altitudes that may be due to time-outs in the data set



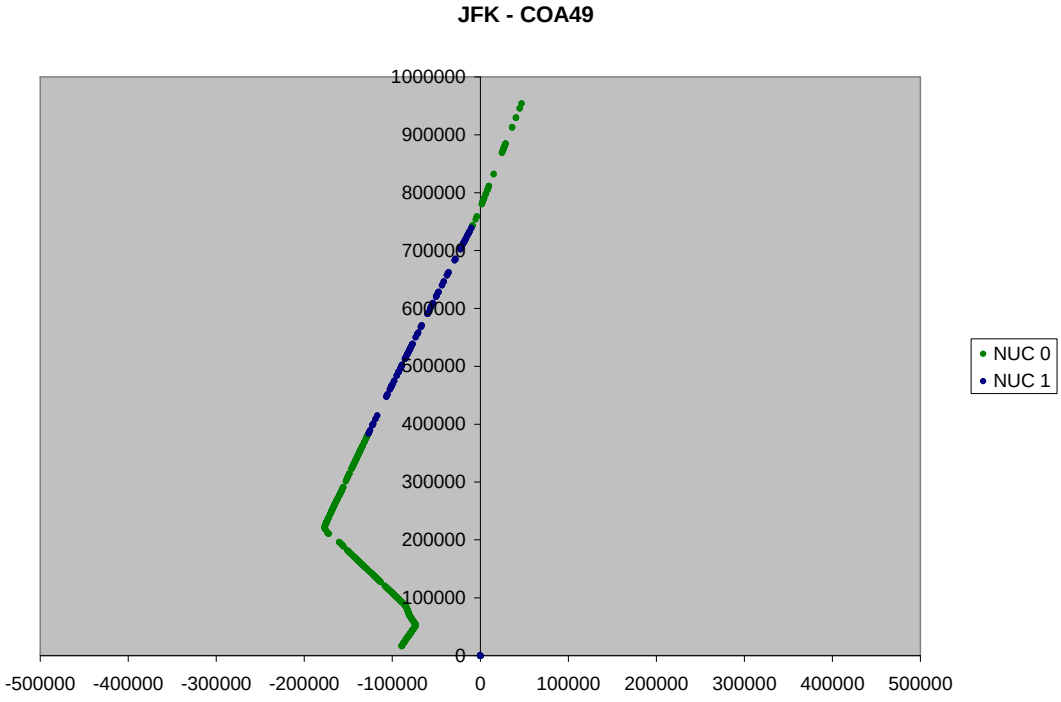


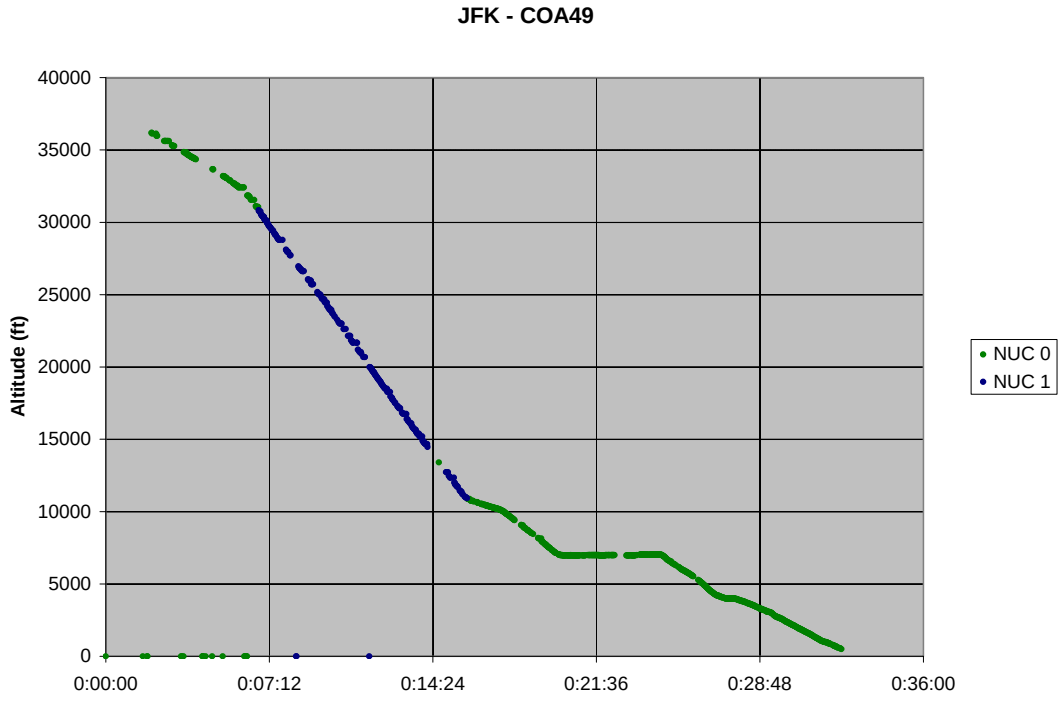
- ❑ X/Y data appears to form a reasonable track
- ❑ Altitudes appear to be reasonable



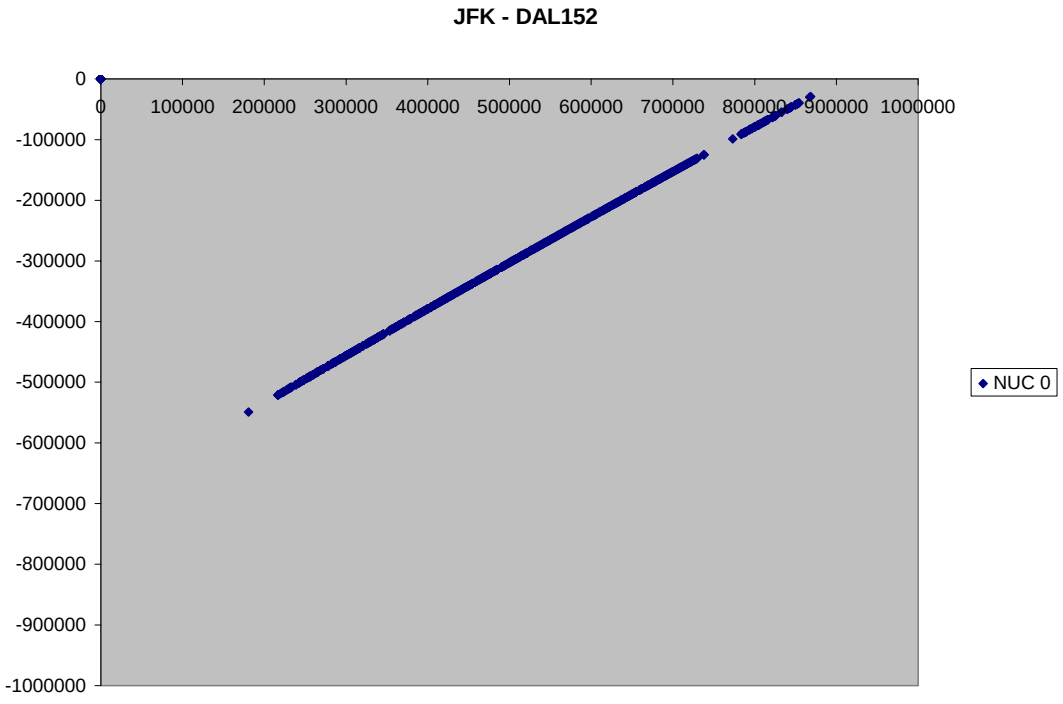


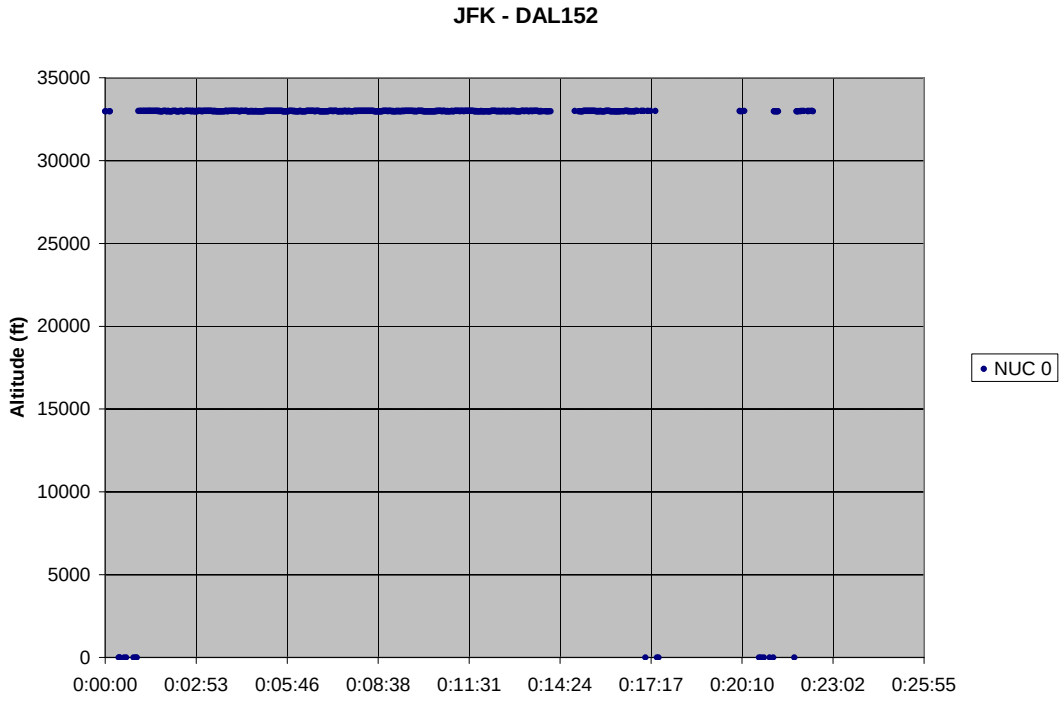
- ❑ X/Y data appears to form a reasonable track
- ❑ Altitudes appear to be reasonable





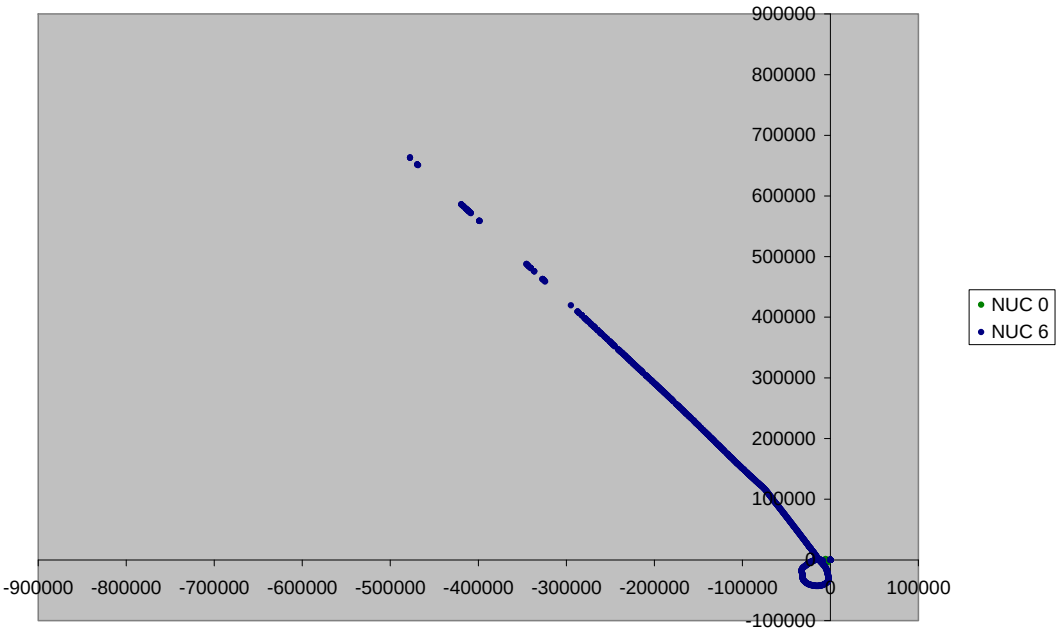
- ❑ X/Y data appears to form a reasonable track
- ❑ Altitudes appear to be reasonable



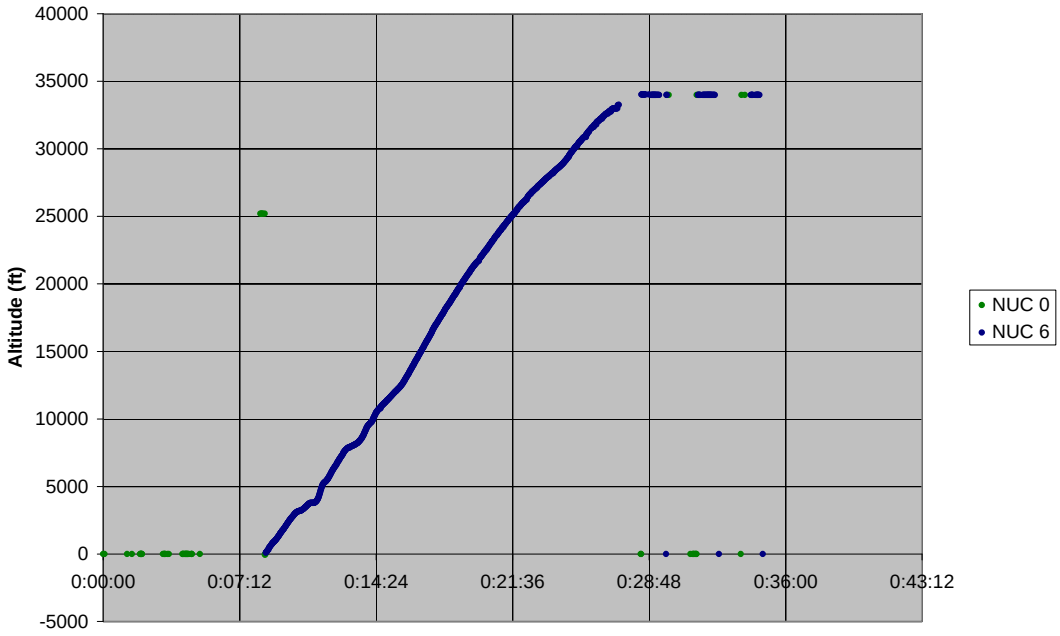


- ❑ X/Y data appears to form a reasonable track
- ❑ Altitudes appear to be reasonable

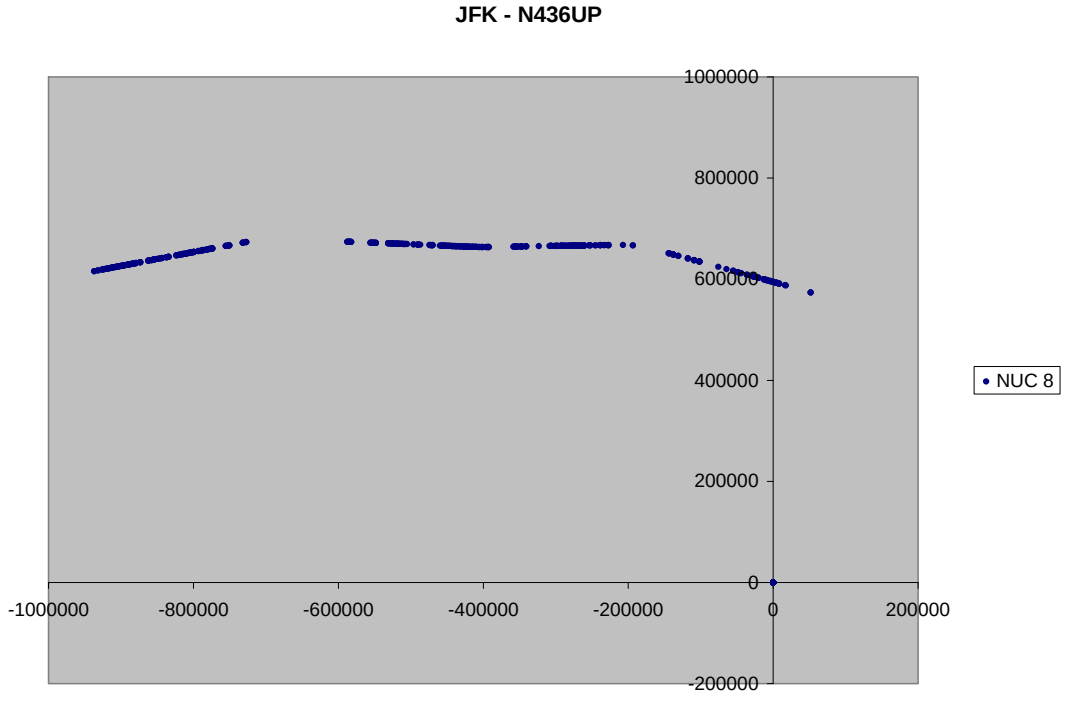
JFK - KAL258

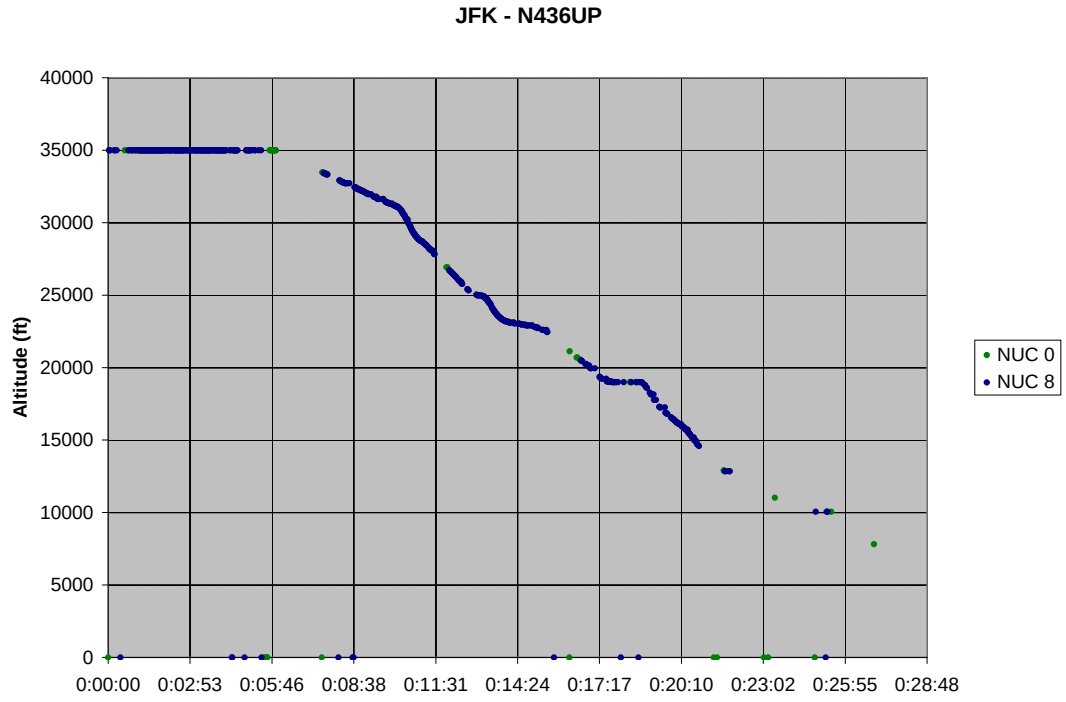


JFK - KAL258



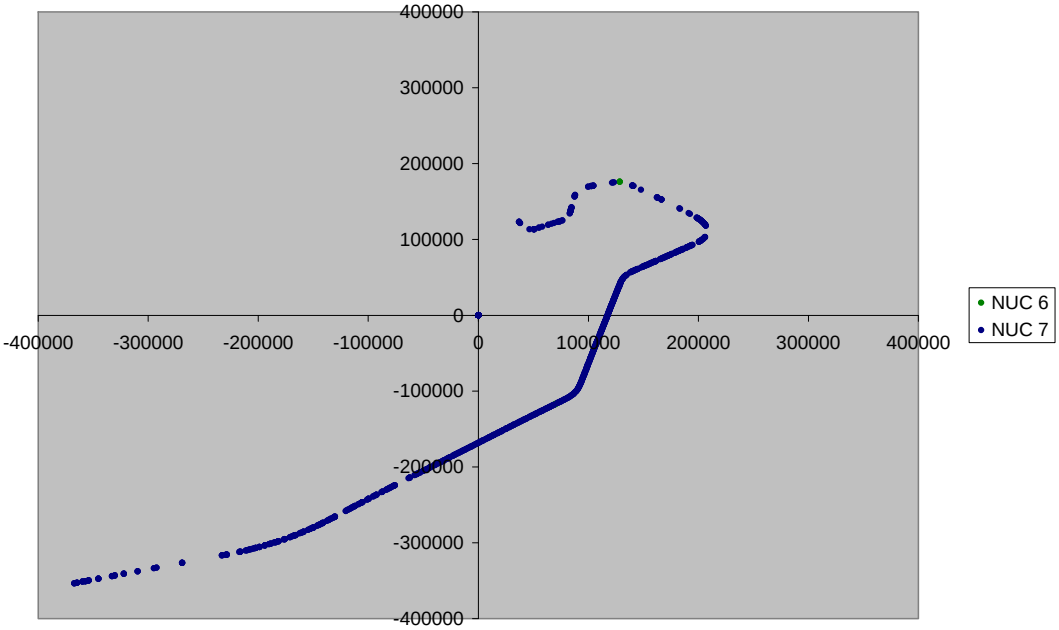
- ❑ X/Y data appears to form a reasonable track
- ❑ Altitudes appear to be reasonable





- ❑ X/Y data appears to form a reasonable track
- ❑ Altitudes appear to be reasonable

JFK - N637JB



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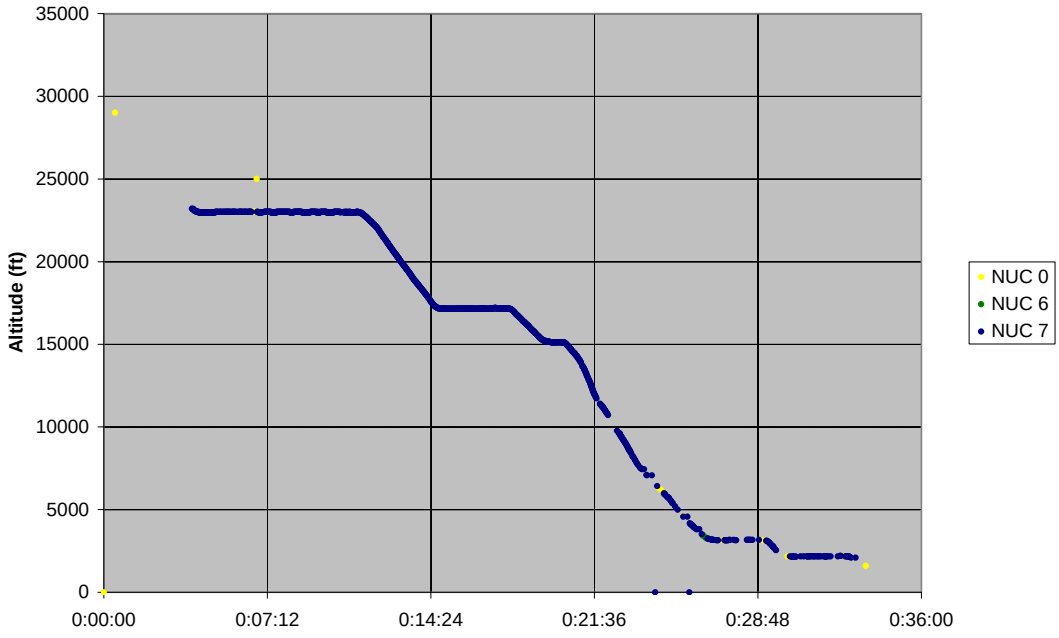
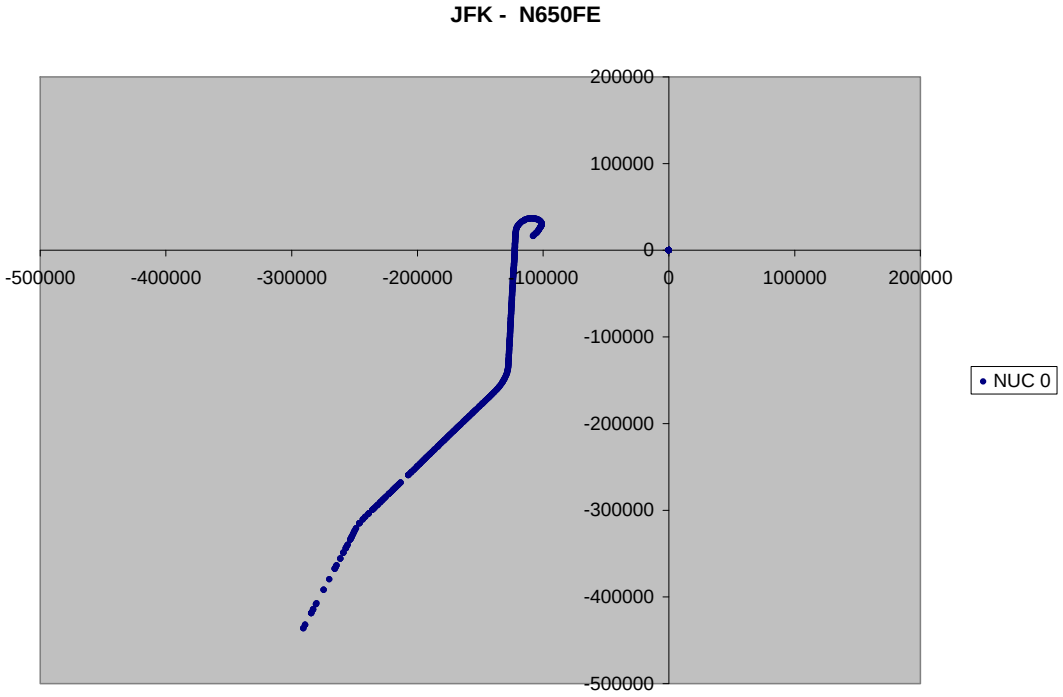
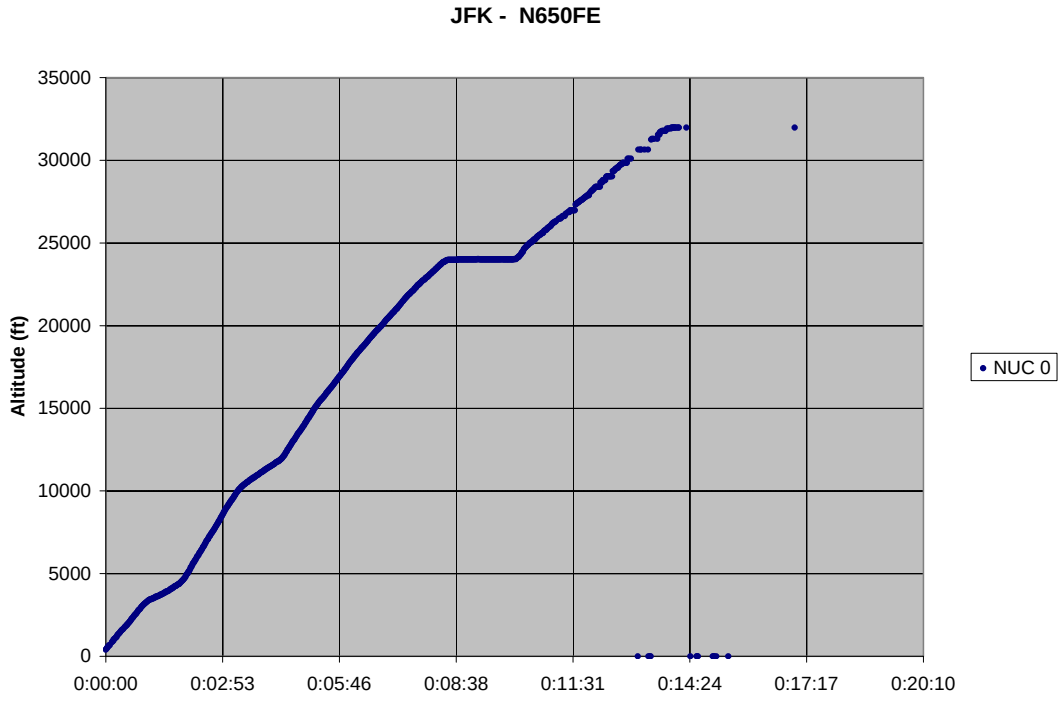
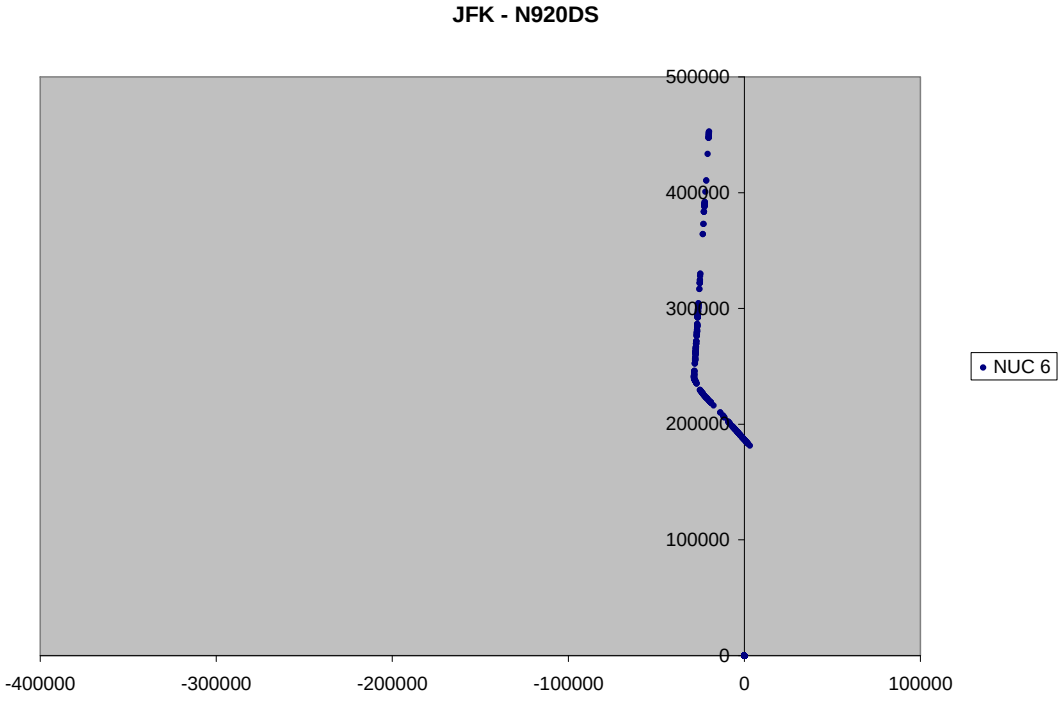


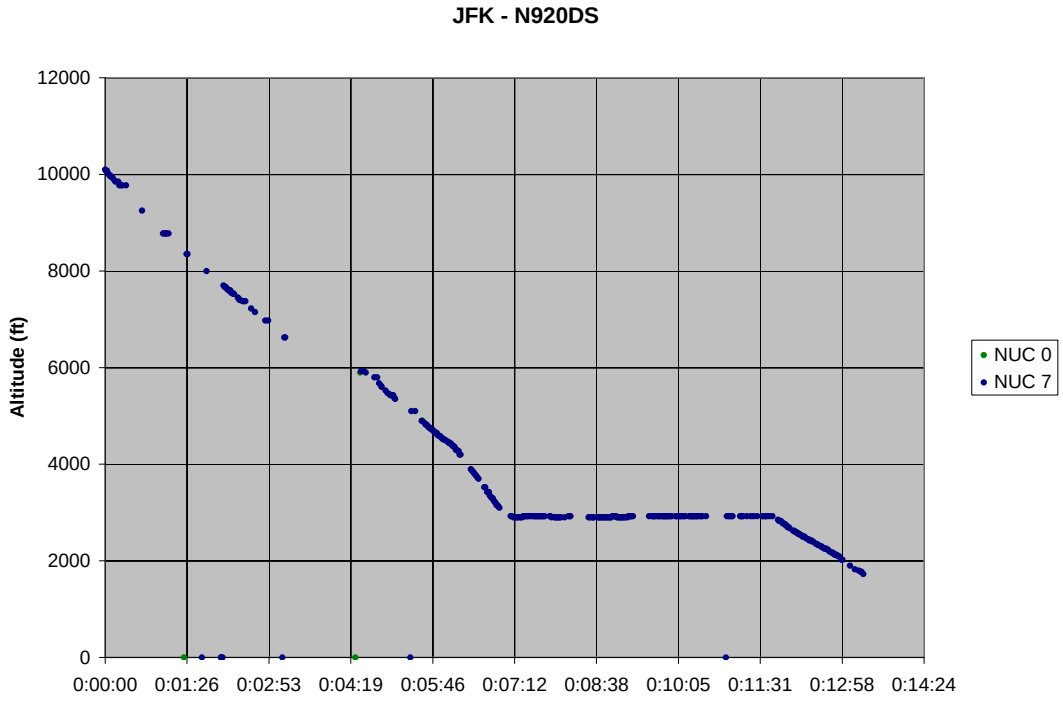
- ❑ X/Y data appears to form a reasonable track
- ❑ Altitudes appear to be reasonable





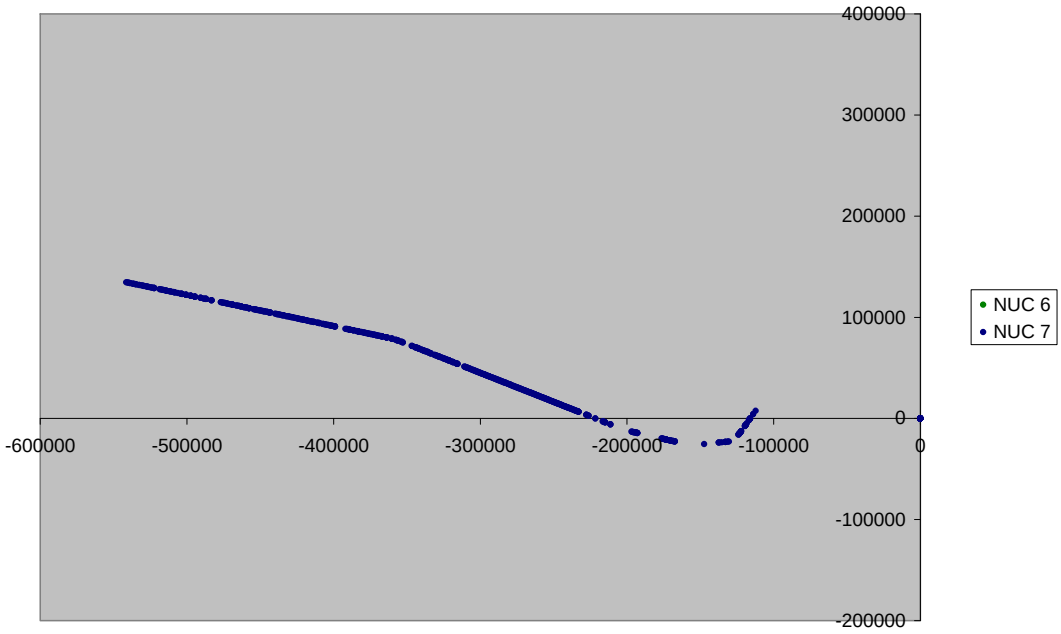
- ❑ X/Y data appears to form a reasonable track
- ❑ Altitudes appear to be reasonable



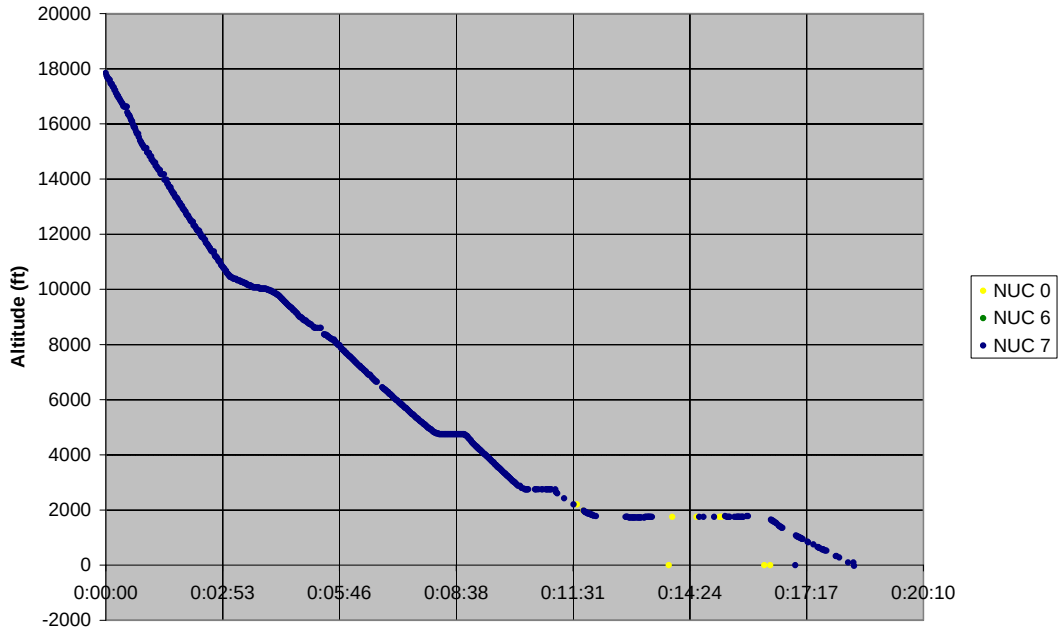


- ❑ X/Y data appears to form a reasonable track
- ❑ Altitudes appear to be reasonable

JFK - N37277

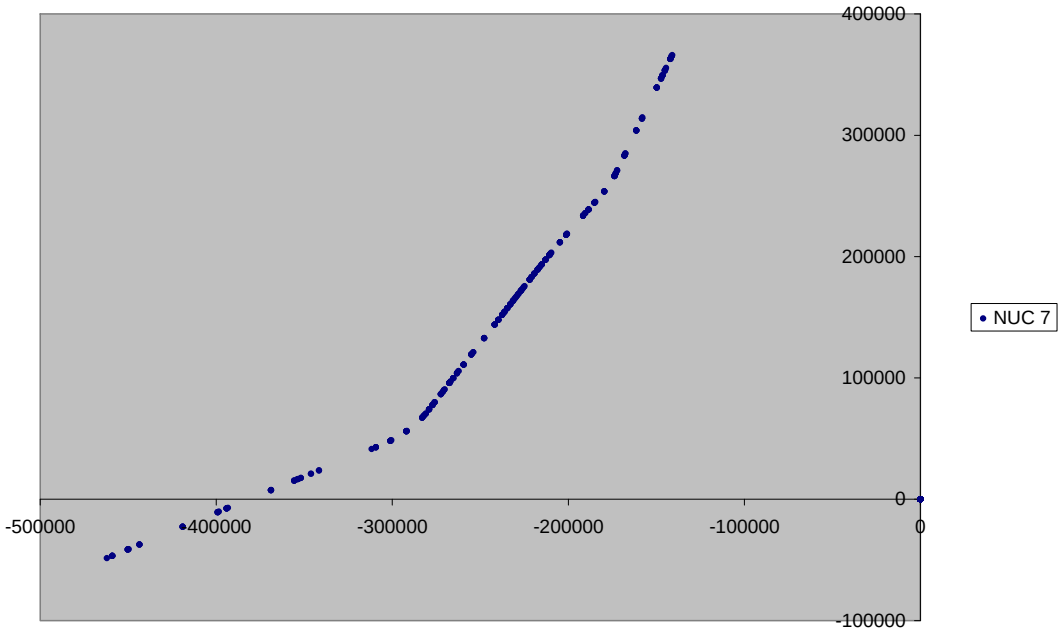


JFK - N37277



- ❑ X/Y data appears to form a reasonable track
- ❑ Altitudes appear to be reasonable

JFK - QTR051



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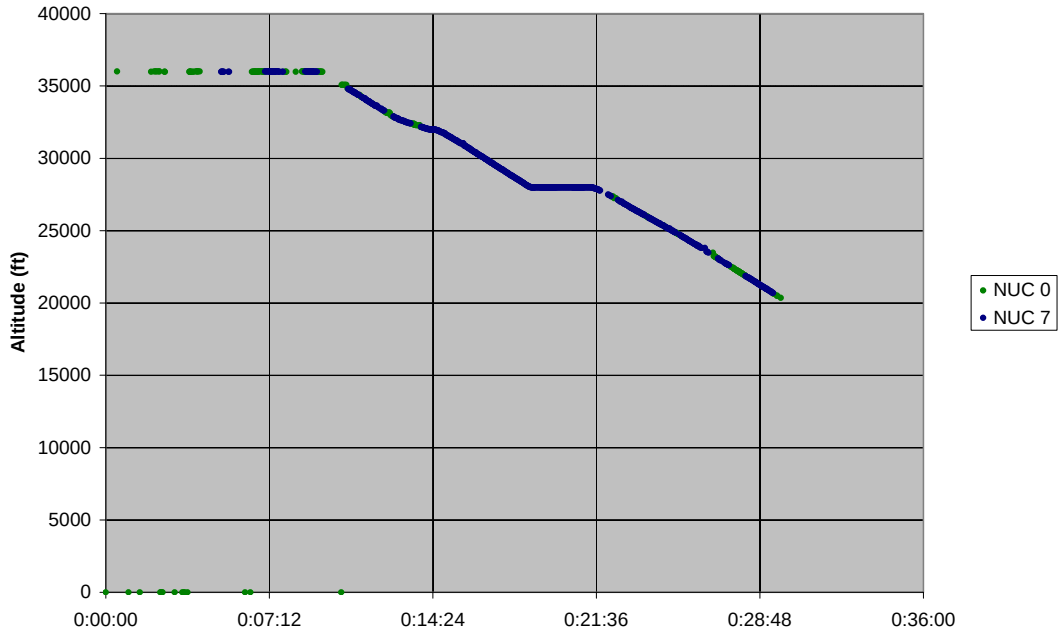
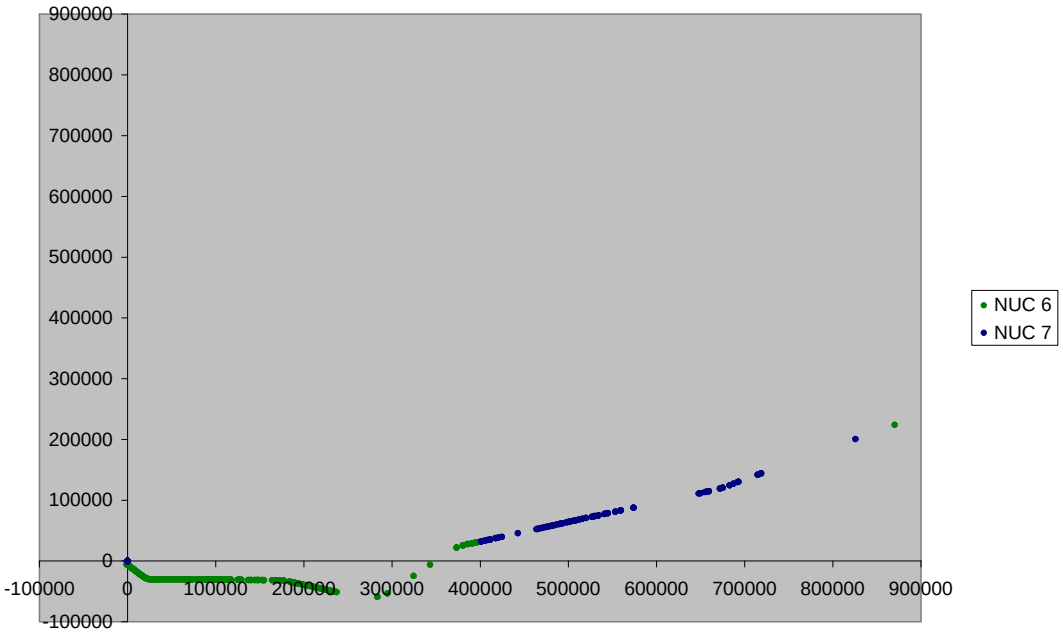
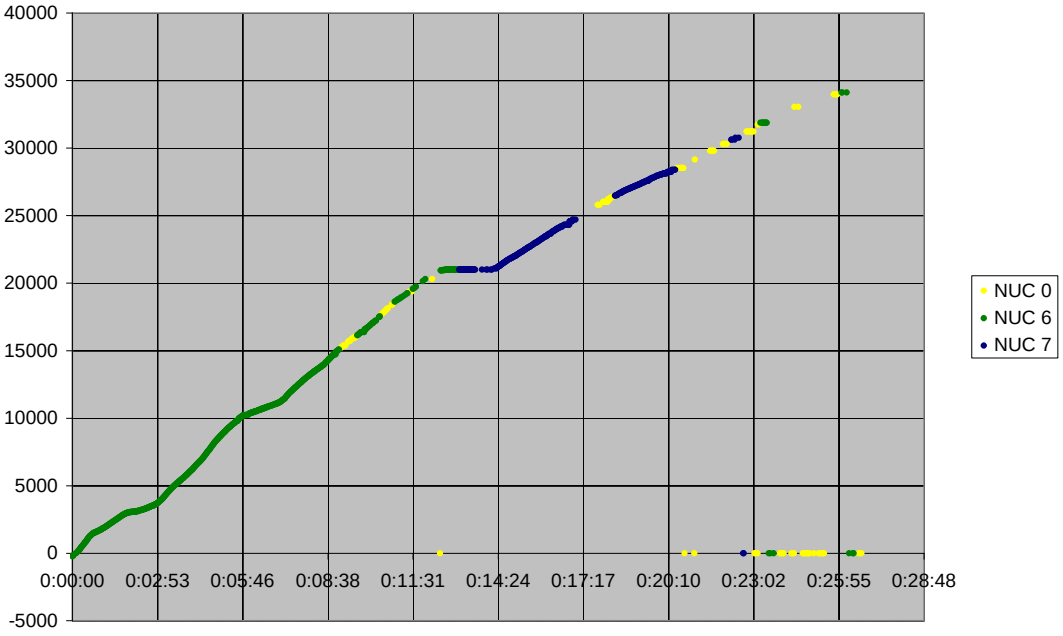


- ❑ X/Y data appears to form a reasonable track
- ❑ Altitudes appear to be reasonable

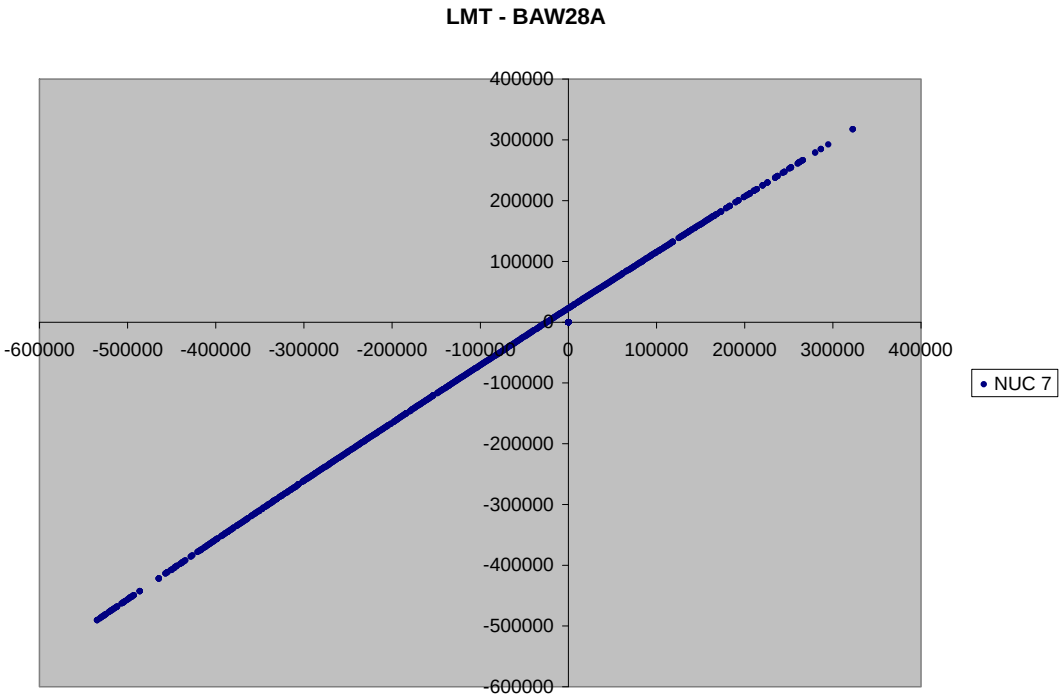
JFK - THY2

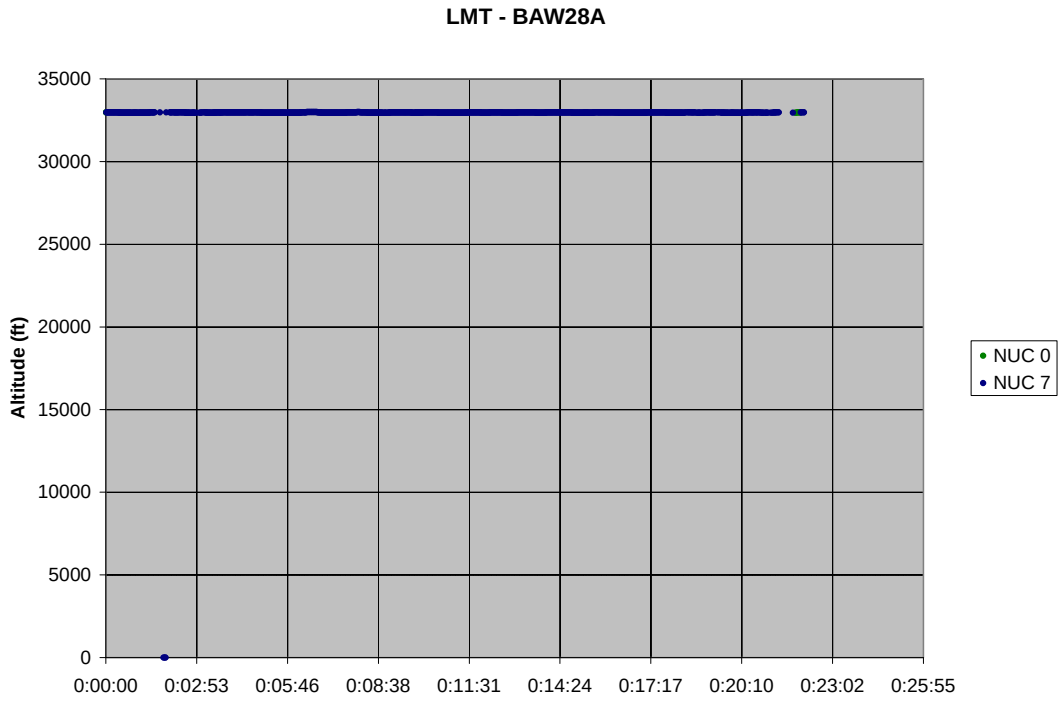


JFK - THY2

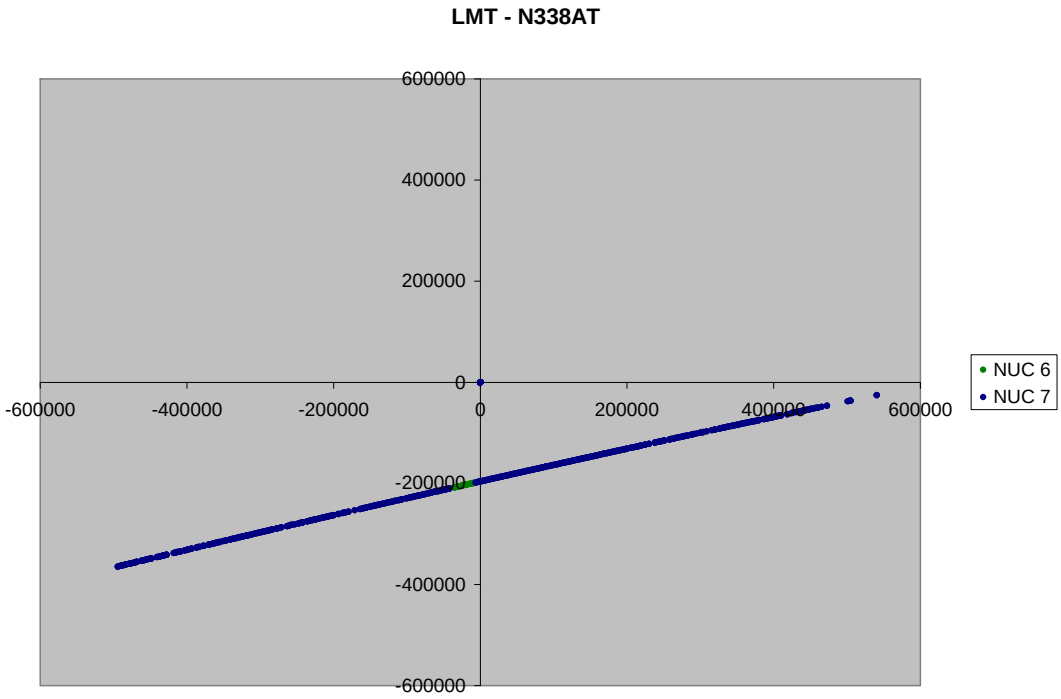


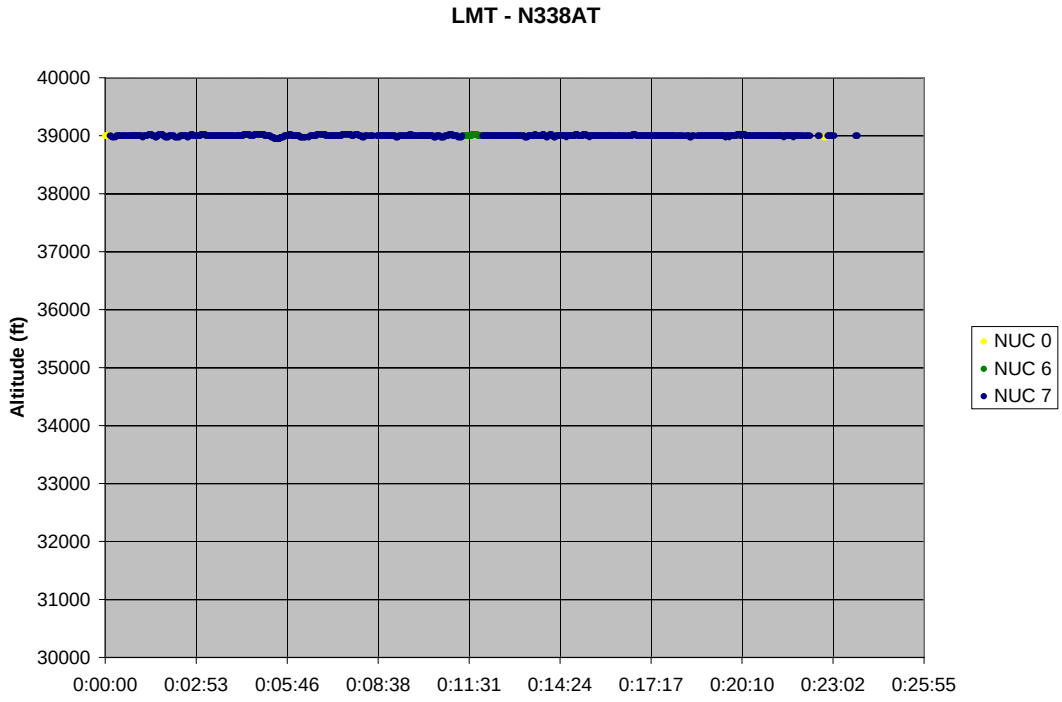
- ❑ X/Y data appears to form a reasonable track
- ❑ Altitudes appear to be reasonable – some zero altitude points that may be due to time-outs in data set



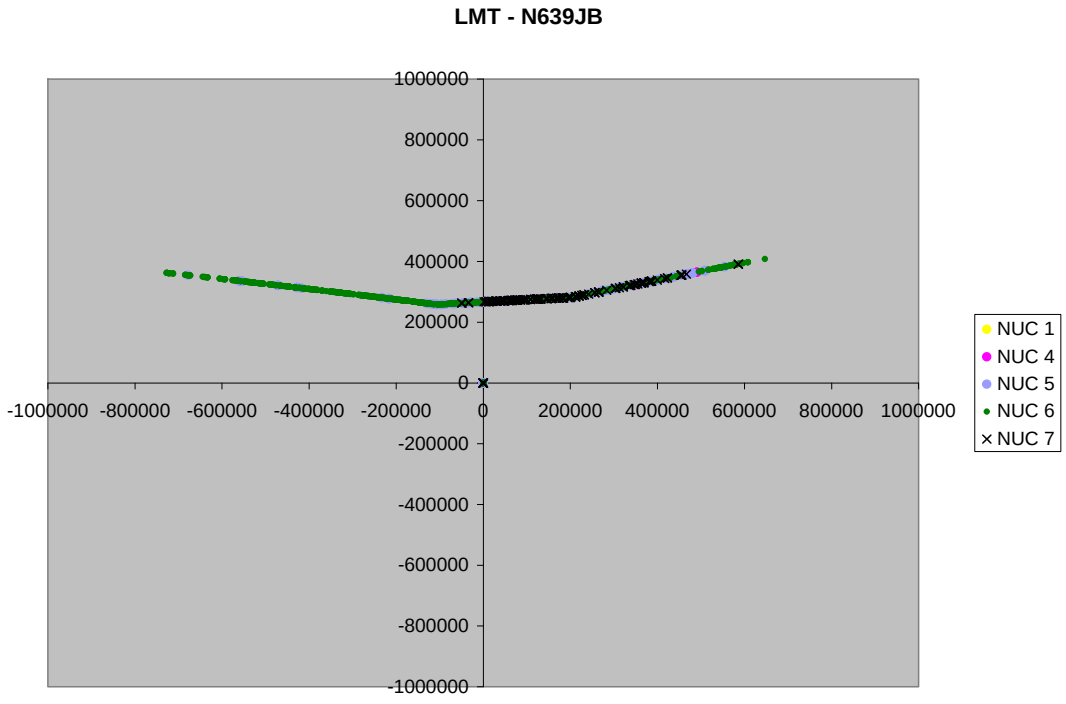


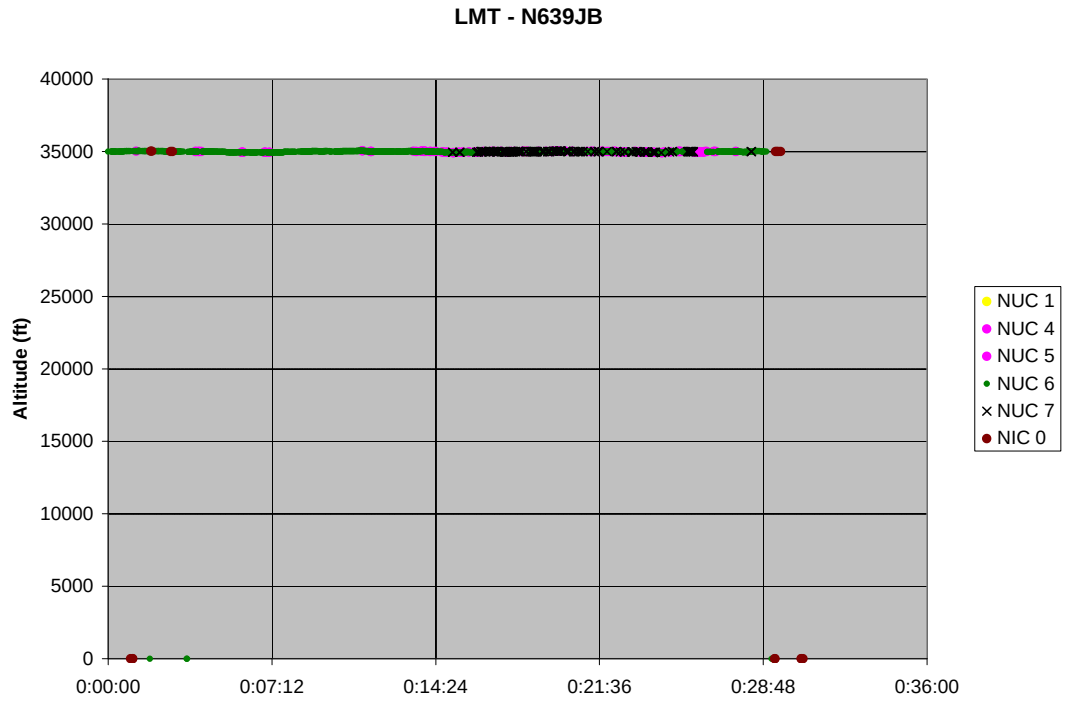
- ❑ X/Y data appears to form a reasonable track
- ❑ Altitudes appear to be reasonable



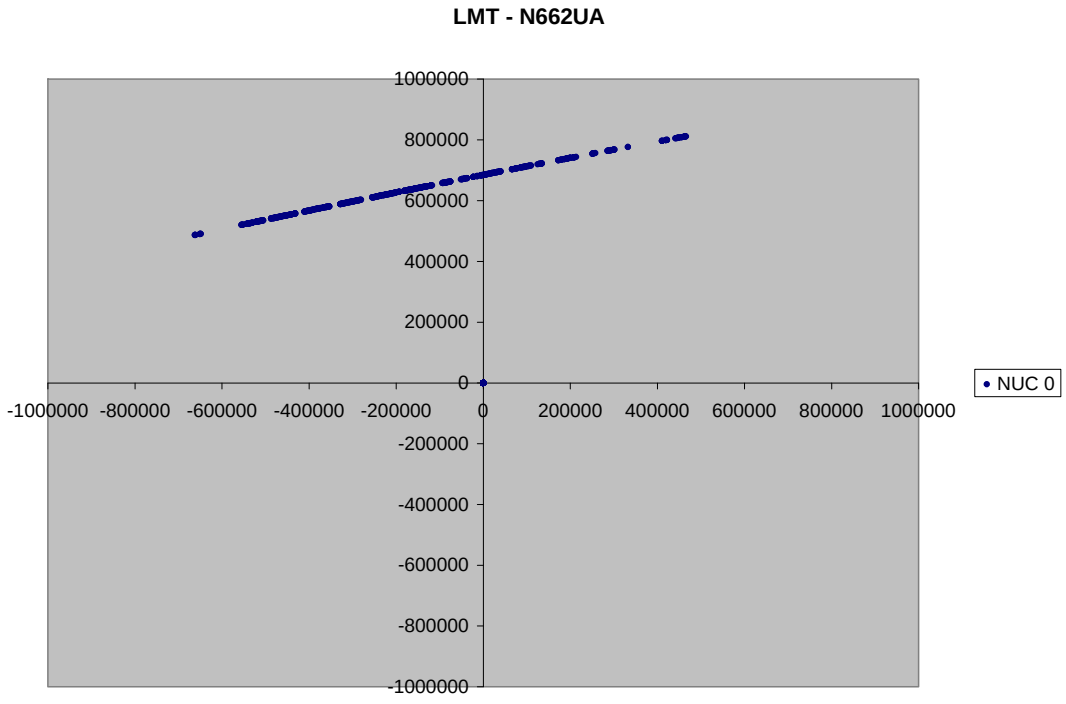


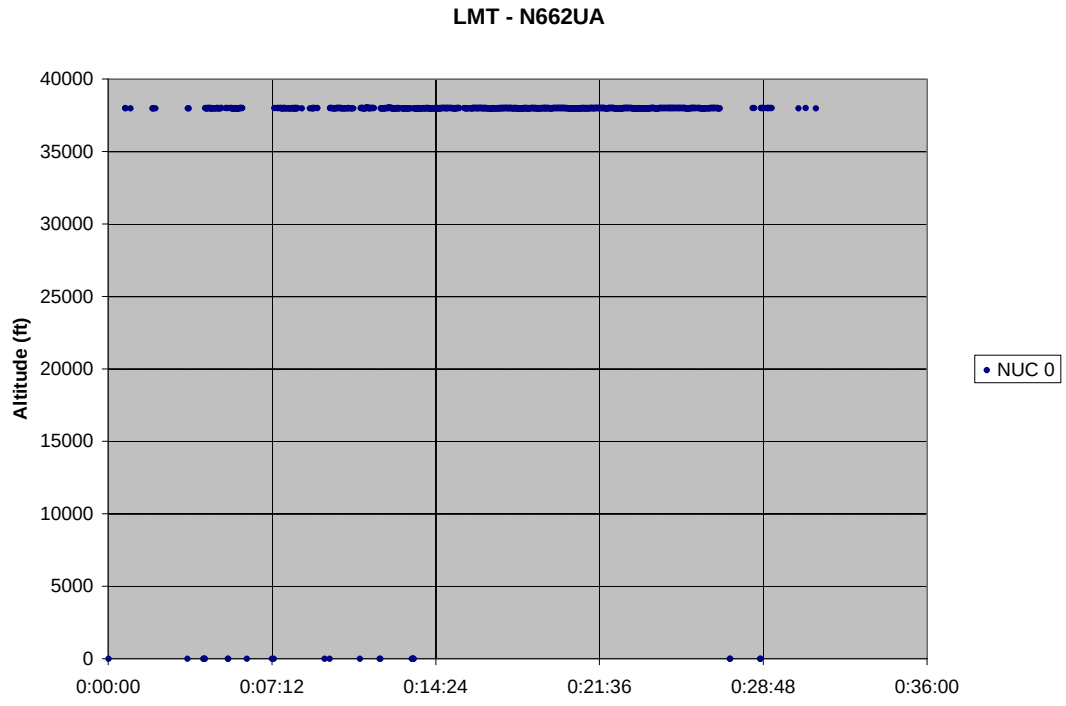
- ❑ X/Y data appears to form a reasonable track
- ❑ Altitudes appear to be reasonable



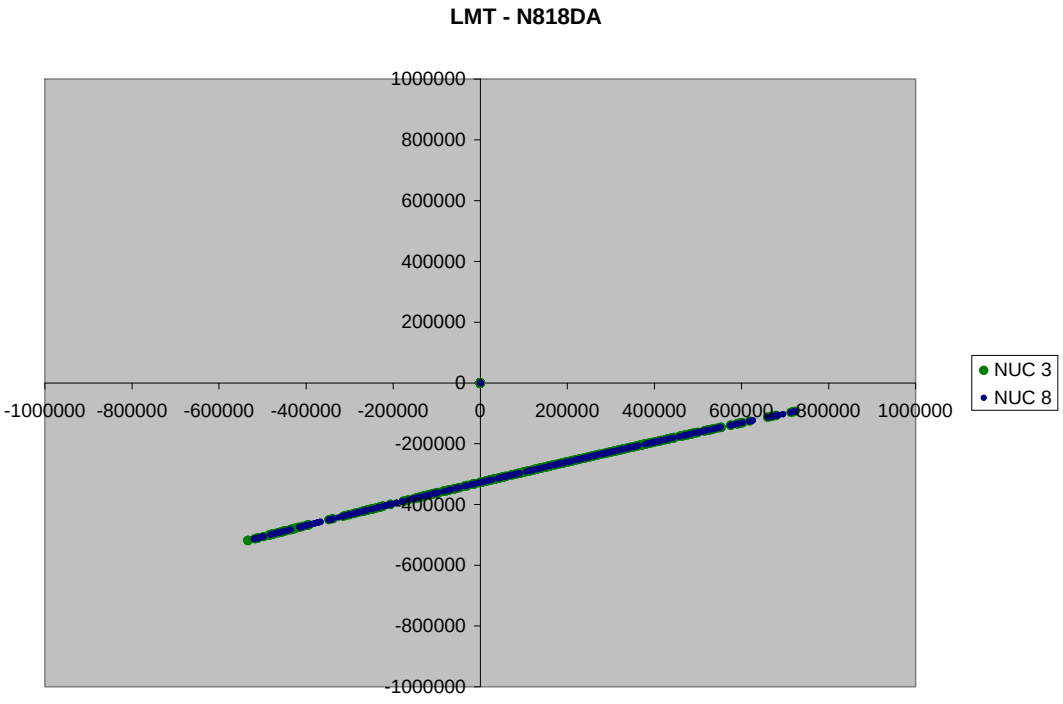


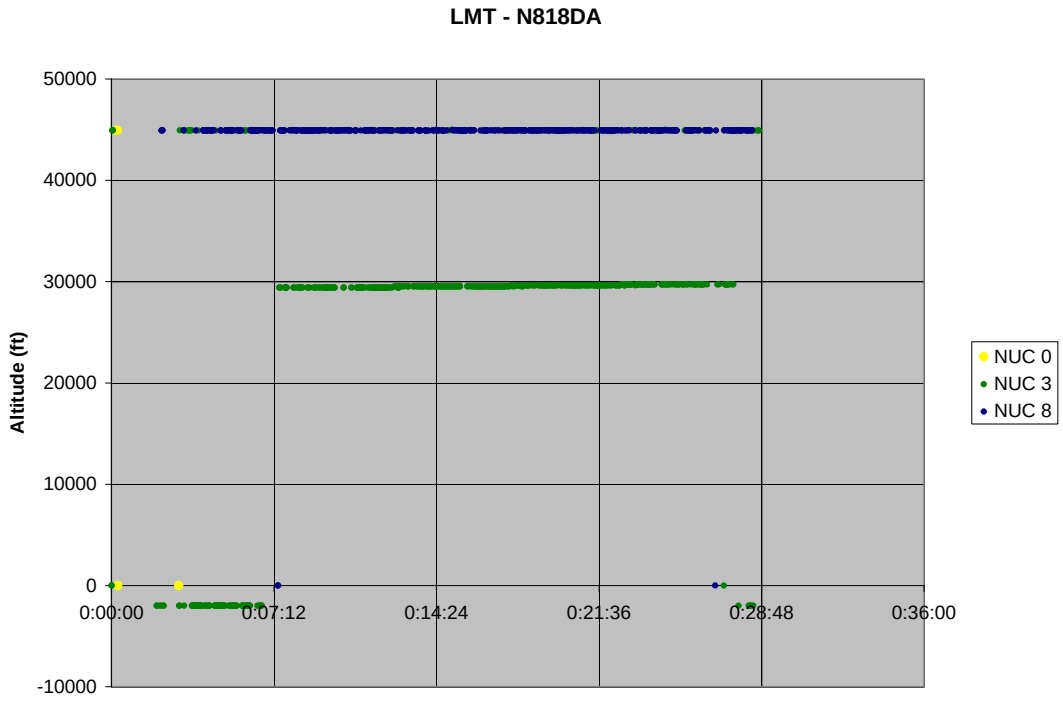
- ❑ X/Y data appears to form a reasonable track
- ❑ Altitudes appear to be reasonable
- ❑ Large number and wide variation of NUC values reported



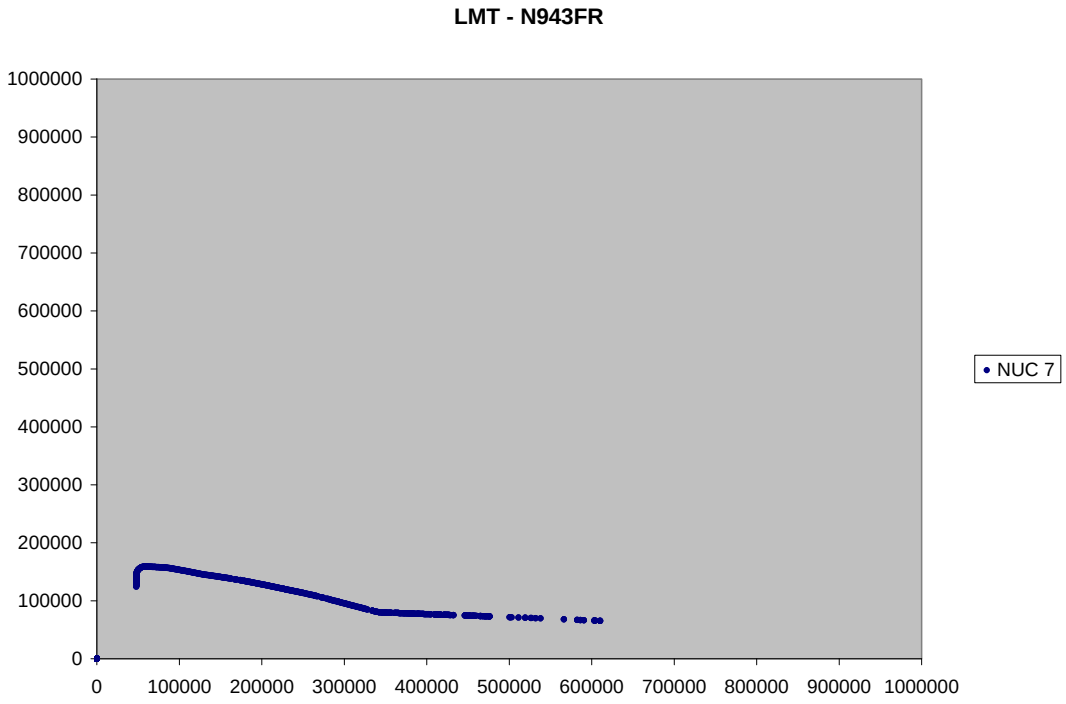


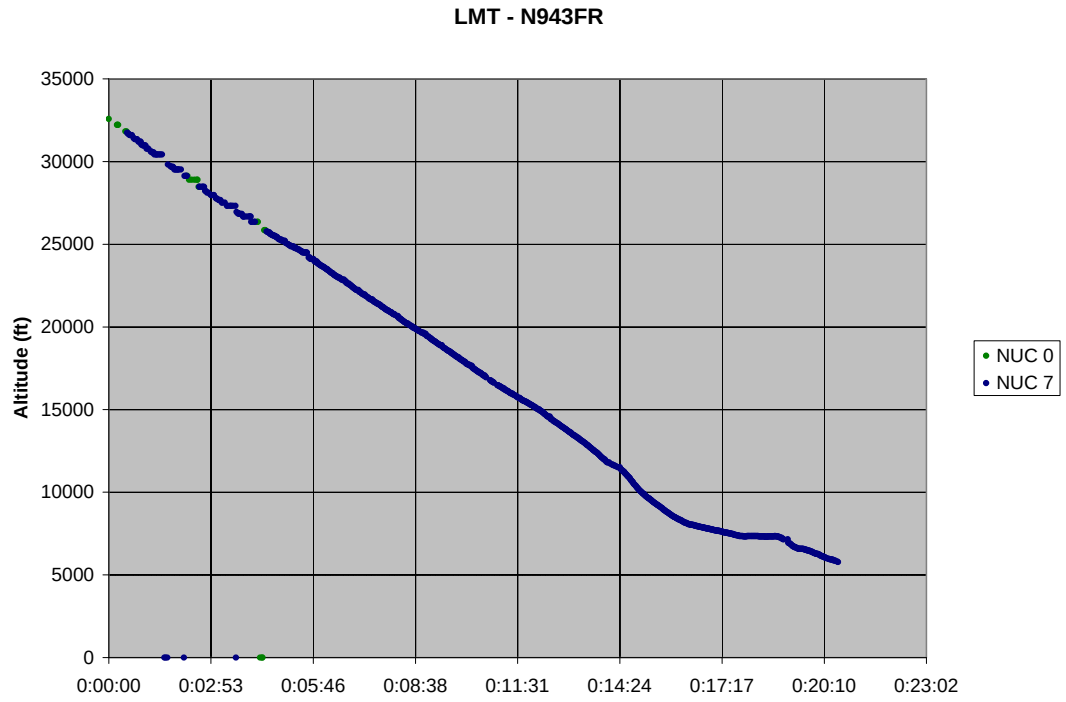
- ❑ X/Y data appears to form a reasonable track
- ❑ Altitudes appear to be reasonable



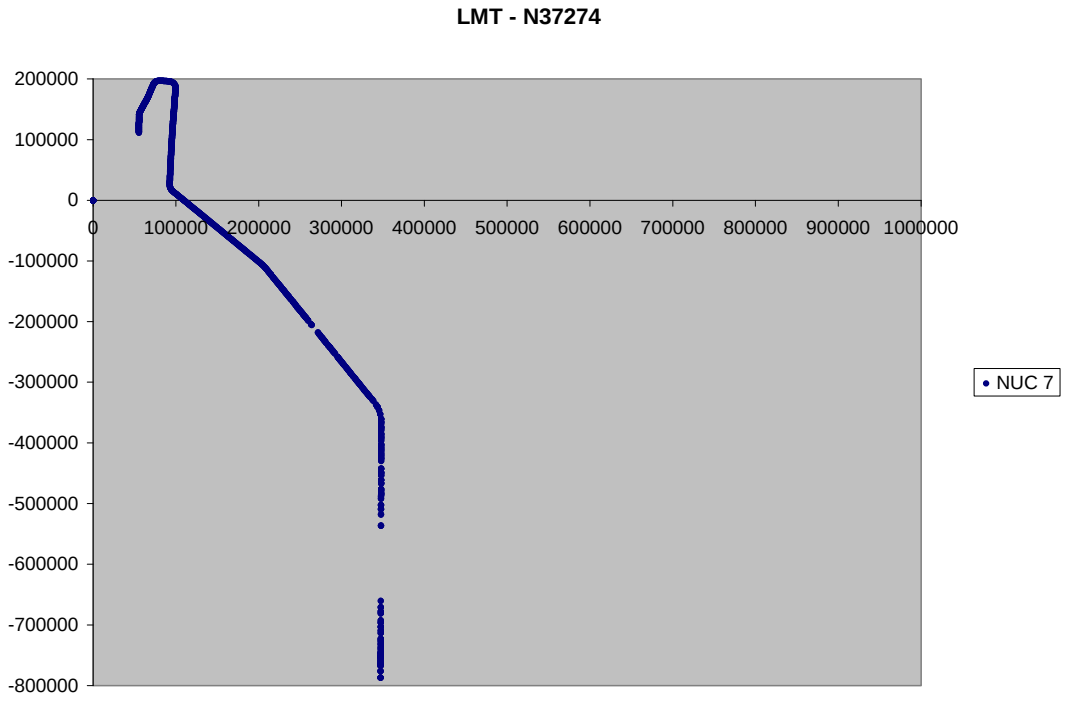


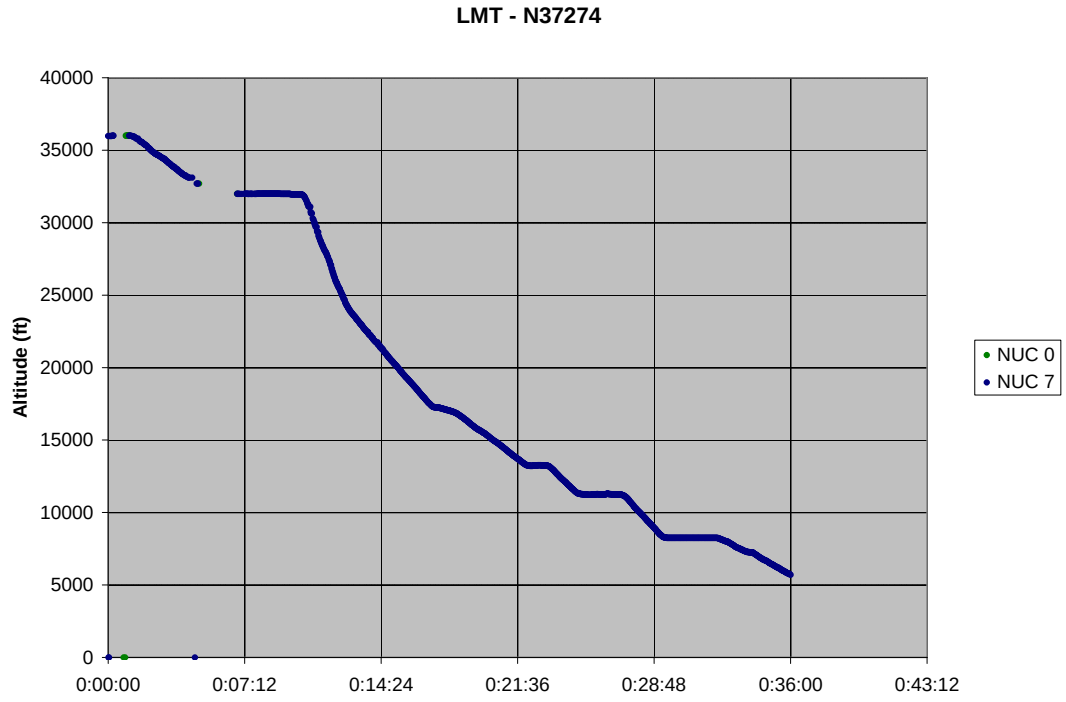
- ❑ X/Y data appears to form a reasonable track
- ❑ Altitudes shows significant errors that correlate to low NUC values



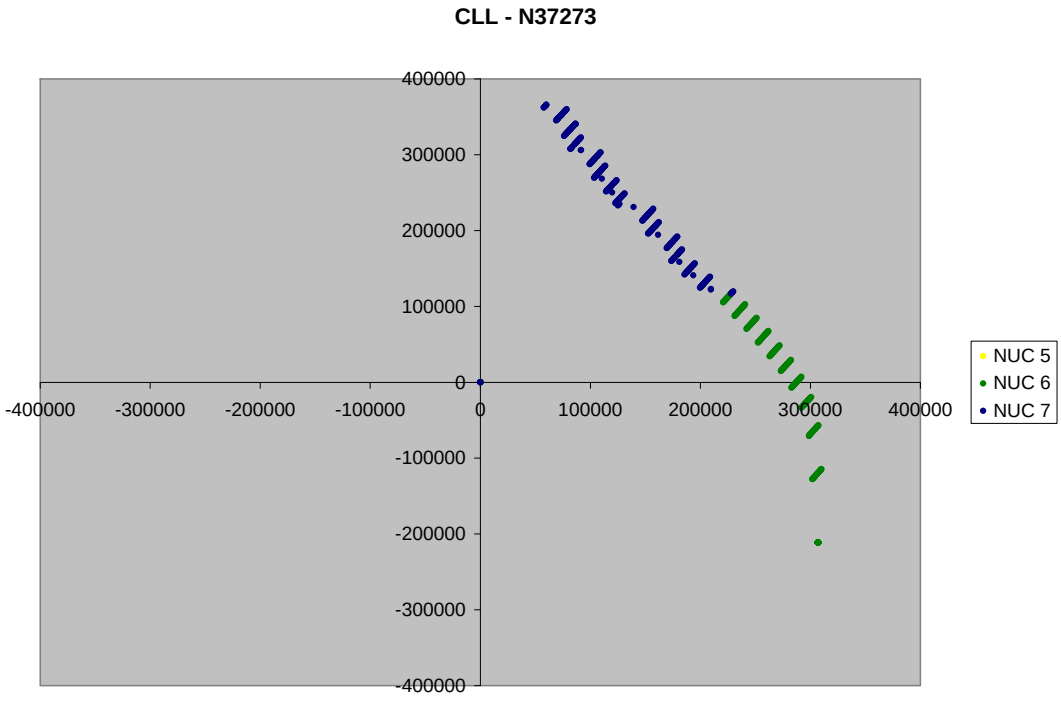


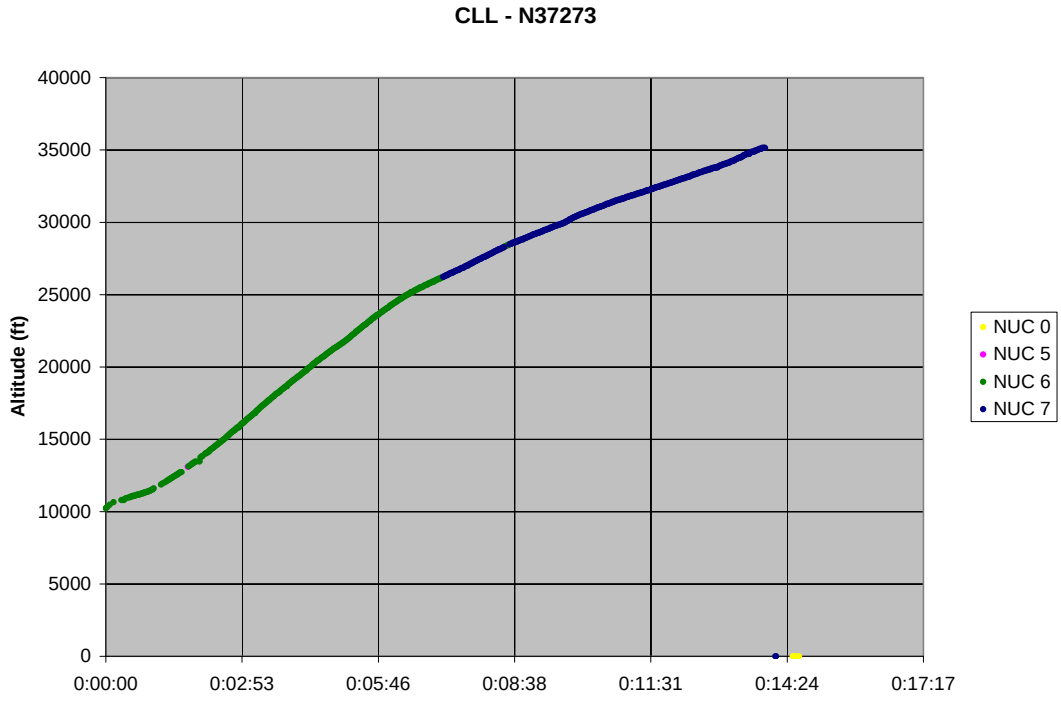
- ❑ X/Y data appears to form a reasonable track
- ❑ Altitudes appear to be reasonable





- ❑ X/Y data appears to form a reasonable track
- ❑ Altitudes appear to be reasonable





- ❑ X/Y data appears to have some reporting or encoding issues
- ❑ Altitudes appear to be reasonable

APPENDIX R—AIRCRAFT ADS–B ANTENNA DIVERSITY AND TRANSMIT POWER REQUIREMENTS

Typical Application	Equipage Class	Transmit RF Power Delivered to Antenna System	Intended Transmit Antenna Diversity
1090 MHz Extended Squitter			
Aid to Visual Acquisition (Only) (Minimum)	A0	Low Power of 70 Watts minimum (Altitude always below 15,000 feet	Single Antenna
Conflict Avoidance (Basic)	A1	Medium Power of 125 Watts minimum (No altitude restriction)	Antenna Diversity
Separation and Sequencing (Enhanced)	A2	Medium power	Antenna Diversity
Deconfliction Planning (Extended)	A3	High Power of 125 Watts minimum, 200 Watts recommended	Antenna Diversity
Transmit Only Airborne Vehicle	B0	Low Power (Altitude always below 15,000 feet)	Single Antenna
Transmit Only Airborne Vehicle	B1	Medium Power	Antenna Diversity

Typical Application	Equipage Class	Transmit RF Power Delivered to Antenna System	Intended Transmit Antenna Diversity
UAT			
Aid to Visual Acquisition (Only)	A0	Low Power of 7 Watts minimum (Altitude always below 18,000 feet	Single Antenna
Conflict Avoidance	A1L	Low Power (Altitude always below 18,000 feet)	Dual Antenna with Transmission Antenna Alternating between Top and Bottom
Conflict Avoidance	A1H	Medium Power of 16 Watts minimum (No altitude restriction)	Dual Antenna with Transmission Antenna Alternating between Top and Bottom
Separation and Sequencing	A2	Medium Power	Same as A1H
Deconfliction Planning	A3	High Power of 100 Watts minimum	Same as A1H
Transmit Only Airborne Vehicle	B0	Low Power (Altitude always below 18,000 feet)	Single Antenna
Transmit Only Airborne Vehicle	B1	Medium Power	Dual Antenna with Transmission Antenna Alternating between Top and Bottom

APPENDIX S – JHUAPL UAT MODIFIED A0 SINGLE ANTENNA PERFORMANCE ANALYSIS

The ARC requested a study of single antenna performance for a modified A0 (A1) to determine if there were additional opportunities for single antenna installations. The study was conducted by Johns Hopkins University Applied Physics Lab (JHUAPL).

JHUAPL was asked to evaluate three scenarios:

- **Scenario 1:** A modified single antenna A0 on surface at LAX receiving ADS–R.
- **Scenario 2**: A modified single antenna A0 on surface at a general aviation airport transmitting ADS–B.
- **Scenario 3:** A modified single antenna A0 at range R from a ground receiver transmitting ADS–B.

The results of the analysis for each of the three scenarios are described below.

New UAT Analysis Scenario 1: Modified A0 with single bottom-mounted antenna on surface at LAX in LA 2020.

Assumptions:

- Single bottom antenna, modified A0 on surface at LAX in LA2020 scenario
- Ground transmissions:
  - Low-power ground transmitter of ADS–R on airport surface
  - No high power ground transmitter within the line of sight (LOS)
- Aircraft is stationary
- Transmit power: 17 watts (low-performing A1H)
- Single multipath ground reflection
- Ground transmit power variable from 1 W to 1 kW, transmitting all 1090 ES ADS–B on UAT
- DME/TACAN ground transmit antenna pattern
- Range variable = 1 nm, 3 nm, 5 nm

Appendix S, Table 1: Simulated performance of ground station receiving modified A0 with single bottom-mounted antenna on surface at LAX in LA 2020: 95 percent maximum update interval results versus ground transmitter power and range from ground station.

Ground Transmitter Power (Watts)					
Range (nm)		1	10	100	1000
	1	2.0 s	1.2 s	Not evaluated	Not evaluated
	3	Not evaluated	3.0 s	2.0 s	Not evaluated
	5	Not evaluated	Not evaluated	6.9 s	2.1 s

These results should be compared with a required 95 percent update interval of 2 seconds for ASSA and FAROA applications. It should be noted that the single-antenna A1H on the airport surface meets the ASSA and FAROA requirement for 2.0 second 95 percent maximum update interval when the aircraft is within 1 mile of a low power (1-10 Watts) ground station. ITT indicated to the ARC that ground stations would be located at on major airports such that all aircraft in movement areas would always be within one nautical mile of a ground station.

New UAT Analysis Scenario 2: Modified A0 aircraft with single bottom-mounted antenna on surface at a GA airport near LAX in LA 2020 transmitting to an A1H aircraft with antenna diversity on approach. It should be noted that having the receiver alternate between the top and bottom antennas in the A1H aircraft with antenna diversity on approach makes this scenario more conservative (i.e. increasing maximum update interval) than one with an A0 or A1H installation with a single bottom-mounted antenna.

Assumptions:

- Single bottom antenna, modified A0 transmitting on surface at general aviation airport in LA2020 scenario
- High power (100 W) ground transmitter located 5 nm from A1 receiver
    - Area ADS–R Ground transmitter interferes with reception of ADS–B transmissions from aircraft on the ground
    - Variable number of ground messages transmitted per second
- Modified A0 Transmit power: 17 watts (low-performing A1H)
- Variable single multipath ground reflection (model predicts no multipath effect at 3 nm and 5 nm)

Appendix S, Table 2: Modified A0, UAT aircraft with single bottom-mounted antenna on surface at a GA airport near LAX in LA 2020 transmitting to an A1H UAT aircraft with antenna diversity on approach.

Range →		**3 nm**	**5 nm**	**3 nm**	**5 nm**
Number of ground station message transmissions per second →		**0**	**0**	**400**	**400**
Multipath Effect (1)	**0 dB**	2.1 s	2.0 s	3.9 s	3.4 s
	-10 dB	2.1 s	2.1 s	3.9 s	4.0 s
	-20 d|B	3.0 s	6.5 s	5.9 s	12.8 s

These results should be compared with a required 95 percent update interval of 2 seconds for ASSA and FAROA applications.

Note 1: The TLAT model predicts no multipath effect in this scenario at these ranges (that is 0 dB); -10 dB and -20 dB attenuations are provided for concerns about the effects of maneuvering and fuselage blocking on the 95 percent maximum update interval.

The ARC notes that this worst-case analysis shows that the A1H UAT aircraft with single bottom-mounted antenna on surface is border-line in meeting the 2.0 second 95 percent maximum update interval ASSA and FAROA requirement in DO–289 without ground station interference. In the presence of 400 re-broadcasted 1090 ES ADS–B messages, the 95 percent maximum update interval increases to 4.0 seconds in the presence of 10 times the multipath interference predicted by TLAT models.

The DO–289 ASSA and FAROA 2-second 95 percent maximum update interval requirement is based on an aircraft approaching at 240 knots 3 nm from the airport, 45 seconds from touchdown. These speeds would only occur in a military traffic scenario. The ARC notes that DO–289 indicates the fastest air transport approach speeds top out at 178 knots. Furthermore, these high-approach-speed aircraft are jets and will be on 1090 ES, not UAT, so the critical path for them includes an ADS–R ground station such as the one in scenario 1. General aviation piston aircraft are typically category A (90 knots maximum approach speed) or category B (120 knots maximum approach speed). Using the same DO–289 approach for deriving ASSA and FAROA 95 percent maximum update interval requirements for 240 knots, but substituting 120 knots suggests relaxing this update interval requirement to 4 seconds for predominately general aviation traffic scenarios. Similarly, the requirement can be relaxed to 3 seconds for scenarios involving air transport aircraft approaching at 180 knots.

<u>New UAT Analysis Scenario 3:</u> Modified A0, UAT aircraft with single bottom-mounted antenna banking away from a ground station at LAX in LA 2020.

The rationale for antenna diversity includes concerns about fuselage blockage during maneuvering flight, especially banking, but prior analysis included only random fuselage blocking. This scenario addresses the effects of bank angle on reception of ADS–B by a ground station.

Assumptions:

- Single bottom antenna, modified A0 at FL120 transmitting to surface receiver at LAX in LA2020 scenario.
- Modified A0 Transmit power: 17 watts (low-performing A1H)
- Ground receiver characteristics
    - Ground uplink transmissions prevent simultaneous reception of A0 ADS–B transmissions (0 and 100 uplinks/second)
    - DME/TACAN antenna pattern
- Ranges examined: 10 nm, 30 nm, 50 nm
- Bank angle and antenna orientation with respect to ground station: Held constant for the duration of the simulation.

Appendix S, Table 3: Modified A0, UAT aircraft with single bottom-mounted antenna banking away from a ground station at LAX in LA 2020

Distance (nm) →	10		30		50	
Bank Angle (degrees)	No Uplinks	100 Uplinks	No Uplinks	100 Uplinks	No Uplinks	100 Uplinks
0			2.6 s	5.5 s		
30			3.2 s	6.3 s		
35			4.1 s	7.2 s		
38			5.9 s	12.5 s		
40			97.5 s	100.6 s		

For all ranges, the A1H UAT single antenna installation transmitting at 17 W achieved a 95 percent maximum update interval under 3 seconds with no bank angle and no ground uplinks. The 95 percent maximum update interval in the terminal domain has been decreased to 3 seconds since the publication of DO–282A.

Adding 100 ground uplinks resulted in increase in update interval to ~5 seconds at 10 nm to ~6 seconds at 50 nm with no bank angle.

This is similar to previous all-UAT analysis results for A1H UAT with antenna diversity in DO–282A (Figure K-38). The ARC notes that the prior A1H analysis shows very similar results for A0 and A1H, but neither meets the new 3-second 95 percent update

interval requirement for terminal area past 15 nm range from the ground station. A comparison of the prior results with the new A1H UAT single bottom-mounted antenna results suggests that adding antenna diversity will not improve the A1H UAT 95 percent maximum update interval.

In the modified A0, UAT analysis, increasing bank angle resulted in gradual increase in update interval up to a critical angle, where the 95 percent maximum update interval rises sharply. For example, at 30 nautical miles, the critical bank angle is between 38 and 40°. Critical angle varies with range; greater range corresponds to smaller critical angle.

The ARC notes that in a terminal area, banking toward one ground station (with a resulting increase in the 95 percent maximum update interval) will result in the aircraft banked away from another ground station (with the resulting decrease in the 95 percent maximum update interval). Furthermore, standard rate turn bank angles range from less than 10 degrees for a 60-knot aircraft to about 26 degrees for a 180-knot airplane. These bank angles are well inside the critical bank angles in Table 3. In a 40-degree bank, times spent in a bank for a 90-degree turn range from about 6 seconds for a 60-knot airplane to about 18 seconds for a 180-knot airplane. At these bank angles, the aircraft is changing its orientation with respect to the ground station significantly in times less than the 95 percent maximum update interval derived from "freezing" the aircraft at a bank angle and distance from the ground station.

The ARC notes that these three cases do not represent a comprehensive analysis of the dual-link architecture and the NPRM should be based upon a more comprehensive analysis of this architecture. In particular, the analysis needs to incorporate proposed actual ground station location and transmit power.

APPENDIX T –ANTENNA DIVERSITY COMMENTS ON COST

The ARC recognizes that the cost of over-specification of avionics is very high and can easily cancel benefits.

For 1090 ES costs, AOPA considered Mode S transponder purchases. For example, a Garmin GTX330 costs approximately $4000 versus about $10,000 for a GTX330D (with antenna diversity). This $6000 difference in list price totals to $1.26 billion for the entire general aviation (GA) fleet (approximately 210,000 aircraft), without including the extra antenna's installation cost. Installing the second antenna may run about $1000 extra for an unpressurized aircraft. This will add another $210 million to the cost to the low altitude GA community. The antenna-diversity model is about 240 percent of the cost of the single-antenna model by the time it is installed. The potential difference is $1.47 billion for the GA fleet. AOPA recognizes that the difference in cost between these two transponders is a function of increased transmitting power, true receiver diversity, and amortization of development and certification over a smaller market as well as antenna diversity. Of these factors, the increased transmitter power may account for about 10 percent of the difference in cost. AOPA also recognizes that a mandate can increase the market size to improve amortization of development and manufacturing startup costs. However, the 1090 ES will likely be based on the current Mode S transponders.

Only one certified UAT ADS–B unit is on the market at this time: Garmin's GDL 90, a remote-mounted UAT unit. This unit costs approximately $7000 including three antennas—two UAT and a WAAS antenna because it is a standalone unit—prior to installation. The installed price will probably run closer to $8,000-9,000 if some antenna sharing is possible. If the Mode S differential of 240 percent is appropriated, the single-antenna version of the UAT ADS–B would be about $3500 installed. This potential cost difference across the entire GA fleet would be about $1.05 billion.

Projecting avionics costs 12 years ahead is difficult, but these comparisons suggest that the ADS–B Out costs as mandated by the notice of proposed rulemaking (NPRM) will be a significant percentage of the total airframe value for most of the piston GA fleet. Beyond this potential total $1 billion-plus purchase and installation cost difference to GA, some small aircraft simply do not have the space on top for another antenna and will be essentially grounded or marginalized in 2020 by the NPRM. These numbers warrant careful reconsideration of the antenna diversity requirement.

Some ARC members do not believe the figures provided by AOPA are necessarily representative of the cost of antenna diversity. GAMA was asked by the ARC to review these costs with members and made the following determinations. The cost difference for 1090 ES has been assumed to the same as the UAT cost difference and it also is based on dealer list prices. GAMA believes that the UAT cost will be lower.

The analogy with Mode S is not accepted by several ARC members because of the power difference and significant difference in expected fleets across which to amortize cost of certifying the equipment.

However, without knowing the exact structure of the final rule, GAMA is unable to determine what the full, actual cost of diversity antenna installations would be considering the variables that drive cost including:

- Expected production volumes
- Influence of portions of the GA fleet equipping with UAT versus 1090 ES.
- Timing of a possible equipage mandate

However, GAMA does agree with the basic assumption about the installation costs at $1,000 per aircraft for the second antenna installation.

APPENDIX U—ANTENNA DIVERSITY REFERENCE DOCUMENTS

The ARC developed its recommendations based on information found in the following documents:

- ITT Link Budget (select excerpts) – Impact of lower power and non-diversity antenna installations on the number of ground transmitters.
- Technical Link Assessment Team report 2001 – Modeling and simulations of diversity antenna installations.
- 1090 MHz Extended Squitter Assessment Report, a June 2002 follow-up to the March 2001 TLAT report.
- ICAO Annex 10 Volume IV – Transponder power requirements.
- RTCA DO–260A, Minimum Operational Performance Standards for 1090 MHz Extended Squitter ADS–B and TIS–B.
- Minimum Operational Performance Standards for Universal Access Transceiver (UAT) Automatic Dependent Surveillance – Broadcast (ADS-B), Appendix K, RTCA DO–282A, July 29, 2004.
- Minimum Aviation System Performance Standards for Aircraft Surveillance Applications (ASA), RTCA DO–289, December 9, 2003.
- UAT MOPS Figure K–113 – UAT A3 receiver on surface in LA 2020 scenario receiving A0 transmissions. Red curve reflects application of an agreed surface multi-path model and an assumed bottom-mounted antenna for single antenna installation.

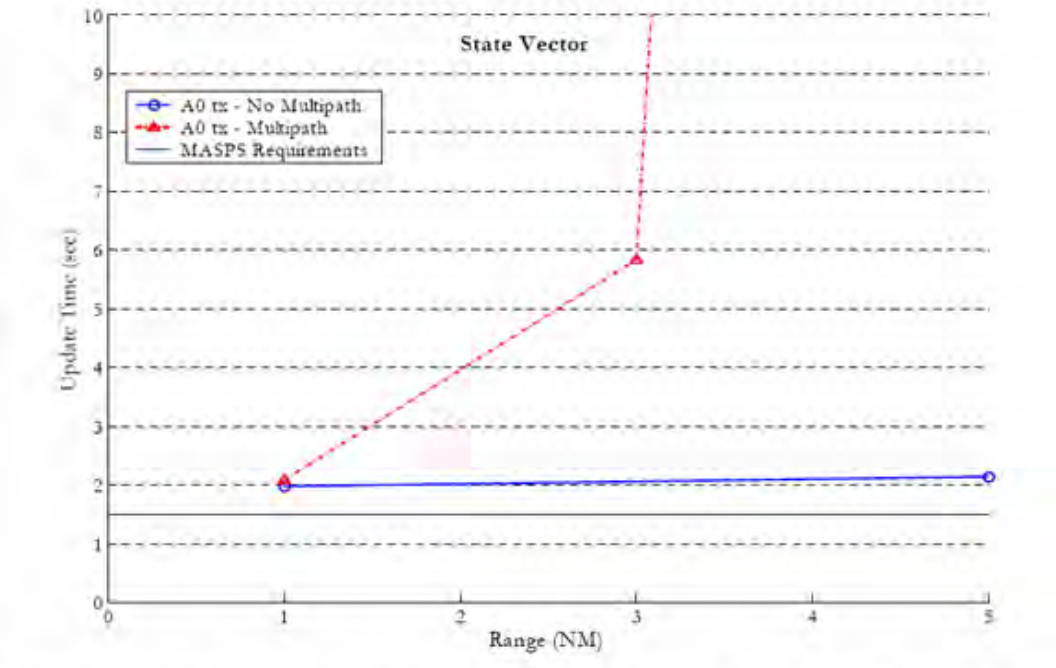
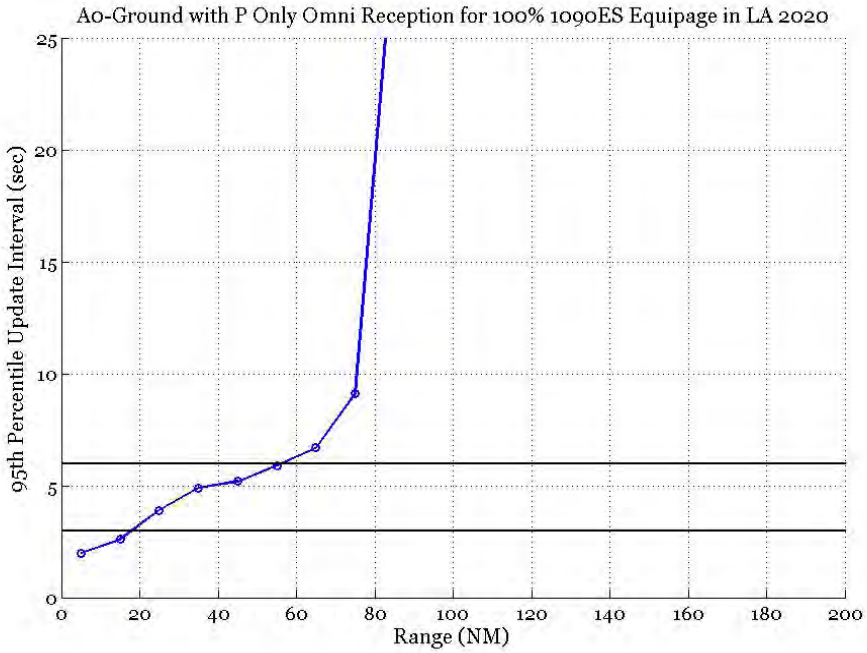


Figure K-113: A3 Receiver on the Surface in LA2020 Scenario Receiving A0 Transmissions

- Larry Bachman, Johns Hopkins – Modeling for A0 to ground in the LA2020 scenario with all aircraft equipped with 1090. Model based on aircraft top-mounted, single antenna, the receiver antenna is a DME-type omni (as planned by ITT), the ground receiver is equipped with an A3 decoder, and updates only come from receptions of p-squitters.



APPENDIX V—FAA JUSTIFICATION OF THE NPRM REQUIRED NAVIGATION ACCURACY CATEGORY FOR POSITION (NACP)

Position accuracy requirements were considered by the FAA for ATC separation services, air-to-air applications, and airport surface applications. Modeling of the current radar surveillance environment for a defined separation standard was performed by the FAA to determine minimum accuracy performance levels required to support the separation minima. Table 1 summarizes these performance levels identified in the FAA Final Program Requirements for Surveillance and Broadcast Services document, Version 2.1, August 6, 2007.

Table 1 Horizontal Position Accuracy

APPLICATION	ACCURACY REQUIREMENT
Enhanced Visual Acquisition	NACp ≥ 5 (0.5 NM)
Conflict Detection	NACp ≥ 5 (0.5 NM)
Airport Surface	NACp ≥ 9 (30 m)
Visual Approach	NACp ≥ 7 (0.1 NM)
En route ATC Surveillance	NACp ≥ 6 (0.3 NM)
Terminal ATC Surveillance	NACp ≥ 8 (0.05 NM)

APPENDIX W— SUMMARY OF ADS–B APPLICATION POSITION ACCURACY REQUIREMENTS

The following is a summary of ADS–B application data accuracy/integrity performance standards currently defined by the Requirements Focus Group (RFG).

Package 1 Ground Applications—

Enhanced Air Traffic Services in Non-Radar Airspace using ADS–B Application (RTCA DO–303/EUROCAE ED–126):

- 5 NM Separation – Required NACp ≥ 5 (0.5 NM), NIC ≥ 4 (2.0 NM), SIL ≥ 2, or NUCp ≥ 4, NACv – not required, Availability – Not Specified
- 3 NM Separation – Required NACp ≥ 6 (0.3 NM), NIC ≥ 5 (1.0 NM), SIL ≥ 2, or NUCp ≥ 5, NACv – not required, Availability – Not Specified

Enhanced ATS in Radar Areas using ADS–B Surveillance Application:

- 5 NM Separation – NACp ≥ 7 (0.1 NM), NIC ≥ 5 (1.0 NM)
- 3 NM Separation – NACp ≥ 7 (0.1 NM), NIC ≥ 6 (0.5 NM)
- 2 1/2 NM Separation In-Trail on Approach – NACp ≥ 7 (0.1 NM), NIC ≥ 7 (0.2 NM)
- 2 NM Dependent Parallel Approach Separation – NACp ≥ 8 (0.05 NM), NIC ≥ 7 (0.2 NM)
- Independent Parallel Approach Separation – NACp ≥ 8 (0.05 NM), NIC ≥ 7 (0.2 NM)

Package 1 Airborne Applications—

Enhanced Airborne Traffic Situational Awareness for In-Trail Procedures Application (RTCA DO–XXX – document in final review and comment process):

- NACp ≥ 5 (0.5 NM), NIC ≥ 5 (1.0 NM), SIL ≥ 2 (potential reduction to SIL ≥ 1)

Enhanced Visual Separation on Approach Application:

- NACp ≥ 6 (Actual requirement specified = 0.35NM), NIC ≥ 5 (Actual requirement specified = 0.75 NM), SIL ≥ 1 (Proposed – safety assessment not complete)

Enhanced Traffic Situational Awareness on the Airport Surface Application:

- Operational Performance Analysis not complete

Enhanced Traffic Situational Awareness during Flight Operations

- Operational Performance Analysis not complete

Airborne Spacing – Enhanced Sequencing and Merging Application:

- Operational Performance Analysis not complete

The following is a summary of ADS–B application data accuracy/integrity performance standards defined in RTCA FRAC draft dated 21, March 2008, Minimum Operational Performance Standards (MOPS) For Aircraft Surveillance Applications System (ASAS)

Airborne Situational Awareness Applications –

Enhanced Visual Acquisition Application:

- NACp ≥ 5 (0.5NM), NIC - Not Applicable, SIL – Not Applicable

Airport Surface Situational Awareness:

- NACp ≥ 9 (30m) (NACp ≥ 7 optional degraded), NIC - Not Applicable, SIL - Not Applicable

Final Approach and Runway Occupancy Awareness:

- NACp ≥9 (30m), NIC - Not Applicable, SIL - Not Applicable

Enhanced Visual Approach:

- NACp ≥ 6 (0.3NM), NIC ≥ 6 (0.5 NM), SIL ≥ 1

Conflict Detection:

- NACp ≥ 5 (0.5NM), NIC - Not Applicable, SIL - Not Applicable

Note that navigation integrity category (NIC) and system implementation level (SIL) requirements are not applicable since the applications are situational awareness applications.

Note – FAA approved performance parameters for UPS Merging and Spacing operations:

- NACp ≥ 7 (0.1 NM), NIC ≥ 6 (0.5 NM), SIL ≥ 2

Note – Future airport surface alerting application standards currently in development by RTCA SC–186 may require position accuracy performance of greater than 9.

APPENDIX X – EQUIPMENT IMPLICATIONS OF ADS–B NAVIGATION ACCURACY CATEGORY (NACP) REQUIREMENTS

The ADS–B Notice of Proposed Rulemaking (NPRM) includes a requirement for ADS–B system participants of a NACp of 9. This requirement is defined by the RTCA ADS–B Minimum Aviation System Performance Standard (MASPS), DO–242A, as indicating that the corresponding ADS–B reported position is accurate, at the 95 percent confidence level, to 30 meters or less horizontally and 45 meters of less vertically. While no availability requirement is levied in the NPRM on this requirement, high availability/continuity will be needed to support robust operations in the national airspace system (NAS). This paper discusses practical implications of the NPRM NACp requirement as well as the implications of less stringent NACp requirements.

The only aircraft position sources which can (with high availability and continuity in all airspace domains) currently supply a NACp≥9 are those based on the global positioning system (GPS).[1] For today's unaugmented GPS receiver to support a NACp≥9 with reasonable availability, that receiver must take a selective availability (SA) Off (also called SA–aware) approach to the calculation of the receiver's Horizontal Figure of Merit (HFOM) output. (The HFOM is the key GPS output used in calculating the NACp associated with a GPS position). That is, the receiver must perform its HFOM calculations without putting a conservative factor into the error estimate for each GPS satellite pseudorange to account for potential effects of SA, as is done in an SA On" approach to HFOM formulation.

SA On receiver algorithms for HFOM would be expected to produce, for a GPS constellation geometry Horizontal Dilution of Precision (HDOP) of 1.5, an HFOM on the order of 100 meters. This level of performance is consistent with the GPS Standard Positioning Service (SPS) specification as it existed when the GPS constellation had its initial operating capability (IOC) for aviation applications in 1993. It is expected that this year, a new SPS specification will be released, increasing performance. SA was turned off within the GPS in 2000 and it is the policy of the U.S. Government that it will remain off.

The availability/continuity, for an SA Off receiver, of an HFOM that supports a NACp≥9 is dependent upon the GPS constellation geometry available to the aircraft. A companion paper addresses availability of various unaugmented GPS receiver HFOM values based upon differing GPS constellation assumptions. Augmentations to the GPS such as the Wide Area Augmentation System (WAAS), Local Area Augmentation System (LAAS), GNSS Regional Augmentation System (GRAS), and the future GPS III Program (which provides two ranging frequencies from each satellite) significantly improve these availabilities. This is because use of both the GPS and the future Galileo satellite

[1] This paper does not discuss details of providing a vertical 95 percent accuracy of 45 meters for a NACp≥9,as the driving applications for this NACp value in the NPRM are on the airport surface. Some enhanced air-to-air ADS–B applications may require a NACp≥9—it is not clear at this time whether these airborne applications will require vertical accuracy better than that of a barometric altimeter.

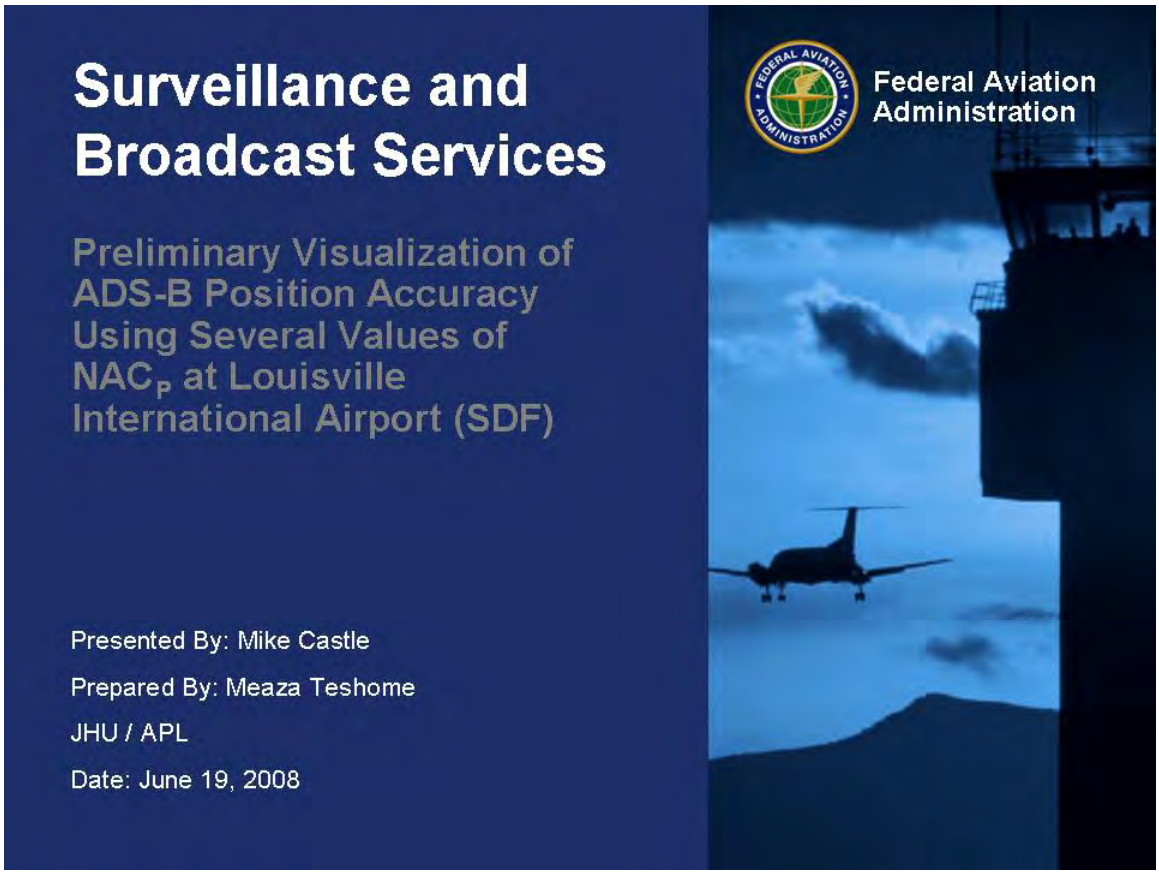
constellation (the first end-state Galileo satellite signal in space) was made available from the Giove B satellite on May 7, 2008).

The availability/continuity of a stringent NACp value can be also be significantly improved by the use of tightly coupled GPS/inertial reference system (IRS) techniques, in which GPS is used to update the inertial position and the inertial is used to: (1) provide improved HFOM values to those provided by GPS alone during periods of nominal GPS performance and (2) maintain a highly accurate navigation position during short periods of degraded GPS performance. Under satellite constellation assumptions not inconsistent with the current number of operational satellites in the constellation[2], tightly coupled GPS/IRS avionics can provide continuous availability of a NACp of 9.

ADS–B NACp values less stringent than 9 will support both air-ground surveillance in the majority of airspace domains and the needs of many aircraft-to-aircraft ADS–B In applications. A NACp of 8 is defined as a horizontal ADS–B position accuracy, at the 95 percent confidence level, of 92.6 meters (0.05 nm) or better. Consistent with the discussion above, a GPS receiver using SA On algorithms in its HFOM calculations will not provide a high availability of an HFOM that supports a NACp of 8 without consistently excellent GPS HDOPs. As can be seen in the companion paper referred to above, an unaugmented SA Off receiver can provide very high availability of an HFOM that supports a NACp≥8 under particular GPS constellation assumptions not inconsistent with the current number of operational satellites in the constellation.
A NACp of 7 is defined as a horizontal ADS–B position accuracy, at the 95 percent confidence level, of 185.2 meters (0.1 nm) or better. Such an accuracy level is, in the May 2008 draft of ADS–B performance standards being developed by RTCA and EUROCAE, seen to be adequate to support 5 nm enroute and 3 nm terminal area air-ground-based ATC separations in high air traffic density airspace regions which also have radar coverage for backup purposes. As can be seen in the companion paper, GPS receivers using SA On algorithms in calculating HFOM can support a high availability (for example, 999) of an HFOM which supports a NACp≥7 under GPS constellation assumptions not inconsistent with the current number of operational satellites in the constellation. SA Off receivers support a very high availability of an HFOM that supports a NACp≥ 7 under a broader set of GPS constellation assumptions.

[2] The Department of Defense has briefed the ATMAC ADS–B Work Group in April 2008 on the potential for the number of GPS operational satellites to significantly decrease compared to the 2008 constellation prior to the availability of a full GPS III constellation.

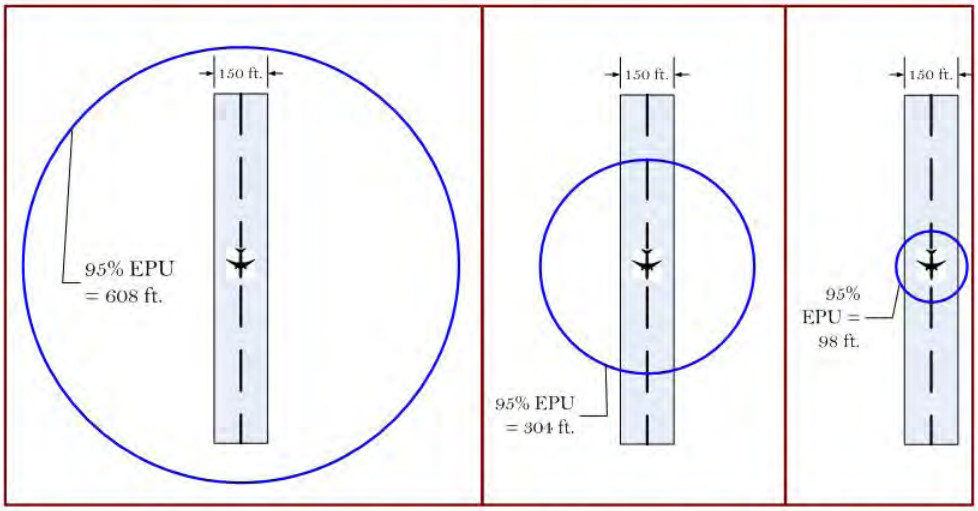
APPENDIX Y – PRELIMINARY VISUALIZATION OF – POSITION ACCURACY USING SEVERAL VALUES OF NACP AT LOUISVILLE INTERNATIONAL AIRPORT (SDF)



Overview

- Purpose of this brief is to aid in visualizing the performance of ADS-B on the surface
- Simulation based on runway / taxiway at the Louisville International Airport (SDF)

Sense of Scale – NAC_P Circles (Radius = EPU) on 150ft. Wide runway

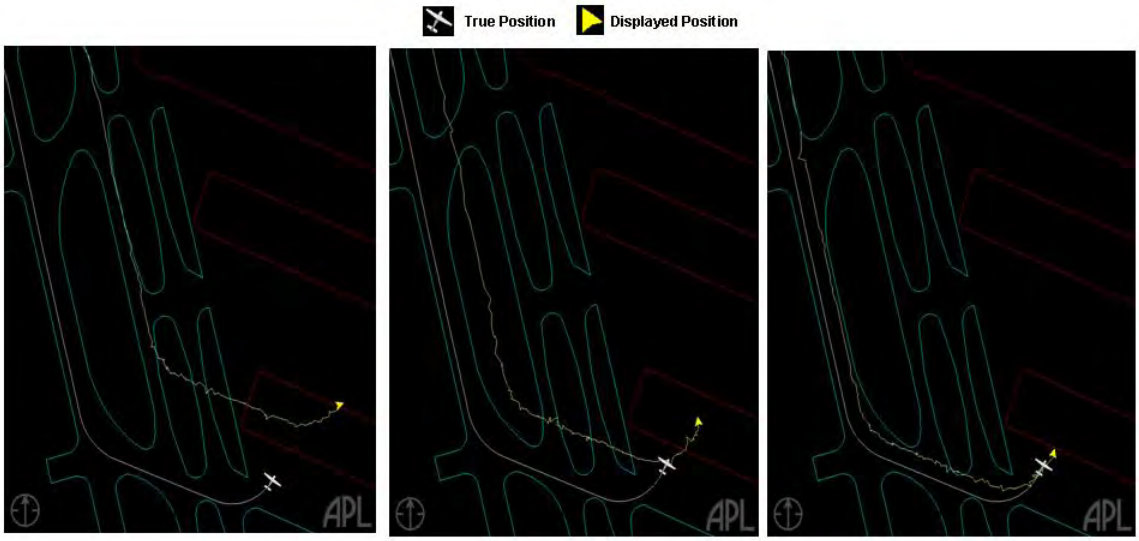


NAC_P=7 Case NAC_P=8 Case NAC_P=9 Case

Assumptions for Simulated Landing/Taxi

- **GPS**
  - 1 Hz updates minimum for position measurement
  - 500 ms uncompensated latency
- **ADS-B Transmit**
  - Position error fixed at the 95% Estimated Position Uncertainty
  - 1090ES
    - Reports based on position message reception
  - UAT
    - Precision mode for NAC 9, non-precision for NAC 7 & 8
- **ADS-B In Reception**
  - 600 ms total own-ship latency from reception of message to CDTI display [ref. ASAS MOPS]
  - 1.5 sec update @ 95% success rate [ref. ADS-B MASPS]
  - Reported position used for display

ADS-B w/ 1090 ES



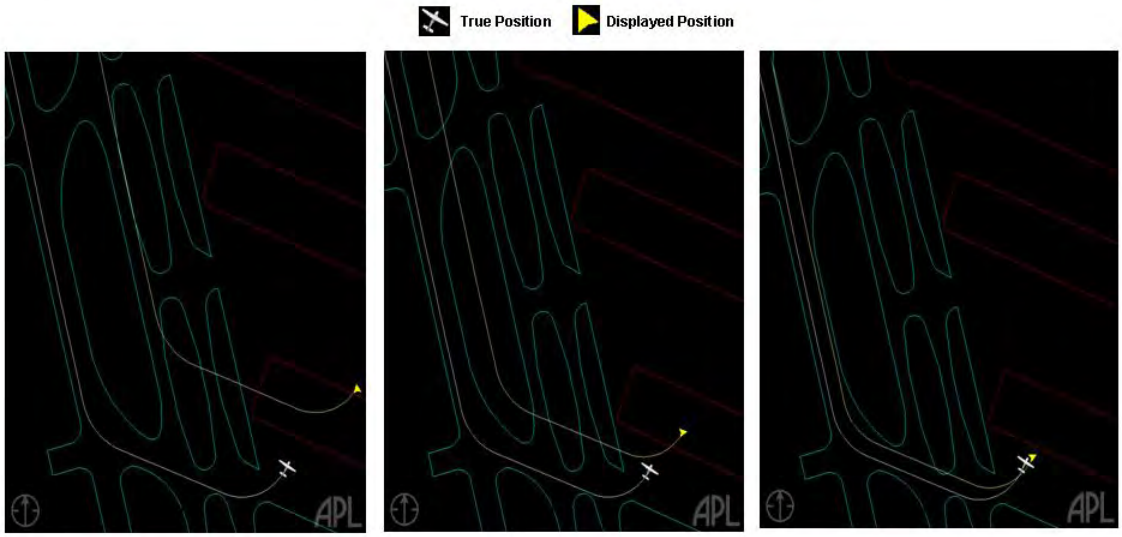
NAC_P 7 NAC_P 8 NAC_P 9

Surveillance and Broadcast Services
June 12, 2008

Federal Aviation Administration

5

ADS-B w/ UAT



NAC_P 7 NAC_P 8 NAC_P 9

Summary

- For NAC 7 and 8, the 95TH percentile error shows that target is not consistently on the movement area
- For NAC 9, the 95TH percentile error indicates that the target is typically on the movement area

APPENDIX Z – GPS SIGNAL-IN-SPACE AVAILABILITY DISCUSSION

GPS Signal-in-Space Availability Discussion

The availability of GPS L1 C/A Standard Positioning Service (SPS) signal to meet various levels of position accuracy and integrity performance is heavily dependent upon the assumptions that go into the availability analysis. An assumption that has one of the largest effects on the availability analysis results is the assumed GPS satellite constellation.

Satellite Constellation Assumptions

Several satellite constellation assumptions are identified in Tables 1 and 2 below.

Table 1: 24 GPS Satellite Constellations

#	Constellation Assumption	Availability of the Number of Satellites (N) in the proper orbital positions				
		24	23	22	21	20
1	100% availability of 24 GPS SVs	100%	0	0	0	0
2	Minimum Guaranteed SPS Performance (21 slots 98%)	N/A	N/A	N/A	[≥ 21 SV's 98%]	N/A
3	RTCA Assumed Model of SPS Minimum Guarantee [Ref. DO-245, §F.3.2]	72%	17%	6.4%	2.6%	2%
4	RTCA Assumed SPS Performance [Ref. DO-245A, §F.3.2]	95%	3%	1.2%	0.48%	$3*(0.4^{(23-N)})\%$
5	Simplified Model of RTCA Assumed SPS Performance	95%	3%	1.2%	0.50%	0.3%
6	IFOR Objective [Ref #3] [Interagency Forum on Operational Rqmts. (IFOR) dated April 25, 2003]	95%	4%	1%	0%	0%
7	IFOR Threshold [Ref #3] [Interagency Forum on Operational Rqmts. (IFOR) dated April 25, 2003]	72%	17%	6.4%	2.6%	20 sats: 1.3% 19 sats. 0.44% 18 sats. 0.26%

Table 2: 27 GPS Satellite Constellations

#	Constellation Assumption	Availability of the Number of Satellites (N) in the proper orbital positions				
		27	26	25	24	23
8	RTCA (24) + 3 satellites	72%	17%	6.4%	2.6%	2%
9	SPS Model (24) + 3	95%	3%	1.2%	0.5%	0.2%
10	27 satellites with 24 guaranteed 100%	98.3%	0.6%	1%	0.1%	0%

Note that the GPS SPS Performance Standard (dated October 2001) [reference #2] provides the following constellation service standard in section 3.2: "In support of the service availability standard, 24 operational satellites must be available on orbit with 0.95 probability (averaged over any day). ***At least 21 satellites in the 24 nominal plane/slot positions must be set healthy and transmitting a navigation signal with 0.98 probability (yearly averaged)****."*

The analyses of various hypothetical satellite constellations presented herein are intended to illustrate the effect that the constellation assumption has on the levels of position accuracy and integrity performance that can be achieved. The minimum performance indicated by the SPS performance standard has been modeled in constellations #3 and #7; however, these are just "models" of the minimum performance and are not guaranteed.

Other Analysis Assumptions

Assumptions other than the satellite constellation also impact the results of the availability analysis. The assumptions used in availability analyses presented herein include:

- GPS L1 C/A Code (single frequency receiver)
  - No baro or inertial aiding.
    - Baro or Inertial Aiding are possible, but have not been analyzed herein. Thus, the signal-in-space results presented are directly related to the HFOM and HPL (as defined in DO-229D) by a fault-free receiver.
- Satellite Mask Angle
  - 2 degrees or 5 degrees
- Satellite orbital constellation
  - For the 24-satellite constellations, the constellation is as defined in the WAAS MOPS (RTCA DO–229D) Appendix B, whereby when satellites have failed, a slot is empty
- User Ranging Accuracy (URA)
  - For SA On GPS Receivers:
    - 33 meters or 33.3 meters (1σ pseudorange error)
    - Assume negligible other errors

- For SA Off GPS Receivers:
  - URA = 4, or 5.7, or 6 meters
    - URA of 5.7 meters corresponds to a URA index of 3 as indicated the RTCA/DO-229D (Table 2-3)
    - URA = 6 meters *(per GPS SPS Performance Standard dated October 2001, §3.4, Table 3-5)*
    - URA = 4 meters. URAs on the order of 6 meters for SA Off is very conservative based upon existing satellite performance. Typically, URA index is broadcast as 0 or 1, which corresponds to URA of 2 meters and 2.8 meters, respectively, based on DO-229D Table 2-3. Even assuming that the URA index is 2 (which is higher than it typically is) it corresponds to a 4 meter URA. Such a value is used in the analysis to illustrate a less pessimistic assumption that is still conservative based upon current constellation performance.
  - Standard tropo, iono, receiver noise, and multipath models per RTCA/DO–229D
- For GPS/WAAS Receivers:
  - User Differential Range Error (UDRE) for GPS and WAAS satellites as computed per WAAS MOPS (DO–229D, Appendix J) based on WAAS system model
  - WAAS System Model:
    - No WAAS reference station or WAAS GEO failures [100% available]
    - 2 WAAS GEOs at 107°W and 133°W used as additional ranging sources that are 100% available
    - 38 WAAS Reference Stations in the Continental United States (CONUS), Canada, and Mexico

- Availability Results: Presented as worldwide average, specific location, or maps
  - Worldwide Availability Average is defined in WAAS MOPS DO-229D (§2.5.9.2):
    - Analysis grid: 2353 points in the Northern hemisphere sampled every 5 minutes over a 12 hour period for a total of 338,832 space-time points (i.e., 2353 points * 144 time samples) as specified in the "Availability Tests" §2.5.9.2 of DO-229D.
  - Specific Location
    - The results presented below for specific locations are based upon an analysis at the following airport locations: (ANC/DEN/DFW/JFK/LAX/MIA/ORD/SEA/SFO/MEM) that are sampled every minute over a siderial day (approximately 24 hour period)
  - Availability Maps
    - Calculations are done for a tight grid of user locations (2 degrees x 2 degrees) that are sampled every 5 minutes over a siderial day

Availability Analysis Results

Availability analyses were run for various assumed constellations identified in Tables 1 and 2 using the assumptions specified above. The results of these analyses are presented in Tables 3 through 6 and Figures 1 through 13 below.

For each satellite constellation analyzed, the availability results are determined by assessing the availability under each full and sub-set satellite constellation configuration, and weighting the results by the probability that the satellite constellation is in that state. In other words, for each constellation analyzed, the overall availability result is determined by analyzing the constellation configurations for no failures as well as all combinations of single, dual, triple, etc. satellite failures as assessed individually, and then weighting the intermediate availability results by the probability that the constellation is in that particular configuration.

Notes on the analysis results:

1. *Dashes (i.e., "—") in the tables indicate that an analysis for that configuration was not conducted and hence results have not been provided.*
2. *The number of decimal places provided in the results tables is not indicative of the number of significant digits in the availability models. The availability analyses are not accurate to the number of decimal places provided in the tables. Nevertheless, a large number of decimal places have been provided in the tables to illustrate how the results for the model change over the various conditions.*

Table #3: GPS Signal-in-Space Availability versus ADS–B Performance Parameter
[With 2 Degree and 5 Degree Satellite Mask Angles]

[Constellation Assumption #1: Assumes 100% availability of 24 satellites, 2 and 5 degree satellite mask angles, URA = 33.3 meters (SA=on) and 5.7 meters (SA=off), no receiver aiding, source Rockwell-Collins Analysis (Ref. #7)]

	ADS–B Performance Parameter	Availability (Worldwide Average) [%]			
		2 Degree Mask Angle		5 Degree Mask Angle	
		SA = On [URA=33.3 m]	SA = Off [URA=5.7 m]	SA = On [URA=33.3 m]	SA = Off [URA=5.7 m]
Position Integrity	**NIC = 5** (1 NM)	≈ 99.9909	> 99.9999	≈ 99.9088	≈ 99.9879
	NIC = 6 (0.6 NM)	≈ 99.9852	> 99.9999	≈ 99.8132	≈ 99.9761
	NIC = 7 (0.2 NM)	≈ 96.9681	≈ 99.9825	≈ 86.7569	≈ 99.8081
Position Accuracy	**NACp = 7** (185.2 m Hor.)	> 99.9999	> 99.9999	> 99.9999	> 99.9999
	NACp = 8 (92.6 m Hor.)	≈ 99.6455	> 99.9999	≈ 98.4019	> 99.9999
	NACp = 9 (30 m Hor., 45 m Vert.)	0	≈ 80.4460 Hor. ≈ 79.4570 Vert.	0	≈ 76.5411 Hor. ≈ 73.2407 Vert.
Velocity Accuracy	**NACv = 1** (10 m/s Hor., 50 fps Vert.)	> 99.9	> 99.9	> 99.9	> 99.9

Table #4: GPS Signal-in-Space Availability versus ADS–B Performance Parameter
[For URA of 4 meters and 5.7 meters]

[Constellation Assumption #1: Assumes 100% availability of 24 satellites, 2 and 5 degree satellite mask angles, URA = 4.0 meters or 5.7 meters (SA=off) as indicated, no receiver aiding, source Rockwell-Collins Analysis (Ref. #7)]

	ADS–B Performance Parameter	Availability (Worldwide Average) [%]			
		SA = Off			
		2 deg. Mask Angle		5 degree Mask Angle	
		URA= 4 m	URA= 5.7 m	URA= 4 m	URA= 5.7 m
Position Integrity	**NIC = 5** (1 NM)	> 99.9999	> 99.9999	≈ 99.9882	≈ 99.9879
	NIC = 6 (0.6 NM)	> 99.999	≈ 99.9998	≈ 99.9796	≈ 99.9761
	NIC = 7 (0.2 NM)	≈ 99.9852	≈ 99.9825	≈ 99.8368	≈ 99.8081
Position Accuracy	**NACp = 7** (185.2 m Hor.)	> 99.9999	> 99.9999	> 99.9999	> 99.9999
	NACp = 8 (92.6 m Hor.)	> 99.9999	> 99.9999	> 99.9999	> 99.9999
	NACp = 9 (30 m Hor., 45 m Vert.)	≈ 86.5437 Hor. ≈ 83.9427 Vert.	≈ 80.4460 Hor. ≈ 79.4570 Vert.	≈ 82.5996 Hor. ≈ 78.5436 Vert.	≈ 76.5411 Hor. ≈ 73.2407 Vert.
Velocity Accuracy	**NACv = 1** (10 m/s Hor., 50 fps Vert.)	> 99.9	> 99.9	> 99.9	> 99.9

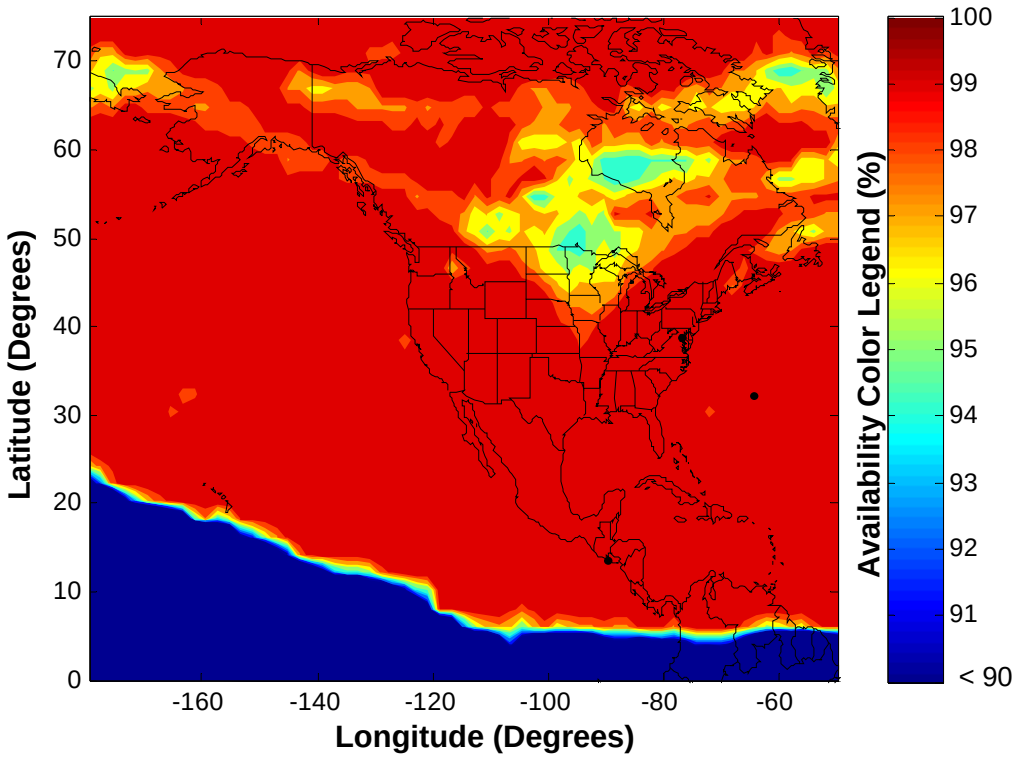


Figure 1: GPS SIS Availability Map of NACp = 9 (Horizontal only) versus Location

[Constellation Assumption #1: Assumes 100% availability of 24 satellites, 2 degree satellite mask angle, URA = 5.7 meters (SA=off), no receiver aiding, source Rockwell-Collins Analysis (Ref. #7)]

Note: For the NACp of 9 in Figure 1 above, only the horizontal accuracy requirement was assessed (i.e., HFOM < 30 meters). Thus, the vertical accuracy requirement of VFOM < 45 meters was not assessed.

Table #5: GPS Signal-in-Space Availability versus ADS–B Performance Parameter
[Constellation Assumption #3: RTCA Assumed Model of SPS Guarantee, 2 degree mask angle, URA = 33.3 meters (SA On) and 5.7 meters (SA Off), no receiver aiding, source Boeing Analysis]
(72% of 24 satellites, 17% of 23, 6.4% of 22, 2.6% of 21, and 2% of 20)

Note: For the 10 specific locations in the United States for which this availability analysis was run, the availability results are presented as the average for the 10 locations, as well as the lowest and highest availability for any location. Analysis (not presented herein) was conducted for a number of locations in Europe, and the results are similar. Specific Locations include: ANC/ DEN/ DFW/ JFK/ LAX/ MIA/ ORD/ SEA/ SFO/ MEM.

	ADS–B Performance Parameter	Availability	
		SA = On	SA = Off
Position Integrity	**NIC = 5** (1 NM)	> 99.7% 99.6069% low 99.9181% high	> 99.91% 99.8800% low 99.9760% high
	NIC = 6 (0.6 NM)	> 99.5% 99.3188% low 99.7948% high	> 99.85% 99.8022% low 99.9524% high
	NIC = 7 (0.2 NM)	≈ 91% 83.7193% low 94.8160% high	≈ 99.4% 99.2336% low 99.6775% high
Position Accuracy	**NACp = 7** (185.2 m Hor.)	> 99.94% 99.9143% low 99.9725% high	> 99.995% 99.9922% low 99.9983% high
	NACp = 8 (92.6 m Hor.)	> 97.00% 96.1491% low 99.0015% high	> 99.984% 99.9781% low 99.9884% high
	NACp = 9 (30 m Hor., 45 m Vert.)	0%	Horizontal only ≈ 98.3% 95.4576% low 98.9495% high
Velocity Accuracy	**NACv = 1** (10 m/s Hor, 50 fps Vert.)	–	–

Table #6: GPS Signal-in-Space Availability versus ADS–B Performance Parameter
[Constellation Assumption #5: SPS Performance, 2 degree mask angle, URA = 33.3 meters (SA On) and 5.7 meters (SA Off), no receiver aiding, source Boeing Analysis]
(95% of 24 satellites, 3% of 23, 1.2% of 22, 0.5% of 21, and 0.3% of 20)

Note: For the 10 specific locations in the United States for which this availability analysis was run, the availability results are presented as the average for the 10 locations, as well as the lowest and highest availability for any location. Analysis (not presented herein) was conducted for a number of locations in Europe, and the results are similar. Specific locations include: ANC/ DEN/ DFW/ JFK/ LAX/ MIA/ ORD/ SEA/ SFO/ MEM.

	ADS–B Performance Parameter	Availability	
		SA = On	SA = Off
Position Integrity	**NIC = 5** (1 NM)	> 99.94% 99.9312% low 99.9862% high	> 99.985% 99.9791% low 99.9960% high
	NIC = 6 (0.6 NM)	> 99.90% 99.8807% low 99.9648% high	> 99.975% 99.9654% low 99.9920% high
	NIC = 7 (0.2 NM)	≈ 94% 87.3783% low 97.0780% high	≈ 99.9% 99.7513% low 99.9443% high
Position Accuracy	**NACp = 7** (185.2 m Hor.)	> 99.99% 99.9854% low 99.9954% high	> 99.9991% 99.9987% low 99.9997% high
	NACp = 8 (92.6 m Hor.)	> 98.50% 97.3722% low 99.7097% high	> 99.997% 99.9963% low 99.9981% high
	NACp = 9 (30 m Hor., 45 m Vert.)	0%	Horizontal Only ≈ 99% 97.4210% low 99.8158% high
Velocity Accuracy	**NACv = 1** (10 m/s Hor, 50 fps Vert.)	–	–

Availability Maps

Availability of Integrity Maps (2 degree mask angle)

Figures 2 and 3 graphically illustrate the "Availability of Integrity" based upon the IFOR Objective and Threshold satellite constellation models.

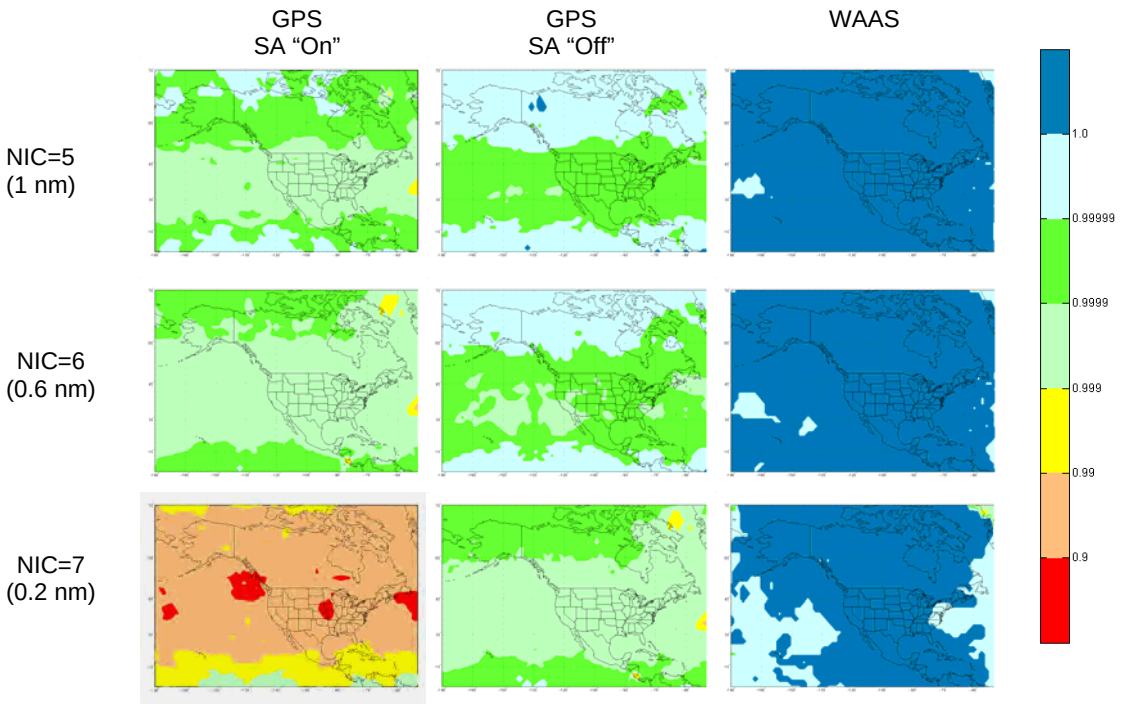


Figure 2: Availability of Integrity
[IFOR Objective - Satellite Constellation #6, Mask Angle = 2 deg]

[Constellation Assumption #6: SPS Performance, 2 degree mask angle, URA = 33 meters (SA On) and 6 meters (SA Off), no receiver aiding, source MITRE Analysis (Ref. #1)]
(95% of 24 satellites, 4% of 23, 1% of 22)

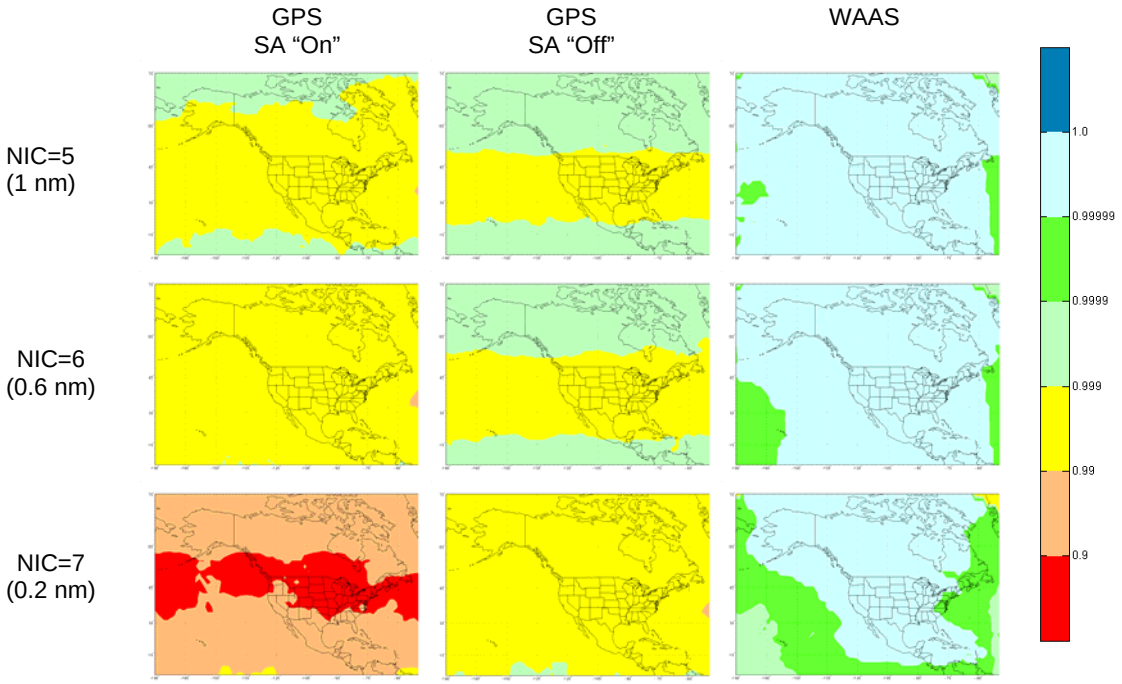


Figure 3: Availability of Integrity
[IFOR Threshold - Satellite Constellation #7, Mask Angle = 2 deg]

[Constellation Assumption #7: SPS Performance, 2 degree mask angle, URA = 33 meters (SA On) and 6 meters (SA Off), no receiver aiding, source MITRE Analysis (Ref. #1)]
(72% of 24 satellites, 17% of 23, 6.4% of 22, 2.6% of 21, 1.3% of 20, 0.44 of 19, 0.26 of 18)

Availability of Accuracy Maps (2 degree mask angle)

Figures 4 and 5 graphically illustrate the "Availability of Accuracy" based upon the IFOR Objective and Threshold satellite constellation models.

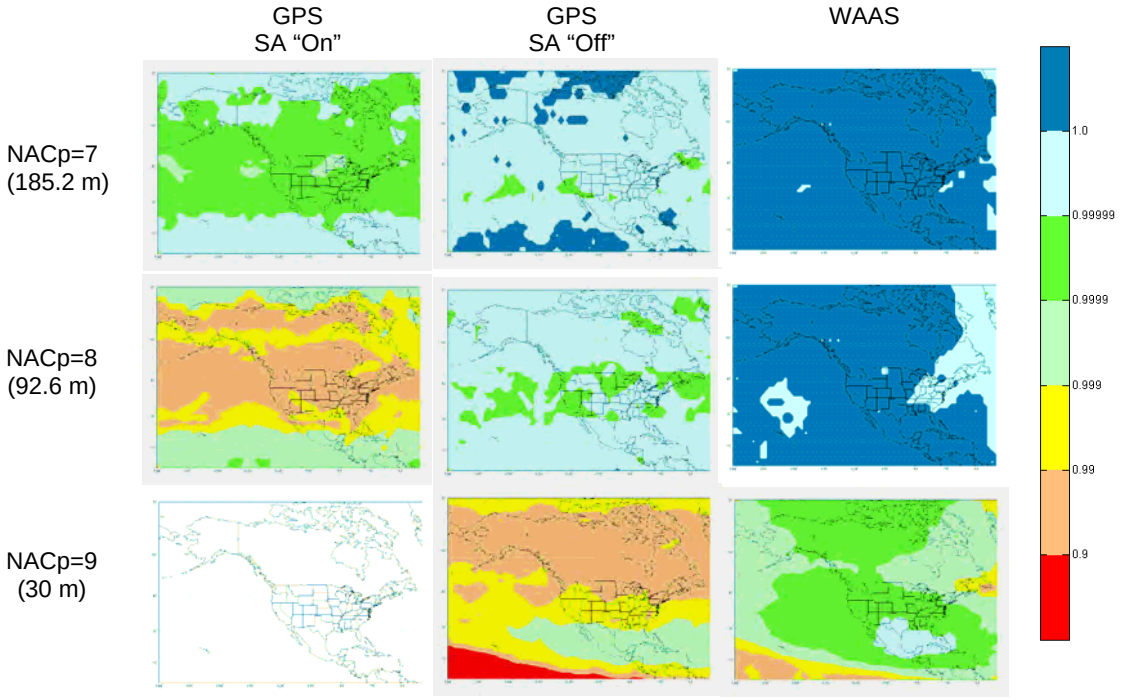
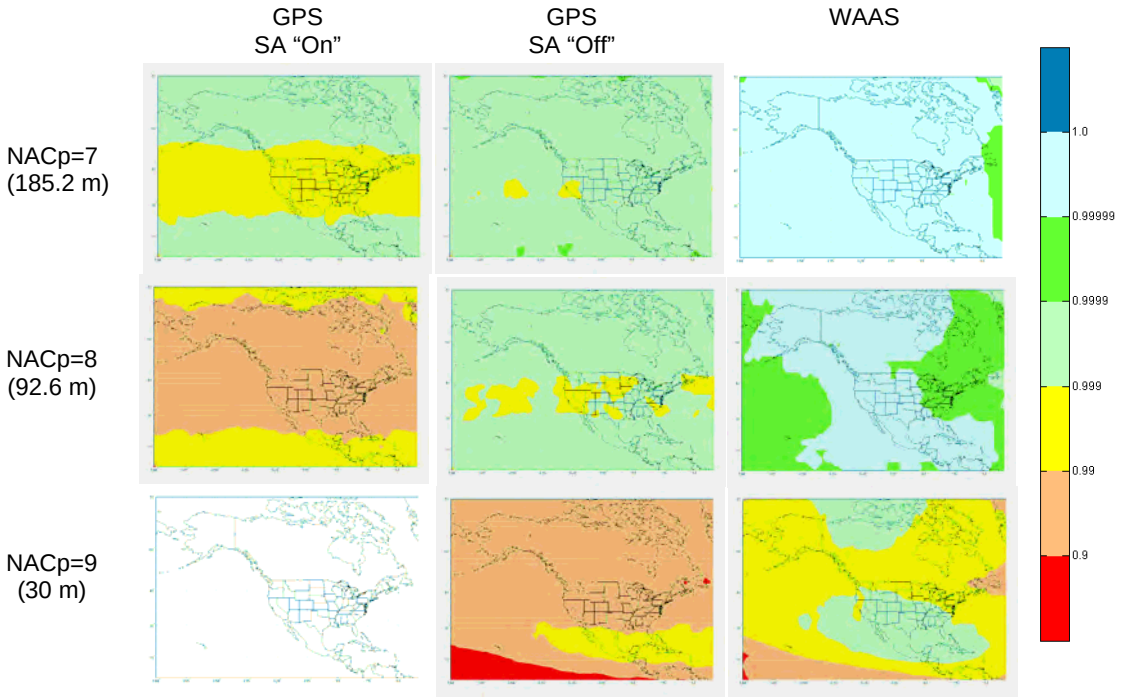


Figure 4: Availability of Accuracy
[IFOR Objective - Satellite Constellation #6, Mask Angle = 2 deg]

[Constellation Assumption #6: SPS Performance, 2 degree mask angle, URA = 33 meters (SA=on) and 6 meters (SA=off), no receiver aiding, source MITRE Analysis (Ref. #1)]
(95% of 24 satellites, 4% of 23, 1% of 22)



<u>Figure 5</u>: Availability of Accuracy
[<u>IFOR Threshold</u> - Satellite Constellation #7, Mask Angle = 2 deg]

[Constellation Assumption #7: SPS Performance, 2 degree mask angle, URA = 33 meters (SA On) and 6 meters (SA Off), no receiver aiding, source MITRE Analysis (Ref. #1)] (72% of 24 satellites, 17% of 23, 6.4% of 22, 2.6% of 21, 1.3% of 20, 0.44 of 19, 0.26 of 18)

<u>Availability of Integrity Maps</u> (For 2 and 5 degree mask angles)

Figures 6 through 9 are graphs that illustrate the "Availability of Integrity" as a function of: a) satellite mask angle, b) SA On and SA Off, and c) two different constellation models (IFOR Objective and IFOR Threshold).

Figures 6 and 7 illustrate GPS availability of integrity for 2 degree and 5 degree satellite mask angles with SA On and SA Off and the IFOR Objective constellation model.

[Constellation Assumption #6: SPS Performance with no receiver aiding, Source MITRE Analysis (Ref. #2)]

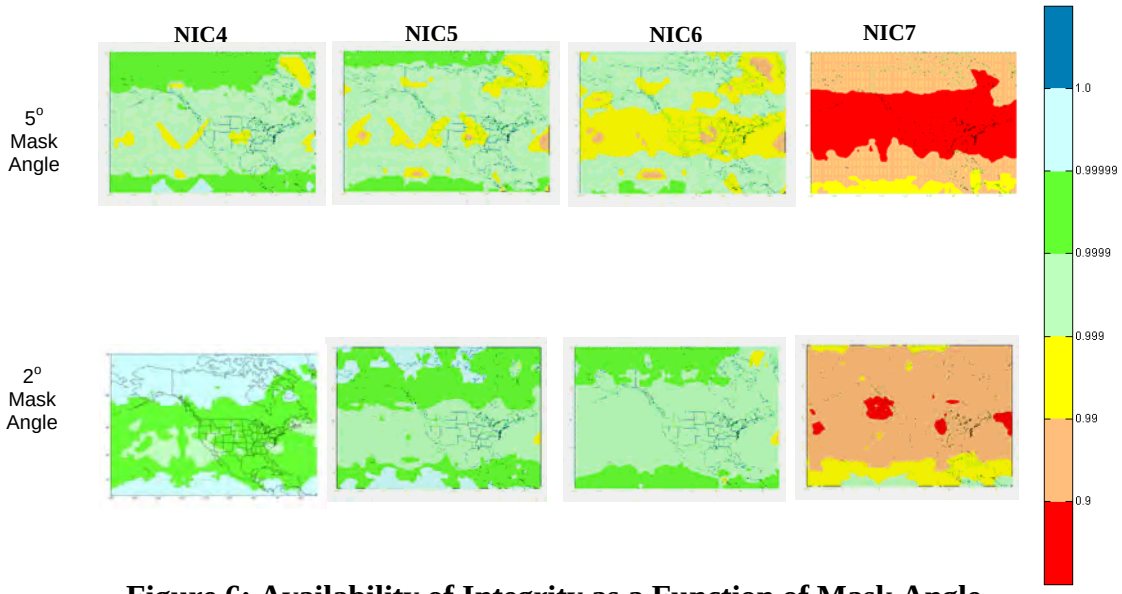


Figure 6: Availability of Integrity as a Function of Mask Angle [SA On (URA = 33 meters), IFOR Objective - Satellite Constellation #6]

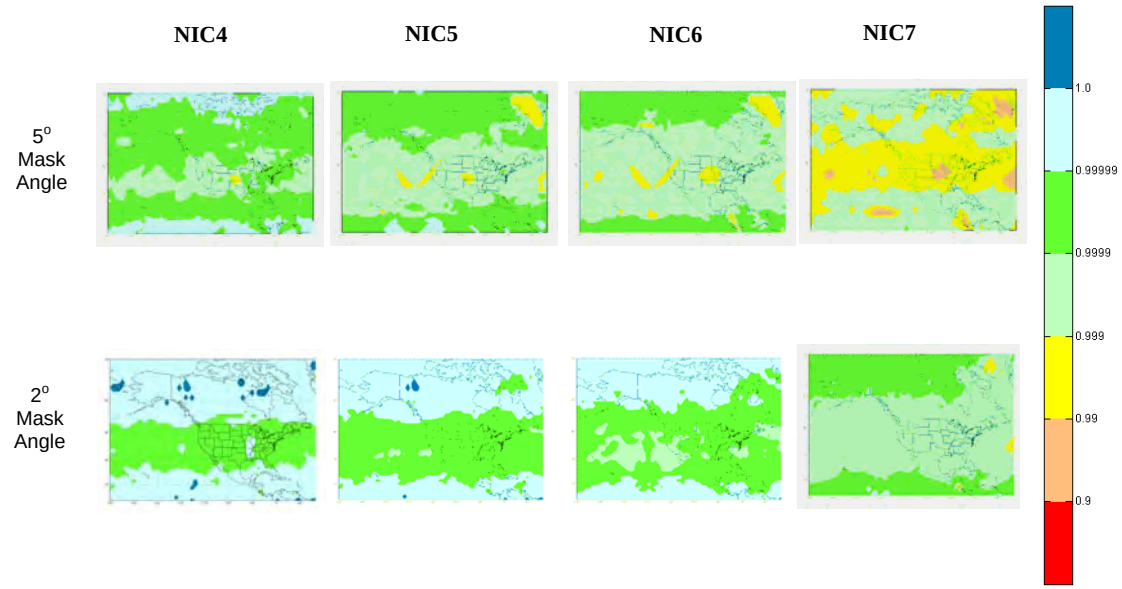


Figure 7: Availability of Integrity as a Function of Mask Angle [SA Off (URA = 6 meters), IFOR Objective - Satellite Constellation #6]

Figures 8 and 9 illustrate GPS availability of integrity for 2 degree and 5 degree satellite mask angles with SA On and SA Off and the IFOR Threshold constellation model.

[Constellation Assumption #7: SPS Performance with no receiver aiding, Source MITRE Analysis (Ref. #2)]

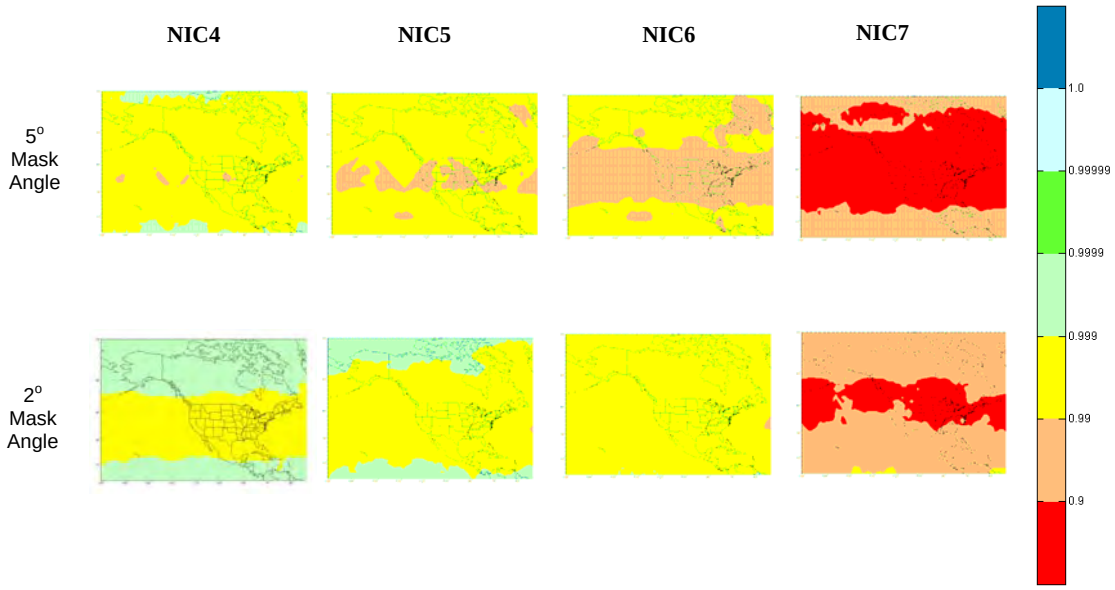


Figure 8: Availability of Integrity as a Function of Mask Angle [SA On (URA = 33 meters), IFOR Threshold - Satellite Constellation #7]

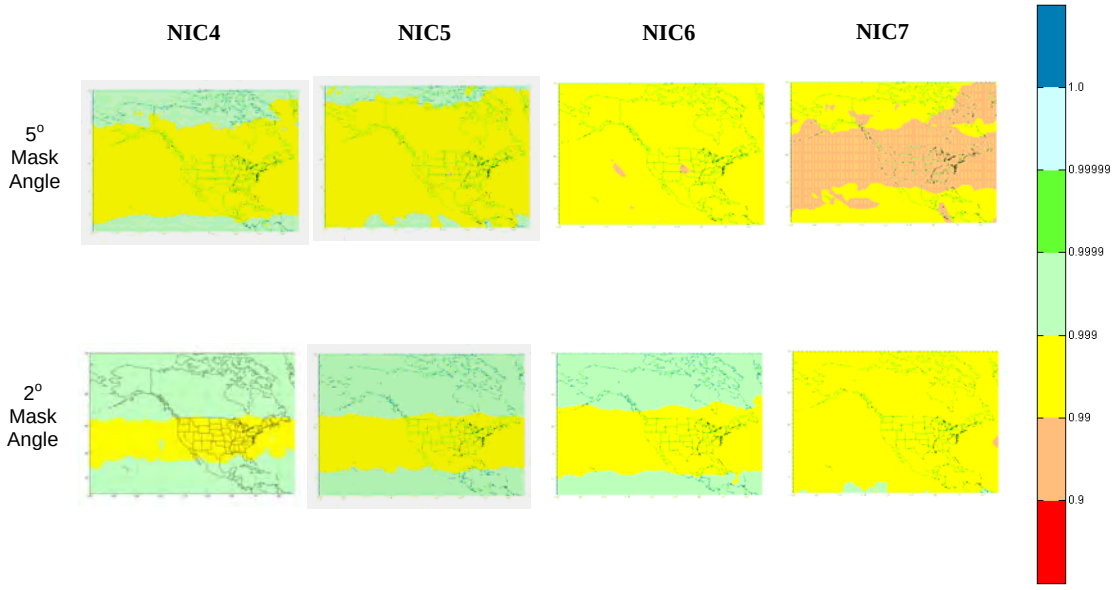


Figure 9: Availability of Integrity as a Function of Mask Angle [SA Off (URA = 6 meters), IFOR Threshold - Satellite Constellation #7]

Availability of Accuracy Maps (For 2 and 5 degree mask angles)

Figures 10 through 13 are graphs that illustrate the "Availability of Accuracy" as a function of: a) satellite mask angle, b) SA On and SA Off, and c) two different constellation models (IFOR Objective and IFOR Threshold).

Figures 10 and 11 illustrate GPS availability of accuracy for 2 degree and 5 degree satellite mask angles with SA On and SA Off and the IFOR Objective constellation model.

[Constellation Assumption #6: SPS Performance with no receiver aiding, Source MITRE Analysis (Ref. #2)]

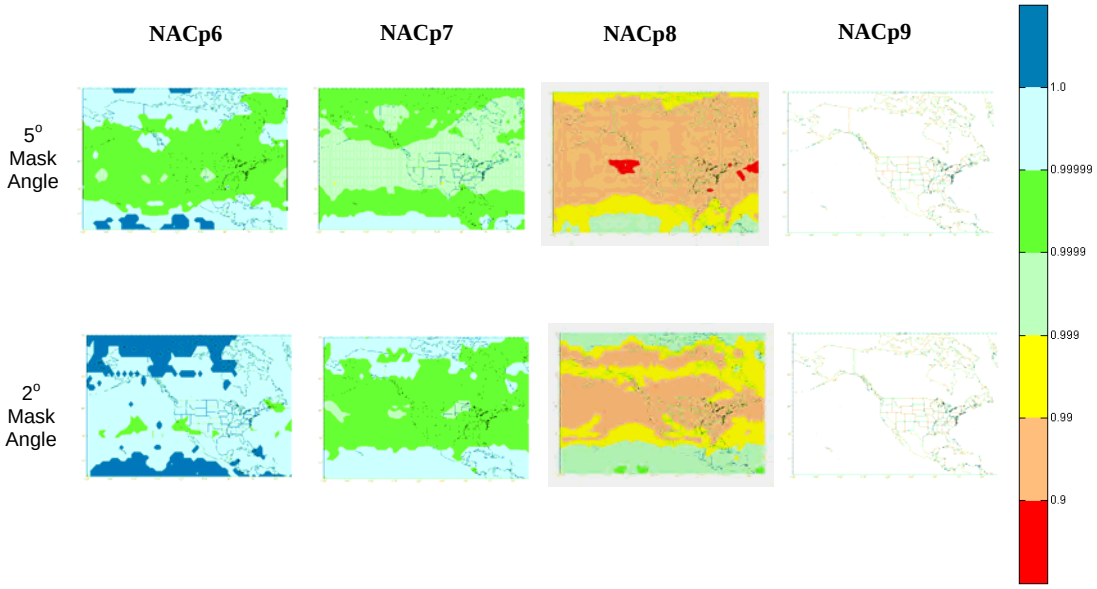


Figure 10: Availability of Accuracy as a Function of Mask Angle [SA On (URA = 33 meters), IFOR Objective - Satellite Constellation #6]

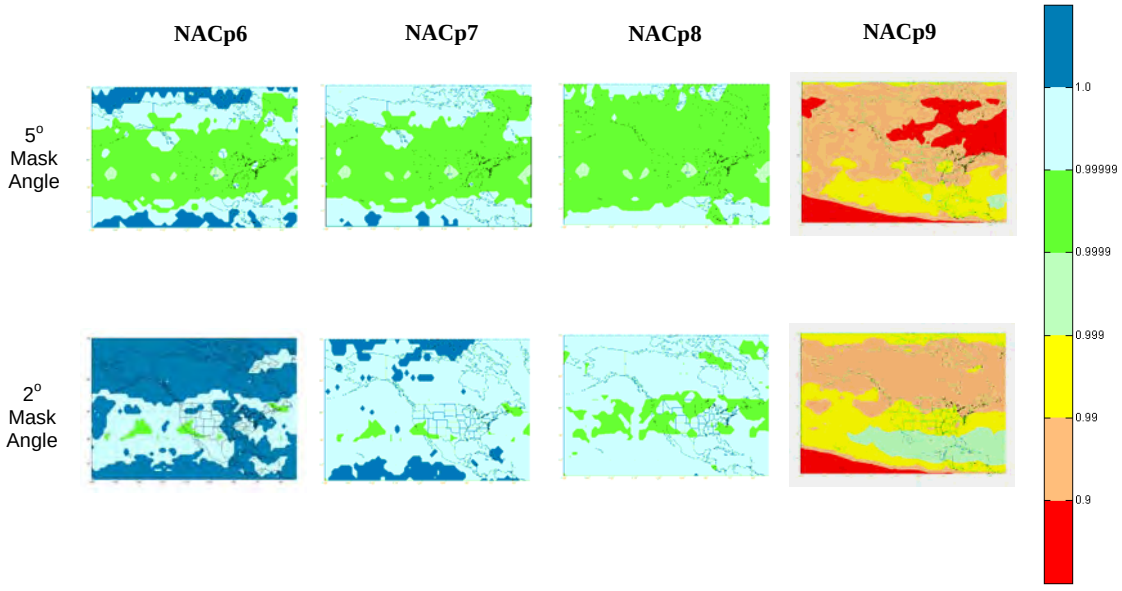


Figure 11: Availability of Accuracy as a Function of Mask Angle [SA Off (URA=6 meters), IFOR Objective - Satellite Constellation #6]

Figures 12 and 13 illustrate GPS availability of accuracy for 2 degree and 5 degree satellite mask angles with SA On and SA Off and the IFOR Threshold constellation model.

[Constellation Assumption #7: SPS Performance, URA = 33 meters (SA=on) and 6 meters (SA Off), no receiver aiding, source MITRE Analysis (Ref. #2)]

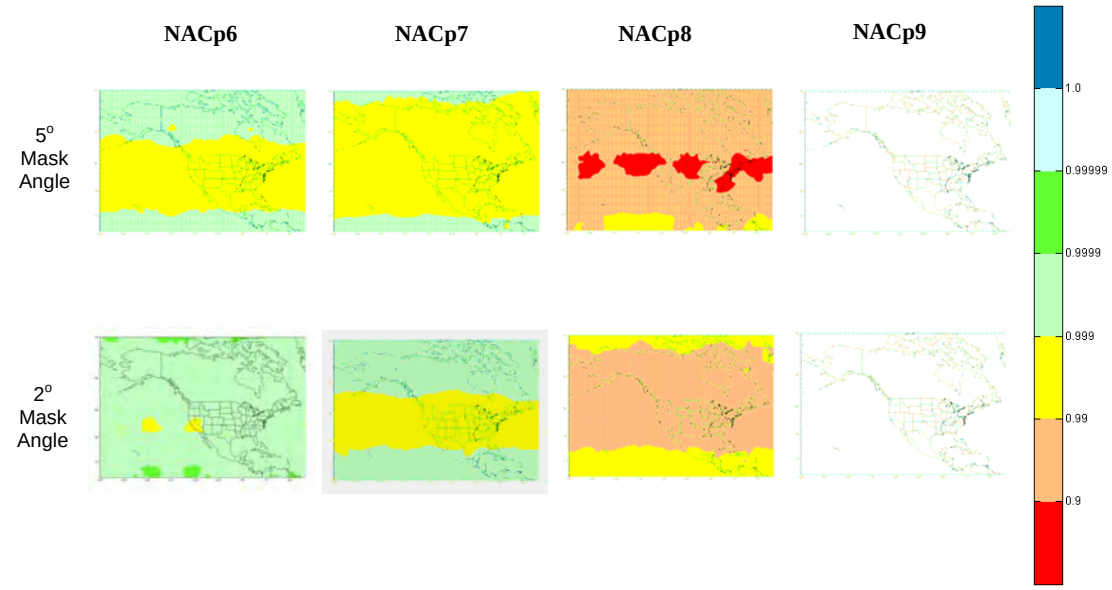


Figure 12: Availability of Accuracy as a Function of Mask Angle
[SA On (URA = 33 meters), IFOR Threshold - Satellite Constellation #7]

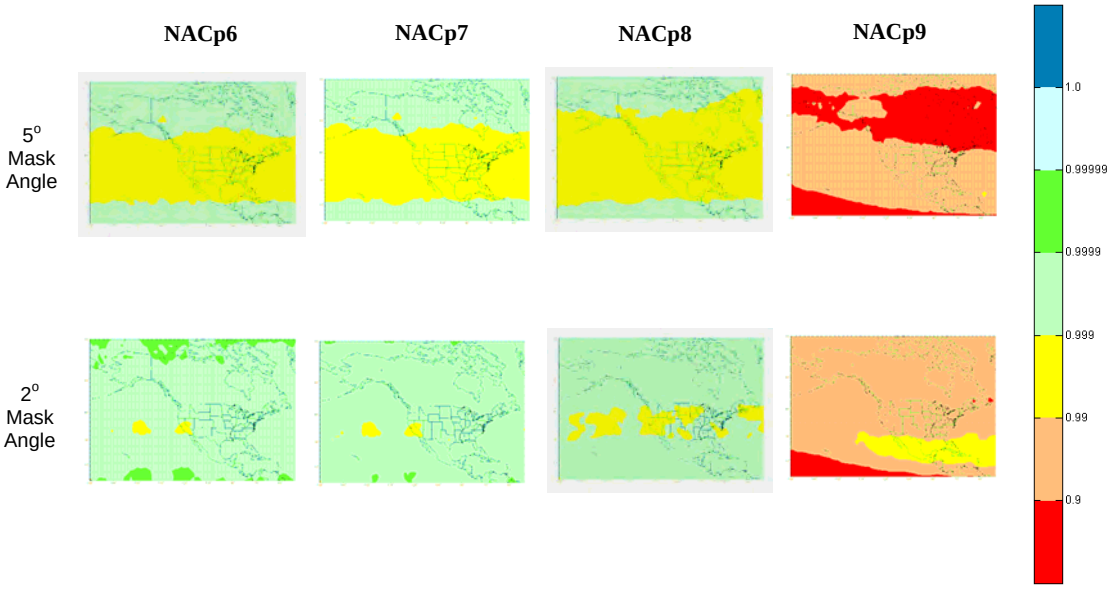


Figure 13: Availability of Accuracy as a Function of Mask Angle
[SA Off (URA = 6 meters), IFOR Threshold - Satellite Constellation #7]

Results Summary

Table 7 summarizes the results of the GPS signal-in-space constellation availability analyses indicating the values of NIC and NACp that meet or exceed 99.9% availability under the various constellation assumptions.

Table 7: NIC and NACp Values Exceeding 99.9% Availability

	#	Constel-lation # (see Tables 1 and 2)	Analysis Locations	Availability > 99.9% [Notes 1 to 6]									
				5 Degree Mask Angle				2 Degree Mask Angle				2 Degree Mask Angle	
				SA On		SA Off		SA On		SA Off		WAAS	
				NIC	NAC_p	NIC	NAC_p	NIC	NAC_p	NIC	NAC_p	NIC	NAC_p
24 Satellite Constellations	1	3 [RTCA Model 21+ 98%]	10 US Location Average	--	--	--	--	4	7	5	8	--	--
	2	3 [RTCA Model 21+ 98%]	SEA	None [Note 2]	None [Note 2]	None [Note 2]	None [Note 2]	3	7	4	7	--	--
	3	5 [SPS Model]	10 US Location Average	--	--	--	--	6	7	7	8	--	--
	4	5 [SPS Model]	SEA	4	7	5	8	6	7	6	8	--	--
	5	7 [IFOR Threshold]	US Grid	Low [Note 3] (≤3)	Low [Note 3] (≤5)	Low [Note 3] (≤3)	Low [Note 3] (≤5)	Low [Note 2] (≤3)	Low [Note 2] (≤5)	Low [Note 2] (≤3)	Low [Note 2] (≤5, but almost meets 7)	7	8
	6	6 [IFOR Objective]	US Grid	Low [Note 2] (≤3)	7	Low [Note 2] (≤3)	8	6	7	7	8	7	8
24+ Satellite Constellations	7	8 [RTCA + 3 Satellites]	10 US Location Average	--	--	--	--	5	7	6	8	--	--
	8	1 [24 sats. 100%] (Note 7)	Worldwide Average	5 (just meets)	7	6	8	6	7	7	8	--	--
	9	9 [SPS + 3 Satellites]	10 US Location Average	--	--	--	--	6	7	7	9 [Hor. Only]	--	--
	10	10 [27 satellites with 24 guaranteed 100%]	10 US Location Average	--	--	--	--	6	7	8	9 [Hor. Only]	--	--

Table Notes:

Note 1: These availability results of meeting a level of NIC and NACp performance are based solely on the HPL and HFOM output by a "fault-free" GPS receiver, and do not include any effects of compensated/uncompensated latency per RTCA requirements. Similarly, the results do not include any effects for the difference between the GPS antenna and the aircraft surveillance position reference point. A "fault-free" receiver means that the receiver complies with relevant minimum operational performance standards (MOPS) [for example, DO–229D for GPS/WAAS].

Note 2: "None" indicates that the analysis for the configuration did not meet the 99.9% availability target with any value of NIC or NACp ≥ 1.

Note 3: "Low" in the table indicates that the availability analysis has been run for this configuration; however, the exact values where NIC and NACp are available at the 99.9% target have not been precisely determined, but are such that NIC ≤ 3 and NACp ≤ 5.

Note 4: For the NACp of 9 in the table, only the horizontal accuracy requirement was assessed (i.e., HFOM < 30 meters). Thus, the vertical accuracy requirement of VFOM < 45 meters was not assessed. There are additional ADS–B Out requirements that must be satisfied for indicating the higher values of NACp (for example, see RTCA/DO–302, §2.2.4.1.1.3).

Note 5: The results in this table are based upon either a URA of 33 or 33.3 meters for SA On, and a URA of either 5.7 or 6 meters for SA Off, as specified in the preceding tables and figures where the source data for this summary table are provided.

Note 6: WAAS results assume no failures of the WAAS system such that there is 100 percent availability of 2 WAAS GEOs and 38 WAAS reference stations.

Note 7: While this is only a 24-satellite constellation, it is recognized that to achieve 100 percent availability of 24 satellites, more satellites will need to be in the constellation.

Conclusion

It is clear that the assumptions significantly impact the achieved level of positioning performance, especially the assumptions about the satellite constellation.

While the results of this analysis are presented in terms of "availability", the authors believe that "continuity" is a more appropriate requirement for specifying ADS–B Out performance. Continuity can be viewed as short term availability and can take into account the current satellite constellation configuration (for example, performance better than the minimum) for near term predictions for when and where the GNSS signal-in-space may not support the minimum ADS–B Out performance requirements. Availability is a long-term average that is typically determined using assumptions commensurate with the expected minimum long-term performance guarantee of the satellite constellation.

References:

1) T. Hsiao and D. O'Laughlin from MITRE CAASD, "GPS and WAAS Availability vs. ADS–B Navigation Integrity Category (NIC) and Navigation Accuracy Category (NAC)" presentation, dated 23 June 2008.
2) Global Positioning System (GPS) Standard Positioning Service (SPS) Performance Standard; by the Assistant Secretary of Defense for Command, Control, Communications, and Intelligence; October 2001.
3) Interagency Forum on Operational Requirements (IFOR) Proposed New GPS Operational Requirements, US Department of Transportation (DOT) Federal Aviation Administration (FAA); April 25, 2003.
4) IS-GPS-200D "NAVSTAR GPS Space Segment / Navigation User Interfaces;" by the GPS Joint Program Office; December 7, 2004.
5) RTCA/DO-229D "Minimum Operational Performance Standards (MOPS) for GPS/WAAS Airborne Equipment," by RTCA SC-159, December 13, 2006.
6) T. Hsiao from MITRE CAASD, "Availability of ADS–B NIC / NAC Values for GPS-Based Avionics in N. America" presentation, dated 14 July 2008.
7) Personal communications with Mahesh Surathu (Rockwell-Collins), Worldwide Availability Analysis Results, August 2008.

APPENDIX AA— ADS–B OUT CONTINUITY REQUIREMENT DISCUSSION

Introduction

The Aviation Rulemaking Committee (ARC) is in the process of devising a set of recommendations on the Federal Aviation Administration's (FAA) ADS–B Out Notice of Proposed Rulemaking (NPRM). There are a number of questions concerning the proposed continuity requirements including:

- Why do we need a continuity requirement?
- How do we justify specifying continuity in a performance-based rule?
- What is the distinction between continuity and availability?
- Why is the industry asking the FAA for an ADS–B Out continuity requirement?
- How does continuity get applied to the equipment?
- How do you test continuity?

Discussion/Answers to the Above Questions

Why do we need a continuity requirement?

A continuity requirement is needed as part of an ADS–B Out performance-based rule. It is not sufficient to only state the minimum performance requirements for navigation accuracy category for position (NACp), navigation accuracy category for velocity (NACv), navigation integrity category (NIC), and system implementation level (SIL). Simply stating the accuracy and integrity requirements—without a continuity requirement—means such requirements are not sufficient to predicate a primary surveillance and separation assurance system on a system that only specifies accuracy and integrity. For example, is it acceptable for an ADS–B Out user who only meets the NACp, NACv, NIC, and SIL when entering the ADS–B Out mandated airspace but has a 99 percent chance of losing the service within the next hour? Clearly, such a system is not acceptable. We need to ensure that aircraft entering ADS–B Out airspace have an acceptably low probability of losing their ADS–B-based primary surveillance system.

How do we justify specifying continuity in a performance-based rule?

It is believed that specifying continuity is the only way to achieve a performance-based rule and we need to allow manufacturers the flexibility to offer different system alternatives that will meet performance requirements. Otherwise, the FAA will be forced to specify specific equipment as they have done in the ADS–B Out NPRM preamble. The preamble states that the global positioning system (GPS)/wide area augmentation system (WAAS) is the only system that will meet the ADS–B Out performance with sufficient "availability". Aircraft operators and equipment manufacturers need the flexibility to meet the performance requirements. They need to be able to select a solution commensurate with both the performance requirements and their needs at an affordable cost. It is necessary to have a full set of performance requirements so that

alternative systems (for example, GPS-only, GPS/WAAS, GPS/inertial, GPS/Galileo) can be assessed against the performance requirements.

What is the distinction between continuity and availability?

Availability assesses the long term performance of the system (typically in terms of years. When availability analyses are done for ADS–B Out, they usually need to consider a pessimistic minimum guarantee of global navigation satellite system (GNSS) constellation performance (for example, 21 GPS satellites 98 percent of the time, with minimum satellite power).

Continuity can be viewed as short term availability (typically in terms of hours or a day). Continuity can take into account the current real-time performance of the satellite constellation (for example, real operational number of satellites and satellite power). Aircraft operators who have equipment that meets the minimum requirements to enter the ADS–B Out airspace (for example accuracy, integrity, and continuity) should not be denied service because of a hypothetical availability calculation with minimum guaranteed GPS performance (for example, having to assume that the constellation only has GPS 21 satellites when there are more than 30 that are operational). A continuity requirement is aligned with the ARC recommendation that the FAA analyze the GNSS constellation and issue notices to airmen (NOTAM), identifying the locations and time periods when the performance of the GNSS signal-in-space is not sufficient to support the application(s) that are intended in the given airspace.

Why is the industry asking the FAA for an ADS–B Out continuity requirement?

The ARC committee should ask the FAA to complete the ADS–B Out requirements by specifying the continuity requirements in addition to accuracy and integrity. This will allow industry to assess whether alternative systems meet the performance requirements. In addition, this will give aircraft operators the ability to select solutions commensurate with the mandated requirements and their needs. Without such a requirement, the performance requirements are not complete.

How does the continuity requirement get applied to the equipment?

There are several alternatives. The first alternative is that all external signals would be required have the capability to meet the ADS–B Out performance requirements, for example, accuracy and integrity, regardless of the continuity requirement for the entire ADS–B Out installation. Thus, continuity needs are allocated among all the elements that support an aircraft's ability to meet the performance of ADS–B Out (for example, GNSS signal-in-space, GNSS receiver, ADS–B Out transponder, interfaces, antennas, power supplies) The allocation of the continuity of the aircraft equipment is architecture-dependent and should not be specified in the NPRM. A single thread installation may need equipment with higher continuity than installations with redundant equipment.

A second alternative would involve two continuity requirements: one for the GNSS signal-in-space (for example, satellite constellation's at 99.9 percent) and a second for the airborne equipment installation (for example, 99.9 percent). There is a fundamentally different impact to the surveillance system if the GNSS signal-in-space does not meet the

performance requirements (as it will affect a large number of aircraft in a given outage region) as compared to when a single aircraft has an equipment failure and can no longer support ADS–B Out.

A third alternative is to only have signal-in-space continuity requirements for the external signals necessary to support ADS–B Out accuracy and integrity performance. This alternative would have no airborne equipment continuity requirements. This is similar to the existing approach for the altitude reports from airborne transponders that support the secondary surveillance Radars (SSR).

The fourth alternative is not adding a continuity requirement to the ADS–B Out requirements, and allowing the FAA to interpret the acceptability of proposed systems to meet the ADS–B Out mandate. Currently, the NPRM states that only GPS/WAAS navigation equipment has acceptable availability and that the FAA is evaluating the GPS/inertial. How does the FAA judge that an alternative system is acceptable to support ADS–B Out? Is GPS/Galileo acceptable? Is GPS with SA–Off with the current constellation performance acceptable? Continuity is the key to assessing acceptability, as it takes into account the current performance of the signal-in-space and not a hypothetical minimum performance.

How do you test continuity?

Equipment continuity performance is demonstrated by analysis. GNSS signal-in-space continuity is expected to be analyzed by the FAA service provider for a set of GNSS equipment configurations. Continuity would also be tested by NOTAMs which would be issued when the signal-in-space performance is not sufficient in a given region for a given time period.

Conclusion

The FAA recognizes there is significant concern with asking the FAA to add a continuity requirement to the ADS–B Out performance specifications. This concern is understandable. If there is no continuity specification, what percentage of the time does an installation need to meet the requirements for NACp, NACv, and NIC? Twenty percent does not meet the surveillance needed for the intended applications and 100 percent is not possible, so the requirement is somewhere in between. How can the industry assess the ability of alternative systems to meet the required ADS–B Out performance if continuity is not specified?

APPENDIX BB – DISCUSSION PAPER ON ASPECTS OF ECHOED OR ADJUSTED QUALITY FACTORS (NIC, NAC) BY THE ADS–B OUT SYSTEM

Note: This appendix applies primarily to 1090 ADS–B OUT.

The RFG has defined high level performance requirements that seem inconsistent with the specifications as defined for the ADS–B Out links.

The specific area of concern in this short paper is with regard to the interface data that is used to encode the NACp, NACv, and NIC.

There are basically three approaches that were considered during the RTCA SC–186 MASPS and MOPS deliberations:

1. All data, position, velocity, NACp, NACv, and NIC valid at interface "D" (the reported time of applicability of the information in the ADS–B Out message)
2. The position data is latency compensated to the interface D, the NACp, NACv, and NIC are "directly" encoded based upon the sensor reported quality values (for example, HFOM and HPL, etc.), and the maximum compensated and uncompensated latency of the position is specified. (Note that for unsynchronized installations, the direct encoding has some minimum thresholds for the NACp and NIC.)
3. Report all data (including position) directly from the sensor (without compensation), and provide a "data age" indication (and perhaps data age uncertainty) such that the ADS–B user can precisely determine when the state data was valid. Thus, position is not latency compensated, but reported exactly as output from the sensor, and the ADS–B system would provide information such that the receiver can figure out the time of applicability (for example, transmit data age).

Alternative #1 seems to be the way that the RFG is assuming that the ADS–B data is provided. This alternative is inconsistent with the way the parameters are defined by the RTCA Link MOPS. Alternative #2 is the way that the RTCA SC–186 has specified encoding ADS–B performance parameters (NACp and NIC) on the datalink. Alternative #3 would probably have the best technical performance (marginally over Alternative #2), but does require additional information on the datalink (for example, data age).

At a high level it seems best and most straightforward from an ADS–B user to define all ADS–B Out parameters (including data quality parameters of NACp, NACv, and NIC) as valid at the time of applicability of the message. Thus, NACp, NACv, and NIC would be quality parameters defined with respect to the indicated time of applicability of the ADS–B reported position. This is the approach that the RFG seems to have chosen.

While alternative #1 seems the most straightforward, it is very problematic for transponder manufacturers to develop and certify "boxes" independent of the aircraft architecture (that is, obtain a transponder technical standard order (TSO)). Several

transponder manufacturers stated this during the RTCA SC–186 MASPS and MOPS developments. It is impractical and is not box level testable to make the transponder manufacturer responsible for adjusting the NACp, NACv, and NIC based upon compensating for the aircraft installation, because the information to do this adjustment is not readily available to the transponder. For example, to bound the position error (with NIC encoding) one would need velocity error bounds and acceleration error bounds during the latency compensation period. This information is not readily available to the transponder. Furthermore, the transponder would likely have to make a worst case maneuver assumption to generically bound the position error during latency period.

Instead, alternatives #2 and #3 are more practical and testable to report the accuracy and integrity performance of the position source based upon the position source reported outputs like HFOM and HPL directly.

Then, additionally for alternative #2, one needs to also specify the performance of the position latency compensation (for example, maximum compensated and uncompensated latencies). This is the basic approach that RTCA SC–186 has taken in their ASA MASPS, ADS–B MASPS, link MOPS, STP MOPS, and ASAS MOPS. Additionally for alternative #3, one would need to indicate the data age (and not latency compensate the position on the transmit side, as this would all be done on the receive side).

For alternatives #2 and #3, when performing the analyses for assessing the suitability of ADS–B Out to meet the performance required for various applications, each application may make different assumptions about what maneuvers may occur during the latency period, rather than artificially inflating NACp and NIC to cover the worst case maneuver (acceleration) and unknown velocity errors.

Conclusion

It is recommended that the ADS–B ARC recommend performance requirements in a manner that is consistent with the existing link MOPS specifications via alternative #2, and probably further clarify with compensated and uncompensated latency specifications. Pursuing Alternative #1 is problematic in that the transponder does not have the appropriate information available and would likely have to make “worst case” assumptions about velocity error bounds and maneuvers during the latency period, which would result in artificially inflating NACp and NIC to cover “worst case” assumptions. Alternative #3, may have marginally better technical performance than Alternative #2 (likely virtually no operational performance difference), but it would require additional data that has not been specified as part of the link MOPS.

Thus, to put this in the words used on our telecon to discuss, the transponder should not be specified based on Alternative #1 and inflate the NACp and NIC from the corresponding quality parameters reported by the position source (for example, HFOM and HPL), because the transponder does not have the information to do so (for example, precise velocity accuracy and error bounds, accelerations and error bounds, maneuver assumptions).

APPENDIX CC — POSITION ERROR AND COMPENSATED/UNCOMPENSATED LATENCY IN MODE S TRANSPONDER ADS–B OUT IMPLEMENTATIONS

Introduction

This paper examines latency and its impact to position error in Mode S transponder ADS–B Out installations assuming a directly connected GNSS sensor without GPS time mark. The paper identifies errors induced by compensated and uncompensated latency. Uncompensated latency numbers achievable by existing and updated avionics is provided.

Three main errors due to extrapolation are examined:

- Extrapolation Error caused by errors in measurement of latency time
- Extrapolation Error caused by inaccurate velocity
- Extrapolation Error caused by not accounting for acceleration

Assumptions

The analysis makes the following assumptions which are true of many existing 1090ES installations:

- Directly coupled 1 Hz Position Sensor (for example GNSS).
- GPS time mark is not wired to the Mode S transponder.
- Installation specific data such as average latency of the position sensor is not known by the transponder.
- Time required to communicate position sensor's data on an aircraft bus to the transponder is not considered.

Discussion

The transponder extrapolates position forward from the **T**ime the **D**ata is **A**vailable (TDA interface B1) on the bus to the **T**ime **o**f **T**ransmission (TOT interface D). Most existing installations do not take into account the latency from TOA of position at sensor to TDA.

The maximum latency which the transponder compensates for is 1.1 seconds. This assumes a 1 Hz position sensor with 100 ms of finite processing time in the transponder. This does not address abnormal conditions when the position source fails – in this case position data may be extrapolated for up to approximately two seconds (RTCA/DO–260A 2.2.3.2.3.1.3.2).

A figure at the end (provided by Boeing) of this document illustrates the timing interaction between the position sources and the transponder.

Extrapolation Error caused by errors in measurement of latency time
Measured latency has two main components:

1) The error in measuring TDA and estimating TOT and computing the difference. Existing implementations perform with an effective error of approximately 100 to 200 ms. (Note: Many existing implementations do not attempt to measure TOT-TDA, but simply extrapolate the position forward every 200 ms asynchronously to the time the position is broadcast). Software based processing improvements can reduce this error by approximately half.

2) The error caused by not accounting for the latency from TOA in the position sensor to TDA. ARINC 743 compliant position sensors limit this error to 200 ms.

The position error is a function of the magnitude of the latency error and the aircraft's velocity and acceleration.

Extrapolation Error caused by inaccurate velocity
The transponder uses the velocity reported by the position sensor to extrapolate position forward. This reported velocity is inaccurate and therefore introduces errors into the extrapolation. This error is a function of the latency and the magnitude of the velocity error. A conservative velocity error of 10 m/s is used in the numerical analysis below.

Extrapolation Error caused by not accounting for acceleration
The transponder extrapolates data using only velocity information. Therefore, if the aircraft is maneuvering / accelerating the extrapolation will have errors. This error is a function of the latency and acceleration.

The total induced error is given by the following:

$$= \left(Latency_{measured} \times Velocity_{error}\right) + \left(Latency_{error} \times Velocity\right) + \left(0.5 \times acceleration \times Latency^{2}{}_{measured}\right)$$

where:

Latency $_{\textbf{measured}}$ is the estimate of latency. This is how much time the transponder will extrapolate forward the position. This is effectively **total extrapolation time**.

Latency $_{\textbf{error}}$ is the difference between the true latency and the transponder's estimate of latency. This is effectively **uncompensated latency**.

Velocity $_{\textbf{error}}$ is the difference between true aircraft velocity and that as reported by the sensor.

Summary Of Errors

The table below provides the estimated error in meters induced by latency induced issues (i.e. errors induced by attempts to compensate as well as uncompensated latency).

Two sets of avionics are considered:

> Existing Avionics: Assumes an average Latency Error or uncompensated error of approximately 400 ms nominal. 200 ms attributed to the transport delay in the position sensor. 200 ms attributed to the transponder.
>
> Updated Avionics: Assumes a total Latency Error or uncompensated latency of approximately 250 ms nominal. (This assumes that the transponder uncompensated latency could be reduced to 50 ms and the transport delay of the GPS sensor is unchanged at 200 ms.)

Three different set of aircraft scenarios are considered:

1) Aircraft is traveling at 600 knots, no acceleration – applicable to enroute environment
2) Aircraft is traveling at 200 knots and 0.55 g acceleration – applicable to the terminal environment.
3) Aircraft is traveling at 30 knots – surface environment

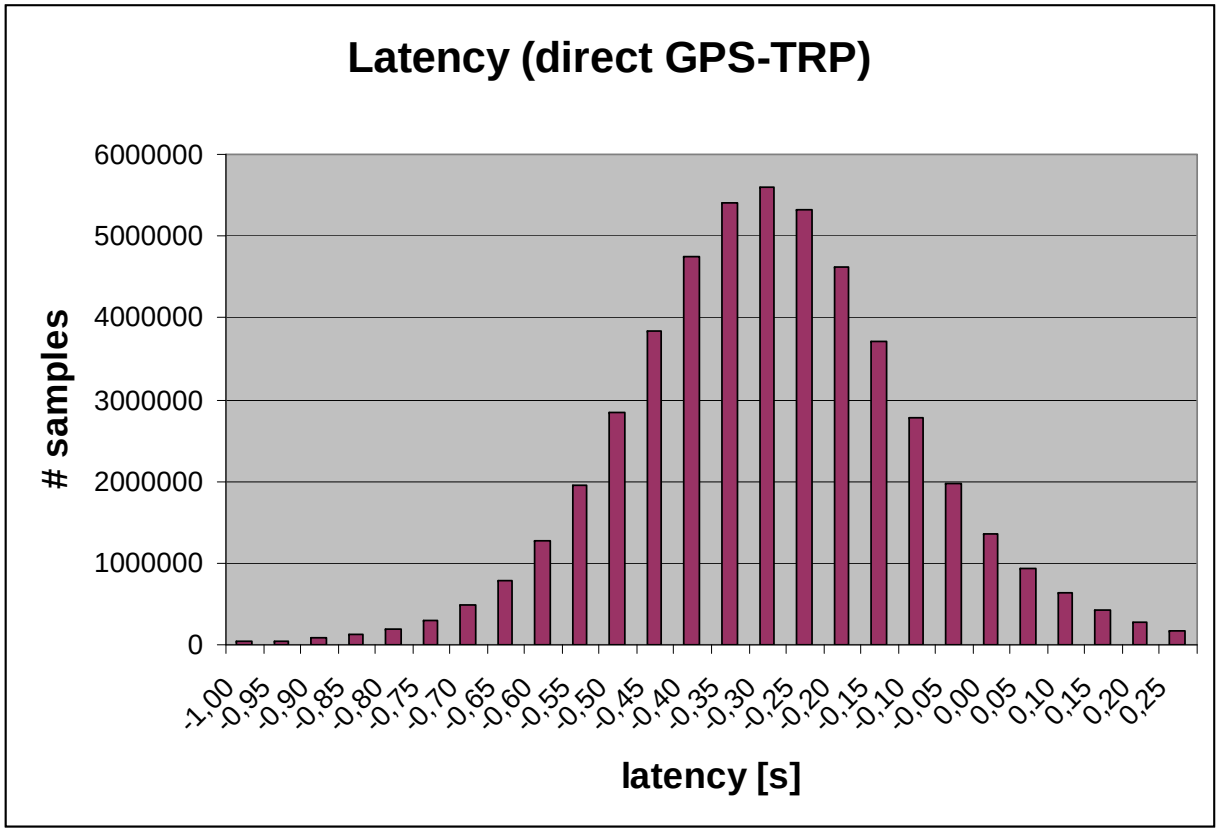
In all cases the Velocity $_{error}$ is conservatively assumed to be 10 m/s and the extrapolation time is set to 1.1 seconds.

The total latency is the sum of the uncompensated latency (Latency $_{Error}$) and total extrapolation time (Latency $_{Measured}$).

Parameter	**Existing Avionics**			**Updated Avionics with better latency handling**		
Latency $_{Measured}$ (s) (e.g. total extrapolation time)	1.1	1.1	1.1	1.1	1.1	1.1
Latency $_{Error}$ (ms) (e.g. uncompensated latency)	400	400	400	250	250	250
Velocity (knots)	600	200	30	600	200	30
Velocity $_{Error}$ (m/s)	10	10	10	10	10	10
accel (g)	0	0.55	0	0	0.55	0
error (m)	**134**	**55**	**17**	**88**	**40**	**15**

The numbers selected for uncompensated latency in existing avionics correlate with uncompensated latency measurements performed by Eurocontrol/CASCADE and are documented in an attached presentation. (One graph of the presentation is provided below) The measurements showed that the mean uncompensated latency for where GNSS is directly connected to the transponder was 0.3 seconds with a sigma of 0.1 seconds. The 95 percent latency was approximately 0.6 seconds.

Uncompensated Latency Modeling
Direct GPS-Transponder Wiring



Uncompensated Latency Modeling (based on 50 million samples, w/o NUC=0):

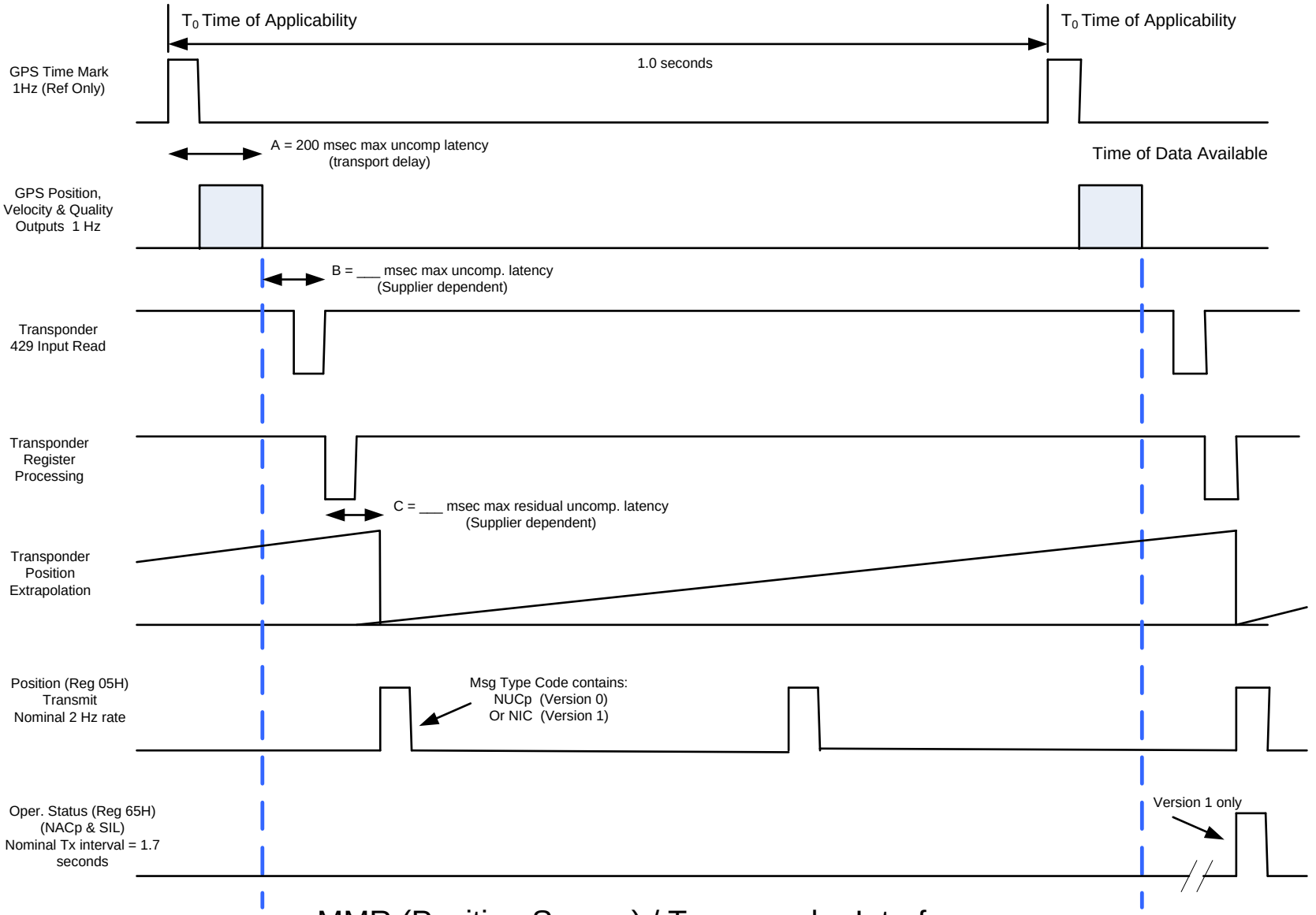
Mean value: -0.3s

Reconstruction error sigma: ≈ 0.15s (TBC)

Resulting latency error sigma: ≈ 0.1s

99.9% @ ≈ -1.0s

Applicable to overall a/c population with such configuration (as for comparison with radar, e.g. range accuracy)



MMR (Position Source) / Transponder Interface Timing

06/23/2008

APPENDIX DD – SUMMARY OF ADS–B OUT LATENCY EVALUATION

The following lists ADS–B OUT latency requirements from application definitions or is inferred from known analysis. This is not a complete list.

Application / Source	Latency Specification	Comment
RAD	~ 0.5 seconds uncompensated latency at 95% and 1.1 seconds at 99.9%	Based on RFG RAD application group discussions during RFG/16 held on June 24-27, 2008.
NRA	≤ 1.5 seconds uncompensated latency	
ITP	≤ 3.0 seconds uncompensated latency.	
Preliminary Evaluation of ADS–B System Performance in ATC Environment, October 1, 2007	0.4 to 0.6 seconds uniformly distributed.	Based on review of the document, specifically section 3.4.3.2 and input from Robert Pomrink. This incorporated the anticipated affects of the 500msec uncompensated latency and the 100msec extrapolation uncertainty

Define Latency Performance Requirements At the Aircraft Level

In Appendix H, Section 5, paragraph (a), the NPRM states that "Upon receipt of the information by the aircraft antenna(s), the navigation position sensor must process the information in less than 0.5 seconds."

The ARC believes that this requirement is written from a GNSS-centric perspective as opposed to a performance requirement for the position source that is not necessarily a GPS-WAAS sensor, but possibly INS.

Furthermore, the latency requirements defined by proposed 14 CFR §91.225 Appendix H are ambiguous. It is not clear whether the end-to-end system latency is allowed to be 1 second or 1.5 seconds.

The ARC recommends that latency requirements should be specified at the aircraft level, not the equipment level, which allows for flexibility in the allocation of latency between avionics equipment.

Latency Reference Time

The NPRM uses time of measurement (TOM) as the reference time for latency measurements.

The notion of information received at the GPS antenna is ambiguous in the sense that the elements of the navigation message come in over a relatively large span of time. Even pseudo-range measurements are accomplished by integrating over a period of time. The time that information is received at the antenna is not an appropriate point of reference. A GPS receiver outputs a position message at a specified measurement time of applicability.

The ARC recommends that latency be referenced to the Time of Applicability of the position provided by the position sensor (for example, time mark for GNSS sensor position sources).

Specify Maximum Uncompensated Latency

The NPRM specifies maximum total latency from time of measurement to time of transmission.

Ideally, the NPRM rule in this area would address the following two areas:

(1) minimize impact to aircraft installation and wiring while

(2) satisfying the ground surveillance (ATC) requirements.

Minimize Impact To Aircraft Installation Wiring

Existing ADS–B Avionics installations (that is, without time mark wired) can meet an uncompensated latency specification ≤ 0.6 seconds. This limit can be reduced further but an agreed to number has not been established in the ARC– although a number between 0.25 and 0.40 seconds seems achievable.

In order to reduce installation costs the latency specification should satisfy the following conditions:

- The GPS time mark signal is not used
- a priori, installation specific knowledge of a GPS receiver's typical latency from TOA of the position to delivery to the transponder is not required (for example Aircraft Personality Module or specific programming per installation).
- All latency times are referenced to the time mark or time of applicability of the position source.

Existing avionics equipment and installations (where GPS is directly connected to the transponder) can support a total average latency time of ≤ 1.5 seconds measured from time of applicability of position or from the time mark. See the appendix on position errors and latency for detailed information.

ATC Surveillance Requirements related to Uncompensated Latency. The RFG RAD group is considering these requirements. The current draft state of these requirements is an uncompensated latency of 0.5 seconds at 95 percent and 1.1 seconds at 99.9 percent.

FAA analysis of surveillance performance requirements has used an uncompensated latency uniformly distributed between 0.4 and 0.6 seconds.

Additional Background Information On Application Driven Latency Requirements and How They are Specified.

RTCA/DO–303 (Safety, Performance and Interoperability Requirements Document for the ADS–B Non-Radar-Airspace (NRA) Application) specifies maximum uncompensated latency – which implies that extrapolation of position data is permitted. This same document indicates that the reported quality factors (for example NIC, NACp, SIL) must be adjusted for uncompensated latency. Several other applications are being considered – the RAD application will likely be the most stringent with respect to accuracy and latency.

Installations will be simplified if ATC surveillance requirements take into account some amount of bounded uncompensated latency.

See appendix BB titled "Discussion Paper on Aspects of Echoed or Adjusted Quality Factors (NIC, NAC) by ADS–B Out System". In addition to providing background information, this discussion favors echoing of the quality data from position sensor and not adjusting it.

The Requirement Focus Group RAD subgroup during its June 2008 RFG/16 meeting came to a tentative agreement that the quality factors can be "echoed" by the broadcast equipment as long as the uncompensated latency is bounded.

Recommendations

The ARC recommends that maximum uncompensated latency be specified such that it minimizes or eliminates installation wiring changes of existing ADS–B OUT implementations while meeting ATC surveillance requirements. Specifying both the total latency and uncompensated latency is strongly recommended.

> *Specifically, most existing ADS–B OUT installations (where the GPS sensor is directly connected) can achieve a 95% uncompensated latency of $\leq$ 0.6 seconds and an average total latency of 1.5 seconds. Smaller uncompensated latency can be achieved by existing avionics or by minor updates to existing transponders. Agreement to supportable numbers are under discussion by WGC*

Latency of Changes in NIC, NACp, or SIL

The proposed Appendix H Performance Requirements for Automated Dependent Surveillance Broadcast Section 3 (b) mandates that changes in NIC, NAC, or SIL must be broadcast within 10 seconds.

Industry has evaluated the 10 second requirement and does not believe that it can be practically engineered. The equipment evaluated consume the entire 10 seconds, which leaves no time for the aircraft installation's time requirements. As an example, there has been no allocation beyond the 10 seconds for actual broadcast which is asynchronous to the position source output.

A minimum of 12.1 seconds is needed for transmitting the NIC, and a minimum of 3.1 seconds is needed to transmit changes in the NACp, NACv, and SIL. These proposed allocations are consistent with the RTCA/DO-289 and allow a 10 second time-to-alert positioning source, plus 1 second between interfaces A1 and B1 (Table 3-1), and 1.1 seconds between interfaces B1 and D (per section §3.1.1.3 in the ASA MASPS – RTCA/DO-289) for the transmission of integrity containment bound NIC which is broadcast as part of the state data. The proposed allocation for broadcasting changes in the status data of NACp, NACv, and SIL allow an additional 1 second from the MASPS allocations between interfaces A1 and B1 (1 second) and B1 and D (1.1 second). The rationale is that for 1090ES transmissions, status data (which includes NACp, NACv, and SIL) is broadcast in lower rate messages than state data.

The ARC recommends that the FAA evaluate the requirement of the equipment to broadcast a change in NIC, NAC or SIL within 10 seconds and determine whether 10 seconds is the appropriate value and if possible relax the requirement so that it can be satisfied with existing equipment.

Specifically,

- *changes in NIC could be broadcast within 12.1 seconds*
- *changes in NACp, NACv, and SIL could be broadcast within 3.1 seconds.*

However, due to the difficulty associated with changing a regulation, proposed 14 CFR 91.225 Appendix H may not be the appropriate source for latency requirements. Latency requirements should be defined in RTCA MOPS, TSO, or other appropriate documents that are referenced through Appendix H.

Specify Minimum Performance Requirements

The ARC recommends that the FAA specify the minimum performance requirements per airspace category. The rationale for this recommendation is that if minimum requirements are not defined for a particular airspace then users (installers and equipment manufacturers) will not be able to provide for alternative sources of position which could be adequate for less critical airspace (including en route airspace) and could increase the availability of ADS–B in a cost effective manner.

The ARC recommends that the FAA define minimum performance requirements, including maximum total and uncompensated latency requirements, per airspace category to enable the widest possible use of different position sources thus reducing the cost of providing the required performance at the desired availability.

APPENDIX EE – TIGHTLY COUPLED GPS/IRS NAVIGATION FOR ADS–B

Tightly Coupled GPS/IRS Navigation for ADS–B

Mark Manfred
Thomas Ryno
Honeywell International
Minneapolis, Minnesota

Abstract

The FAA has proposed challenging requirements for the ADS–B navigation sensor. The FAA's recent Notice of Proposed Rulemaking (NPRM) for ADS–B concludes WAAS meets the proposed requirements but says the FAA is considering whether tightly coupled GNSS/IRS navigation is an acceptable alternative[1].

Navigation systems that tightly integrate GPS with an Inertial Reference System (IRS) are indeed an excellent positioning source for ADS–B. Air transport and business aircraft are beginning to use such systems for a variety of reasons unrelated to ADS–B, for example to improve availability for RNP 0.1 operations. This trend will accelerate over the coming decade.

This paper describes tightly coupled GPS/IRS navigation systems and the benefits they provide. It shows they not only meet the ADS–B NPRM requirements for horizontal positioning, but they also offer several additional benefits that enhance ADS–B's capability to maintain air traffic flow under challenging conditions that would otherwise impede it.

Description of Tightly Coupled GPS/IRS navigation Systems

The aviation community has long recognized that GPS and IRS navigation provide complementary benefits. GPS provides accurate positioning that doesn't degrade over time. IRS provides autonomous, high frequency, low noise positioning that isn't susceptible to interference or jamming. Tightly coupled GPS/IRS navigation systems exploit the best characteristics of both systems, and more.

Before proceeding, we first need to clarify some ambiguous terminology. The aerospace community has not developed consistent definitions for the terms "tightly coupled GPS/IRS" and "loosely coupled GPS/IRS". This paper will assume the definitions that are generally prevalent within the commercial aviation sector. Tightly coupled GPS/IRS will mean a navigation system that combines GPS pseudorange signals with IRS inertial signals, typically in a Kalman filter. Loosely coupled GPS/IRS will mean a navigation system that mixes GPS position signals with IRS inertial signals, typically in a complementary filter within the Flight Management System (FMS).

Honeywell's latest Air Data Inertial Reference System (ADIRS) includes a tightly coupled GPS/IRS algorithm called HIGH (Honeywell Inertial GPS Hybrid). It is representative of tightly coupled GPS/IRS navigation systems and is the focus of this paper. The heart of the HIGH algorithm is a Kalman filter that continuously estimates 36 error states within both the GPS and IRS. This allows HIGH to compensate for many GPS and IRS errors. It also allows the compensated (hence highly accurate) inertial signals to supplement GPS signals, especially when the GPS receiver can only track a few (or zero) satellites. It provides a robust navigation solution with exceptional performance.

Benefits for RNP operations

Many airlines want tightly coupled GPS/IRS navigation systems for reasons that have nothing to do with ADS–B. Their primary motivation is to improve availability for RNP operations, especially RNP 0.1. This section describes these benefits.

The availability of RNP operations is largely determined by the magnitude of the HFOM and HIL signals from the aircraft's navigation system. Horizontal Figure of Merit (HFOM) is a parameter that represents the 95% horizontal accuracy of the position signal, and Horizontal Integrity Limit (HIL) represents the maximum position error to a 99.99999% confidence level. RNP operations are available only if the HFOM and HIL signals are lower than specific thresholds that have been established for the operation. Hence, lower HFOM and HIL values improve availability for these operations. Typical HFOM and HIL thresholds for an RNP 0.1 operation are approximately 0.08 nm and 0.16 nm, respectively. HIL is generally more important than HFOM for RNP operations.

HIGH calculates HFOM and HIL signals that are significantly lower (i.e., better) than those from a standalone GPS receiver, including the latest GPS receivers that are tuned for SA-Off. This benefit occurs under all conditions, but the largest benefit occurs when the GPS satellite geometry is adverse, which is the condition when improvement is most needed. For example, Figure 1 compares simulated HIL signals from HIGH and from a snapshot RAIM algorithm (equivalent to an SA-Off GPS receiver) when the GPS constellation is adverse[2]. The snapshot RAIM HIL makes a large step increase at 15.4 minutes when one of the tracked satellites falls below the horizon. HIGH uses inertial data to compensate for the missing satellite data, with the result that its HIL avoids the step increase and remains well contained. This allows HIGH to provide 100% availability for RNP 0.1 operations even with an industry-standard Martinez 24 satellite constellation, including operation through RAIM holes.

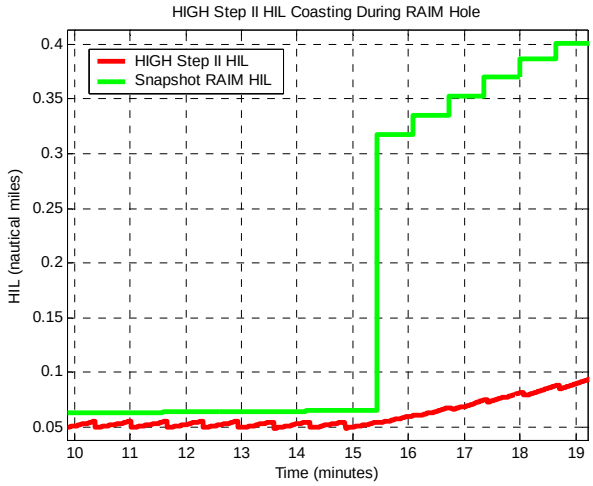


Figure 1
HIL comparison with adverse satellite geometry

Another adverse GPS condition occurs near airports that are surrounded by high mountains. RNP 0.1 operations are disproportionately used at such airports, for example Queenstown, New Zealand and Quito, Ecuador. The mountains mask GPS satellites that are low on the horizon. This increases the HFOM and HIL signals from a GPS receiver, which limits availability for such operations. The "GPS SA-Off" curve in Figure 2 illustrates this.[3] It is a simulation of HIL from a GPS SA-Off receiver during an RNP 0.1 approach to Queenstown using the actual 27 satellite constellation from September 15, 2007. Note that its HIL exceeds the RNP 0.1 threshold during the final 30 seconds of flight as the airplane descends below the nearby mountains. This means the crew would need to abort the approach. In reality, the airline's flight operations would adjust the flight schedule to ensure arrival when the satellite geometry was more favorable. This avoids the need to abort the landing, but such scheduling constraints impose adverse consequences of their own.

HIGH again solves this problem by combining GPS signals with highly calibrated inertial data to reduce HFOM and HIL. The "HIGH" curve in Figure 2 illustrates this[3]. Its HIL remains below 0.06 nm and hence allows the approach to continue with considerable margin. It avoids the need to adjust the flight schedule to ensure adequate satellite coverage during landing.

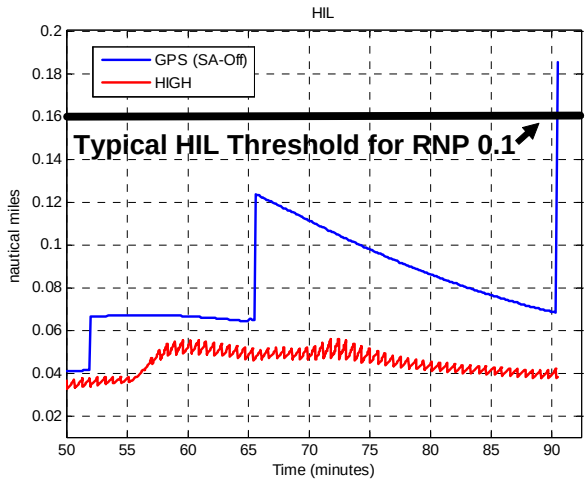


Figure 2 HIL comparison during approach to Queenstown

There have also been numerous instances where airborne receivers have lost all GPS signals. The most prevalent causes are GPS testing, ground-based RF interference, sun spots and ionospheric scintillation. HIGH provides exceptional benefit when this occurs. It continues to transmit its position signals by coasting on high accuracy inertial signals that were precisely calibrated by GPS before GPS was lost. It also continues to calculate optimal HFOM and HIL signals that degrade slowly after GPS is lost. This allows RNP operations to continue without interruption through many temporary GPS outages or outages that affect a limited geographic region. Figure 3 shows typical HIL performance from HIGH after GPS is lost[2]. It shows that HIGH can coast through a total GPS outage of approximately eight minutes while maintaining HIL at less than the typical RNP 0.1 threshold of 0.16 nm.

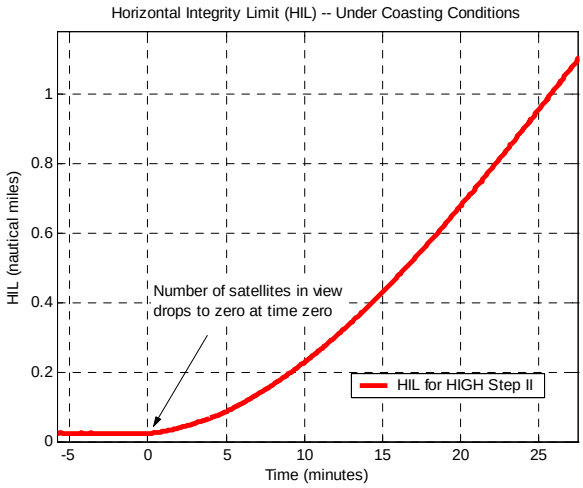


Figure 3 HIL from HIGH after all GPS satellites are lost

Airplanes with loosely coupled GPS/IRS are much less tolerant to GPS outages. The FMS in such airplanes calculates position after GPS is lost by "coasting" the last valid GPS position using IRS signals that were not previously calibrated by GPS, hence the coasted position signal is considerably less accurate than with HIGH. This forces the FMS to assume a conservative estimate for HIL that increases rapidly (typically 0.15 nm per minute) after GPS is lost. Consequently, the airplane can only tolerate about a minute of GPS outage before an RNP 0.1 operation becomes unavailable.

HIGH also improves navigation update rate and latency compared to GPS receivers. Most commercial aviation GPS receivers update their position signals at a 1 Hz rate and with up to 200 msec of latency. HIGH, on the other hand, uses high frequency inertial data to update its navigation signals at a 12.5 Hz rate and with less than 160 msec of latency.

HIGH Performance for ADS–B

This section shows that tightly coupled GPS/IRS meets the challenging ADS–B horizontal navigation requirements that are proposed in the NPRM, without requiring

WAAS. The NPRM horizontal positioning requirements can be summarized as[1]:

- 95% Horizontal Position Accuracy Bound less than 30m (NACp 9)
- Horizontal position integrity less than 0.2 nm at 99.999% confidence level (NIC 7, SIL 2)

HIGH achieves these requirements with the current GPS constellation, and performance will be even better with constellation improvements that will be available by year 2020.

The NPRM also proposes accuracy requirements for velocity. These requirements (10 m/sec, 95%) are not challenging and are easily achieved with either HIGH or with a GPS SA-Off receiver.

Honeywell used a simulation to analyze the HFOM, HIL and VFOM signals from HIGH and from a GPS SA-Off receiver under the conditions specified in RTCA DO229. This analysis encompasses 338,832 time-space points representing twelve hours of five minute time increments at 2353 grid locations covering the northern hemisphere. The analysis was performed with both a current (March 2, 2008) GPS satellite constellation and with an industry standard Martinez-24 constellation.

Horizontal Accuracy

ADS–B uses the HFOM signal to determine the horizontal position error bound. Figure 4 compares HFOM from HIGH and from a GPS SA-Off receiver using the current satellite constellation. Note that HFOM from HIGH (shown in red) never exceeds the 30m NPRM accuracy requirement. This means HIGH provides 100% availability for the NPRM horizontal accuracy requirement using the current constellation. Our analysis also shows that HIGH provides 100% availability using the Martinez-24 constellation. The GPS SA-Off receiver, on the other hand, does not provide 100% availability. Its HFOM (shown in blue) frequently exceeds the 30m requirement.

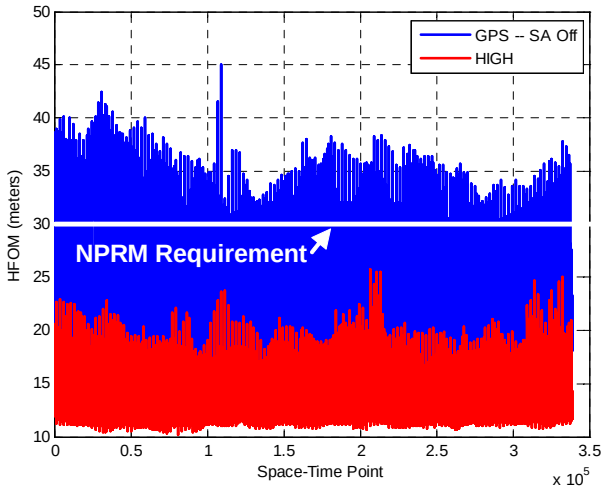


Figure 4 HFOM from HIGH and GPS Receiver

Horizontal Integrity

ADS–B uses HIL to determine the horizontal position integrity. Figure 5 shows HIL from HIGH and from a GPS SA-Off receiver using the current satellite constellation. HIL from HIGH (shown in red) always remains well below the proposed NPRM requirement of 0.2 nm, hence HIGH provides 100% availability using the current satellite constellation. Our analysis also demonstrated that HIGH provides 100% HIL availability using the Martinez-24 satellite constellation. HIL from the GPS receiver is usually below the 0.2 nm requirement however its availability is not quite 100% because its HIL occasionally exceeds the 0.2 nm requirement.

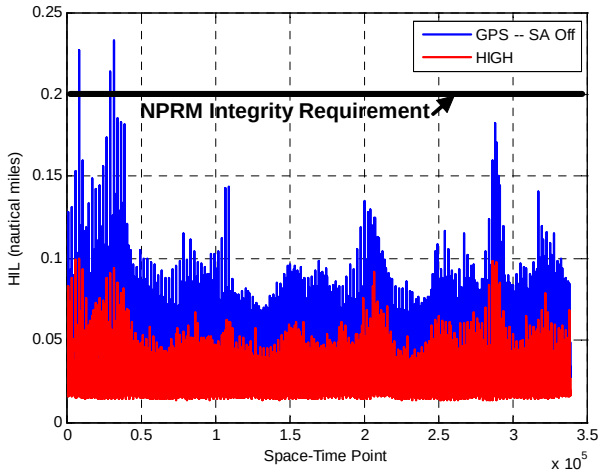


Figure 5 HIL from HIGH and GPS Receiver

HFOM and HIL performance for both GPS receivers and HIGH will improve by year 2020 due to future enhancements to GNSS constellations. Examples of such enhancements include:

- Better GPS orbit predictions (improved ephemeris)
- Better GPS residual ionospheric error modeling
- GPS Block IIF satellites, which begin launching in 2009, will transmit on both L1 and L5 frequencies to nearly eliminate ionospheric errors
- Longer GPS codes and higher chipping rates
- There is potential for more GPS satellites (Block III) and modified orbits

Vertical Accuracy

There is one NPRM requirement that HIGH doesn't consistently meet with the current GPS constellation, however that requirement doesn't seem critical for ADS–B. The NPRM proposes a 45m requirement for vertical accuracy. This requirement applies to geometric altitude which is the altitude derived from GPS rather than from a barometric altimeter. It should be noted that aircraft vertical separation is based on barometric altitude, not geometric altitude, hence geometric altitude is not as critical as barometric altitude for ADS–B. Honeywell is working with the FAA to re-examine the requirements for vertical altitude accuracy

GPS receivers and HIGH each transmit a signal called Vertical Figure of Merit (VFOM) that represents the 95 accuracy bound for geometric altitude. Figure 6 compares VFOM from HIGH and from a GPS SA-Off receiver using the current (3/2/08) GPS constellation. It shows that HIGH is better than the GPS receiver, but neither offers good availability against the proposed NPRM requirement of 45m. VFOM from HIGH ranges from 17m to 68m, and VFOM from the GPS receiver varies from 17m to 97m. This performance will improve as the GNSS constellation improves, however Honeywell hasn't determined whether these improvements will enable HIGH to meet the proposed 45m vertical accuracy requirement.

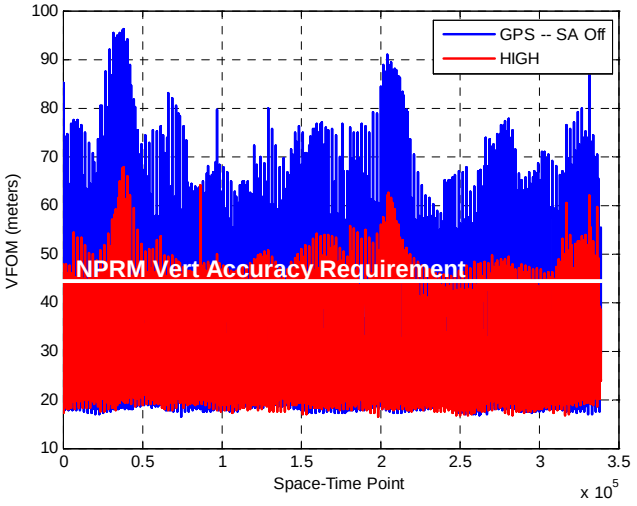


Figure 6 VFOM from HIGH and GPS Receiver

Benefits for ADS–B

The previous section showed that HIGH meets the horizontal accuracy requirements for ADS–B. This section describes several unique and important benefits that HIGH offers for ADS–B.

Worldwide operation.

HIGH operates anywhere in the world. HIGH allows ADS–B to use a single navigation system for all operations, regardless of location. It also makes it easier to harmonize ADS–B requirements internationally because countries that don't have SBAS coverage will resist requiring SBAS for ADS–B.

Operation with degraded GNSS constellation.

Tightly coupled GPS/IRS can help maintain air traffic flow when WAAS isn't available. The ADS–B NPRM acknowledges that WAAS will not always be available. Solar flares, ionospheric scintillation and planned testing or degradation of the GNSS constellation are examples of conditions that can disrupt WAAS positioning.[1] The FAA's backup plan is to issue NOTAMs to pilots when this occurs, and revert from ADS–B to a backup system of Secondary Surveillance Radars (SSRs).

This backup plan will disrupt air traffic however. Surveillance radars can't provide the same position accuracy or integrity as WAAS, nor will they cover all airspace. ATC will need to increase aircraft separation when WAAS isn't available, which will reduce capacity. Air traffic will increase over the coming decades beyond the point that traffic flow can be maintained when aircraft separation is based on surveillance radar.

Tightly coupled GPS/IRS mitigates this problem. It will continue to meet the NPRM horizontal nav requirements indefinitely during ionospheric storms that affect WAAS but not GPS. Even if all GPS is lost, it allows an aircraft's ADS–B transponder to continue transmitting its position, accuracy (NACp, NACv) and integrity (NIC) parameters. This allows Air Traffic Control to continue to draw accuracy and integrity containment circles around the airplane's reported position. The radius of these circles will slowly grow after GPS is lost, but they will remain useful for significant periods after GPS is lost. For example, Figure 3 shows that HIGH will meet the full ADS–B integrity requirement (0.2 nm) for nine minutes after all GPS is lost. This allows an airplane cruising at 450 knots to traverse a 67 nm interference region while continuing to transmit its position with Navigation Integrity Category 7 (0.2 nm integrity).

These benefits accrue even though all airplanes won't be equipped with tightly coupled GPS/IRS. When GPS is unavailable, ATC can draw tight integrity containment circles around each airplane that is equipped with tightly coupled GPS/IRS. This allows ATC to significantly reduce separation between two airplanes that are so equipped, and (to a lesser extent) between an airplane so equipped and one that is not so equipped. The benefit obviously increases as more air transport aircraft are equipped with tightly coupled GPS/IRS.

More accurate ATC position.

Tightly coupled GPS/IRS improves the accuracy of the ADS–B position signal for enroute aircraft. The accuracy of the transmitted position signal is dominated by latency requirements. The NPRM requires latency to be less than 500 msec sec for the navigation sensor. HIGH has 160 msec of latency, which reduces the latency error in the transmitted ADS–B position by 69m for an aircraft travelling at 450 knots. HIGH also provides velocity errors well under 1 meter/second, which is small compared to the 10 m/s requirement proposed for ADS–B. This allows ATC to more accurately predict an airplane's future position.

Oceanic Operations.

HIGH may also provide unique benefits if GNSS is lost in oceanic regions. Concepts have been proposed to use ADS–B for oceanic tactical operations (e.g., passing maneuvers, in-trail climb/descent, etc.) by having aircraft

communicate their positions to each other over ADS–B. If GNSS is lost, ADS–B positioning for airplanes without HIGH would revert to FMS coasting using uncalibrated IRS signals. This means their ADS–B transponders would transmit NACp and NIC values that degrade rapidly after GPS is lost. Airplanes with HIGH would coast their ADS–B positioning on highly calibrated inertial signals, hence their NACp and NIC values will degrade at a much slower rate. This facilitates oceanic tactical maneuvers based on ADS–B after GNSS is lost.

Conclusions

This paper shows that tightly coupled GPS/IRS meets the ADS–B NPRM requirements for horizontal navigation, and that it significantly mitigates problems that occur when WAAS or GPS signals become marginal or unavailable. Many airplanes will be equipped with tightly coupled GPS/IRS in the coming years and these airplanes can easily realize its benefits for both RNP and for ADS–B.

The paper also shows that HIGH with the current GPS constellation doesn't meet the NPRM proposed accuracy requirement for geometric altitude. This does not jeopardize aircraft separation however because separation is based on barometric rather than geometric altitude.

HIGH is currently in revenue service on the Airbus A380 and is in development for incorporation into Honeywell's LASEREF® IRUs. An upgrade to HIGH will be available for all Honeywell 4 MCU ADIRU, LASEREF® V and LASEREF® VI applications, including:

Air Transport & Regional:

- A320/A330/A340
- Embraer 170/175/190/195
- Boeing 787
- Boeing 737/747/757/767

Business Jets:

- Gulfstream G100 Retrofit, G350, G450, G500, and G550
- Raytheon Hawker 4000
- Dassault Falcon 900EX, 2000EX, and 7X
- Beechcraft King Air Retrofit

Tankers & Transports:

- C5-AMP Retrofit
- C-130 Retrofit
- B-707 Retrofit

High Performance Aerobatic Trainers

- T-38N Trainer Retrofit
- Pilatus PC-21, PC-7, and PC-9 Trainers

Helicopters

- Eurocopter AS-365

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[1] October 5, 2007, "Automatic Dependence Surveillance – Broadcast (ADS–B) Out Performance to support Air Traffic Control (ATC) Service", Federal Register, Volume 72, Number 193, p. 56956.

[2] Call, Curt, Mike Ibis, Jim McDonald, Kevin Vanderwerf, May, 2006, "Performance of Honeywell's Inertial/GPS Hybrid (HIGH) for RNP Operations", Proceedings of Position Location and Navigation Symposium-2006, Monterrey, CA.

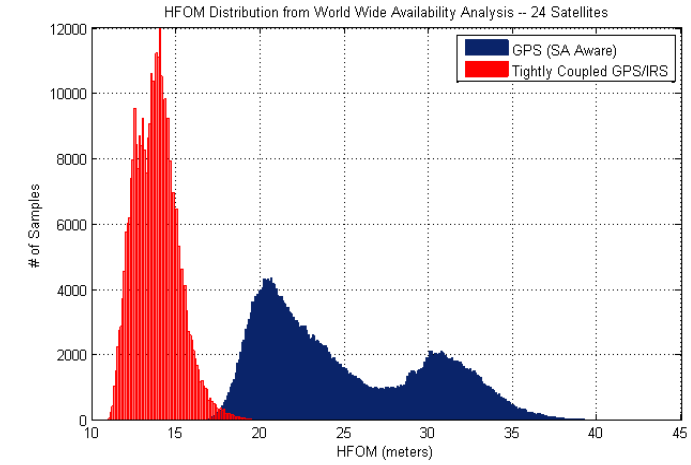
[3] McDonald, Jim, Joshua Kendrick, "Benefits of Tightly Coupled GPS/IRS for RNP Operations in Terrain Challenged Airports", Proceedings of Position Location and Navigation Symposium-2008, Monterey, CA.

APPENDIX FF—UPDATE TO APPENDIX EE
TIGHTLY COUPLED GPS/IRS NAVIGATION FOR ADS–B

See Appendix EE for a full explanation of tightly coupled GPS/IRS Navigation for ADS–B.

The histograms in the following figure compare the horizontal figure of merit (HFOM) from a tightly-coupled global positioning system (GPS)/inertial reference system (IRS) and from a selective availability (SA) Aware GPS receiver. They highlight the accuracy improvement that can be gained by tightly coupling GPS with IRS. Both histograms cover the 300,000+ space-time points per DO-229D and they assume the same Martinez-24 satellite constellation.

HFOM Distribution GPS SA Aware and Tightly Coupled GPS/IRS



1 HONEYWELL - CONFIDENTIAL File Number

APPENDIX GG —ACAS/ADS–B INTEGRATION WORK ESTIMATE AND ACTIVITIES

The ARC recognizes that legacy transponders (Mode A/C/S) are required to support the backup surveillance strategy of a reduced network of Secondary Surveillance Radars (SSR's) to ADS–B during events of GPS positioning loss or degradation. Also, the ARC recognizes that legacy transponders are required to support today's ACAS operations. It is important to note that both of these systems provide an independent source of surveillance in the airspace to ADS–B.

As the ADS–B surveillance infrastructure evolves through operational experience, identification of new sources of positioning systems, and standards development, opportunities to integrate ADS–B surveillance with airborne collision and avoidance systems (ACAS) and develop new surveillance architectures could result in the reduction of avionics equipment required to support these new systems/architectures. The assumptions and necessary tasks are outlined below.

Assumption of changes required to replace ACAS active surveillance with ADS–B passive surveillance:

- Primary algorithm changes are in the surveillance processing
- May require some algorithm changes to the CAS logic, since the CAS logic also has filters that may have been tailored specifically for the performance characteristics of active surveillance
- Requires capability to process ADS–B messages via both UAT and Mode S?

Potential analysis to determine the cost and benefits of replacing ACAS active surveillance with ADS–B passive surveillance before standards development begins.

Required standards development task and approximate time:

- Develop a MASPS with associated safety study (3 years)
    - Collision risk ratio analysis using new surveillance processing algorithms and any needed modifications to the CAS logic
    - Analyze impact of using ADS–B for spacing or separation procedures and collision avoidance
    - Analyze affect of losing crosslink capability to coordinate maneuver direction
    - Collect and analyze data on ADS–B out performance for aircraft that meet or are close to meeting the NPRM requirements (probably need European data) to validate performance of ADS–B
    - Update hazard analysis as needed for ADS–B performance characteristics
- Develop Initial SARPs (2 years)
- Develop Initial MOPS Requirements (2 years)
- Implement and certify on a few aircraft with a limited STC (1 year)
- Fly for one year and validate initial requirements and fixes (1 year)

- Develop Final SARPS (2 years)
- Develop Final MOPS Requirements (2 years)
- Implement and certify fleet wide (2 years)

RTCA recently approved SC–218 to assess the ADS–B ACAS relationship within the NAS from 2020-2025. SC–218 will develop an in-depth report and develop concepts for interoperation between ADS–B and ACAS, with emphasis on operational concepts and technical strategy and recommendations for the FAA and industry actions to implement these concepts and strategies.

Key issues to be considered by SC–218 include:

- The degree to which ACAS or another future collision avoidance system should remain relatively independent or separation assurance mechanisms in the NAS
- The use of ADS–B data by ACAS
- The degree to which airspace users will need to retain Mode A/C/S transponders to support ACAS interrogations and potential time frames for equipage changes.

Additional issues that require consideration include

- User community support for new ACAS standards development
- User community support for changes to ACAS that may not be required for safety
- International support and harmonization of standards
- Would require FAA and ICAO mandate to ACAS equipage with new capability before Mode A/C/S transponders could be replaced by ADS–B Out
- SC–218 time line to consider key issues
- Interim Interoperability

APPENDIX HH —APPROVING 1090 ES (DO-260-APPROVED) EQUIPAGE

Since the DO–260 standard was incomplete at the time many transponders were upgraded to meet the European Elementary/Enhanced Surveillance mandate, transponder manufacturers implemented DO–260 requirements in dissimilar ways. The result is that installations were approved with the following Airplane Flight Manual (AFM) limitation: "Extended Squitter transmissions have been demonstrated for proper operation and non-interference but have not been certified."

The ARC recommends that the FAA adopt the same compliance basis as used by Europe (CASCADE) and Canada (Hudson Bay) using EASA AMC 20–24 to approve use of existing DO-260-approved equipage in the NAS in support of 5 nm separation standards in radar (RAD) and non-radar airspace (NRA). This is intended to represent the first phase of ADS–B Out implementation. The long-term intent is to support operations based on the DO–260A Change 3 standard.

Regulatory Approval for Operation of Existing DO-260-Approved – After submission of a data package from Boeing to the FAA, providing information indicating adherence to the requirements of AMC 20–24, the FAA provided approval for Boeing to modify the AFM limitation. Airbus has gained approval from EASA for operation of existing 1090 ES equipment for NRA, in support of the CASACADE Programme, based on an earlier draft of the AMC 20–24.

AFM Changes – Using EASA AMC 20–24 as the compliance basis, the FAA proposed that the AFM's be updated to indicate: "Extended Squitter transmissions have been demonstrated for proper operation per EASA AMC 20-24 'Certification Considerations for the Enhanved ATS in Non-Radar Areas using ADS-B Surveillance (ADS-B NRA Application via 1090 MHz Extended Squitter' for broadcast of ADS-B related position information."

Classes of Boeing DO-260-Approved Transponder Installations and Work Required for Proper Operation

New Production Aircraft – (737NG, 747-400, 767, & 777) - Boeing will provide the AFM modification with delivery of airplane.

In Service Airplanes with approved wiring and equipment (737NG, 747-400, 757, 767 & 777) – Boeing will provide AFM modification as an AFM update.

In Service Airplanes without Boeing production or service bulletin wiring and equipment (737NG, 747-400, 757, 767 & 777) –Service Bulletin is available to provide for DO-260-approved and Elementary/Enhanced Surveillance upgrade. These Service Bulletins will include the new AFM wording.

Other in Service Airplanes (Out of Production)– Service Bulletins are under review.

Future Boeing Airplanes – 787 and 747-8 will have new AFM wording with delivery of airplane and will indicate compliance with DO–260A Change 2. [Note: NOT DO-260A Change 3]

Classes of Airbus 1090 ES Transponder Installations

1. New Production Aircraft – A380 or SA/LR

On the A380 fleet ADS-Out is basic through AESS. It has been certified using RTCA DO–260A technical standard and EASA/FAA approval has been included in the AFM with a compliance statement referencing ED–126. Since then, the official version of the AMC 20-24 has been released. Airbus will perform a non-impact analysis to support approval of AFM wording modification to get compliance statement to reference the official version of the AMC 20–24.

For the SA/LR fleet ADS–B function is available respectively through Mod 37153/ Mod 55661. The modifications are available as an option for production aircraft. It has been certified using RTCA DO–260 and EASA approval has been included in the AFM with a compliance statement referencing ED–126. Since then, the official version of the AMC 20–24 has been released. Airbus will perform a non-impact analysis to support approval of AFM wording modification to get compliance statement to reference the official version of the AMC 20–24. FAA approval is still pending but during their investigation of Mod 37153 and Mod 55661, FAA determined no need for Issue Paper and thus endorsed the EASA AMC 20–24 as an acceptable standard for these operations.

2. In Service SA /LR Aircraft with approved wiring and equipment

The minimum configuration to certify ADS–B Out through an AFM update is as follows:

- Wiring provisions for Enhanced Surveillance
- Collins TPR–901 P/N 822–1338–021, Honeywell TRA–67A P/N 066011127–1402, ACSS XS–950 P/N 751–7800–10005
- Hybrid IRS
- MMR or Honeywell GPSSU

A Service Bulletin for AFM modification is available from Airbus Upgrade Services.

3. In Service SA /LR Aircraft without wiring provision or equipment

For the operators interested in ADS-B Out applications or needing upgrade to the required technical standard, a set of optional or customized Service Bulletins are available from Airbus Upgrade Services.

4. Other in Service Airplanes (Out of Production – A300/A310)–

Situation is under review.

5. Future Airbus Airplanes – A350

A350 will have new AFM wording with delivery of airplane and will indicate compliance with DO–260A Change 2. [Note: Has not been upgraded to reflect DO-260A Change 3 as identified in this NPRM.]