September 30, 2011

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Air Traffic Organization
Federal Aviation Administration
800 Independence Avenue SW.
Washington, DC 20571

Ms. Margaret Gilligan
Associate Administrator for Aviation Safety
Aviation Safety Organization
Federal Aviation Administration
800 Independence Avenue SW.
Washington, DC 20571

Subject: Automatic Dependent Surveillance–Broadcast (ADS–B) In Aviation Rulemaking Committee (ARC) — Recommendations to Define a Strategy for Incorporating ADS–B In Technologies into the National Airspace System (NAS)

Dear Ms. Gilligan and Mr. Grizzle:

The Federal Aviation Administration (FAA) chartered the Automatic Dependent Surveillance–Broadcast (ADS–B) In Aviation Rulemaking Committee (ARC) on June 30, 2010, to provide a forum for the U.S. aviation community to define a strategy for incorporating ADS–B In technologies into the National Airspace System (NAS). The ARC was tasked to provide recommendations that clearly define how the community should proceed with ADS–B In while ensuring compatibility with ADS–B Out avionics standards defined in §§ 91.225 and 91.227 of Title 14, Code of Federal Regulations.

The ARC supports ADS–B as the primary mechanism to provide future surveillance for ATC in the NAS and finds there are four primary recommendations on how the FAA should integrate ADS–B In into the NAS. First, the ARC finds, based on the current maturity of ADS–B In applications and uncertainties regarding the achievable benefits, there is not a NAS user community business case for near-term ADS–B In equipage. Therefore, at this time, the ARC does not support an equipage mandate. The ARC recommends the FAA demonstrate to the satisfaction of the user community that equipage benefits are both achievable and operationally implementable in a cost-effective manner.

The ARC recommends the FAA transition from delegated separation applications to defined interval applications and classify the majority of ADS–B In applications previously classified as delegated separation as defined interval. The ARC provides a number of recommendations regarding defined interval, including a phased implementation plan for a full-fledged transition to defined interval operations.

The ARC notes operational demonstrations of ADS–B In applications are in various stages of maturity but the required equipment standards, certification guidance, and operational approval guidance are not sufficiently mature to enable widespread manufacture of avionics and implementation of ADS–B In applications other than those directed toward situational awareness. The ARC recommends the FAA use these demonstration projects to mature the equipment standards, certification guidance, and operational approval guidance to allow NAS-wide ADS–B In implementation. The ARC also recommends these field trials to validate key assumptions and benefits and to assist in relating benefits to equipage rates.

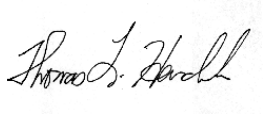
The ARC also undertook an extensive review of the ADS–B In applications listed in the FAA's Application Integrated Work Plan and ranked the applications by order of maturity, operational impact, and level of interest from operators. The ARC recommends the FAA focus funding on accelerating the development of equipment standards, certification guidance, operational approval guidance, and any necessary policy adjustments to enable operational implementation of these applications.

The ARC also provides the FAA with a number of other technical recommendations on integrating ADS–B into the NAS.

We trust this report will be helpful in your decisionmaking process. The ADS–B In ARC stands ready to help the FAA with any additional tasks as needed.

Sincerely,

Steven J. Brown
ADS–B In ARC Co-Chair
National Business Aviation Association



Thomas L. Hendricks
ADS–B In ARC Co-Chair
Air Transport Association of America, Inc.

Enclosure
Copy to Mr. Doug Arbuckle, ADS–B In ARC Designated Federal Official, and all ARC members.

A Report from the

ADS–B In Aviation Rulemaking Committee to the Federal Aviation Administration

Recommendations to Define a Strategy for Incorporating ADS–B In Technologies into the National Airspace System.

September 30, 2011

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EXECUTIVE SUMMARY

BACKGROUND

The Federal Aviation Administration (FAA) chartered the Automatic Dependent Surveillance–Broadcast (ADS–B) In Aviation Rulemaking Committee (ARC) June 30, 2010, to provide a forum for the U.S. aviation community to define a strategy for incorporating ADS–B In technologies into the National Airspace System (NAS). The FAA tasked the ARC to provide recommendations for how the community should proceed with ADS–B In while ensuring compatibility with ADS–B Out avionics standards defined in §§ 91.225 and 91.227 of Title 14, Code of Federal Regulations (14 CFR) (the ADS–B Out rule). The FAA tasked the ARC to submit its recommendations to the Administrator through the Chief Operating Officer, Air Traffic Organization and the Associate Administrator for Aviation Safety by September 30, 2011.

In addition, the FAA requested the ARC provide near-term recommendations on—

1. Whether the FAA should continue development of Flight-deck-based Interval Management–Spacing (FIM–S), Interval Management–Delegated Separation (IM–DS), and Airport Traffic Situation Awareness with Indications and Alerts (SURF–IA); and

2. How to proceed with legacy ADS–B Out avionics issues.

In this report and its appendices, the ARC provides the FAA recommendations regarding strategy and policy, applications, and the business case. Among the strategy recommendations, the ARC discusses the issue of equipment mandate, defined interval (DI) versus delegated separation (DS), a prioritization of applications, and operational demonstrations. The broad strategic recommendations are briefly discussed below. The ARC also makes several technical recommendations in the broad areas of ADS–B traffic data on non-technical standard order (TSO)–C195 displays, hazard level determinations for applications, data communications in the NAS, retaining the ADS–B requirements as established in the rule for ADS–B link, the future integration of the Airborne Collision Avoidance System (ACAS) with ADS–B, spoofing, ownship position source, and areas for future research emphasis. All of the ARC's recommendations are listed in the last section of this executive summary.

NO ADS–B IN MANDATE

The ARC supports ADS–B as the primary mechanism to provide future surveillance for air traffic control (ATC) in the NAS, and recognizes this future system as a foundational element of transforming the NAS to the Next Generation Air Transportation System (NextGen). However, the ARC believes there is not a NAS user community business case for near-term ADS–B In equipage to justify an equipage or airspace mandate. While many ADS–B In applications show significant promise, additional development and analysis are required before operators can justify investment or implementation decisions.

Based on currently available cost/benefit information, the ADS–B In ARC concludes there is not a positive business case for air carrier or general aviation (GA) operators for widespread ADS–B In implementation in the near- or mid-terms. The ARC finds the FAA should develop

clearly defined regulations, certifications, and detailed specifications for the ADS–B In applications to provide acceptable levels of uncertainty and risk. Therefore, the ARC does not support an ADS–B In mandate at this time, but supports the voluntary deployment of ADS–B In capabilities in the NAS as the near-term option. Accordingly, the ARC recommends the FAA clearly demonstrate that equipage benefits are indeed both achievable and operationally implementable in a cost-effective manner, including operations in a mixed equipage environment. A follow-on activity could then determine if an ADS–B In mandate is warranted.

Defined Interval versus Delegated Separation

In delegated separation applications, the air traffic controller delegates separation responsibility and transfers the corresponding tasks to the flightcrew, which ensures that the applicable separation minimums are met. After a careful review of ADS–B In delegated separation applications, the ARC recommends the FAA classify the majority of ADS–B In applications previously classified as delegated separation using the alternative concept of defined interval. Under a defined interval task, an air traffic controller maintains separation responsibility while assigning pilots a spacing task that must be performed within defined boundaries. This will enable a range of applications where dynamic interval spacing, closer than that currently allowed by traditional separation standards, may be possible. The ARC also provides the FAA with a phased rollout plan for a transition to full-fledged defined interval operations within the NAS.

Prioritized Applications

The ARC reviewed the applications in the FAA Application Integrated Work Plan (AIWP), identified several additional ADS–B In applications, and assigned priorities to the most promising ADS–B In applications considering maturity, operational impact, and safety with specific input from operators about which applications they view as suitable to their operations. As a result, the ARC recommends the FAA focus funding on accelerating the development of equipment standards, certification guidance, operational approval guidance, ground automation for the applications, and any necessary policy adjustments to enable operational implementation of the 10 applications listed below, in priority order:

1. CDTI-Assisted Visual Separation (CAVS),
2. Flight-deck-based Interval Management–Spacing (FIM–S),
3. Traffic Situation Awareness with Alerts (TSAA),
4. Oceanic In-Trail Procedures (ITP),
5. CDTI-Enabled Delegated Separation (CEDS) (ending in a visual approach),
6. Ground-based Interval Management–Spacing (GIM–S) with Wake Mitigation,
7. Flight-deck-based Interval Management—Defined Interval (FIM–DI),
8. FIM–DI for Closely Spaced Parallel Runway Operations (CSPO),
9. Oceanic Interval Management (IM), and
10. Airport Traffic Situation Awareness with Indications and Alerts (SURF–IA) at airports with surface multilateration systems).

The ARC finds the following applications are less defined as to their deployment and use in the NAS and would require significant resources to mature. Therefore, the ARC recommends the FAA leave the following AIWP applications in its far-term research phase at this time:

- Self-separation,
- Flow corridors,
- DS crossing and passing,
- Independent closely spaced routes, and
- Independent closely spaced parallel approaches.

DEMONSTRATION AND OPERATIONAL EVALUATIONS

The ARC provides the FAA with numerous recommendations regarding the FAA's continued use of demonstration projects and in certain instances, recommends the acceleration of these demonstration projects. The ARC finds these activities will enable government and industry to better understand the benefit mechanisms and costs of implementation. This, in turn, could provide the catalyst to redirect or focus available resources as the most promising technologies and capabilities emerge. The ARC finds these demonstration projects also will enable the FAA to mature the equipment standards, aircraft certification guidance, and operational approvals necessary for NAS-wide ADS–B In implementation.

FUTURE ARC TASKING

The ARC provides the FAA with a few recommendations on future tasks for the ARC. These include the ARC—

- Considering the impact of future collision avoidance systems on ADS–B In;
- Reviewing the results of the RTCA, Inc., Special Committee (RTCA SC) 206 analysis of alternative delivery architectures for Aeronautical Information Service (AIS) and meteorological (MET) data, and the FAA's view of this analysis in the context of the ARC's wake recommendations;
- Providing further recommendations about dual frequency and multi-constellation Global Navigation Satellite System (GNSS) and ADS–B In to the FAA after reviewing the FAA's assessment of the readiness of using dual frequency and multi-constellation GNSS to support surveillance and navigation needs and the way forward for dual frequency GNSS;
- Continuing further work to define Flight-deck-based Interval Management (FIM–DI) for Closely Spaced Parallel Runway Operations (CSPO); and
- Offering further recommendations following the FAA response to this report.

COMPLETE LIST OF ADS–B IN ARC RECOMMENDATIONS

No.	Report Section	Recommendation
Strategic/Policy Recommendations		
1	2.4.3	The ARC recommends the FAA develop an integrated communications, navigation, and surveillance (CNS) roadmap to help industry better understand future capabilities, benefits, and investments. The ARC recommends the roadmap include— • A phased transition path to what will be available in 15 to 20 years; • The avionics integration required onboard the aircraft for the different systems, especially those in common between the technologies; • Known plans for mandating avionics equipment; • Bundled avionics upgrades with a goal that aircraft operators only have to upgrade every 5 to 7 years for aircraft avionics supporting all CNS/air traffic management functionality; • Upgrades integrated among the NextGen programs, not done individually, and reflecting evolving international requirements for U.S. operators; and • Appropriate benefit-cost justification for each phase.
2a	3.1	The ARC recommends no ADS–B In equipage mandate at this time.
2b	3.1	The ARC recommends the FAA incentivize voluntary equipage as its ADS–B In strategy for the foreseeable future.
2c	3.1	The ARC recommends the FAA continue ADS–B In demonstration projects and, where possible, accelerate existing and future demonstration projects. The ARC finds these activities will enable government and industry to better understand the benefit mechanisms and costs of implementation. This, in turn, could provide the catalyst to redirect or focus available resources as the most promising technologies and capabilities emerge.
5a	3.2	Building on today's current separation standards while maintaining the traditional roles and responsibilities of the pilot and air traffic controller, the ARC recommends the FAA develop and transition to a risk-based DI criteria.
5c	3.2	The ARC recommends the FAA develop a standardized national policy for approval of DI applications administered through the operators certificate management offices.
6	3.3	The ARC recommends the FAA use these demonstration projects to mature the equipment standards, aircraft certification guidance, and operational approvals necessary for NAS-wide ADS–B In implementation.

No.	Report Section	Recommendation
Strategic/Policy Recommendations		
7	3.3	The ARC recommends the FAA aggressively focus on developing Safety and Performance Requirements (SPR) minimum operation performance standards (MOPS) for ADS–B In applications using CDTI to fully unlock the technical and system wide potential of ADS–B In and to aid in reducing business case risk.
8	3.3	The ARC recommends the FAA focus funding on accelerating the development of equipment standards, certification guidance, operational approval guidance, round automation for the applications, and any necessary policy adjustments to enable operational implementation of the 10 applications and/or enabling capabilities listed below (and in table 2 of the report) in priority order (with targeted completion date). 1. CDTI-Assisted Visual Separation (CAVS) (fiscal year (FY) 2012 using ADS–B Out legacy equipage targets and 2013 additionally using TIS–B targets); 2. Flight-deck-based Interval Management–Spacing (FIM–S) (DI based on current separation standards, to include merging of different traffic streams while increasing arrival throughput) (FY 2015); 3. Traffic Situation Awareness with Alerts (TSAA) (2013); 4. Oceanic In-Trail Procedures (ITP) (FY 2013); 5. CDTI-Enabled Delegated Separation (CEDS) (ending in a visual approach) (FY 2016); 6. Ground-based Interval Management–Spacing (GIM–S) with Wake Mitigation (Establish provisioning by calendar year (CY) 2013, ADS–B Out Link MOPS by CY 2015, ADS–B In platform MOPS by CY 2015, GIM–S with Wake Mitigation at core airports by the end of CY 2018); 7. Flight-deck-based Interval Management–Defined Interval (FIM–DI) (Operational trial by FY 2017 with a push to be operational 2 years following completion of the trial); 8. FIM–DI for Closely Spaced Parallel Runway Operations (CSPO) (FY 2017); 9. Oceanic Interval Management (IM) (FY 2015); and 10. Airport Traffic Situation Awareness with Indications and Alerts (SURF–IA) at airports with surface multilateration system (FY 2017).

No.	Report Section	Recommendation
Strategic/Policy Recommendations		
9	3.3	The ARC recommends the FAA delay work on the following applications list in AIWP version 2 until the applications listed in recommendation 8 are fully mature. The ARC finds these applications' use in the NAS is less defined and would require significantly more resources. • Self-separation, • Flow corridors, • DS crossing and passing, • Independent closely spaced routes, and • Independent closely spaced parallel approaches.
11	3.3	The ARC recommends the FAA develop policy, equipment standards, certification guidance, operational approvals, procedures, and ground automation to allow maximum use of retrofit hardware and software. The ARC finds full implementation of ADS–B In applications may be significantly delayed if there is not a viable retrofit solution.
14e	3.4.1	The ARC recommends the FAA accelerate the development of avionics specification and certification standards as operators begin to overhaul their aircraft fleets and seek to reduce any uncertainty in their fleet decisionmaking process.
14f	3.4.1	The ARC recommends the FAA undertake significant efforts to develop international standards after the benefits are also established as achievable and operationally implementable.
14g	3.4.1	At this time, the ARC does not support an equipage mandate because of the benefit uncertainty. Accordingly, the ARC recommends the FAA clearly demonstrate that equipage benefits are indeed both achievable and operationally implementable in a cost-effective manner, including operations in a mixed equipage environment. A follow-on ARC activity could then determine if an ADS–B In mandate is warranted.
22	3.5.1.5.3	The ARC recommends the FAA maintain its current direction, which is to not initiate rulemaking to raise the position accuracy or integrity performance requirements in 14 CFR § 91.227 (the ADS–B Out rule).
25	3.5.1.5.3	The ARC recommends the FAA assess the readiness of using dual frequency and multi-constellation GNSS to support surveillance and navigation needs and provide a detailed overview of the way forward for dual frequency GNSS to the ARC by spring 2012. At that time, the ARC may exercise its discretion to provide further recommendations about dual frequency GNSS and ADS–B In to the FAA.

No.	Report Section	Recommendation
Strategic/Policy Recommendations		
26	4.1.4	The ARC recommends the FAA provide guidance that specifically allows installations of TSO–C195 and subsequent ADS–B In Airborne Surveillance and Separation Assurance Processing (ASSAP) systems with non-TSO–C195 traffic displays that use existing Traffic Collision and Avoidance System (TCAS I)/Traffic Advisory System (TAS)/Traffic Information System (TIS)(–A) and Capstone-based universal access transceiver (UAT) ADS–B/ Traffic Information System–Broadcast (TIS–B) symbology for situational awareness of surrounding aircraft. It should be clear that minor changes or enhancements may be made to previously approved traffic functionality on displays without requiring equipment to be made fully compliant with TSO–C195 requirements. The ARC finds this approach suitable for GA aircraft
27	4.1.4	The ARC recommends the FAA provide guidance that specifically allows the continued use of previously certified and operationally approved non-TSO–C195 ADS–B In CDTI with previously approved symbology but limited to previously approved traffic functions and applications. It should be clear that minor changes or enhancements may be made to previously approved traffic functionality on displays without requiring equipment to be made fully compliant with TSO–C195 requirements. The ARC makes this narrow recommendation for specific existing air carrier aircraft.
28	4.2	The ARC recommends the FAA, as part of any research and development work directed toward applications, assess the benefits of splitting applications into a two-phased deployment plan that would enable near-term benefits from avionics at a Major hazard level and far-term benefits from avionics at a Hazardous hazard level. The ARC finds this may further facilitate retrofit and early deployment of these applications.
29	4.4.2.3	The ARC recommends the FAA permit the use of legacy equipment on an application-by-application (or version number-by-version number) basis if the application is envisioned to be enabled in the NAS before 2020.
30	4.4.2.3	The ARC recommends the FAA include TCAS range validation as part of the evaluation (flight trials and operational evaluations) of ADS–B In applications deployed before 2018 to enable deployment in an environment with legacy ADS–B Out avionics.
31	4.4.4	The ARC recommends the FAA provide a briefing to the ARC on the results of the RTCA SC–206 analysis of alternative delivery architectures for AIS and MET data, and the FAA's view of this analysis, in the second quarter of 2012.
42	4.4.7	The ARC does not believe there is sufficient maturity in the wake or other potential data that could be added to RTCA Document (DO)–260C/DO–282C at this time and recommends the FAA not change the link MOPS requirement in § 91.227 pending additional work related to wake including consideration whether a rulemaking is required or can be achieved through voluntary means as identified in recommendation No. 38.

No.	Report Section	Recommendation
Strategic/Policy Recommendations		
43	4.5	The ARC recommends the FAA develop, as a priority, a future collision avoidance system that integrates ACAS and ADS–B as well as considers the operational concepts envisioned in NextGen.
44	4.5	The ARC recommends the FAA provide a briefing to the ARC in early 2012 about the FAA's response to RTCA SC–147 recommendations about future collision avoidance systems. At that time, the ARC will consider the impact on ADS–B In and exercise its discretion to provide additional recommendations to the FAA before the expiration of the ARC charter on June 30, 2012.
50	Appendix H	The ARC recommends the FAA adopt an NAS state wherein traditional legacy ATC separation standards evolve into a multi-dimensional safety-based analysis of operational relationships. The ARC finds NextGen separation should be governed by circumstance and defined to achieve or maintain an allowable proximity.
51	Appendix H	The ARC recommends the FAA retain responsibility for ensuring separation. The ARC finds the FAA should incorporate exceptions for operations wherein flightcrews are specifically authorized to interval their aircraft to/or on the final approach course in relation to another aircraft or the airport. The ARC envisions that "visual-equivalent" technologies such as ACAS, CDTI, CEDS or FIM–S applications should expand the incidence of exceptions.
55a	Appendix J, 1.1	The ARC recommends the FAA accomplish human factors studies to help maximize the usefulness of retrofit electronic flight bag (EFB) installations.
61	Appendix K, 5.3	The ARC recommends the FAA make no changes to the ADS–B Out rule at this time.
Application-Specific Recommendations		
3a	3.2	The ARC recommends the FAA classify the majority of ADS–B In applications previously classified as DS using the alternative concept of DI. The CAVS and CEDS applications will continue to be classified DS.
3b	3.2	The ARC recommends the FAA work with the appropriate regional and international standards bodies to harmonize the use of DI.
4a	3.2	The ARC recommends the FAA allow for the use of a distance metric for IM applications as decision support tools are developed for transition to time-based separation intervals because air traffic controllers are familiar with working from distance-based intervals.
4b	3.2	The ARC recommends the FAA work with the appropriate regional and international standards bodies to harmonize uses of distance-based and time-based intervals.

No.	Report Section	Recommendation
Application-Specific Recommendations		
5b	3.2	The ARC recommends the FAA use the following phased approach to roll out and transition to a full-fledged DI operation within the NAS. However, the ARC finds oceanic DI management would not require a phased implementation because of its unique operational environment of procedurally separated airspace. 1a. Apply DI in VMC with IFR separation, as defined by current separation standards (applied to applications 6a, 6b, 6c, and 6d, as defined in section 3.3 of this report). 1b. Apply DI in IMC with IFR separation, as defined by current separation standards (applied to applications 6a, 6b, 6c, 6d, FIM–S, and FIM–DI, as defined in section 3.3 of this report). 2a. Apply DI in VMC with DI separation standards, as defined by current separation standards (applied to applications 8c, 8d, 8g, 8h, and FIM–DI for CSPO, as defined in section 3.3 of this report). 2b. Apply DI where DI standards are used to runway occupancy limits (applied to applications FIM–S, FIM–DI, and FIM–DI for CSPO, as defined in section 3.3 of this report). 3. Include continued evolution of concepts wherein traditional legacy ATC separation standards evolve into a multidimensional safety-based analysis of operational relationships. See appendix H, Defined Interval, to this report.
5d	3.2	The ARC recommends the FAA develop DI separation standards and third-party identification using risk-based analysis. See appendix I, Phraseology and Third Party ID, to this report. The ARC finds this will allow for evaluating acceptable proximity standards with the adoption of new technology such as ADS–B, CDTI, and/or improved air traffic controller and pilot decision support tools.
10	3.3	The ARC recommends its continued efforts to further define Flight-deck-based Interval Management (FIM–DI) for Closely Spaced Parallel Runway Operations (CSPO).
12	3.3	In January 2011, the FAA provided a briefing to the ARC regarding program development and funding to support ADS–B In applications. Based on the information from that briefing as supplemented by the work of the ARC, the ARC recommends the FAA— • Continue funding and development of GIM–S to initial operational capability. The ARC finds the GIM–S tool is required in the ATC automation for successful FIM–S and FIM–DI implementation. • Amend the AIWP to be consistent with table 2.
18	3.5.1.5.2	The ARC is pleased to see the progress made by the FAA to better define and analyze the SURF–IA technical issues involved in line of sight and dropout, and recommends the FAA continue development work to fully resolve both the line-of-sight problem and the dropout problem.

No.	Report Section	Recommendation
Application-Specific Recommendations		
19	3.5.1.5.2	With regard to evaluating line-of-sight, the ARC recommends the FAA assess the mitigation that would be achieved by deploying SURF–IA even with existing line-of-sight problems based on the FAA's runway incursion data; that is, if a "partially functioning SURF–IA applications were deployed at those specific airports where there were events, to what degree would alerts have been issued and with what degree of delay."
20	3.5.1.5.2	If the FAA elects to move forward with a "partially functioning" SURF–IA application, the ARC recommends the FAA fully assess the human factors implications of that approach. The ARC noted there are specific concerns with pilots starting to rely on a system that may not give them what they are expecting at all times.
21	3.5.1.5.3	Surface multilateration will be available at 44 airports in the NAS and could provide for a fully functioning SURF–IA application at these airports. While additional research and development will be required, the ARC finds the Surveillance and Broadcast Services (SBS) office should fully fund the development work of navigation accuracy category (NAC) performance mitigations, making it a high priority in concert with addressing line-of-sight and dropout problem activities.
23a	3.5.1.5.3	The ARC recommends the FAA analyze the rate of pilot deviation type runway incursions at the 44 airports where the SURF–IA ADS–B In application is initially implemented to assess the application's benefits.
23b	3.5.1.5.3	The ARC recommends the FAA undertake a benefit-cost assessment for expanding surface multilateration to support SURF–IA at non-multilateration airports where runway incursion events are prevalent or may be likely.
23c	3.5.1.5.3	The ARC recommends the FAA fund the required research, operational evaluations, and development work to complete validated MOPS and any related guidance to deploy SURF–IA at airports with multilateration capability by 2017.
24	3.5.1.5.3	The ARC recommends the FAA undertake a study to determine the opportunity to deploy SURF–IA at GA airports with the assumption that the majority of the activity at the airport will be with aircraft that are Wide Area Augmentation System (WAAS)-equipped and with consideration of known technical issues such as signal drop-out and line-of-sight.
32a	4.4.4	The ARC recommends the FAA investigate the possibility of adding either the minimum (Wind Speed, Wind Direction, Pressure Altitude, Aircraft Position, Aircraft True Airspeed, and Aircraft Heading) or practical minimum (Wind Speed, Wind Direction, Static Temperature, Aircraft Type, Pressure Altitude, Aircraft Position, Aircraft True Airspeed, Aircraft Heading, Aircraft Weight, and Atmospheric Turbulence (eddy dissipation rate (EDR))) set of data to the 1090 MHz extended squitter (1090 ES) by reformatting existing squitters to support ADS–B wake-related applications.

No.	Report Section	Recommendation
Application-Specific Recommendations		
32b	4.4.4	The ARC recommends the FAA confirm, through its 1090 MHz Spectrum Congestion Mitigation Project, the two low-transmission-rate extended squitters of RTCA DO–260B, appendix V that support wake-related applications can be added to the ADS–B Out message set without unacceptable impact to 1090 MHz spectrum congestion.
32c	4.4.4	If the FAA confirms that the RTCA DO–260B, appendix V squitters that support wake-related applications can be added to the ADS–B Out message set, the ARC recommends the FAA coordinate with the International Civil Aviation Organization ICAO to increase to the current maximum transmission rate of 6.2 squitters average per second per aircraft to 6.4 squitters per average per second.
32d	4.4.4	Should the FAA not be able to confirm that the RTCA DO–260B, appendix V squitters can be added to the ADS–B Out message set, the ARC recommends the FAA consider multiple parameter transmission paths, including the use of new broadcast technologies such as phased modulation, to service the data needs of ground-based and air-to-air wake-related applications.
33	4.4.4	The ARC recommends the FAA establish a GIM–S with Wake Mitigation implementation program consistent with the schedule in figure 1.
34	4.4.4	The ARC recommends the FAA establish performance standards for EDR computational approaches by the end of 2012, consistent with the timeline for implementation of GIM–S with Wake Mitigation presented in figure 11.
35	4.4.4	The ARC recommends the FAA immediately initiate the necessary activities to, through appropriate standards bodies, standardize EDR data value encoding and label definition to support figure 11's timeline provisioning specification completion date of 2013.
36	4.4.4	The ARC recommends the FAA further mature its operational concepts for wake vortex mitigation to support development of an aircraft provisioning specification for wake applications by the end of 2013. The ARC finds the completion date of 2013 will permit early adopters of ADS–B Out to provision for this capability and later activate the capability with a software change to ADS–B avionics. This would minimize the risk of having to open up the aircraft for additional wiring in favor on a more limited change to the aircraft equipage.
37	4.4.4	The ARC recommends the FAA target completion of a safety risk management document for GIM–S with Wake Mitigation by the end of 2017.
38	4.4.4	The ARC recommends the FAA develop the GIM–S with Wake Mitigation application with an initial approach of voluntary equipage. The ARC finds as the development of the application progresses and the benefits are better understood, voluntary equipage with the FAA issuing catch-up rulemaking requiring equipage after 2020 may be a possibility, given appropriate consultation with the aviation community.
39a	4.4.5.2	The ARC recommends the FAA validate the 60 to 80 percent estimate in the reduction in the number of TCAS interrogation responses.

No.	Report Section	Recommendation
Application-Specific Recommendations		
39b	4.4.5.2	If the estimate is validated, the ARC recommends the FAA update the hybrid surveillance MOPS and, if warranted, the TCAS MOPS as well.
49	Appendix G	The ARC recommends the FAA ask airframe manufacturers to define the deceleration characteristics of their aircraft based on gross weight, flap setting, and wind field conditions so that the flight time from the end of a DI task until the aircraft crosses the runway threshold can be accurately estimated.
52	Appendix I	The ARC recommends the FAA develop national policy, procedures, and standards to enable the use of Third Party Flight ID (TPID) by the end of FY 2012.
53	Appendix J	The ARC recommends the FAA conduct the necessary research and provide the resources to result in the enabling of TIS–B to supplement traffic information to support CAVS/CEDS during mixed equipage operations before the ADS–B Out mandate, at least at the "Core" airports.
54	Appendix J, 1.1	The ARC recommends FAA CAVS/CEDS standards work considers the added value of a passive wake situation awareness display.
55b	Appendix J, 1.1	If an EFB is installed in a position that is currently acceptable for paper chart display (chart clip), the ARC recommends the FAA also allow it to be acceptable for CAVS/CEDS applications. See appendix J–4 for further information.
56a	Appendix J, 2.1	The ARC recommends the FAA determine if avionics certified for Visual Separation Approach (VSA) can qualify for CAVS operations.
56b	Appendix J, 2.1	If the FAA finds VSA certified avionics cannot be used for CAVS, the ARC recommends the FAA define the differences.
56c	Appendix J, 2.1	The ARC recommends the FAA conduct an analysis to use TIS–B to support the acquisition and following of the traffic-to-follow aircraft to dramatically improve CAVS benefits during mixed equipage operations.
57	Appendix J, 2.1	The ARC recommends the FAA incorporate wake turbulence considerations and trajectory closure rate awareness into CAVS operator training programs.
58	Appendix J, 2.3	The ARC recommends the FAA standards work determine if current phraseology can accommodate CEDS.
59	Appendix K, 2.6	The ARC recommends the FAA write the CAVS/CEDS standards as broadly as possible and take a functional approach to advance CAVS/CEDS to as many applications as possible.

No.	Report Section	Recommendation
Business/Benefit Case Recommendations		
13	3.4.1	The ARC recommends the FAA research efforts to identify and validate a range of financial and operational incentive options that can be targeted toward airspace users and mitigate risks.
14a	3.4.1	The ARC recommends the FAA focus on improving benefit-cost analyses by developing better inputs and local-level analyses to help improve credibility within the operator community.
14b	3.4.1	The ARC recommends the FAA support further field trials to validate key assumptions and identified benefits. In particular, the FAA should pay special attention to the relationship between ADS–B In benefits and equipage rates.
14c	3.4.1	The ARC recommends future FAA activities take a close look at ADS–B In and how it will intersect with regional carrier operations.
14d	3.4.1	If benefits are not linear with ADS–B In equipage (there will be a mix of equipped and non-equipped aircraft), the ARC recommends the FAA explore air traffic controller tools and procedures to overcoming mixed equipage barriers to obtain full benefits for the application. The industry business case indicates a substantial positive change in present value when moving from square to linear benefits.
60	Appendix K, 5.2	The ARC recommends the FAA prioritize the applications as follows, in terms of airport implementation: 1. Hartsfield-Jackson Atlanta International Airport (ATL), 2. John F. Kennedy International Airport (JFK), 3. McCarran International Airport (LAS), 4. Philadelphia International Airport (PHL), 5. LaGuardia Airport (LGA), 6. San Francisco International Airport (SFO), 7. Los Angeles International Airport (LAX), 8. Newark Liberty International Airport (EWR), 9. Charlotte Douglas International Airport (CLT), and 10. Washington Dulles International Airport (IAD).
62	Appendix K, 5.3	The ARC recommends the FAA monitor other NextGen improvements to determine if a business case for mandating higher Navigation Performance can be made.
63	Appendix K, 5.3	The ARC recommends the FAA conduct further research to determine whether incorporation of the wake parameter into the ADS–B Out message set is warranted.
64a	Appendix K, 5.4	The ARC recommends the FAA implement a NextGen portfolio activity that looks at all the proposed investments from a portfolio perspective and identify potential cost synergies, benefit overlaps, and other portfolio interactions.

No.	Report Section	Recommendation
Business/Benefit Case Recommendations		
64b	Appendix K, 5.4	Once these operational and technical interactions are better understood, the ARC recommends the FAA look at the collection of applications across the portfolios and make sure they make sense together and they do not cause conflict in their implementation.
65	Appendix K, 6.0	The ARC recommends the FAA take the following next steps for the benefit-cost analysis: 1. Mixed Equipage Benefits Impact: If possible, establish whether benefits are linear with equipage, or square with equipage, or something else. This uncertainty has major implications regarding whether to equip, whether mandates are required, etc. This can be done through expert interviews, trials, simulations, etc. The ARC could not come to consensus on this issue. 2. Updates to FAA provided monetary value: Accurate data inputs are a prerequisite to any solid and credible analyses. The ARC recommends that the FAA invest resources in maintaining a current set of economic criteria to be used as the basis for any benefit-cost analyses. The FAA currently uses two documents: "Economic Values For FAA Investment And Regulatory Decisions, A Guide", October 3, 2007 and "Economic Information for Investment Analysis", March 16, 2011. These documents rely on cost inputs that are less than relevant today given material changes experienced by all user groups. For example, aircraft operating costs for air carriers and GA rely on values set from 2002 and 2003 respectively that have been inflated over time to 2010 levels. Given the plethora of data which is both reliable and current, the FAA has the opportunity to improve data quality and should do so without hesitation. 3. Equipage Cost Synergies: Identify if any of the identified equipage costs will be required for other NextGen programs or other new features that the air carriers are pursuing. This can reduce the true cost incurred for ADS–B equipage. One scenario is that operators are considering upgrading CRT displays to LCD displays for 757/767 aircraft. This would cover part of the cost for upgrading to ADS–B In. 4. Top Five Application Benefits: The top five applications contribute 77 percent of the total benefits. Three of the next applications in the list require higher Navigation Performance than specified in the RTCA DO–260 B mandate. Focus on the top five applications in terms of additional data gathering to increase confidence in the results. Develop credible ranges of possible benefits in order to conduct a meaningful sensitivity analysis. Conduct trials, simulations, experiments, etc. to reduce the uncertainty on key benefit assumptions and increase stakeholder confidence in benefits estimates. 5. Capacity Sensitivity Analysis: A majority of the benefits in the air transport business case come from increases in capacity. When modeling capacity increases, adjustments to the traffic forecast are made when delay reaches unacceptable levels. Flights may be cut or re-distributed to less busy times in the day. The bottom line is that modeling benefits from increased capacity is an art and not a science. A sensitivity analysis should be done around these assumptions to determine the impact of these assumptions and how conservative or aggressive the current analyses are.

No.	Report Section	Recommendation
Infrastructure/Implementation Recommendations		
		6. Equipage percent: The benefit-cost analyses are highly sensitive to the equipage assumptions which are highly sensitive to incentives and to the degree to which operators believe the business case.
15	3.4.2	Because the cost of the changes to allow for continuous uplink of current TIS–B and Automatic Dependent Surveillance–Rebroadcast (ADS–R) data could be a limiting factor to implementing the ARC recommendation for continuous uplink on UAT, the ARC recommends the FAA conduct a full analysis of recommendations 16 and 17 and share the results with the ARC before June 2012.
16	3.4.2	The ARC recommends the FAA provide continuous uplink, while not requiring ADS–B Out, of the TIS–B and ADS–R over the current UAT link only (not the 1090 ES) starting today through the ADS–B Out mandate of January 1, 2020, to allow users to recognize and take advantage of this situational awareness benefit of ADS–B In.
17	3.4.2	As a result of the need for greater traffic and weather information to improve the GA business case, the ARC recommends the FAA expand ADS–R and Flight Information Service–Broadcast service volumes and associated ADS–B infrastructure to improve coverage at GA airports and low altitude airspace.
40	4.4.5.4	The ARC recommends the FAA continue ongoing work to address 1090 MHz spectrum congestion and determine the mitigations needed, based on expected traffic growth, to enable the range for the expected inventory of ADS–B In applications while also increasing the squitter rate above the current 6.2 per second average over a 60-second period and determine the additional data transmission rate that could be achieved and which applications would be enabled.
41b	4.4.5.2	If backward compatibility, viability, and robustness for phased modulation are demonstrated with current uses of 1090 MHz, the ARC recommends the FAA develop applicable ADS–B MOPS requirements and test updates, and support ICAO Standards and Recommended Practices efforts to include the phase modulation Out and In capability within the next RTCA DO–260 MOPS update, and have international agreements in place for use when the MOPS is issued.
45a	4.6	The ARC recommends the FAA perform a risk analysis on the susceptibility of ADS–B In to intentional spoofing.
45b	4.6	Based on the findings of recommendation 45a, the ARC recommends the FAA provide guidance to manufacturers and operators on any required operational mitigations necessary.
45c	4.6	The ARC recommends the FAA brief the ARC on the results of the risk analysis recommended in 45a when completed.
46a	4.6	The ARC recommends the FAA evaluate the various filtering techniques of ground and aircraft systems because pilots and air traffic controllers may view different operating pictures because of varying filtering and validation criteria.

No.	Report Section	Recommendation
Infrastructure/Implementation Recommendations		
46b	4.6	The ARC recommends the FAA evaluate any risks incurred by aircraft and ground systems generating different traffic depictions, and any effect of automatically filtering valid aircraft that do not meet the ADS–B Out requirements for separation purposes. The ARC expects these evaluations will be part of the standard FAA certification process.
47	4.7.2	The ARC recommends the FAA revise Advisory Circular (AC) 20–172 from "Position sources interfaced to the ASSAP equipment must meet the criteria in AC 20–165", to "Position sources interfaced to the ASSAP equipment must meet the requirements in TSO–C195, table 2–3". For updates to AC 20–172, the FAA should reference the updated TSO and corresponding table in the new document.
Research Recommendations		
41a	4.4.5.4	The ARC recommends the FAA research, prototype, and demonstrate the phase modulation transmission function to determine its robustness and viability in the current and envisioned 1090 interference ADS–B environment. This includes ensuring backward compatibility with existing receivers that share the 1090 MHz frequency including Mode 5 systems used by the U.S. military, the North Atlantic Treaty Organization, and other allies. The ARC notes the research should include confirmation that the phase modulation does not interfere with Mode 5 systems nor do the Mode 5 systems interfere with the proposed phase modulation. The ARC also notes this backward compatibility and viability with current uses of the 1090 MHz frequency should be ensured before endorsement by the ARC and U.S. Government.
48a	4.8	The ARC recommends the FAA coordinate amongst the appropriate research organizations the following research activities to further the analyses performed by the ARC and to support mid-term FAA ADS–B In implementation activities: 1. Develop and refine the less mature applications in table 2 through the development of new or expanded concepts of operations and proof of concept exploration though demonstration, simulation, or experimentation. This work is necessary for the FAA and the ARC to better understand the potential costs, benefits, and implementation timelines of the applications. 2. Replicate the nearer term AIWP applications in simulation, and specifically report on benefit metrics of interest to industry operators (such as fleet fuel savings and time savings) and of interest to the FAA on a national level (aggregated fleet fuel savings, carbon footprint reduction, congestion reduction, controller impact, and automation impact). This work is necessary to firm up the applications benefits case including implementation timelines. 3. Investigate mixed equipage environments (specifically the characterization of benefit and the equipage linearity or order of the benefit function to better justify the inclusion, or not, of an equipment mandate for specific applications). This work is necessary to firm up the applications benefits case including implementation timelines.

No.	Report Section	Recommendation
Research Recommendations		
		4. Investigate the suitability of using TIS–B as a surveillance source for specific applications. If TIS–B were to be found suitable, some applications could be significantly accelerated and benefits could be realized much sooner. This work is necessary to firm up the applications benefits case including implementation timelines. 5. Investigate the placement of CDTI and related auxiliary displays in the cockpit (for example, side versus forward field of view) to determine optimal placement of the avionics to ensure maximum usefulness and benefit to ADS-B In applications while also considering the cost and desired timelines of retrofit/forward-fit for the applications. This work is necessary for the FAA and the ARC to better understand the potential costs, benefits, and implementation timelines of the applications. 6. Complete the TPID research, as this is a basic enabler to many of the applications. This work is necessary to firm up concepts of operations in support of upcoming operational approvals. 7. Support operational trials and demonstrations via demonstration/trial design, data collection, and analysis. This support is necessary to provide technical expertise for developing, executing, and analyzing the trial/demonstration to ensure the trial goals will be met.
48b	4.8	The ARC recommends the FAA ensure the research studies designed specifically in support of the ARC and the FAA should use current ADS–B standards and practices as a baseline for near- and mid-term applications. Hypothetical standards acceptable for longer term research (for example, proposed extensions or not-yet-well-defined conventions such as extended intent data or ideal range/reliability assumptions) may not directly support nearer term applications development and rulemaking.

1.0 AVIATION RULEMAKING COMMITTEE TASKING

The Federal Aviation Administration (FAA) chartered the Automatic Dependent Surveillance–Broadcast (ADS–B) In Aviation Rulemaking Committee (ARC) on June 30, 2010, to provide a forum for the U.S. aviation community to define a strategy for incorporating ADS–B In technologies into the National Airspace System (NAS).[1] The FAA tasked the ARC to provide recommendations that clearly define how the community should proceed with ADS–B In while ensuring compatibility with ADS–B Out avionics standards defined in §§ 91.225 and 91.227 of Title 14, Code of Federal Regulations (14 CFR). The FAA tasked the ARC to submit its recommendations to the Administrator through the Chief Operating Officer, Air Traffic Organization (ATO) and the Associate Administrator for Aviation Safety by September 30, 2011. This report provides the ARC's response to the ARC charter.

The FAA also tasked the ARC to complete follow-on work related to the original submission and prepare a summary report detailing recommended next steps by June 1, 2012.

In addition, the FAA requested the ARC provide near-term recommendations on—

- Whether it should continue development of Flight-deck-based Interval Management–Spacing (FIM–S), Interval Management–Delegated Separation (IM–DS), and Airport Traffic Situation Awareness with Indications and Alerts (SURF–IA); and
- How to proceed with legacy ADS–B Out avionics issues.

The FAA is working toward a Joint Resources Council (JRC) decision by 2012, which will frame the Surveillance and Broadcast Services (SBS) development of ADS–B from 2014 to 2020. The ARC has specifically tried to assist the FAA in prioritizing the activities to be addressed by the JRC.

The ARC will remain active through June 2012 and has identified several tasks and activities that will be further developed over the next 9 months and may result in additional recommendations to the FAA. The ARC identified a number of strategic ADS–B In implementation issues related to the ARC's charter. To achieve success in this key Next Generation Air Transportation System (NextGen) area, the ARC finds a continuing close partnership between the FAA and the broad aviation community will be essential. As appropriate, the ARC will be available to offer the FAA additional analysis and recommendations to support ADS–B In implementation.

Among these issues are: (1) Trials and demonstrations refining the business case, (2) evaluating installation and certification capacity to meet capability deadlines, and (3) planning for global interoperability to ensure a seamless stream of benefits for both aircraft operators and air traffic management (ATM) service providers.

The ARC also believes the real value of significant work on these and other key strategic issues could extend beyond the timeframe of the current ARC charter and the ARC may recommend the FAA further extend the ARC charter.

[1] See appendix A to this report for a list of all ARC members and alternates, subject matter experts, and individuals providing the ARC with substantive briefings.

2.0 BACKGROUND

The Century of Aviation Reauthorization Act (Public Law 108–176) was enacted December 12, 2003. The law sets forth requirements and objectives for transforming the U.S. air transportation system to meet the demands of the 21st century. Section 709 requires the Secretary of Transportation to establish in the FAA a joint planning and development office to manage work related to the development of NextGen. ADS–B was identified as a cornerstone technology in the implementation of NextGen.

2.1 ADS–B

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 NextGen to accommodate the projected increase in air traffic volume. NextGen is designed to take advantage of the latest technologies, provide enough flexibility to accommodate new travel options, and be robust enough to handle a significant increase of baseline of operations. Recognizing the limits of a radar infrastructure for NextGen, the FAA proposed a new surveillance system for the NAS: ADS–B.

To develop, implement, and manage an ADS–B system, the FAA created the national SBS program office within the ATO. The objective of the SBS program office is to develop a multisegment, life-cycle-managed, performance-based strategy that aligns with and enables the NextGen vision and generates value for the NAS. 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 SBS ADS–B system being deployed today will provide air traffic 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 will present the same information to flightcrews through cockpit displays and enable additional more advanced, highly beneficial NextGen applications.

The SBS program will provide services in all areas of the NAS currently covered by radar and in some non-radar airspace (NRA), including the Gulf of Mexico, off the east coast, and other areas. Almost half of that infrastructure is already in place and operational. In its response to the ARC's November 1, 2010, letter, the FAA stated the current scope of the SBS program (through 2013) includes the following, which are all funded through fiscal year (FY) 2013:

- Two classes of services—
    - Air-to-ground surveillance for air traffic control (ATC) separation and advisory services and ATC spacing services (consisting of a Ground Interval Management tool called Ground-based Interval Management–Spacing (GIM–S)), and

- Pilot advisory services (Traffic Information Service–Broadcast (TIS–B), Flight Information Service–Broadcast (FIS–B), and Automatic Dependent Surveillance–Rebroadcast (ADS–R)).

- Development support for three ADS–B In pilot applications (In-Trail Procedures (ITP), FIM–S, and Traffic Situation Awareness with Alerts (TSAA)).

The FAA previously supported development of the following ADS–B In applications: traffic situation awareness, airport traffic situation awareness, and traffic situation awareness for visual approach. Later phases of the program will support additional ADS–B In applications as defined in the planned revision to the FAA Application Integrated Work Plan (AIWP). The ARC, through this report, is providing industry perspective about how to develop and prioritize these later phases of the ADS–B program. In addition to developing and deploying ground infrastructure, the maturing of ADS–B standards and the researching of advanced ADS–B In concepts have been ongoing goals of the SBS program.

2.1.1 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 in the aircraft and in ATC, as shown in figure 1.

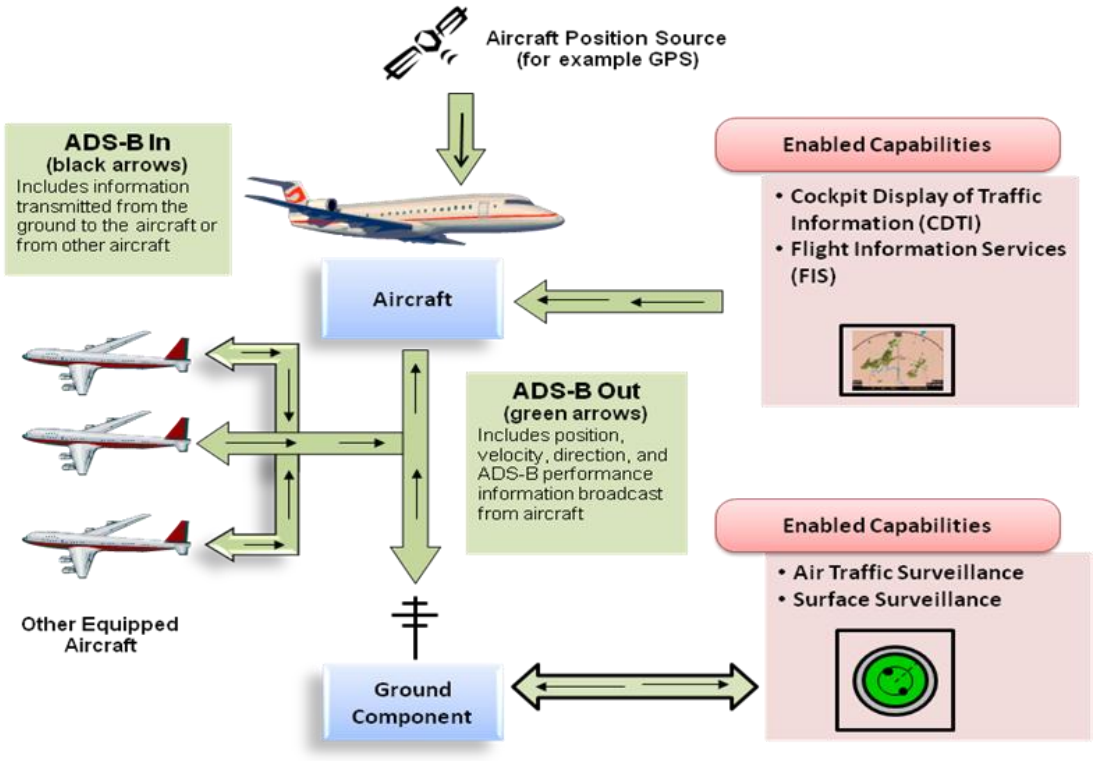


Figure 1—ADS–B System Overview

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 ADS–B Out rule requires most operators to equip with ADS–B Out using an airspace rule, 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 giving a flightcrew the ability to have situational awareness of proximate traffic or use advanced air-to-air ADS–B In 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 (TIS–B, FIS–B, and ADS–R), and
- Capabilities added by the air-to-air receipt of ADS–B Out from other aircraft.

2.1.2 ADS–B Out

As shown in figure 2, 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 and are now mature. Current equipage varies as aircraft have equipped with ADS–B Out according to the standards at the time of equipage. The ADS–B Out rule (further discussed below) establishes and requires specific performance standards, which will ensure uniform equipage and performance capability of the equipage. This uniform and widespread equipage will eventually enable widespread ADS–B In applications and a higher level of benefit to users and the FAA.

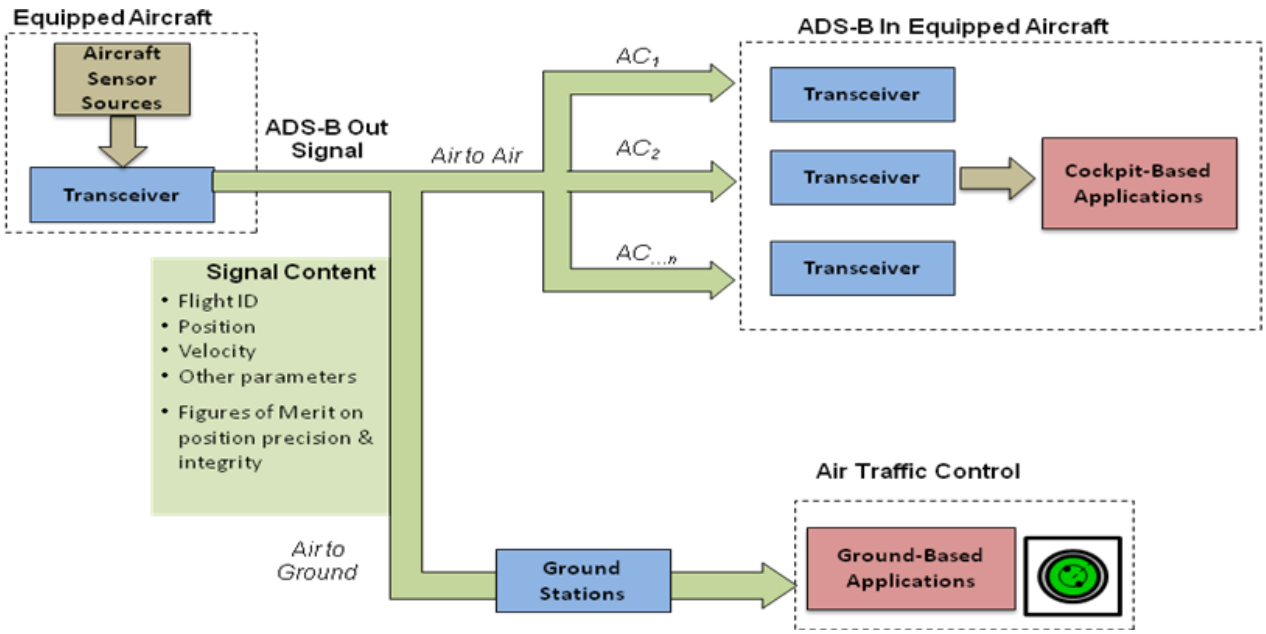


Figure 2—ADS–B Out Signal and Enabled Capabilities

2.1.3 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 3.

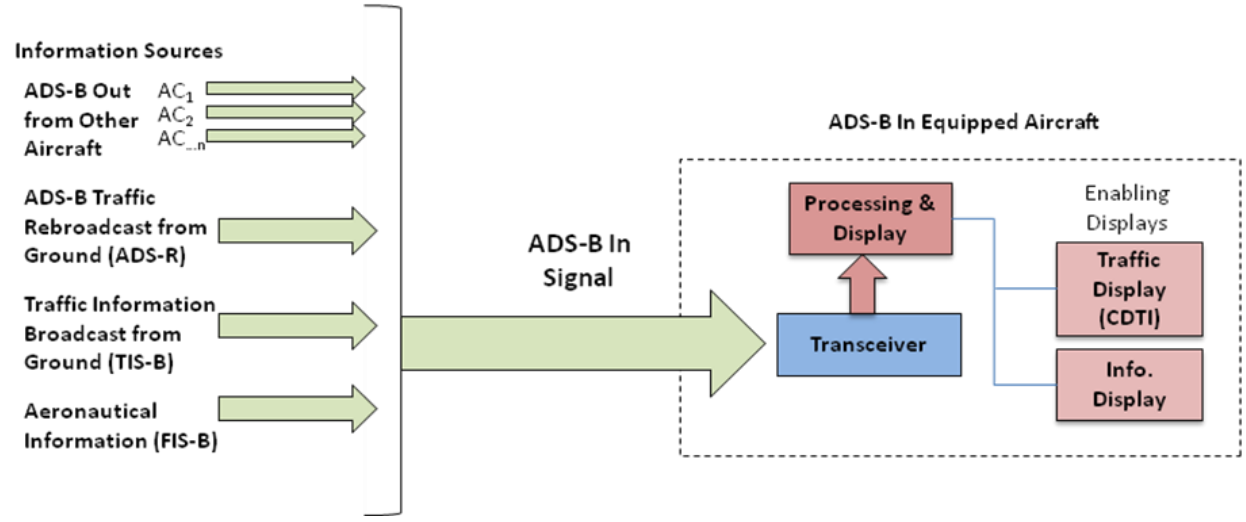


Figure 3—ADS–B In Signal Sources and Enabled Capabilities

As shown in figure 3, 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.

As discussed in the AIWP and the subject of the ARC, ADS–B In, at the most basic level, enhances the flightcrew's situational awareness of other aircraft operating within their proximity. The next step is to allow flightcrews to maintain visual separations during marginal conditions, and later instrument meteorological conditions (IMC), thus maintaining higher capacity during less-than-optimal visibility (a major problem to be solved in the NAS). Other mature applications include passing maneuvers in NRA and improved spacing maneuvers to improve predictability of aircraft arrivals. Future applications may include improved parallel runway operations, closely spaced routes, advanced crossing and passing maneuvers, and flow corridors. ADS–B In also would sustain the level of flight safety provided by current radar-based surveillance systems, and may support reduced traffic separation distances and allow for increased traffic volumes.

Before implementing ADS–B In, the FAA should 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. 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.

As mentioned earlier, the SBS program's next phase will be concentrating on ADS–B In applications, as they are considered to be the most beneficial to the users and FAA and are the enablers to the NextGen vision. Through its recommendations, the ARC is helping the FAA determine an evolution path for ADS–B In to ensure the most beneficial and economical way to meet the NextGen vision.

2.2 ADS–B OUT ARC

On July 15, 2007, the FAA chartered the ADS–B Out ARC to provide a forum for the U.S. aviation community to discuss and review a notice of proposed rulemaking (NPRM) for ADS–B Out, formulate recommendations on presenting and structuring an ADS–B Out mandate, and consider additional actions that may be necessary to implement those recommendations. While the NPRM was being finalized, the ADS–B Out ARC was tasked with developing a report on optimizing the operational benefits of ADS–B Out before implementation of a nationwide ADS–B Out airspace rule.

The ADS–B Out ARC's first task was to develop recommendations to the FAA on optimizing the operational benefits of ADS–B Out before implementation of a nationwide ADS–B Out airspace rule. During its work on this initial task, the ADS–B Out ARC had no knowledge of the NPRM's contents. In its task 1 report, the ADS–B Out ARC explained the operational benefits of ADS–B and provided recommendations on how to accelerate delivery of these benefits to NAS users through equipage with ADS–B before the expected compliance date. The ADS–B Out ARC stated it believed that some combination of financial incentives and operational benefits would be needed to significantly accelerate ADS–B equipage before the NPRM compliance date. The ADS–B Out ARC stated it had confidence in the FAA's ability

to deploy the ADS–B ground infrastructure, but expressed concerns with the FAA's ability to provide early operational benefits with the existing NAS surveillance infrastructure. The ADS–B Out ARC provided the FAA 12 recommendations, including the following key recommendations:

- Collaborate with the aviation industry and aggressively develop an appropriate combination of financial incentives and accelerated operational benefits.
- Accelerate and prioritize the identification of operations enabled by ADS–B, with the approval of reduced separation standards for initial operations with a high level of user benefits by 2012.
- Establish certification requirements for aircraft displays for ADS–B In applications by 2010.

After the FAA published its NPRM on ADS–B Out, the ADS–B Out ARC was tasked with making specific recommendations to the FAA concerning the proposed rule based on the comments submitted to the docket. After review and analysis of the comments to the docket, the ADS–B Out ARC made 36 summary recommendations regarding the ADS–B link strategy, program, business case, required equipment, security, and privacy. The ADS–B Out ARC divided its recommendations into two broad categories: recommendations to be resolved before any rule is adopted and recommendations for future action. The following list summarizes the ADS–B Out ARC's key recommendations:

- The ADS–B Out ARC validated the proposed ADS–B dual link strategy, assuming there were no changes to existing collision avoidance and surveillance avionics. However, the FAA had identified the need to reduce congestion on the 1090 MHz frequency used by ADS–B, ground surveillance systems, and collision avoidance systems. This was needed to ensure successful introduction of ADS–B Out while supporting current and envisioned ADS–B In applications for NextGen. Because reducing frequency congestion may require changing existing collision avoidance and surveillance avionics, the ADS–B Out ARC recommended 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 ADS–B Out 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 ADS–B Out ARC recommended 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 ADS–B Out 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 ADS–B Out ARC also recommended the FAA incentivize operators to voluntarily equip early for the 2020 mandate.
- The ADS–B Out ARC identified additional measures that would benefit the low-altitude community, and recommended the FAA take advantage of this opportunity to provide a positive business case for that large segment of the aviation community.

- The ADS–B Out ARC recommended the FAA revise some of the performance-based standards proposed in the NPRM to achieve envisioned operational efficiencies at a lower impact to airspace users.
- The ADS–B Out ARC recommended the FAA, in partnership with industry, define a strategy for ADS–B In by 2012, ensuring compatibility with ADS–B Out avionics. The ADS–B Out ARC also recommended the FAA ensure this program defines how to proceed with ADS–B In beyond the voluntary equipage concept included in the NPRM.

2.3 ADS–B OUT FINAL RULE

On May 28, 2010, the FAA issued the ADS–B Out final rule, 75 Federal Register (FR) 30160, that amended 14 CFR by adding equipage requirements and performance standards for ADS–B Out avionics on aircraft operating in Class A, B, and C airspace as well as certain other specified classes of airspace within the NAS. Operators will have two options for equipage under the ADS–B Out rule: the 1090 MHz extended squitter (1090 ES) broadcast link or the Universal Access Transceiver (UAT) broadcast link. Generally, this equipment will be required when operating in certain classes of airspace. In the final rule, the FAA also only adopted performance requirements necessary for ADS–B Out. It did not adopt higher proposed standards that would enable all of the initial ADS–B In applications. The final rule also specified performance requirements for accuracy and integrity (navigation accuracy category for position (NAC_P), navigation accuracy category for velocity (NAC_V), and navigation integrity category (NIC)) and any operator must meet these requirements to operate in airspace where ADS–B is required. Any ADS–B position source that meets the specified performance standards is acceptable and complies with the requirements in the final rule. In the final rule, the FAA also reconsidered antenna diversity and concluded that a single bottom-mounted antenna is the minimum requirement for ATC surveillance. The FAA did, however, require aircraft to transmit signals at a certain power level to ensure ground stations and ADS–B In-equipped aircraft and vehicles can receive the transmitted signals. In addition, under the final rule, latency cannot exceed 2 seconds, and within that 2 seconds uncompensated latency cannot exceed 0.6 seconds. Table 1 summarizes some of the final rule requirements.

Table 1—Summary of Substantive Final Rule Requirements

Issue Area	Final Rule
Technical Standard Order (TSO)	Requires performance standards as defined in TSO–C166b (1090 ES) or TSO–C154c (universal access transceiver)
Airspace	Requires all aircraft in Class A airspace (flight level 180 and above) to transmit on the 1090 ES broadcast link Requires ADS–B performance standards for operations in Class E airspace at and above 10,000 ft mean sea level, excluding the airspace at and below 2,500 ft above ground level
Navigation Accuracy Category for Position ($NAC_{P)}$	Requires NAC_P<0.05 nmi ($NAC_P \geq 8$)
Navigation Integrity Category (NIC)	Requires changes in NIC be broadcast within 12 seconds
Surveillance Integrity Level (SIL)	Requires a system design assurance of 2 and a SIL of 3
Antenna Diversity	Does not require antenna diversity
Total Latency	Requires uncompensated latency ≤0.6 seconds and maximum total latency ≤2.0 seconds
Message Elements	Does not require a broadcast message element for “receiving air traffic control services”
An ability to turn off ADS–B Out	Does not require the pilot be able to disable or turn off

2.4 ADS–B IN ARC—APPROACH TO CURRENT TASK

As part of its final report, the ADS–B Out ARC recommended 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."[2] Based on this recommendation, the FAA concluded the original ADS–B Out ARC should sunset and a new ADS–B In ARC should be established. The ARC was chartered effective June 30, 2010, for a period of 2 years.

The ARC began its work in July 2010 to discuss its task and approach to providing the FAA its recommendations by the September 30, 2011, due date. See appendix A to this report for a list of ARC members and subject matter experts. To complete its work, the ARC formed four working groups comprised of ARC members and industry and government subject matter experts to address the tasking as follows:

- Working group 1, Planned Operations, was formed to make recommendations on ADS–B applications. This included—
  - Developing an understanding of the applications and their interdependencies, assumptions, feasibility, and industry interest.
  - Prioritizing applications.
  - Air traffic controller and pilot refinement of "delegated separation."
- Working group 2, Equipment and Performance, was formed to assess the equipment and infrastructure dependencies associated with each ADS–B In application. This included—
  - Recommendations on the following AIWP applications:
    - SURF–IA,
    - FIM–S, and
    - Flight-deck-based Interval Management–Delegated Separation (FIM–DS).
  - Regulatory policy implications with regard to avionics and equipage.
  - Availability and continuity implications from the ADS–B Out requirements.
  - Display avionics integration implications.
  - ADS–B Out/In equipage requirements including the near- and mid-term mixed equipage environment implications.
  - Hazard level.
  - Latency.

[2] See ADS–B Out ARC, task 2, recommendation No. 27.

- Working group 3, Cost and Benefits, was formed to provide accurate benefit and cost estimates. This included evaluating the application bundles and revising them as the working group deems appropriate.
- Working group 4, Modeling and Simulation, was formed to provide the ARC with relevant research.

While completing its work, the ARC also formed two short-term ad hoc groups to address operational approvals and wake mitigation activities.

2.4.1 AIWP Review

One of the first ARC tasks was to review the applications (application matrix) to understand the operational importance of each AIWP application and identify potential variables. The matrix also was to include the probable users and locations for each application and the operational benefit of each application.

To develop the application matrix, the ARC visited The MITRE Corporation Center for Advanced Aviation System Development (CAASD) to review three application simulations, some funded by the FAA and others by independent research. The MITRE CAASD-demonstrated applications were specific examples that did not directly depict a specific application in the AIWP but generally depicted Interval Management (IM). The ARC was shown laboratory cockpit simulations of three ADS–B In applications, which are similar to four applications in the AIWP. This demonstration aided the ARC in understanding the operations and benefits of these future ADS–B In applications. The ARC noted the MITRE CAASD data indicated a significant throughput increase with traffic using the applications.

The ARC then developed the application matrix to comprehensively review each application in the AIWP:

- The operational need or shortfall addressed (safety or capacity/efficiency);
- Any system interdependencies;
- Aircraft equipage requirements;
- Assumed aircraft equipage requirements;
- Variables in the application's concept of operations (CONOPS) that affect the business case;
- Potential additional uses of the application/equipage set;
- The air navigation service provider (ANSP) and/or airport business case;
- The application's feasibility (near-, mid-(2013 to 2019), or far-term), maturity, and readiness;
- Any enablers;
- The cost to implement for air carrier and general aviation (GA) aircraft and the ANSP;
- Whether the benefits are high, medium, or low;

- The benefit mechanism;
- The benefits with mixed equipage;
- The impacts of mixed equipage;
- The benefits with full equipage;
- Who benefits;
- Who or what is impacted adversely;
- Where the application would be used (airspace/location);
- The anticipated application hazard level;
- Whether rule-compliant (current RTCA, Inc., Document 260B (RTCA DO–260B) or RTCA DO–282B) avionics are sufficient;
- Whether the application can be enhanced by a change to RTCA DO–260B or RTCA DO–282B; and
- What work has been accomplished on the application and what additional work is necessary.

During development of the application matrix, the ARC noted the AIWP indicates the preliminary hazard category for all applications is Major, except for advanced versions of paired approaches, which may be Hazardous. The ARC indicated a desire to avoid a dual ADS–B In system architecture, which might be needed to support ADS–B In applications classified at a Hazardous level.

The ARC identified some applications that were variations of what the AIWP defined as FIM–S and FIM–DS. The ARC believed applications 6 and 8, as defined in the AIWP, should be broken down to different specific Interval Management–Delegated Separation (IM–DI) applications because they had differing equipage requirements, varying implementation timeframes, and varying benefits (see further discussion of these applications in section 3.3).

2.4.2 NASA Langley Trip

As a follow-on to the MITRE visit, the ARC also visited the National Aeronautics and Space Administration's (NASA) Langley Research Center in Hampton, Virginia, to identify prominent technology research centers relevant to flightdeck technologies. Between regular ARC meetings, NASA personnel provided state-of-the-art technology briefings, demonstrations, and hands-on tours of the Langley Research Center's Air Traffic Operations Lab and the Integration Flight Deck and Research Flight Deck simulator cabs. Opportunities for future collaboration were identified for several of the Langley Research Center staff.

2.4.3 Technology Roadmap

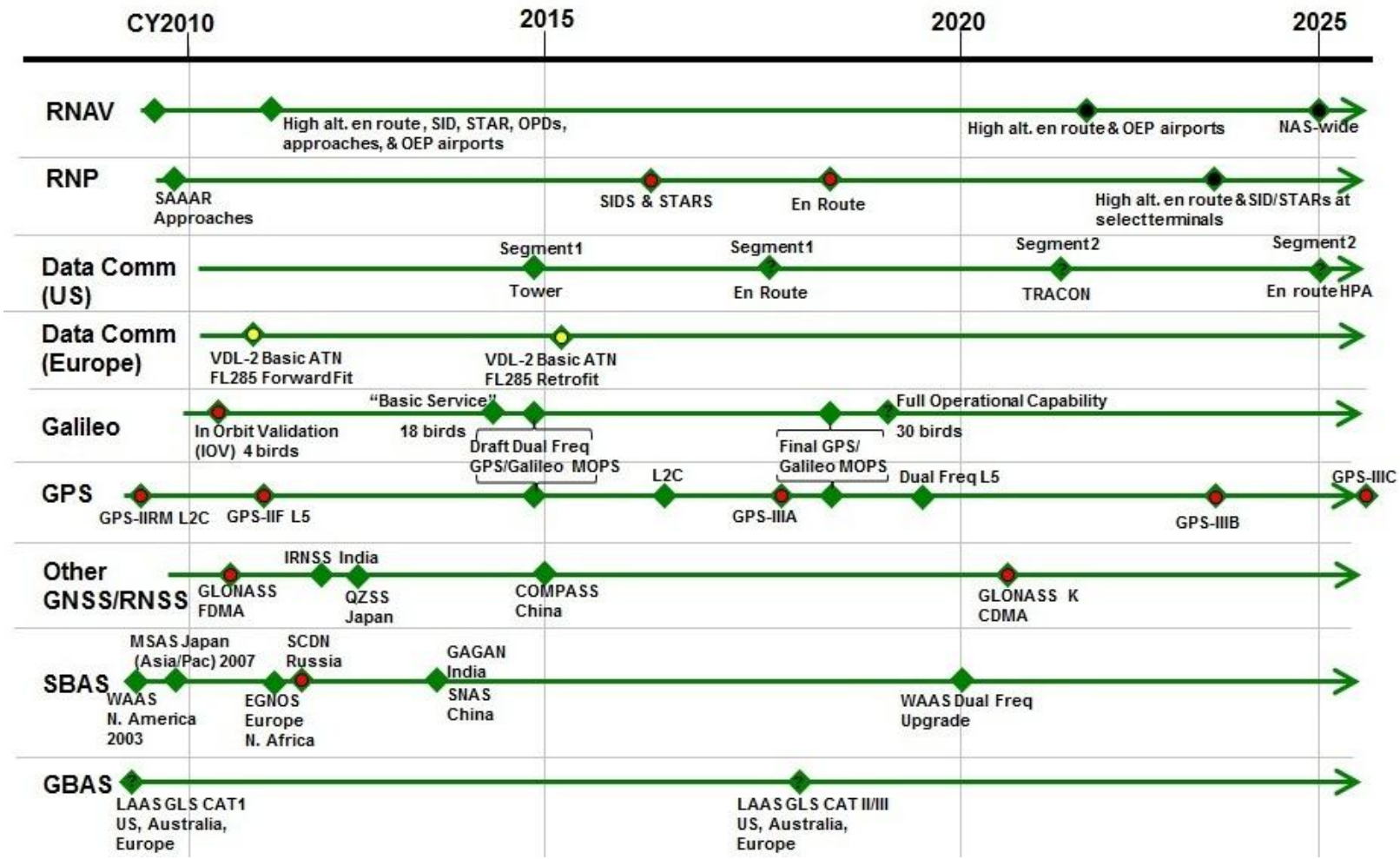
While the ARC is focused on ADS–B, each communications, navigation, and surveillance (CNS)/ATM technology must be viewed as a mandatory subsystem of NextGen, otherwise it may not be optimized for its role in NextGen. There is currently no unified roadmap addressing all three CNS technologies, resulting in a number of questions among the operators regarding:

(1) the existence of interdependences among the various technologies; (2) whether the technologies need to be installed simultaneously; (3) potential financial benefit to the operator from installing them together; and (4) whether the operational benefits increase if multiple technologies are leveraged together. The ARC understands the answers to these questions are difficult and integration is not easy, but they must be addressed.

Recommendation 1: The ARC recommends the FAA develop an integrated CNS roadmap to help industry better understand future capabilities, benefits, and investments. The ARC recommends the roadmap include—

- A phased transition path to what will be available in 15 to 20 years;
- The avionics integration required onboard the aircraft for the different systems, especially those in common between the technologies;
- Known plans for mandating avionics equipment;
- Bundled avionics upgrades with a goal that aircraft operators only have to upgrade every 5 to 7 years for aircraft avionics supporting all CNS/ATM functionality;
- Upgrades integrated among the NextGen programs, not done individually, and reflecting evolving international requirements for U.S. operators; and
- Appropriate benefit-cost justification for each phase.

In support of an integrated approach to enabling NextGen, the ARC offers the FAA the following graphical representation of technology, program, and global interoperability perspectives in figure 4 below. While the ARC finds this representation necessarily identifies some timing uncertainty, it included the notional elements for completeness.


CY2010
2015
2020
2025
RNAV
High alt. en route, SID, STAR, OPDs, approaches, & OEP airports
High alt. en route & OEP airports
NAS-wide
RNP
SAAAR Approaches
SIDS & STARS
En Route
High alt. en route & SID/STARs at select terminals
Data Comm (US)
Segment 1
Tower
Segment 1
En Route
Segment 2
TRACON
Segment 2
En route HPA
Data Comm (Europe)
VDL-2 Basic ATN FL285 Forward Fit
VDL-2 Basic ATN FL285 Retrofit
Galileo
"Basic Service"
In Orbit Validation (IOV) 4 birds
18 birds
Draft Dual Freq GPS/Galileo MOPS
Final GPS/ Galileo MOPS
Full Operational Capability
30 birds
GPS
GPS-IIRM L2C
GPS-IIF L5
L2C
GPS-IIIA
Dual Freq L5
GPS-IIIB
GPS-IIIC
Other GNSS/RNSS
GLONASS FDMA
IRNSS India
QZSS Japan
COMPASS China
GLONASS K CDMA
SBAS
MSAS Japan (Asia/Pac) 2007
WAAS N. America 2003
SCDN Russia
EGNOS Europe N. Africa
GAGAN India
SNAS China
WAAS Dual Freq Upgrade
GBAS
LAAS GLS CAT1 US, Australia, Europe
LAAS GLS CAT II/III US, Australia, Europe

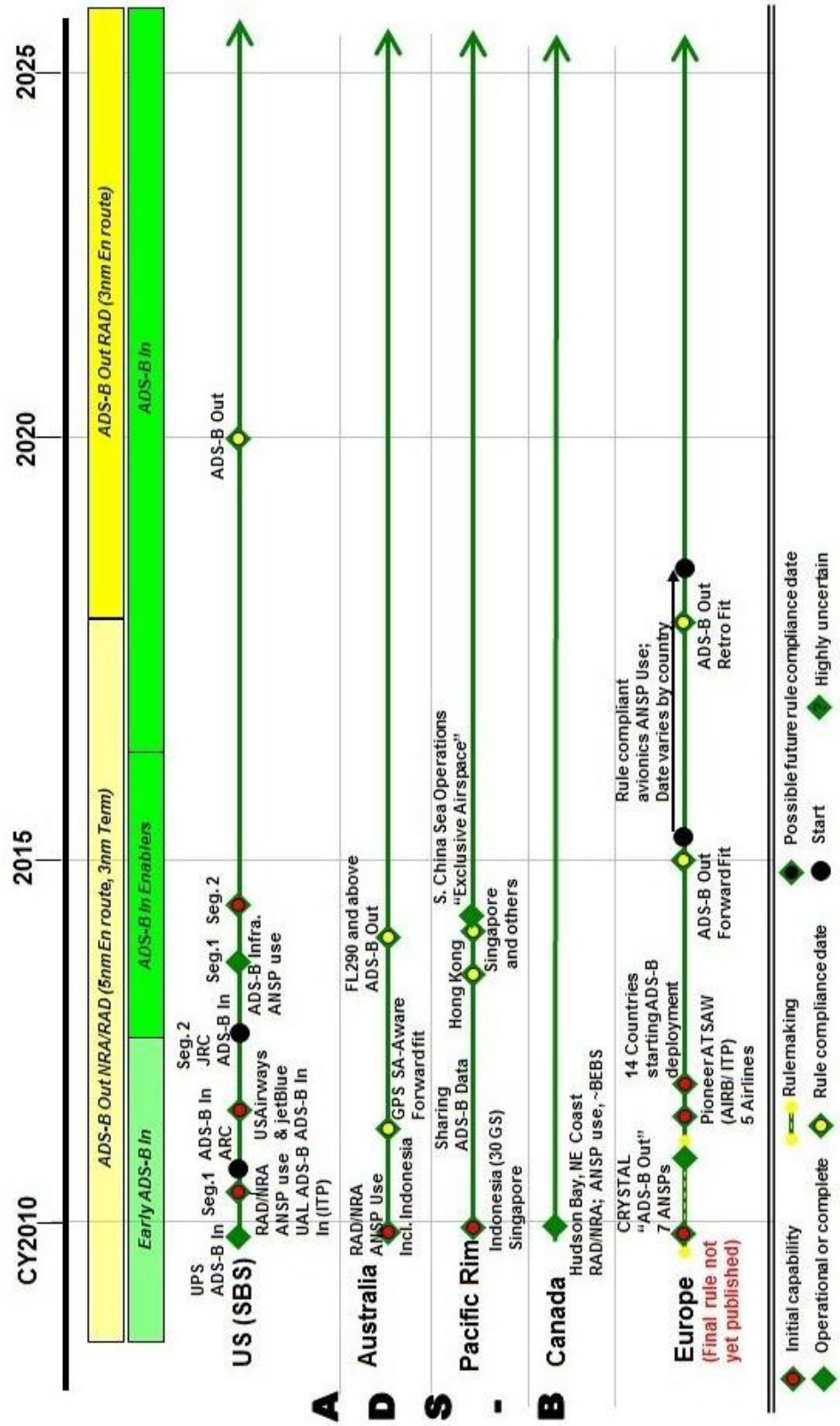


Figure 4—Technology Roadmap

The ARC finds the following conclusions can be drawn from figure 4:

- The use of ADS–B Out is spreading among ANSPs worldwide. Between now and 2015, ADS–B Out will be in widespread use in Australia, the Pacific Rim, and Canada. Shortly thereafter, it will be used over the United States, Europe, and the oceans. Most of these areas will require ADS–B Out equipage through formal rulemaking and mandates. This proliferation of ADS–B use indicates the technology is mature and widespread equipage will become a reality.
- ADS–B Out is a prerequisite for ADS–B In, but while ADS–B Out moves forward, very few firm plans are in place for ADS–B In applications, even though they will likely offer significant benefits to operators and ANSPs. ADS–B In concepts will first require maturation, then prioritization and investment. This investment must include the development of procedures and other air and ground infrastructural elements to enable the future airspace and to ensure benefits.

3.0 STRATEGY RECOMMENDATIONS

The ARC identified three primary strategic recommendations on how the FAA should integrate ADS–B into the NAS. These recommendations related to (1) whether the use of ADS–B In should be mandated, (2) an evolution from delegated separation (DS) to a new concept of defined interval (DI), and (3) a prioritized list of applications to guide the FAA's work through the end of the decade.

Additionally, the ARC conducted a benefit-cost analysis and provides the FAA with specific recommendations about the business case. The ARC also provides the FAA with specific recommendations on operational approvals and ADS–B positioning sources.

3.1 NO EQUIPAGE MANDATE

The ARC supports ADS–B as the primary mechanism to provide future surveillance for ATC in the NAS. However, based on the current maturity of ADS–B In applications and uncertainties regarding the achievable benefits, the ARC finds there is not a NAS user community business case for near-term ADS–B In equipage. At this time, the ARC does not support an equipage mandate because of the benefit uncertainty (see section 3.4 on the business case). In addition, FAA policy, equipment standards, certification guidance, operational approval guidance, procedures, and ground automation are not fully defined for high-benefit ADS–B In applications[3] and capabilities, which the ARC considers a prerequisite for any ADS–B In equipage investment. Many of the ADS–B In applications show significant promise, but additional development and analysis are necessary before aircraft operators can justify investment or implementation decisions.

The ARC finds much of the research and development underway by both government and industry shows great promise and should continue at an aggressive pace. The ARC finds ongoing FAA and industry demonstration projects provide real-world validation of benefits for ADS–B In application.

Recommendation 2a: The ARC recommends no ADS–B In equipage mandate at this time.

Recommendation 2b: The ARC recommends the FAA incentivize voluntary equipage as its ADS–B In strategy for the foreseeable future.

Recommendation 2c: The ARC recommends the FAA continue ADS–B In demonstration projects and, where possible, accelerate existing and future demonstration projects. The ARC finds these activities will enable government and industry to better understand the benefit mechanisms and costs of implementation. This, in turn, could provide the catalyst to redirect or focus available resources as the most promising technologies and capabilities emerge.

[3] Cockpit Display of Traffic Information (CDTI)-Assisted Visual Separation (CAVS), FIM–S, TSAA, CDTI-Enabled Delegated Separation (CEDS), wake vortex parameters, Flight-deck-based Interval Management–Defined Interval (FIM–DI), Oceanic IM, CSPO, and SURF–IA.

3.2 DEFINED INTERVAL VERSUS DELEGATED SEPARATION

Delegated separation ADS–B applications had their genesis in FAA/European Organization for the Safety of Air Navigation's (EUROCONTROL) Principles of Operations for the Use of Airborne Separation Assurance Systems (PO–ASAS), dated June 19, 2001. In these applications, the air traffic controller delegates separation responsibility and transfers the corresponding tasks to the flightcrew, which ensures that the applicable separation minimums are met. The PO–ASAS application hierarchy, in which DS applications form the third tier (after Airborne Traffic Situational Awareness and Airborne Spacing and before Airborne Self-Separation), has been followed in the development and standardization of initial ADS–B In applications.

FIM–S was developed to use ADS–B for a more effective means of aircraft-to-aircraft in-trail spacing. Based on an air traffic controller's clearance, the IM aircraft uses ADS–B In information via the IM application to maintain the desired spacing in trail of a lead aircraft while the air traffic controller maintains responsibility for separation from all traffic using current ATC separation standards for the aircraft type and airspace being used. The DS concept implied a change in the roles and responsibilities of the pilot and air traffic controller for separation of aircraft conducting FIM–DS. Working group 1 deemed it unacceptable for pilots to accept sole responsibility for separation of aircraft as defined in the FIM–DS CONOPS. However, working group 1 found a DI management task delegates a spacing task to the pilot, and the pilot must perform within defined boundaries while the air traffic controller maintains the responsibility for separation. This will enable a range of applications where a closer interval spacing may be possible than that currently allowed by traditional separation standards including spacing stream variations based on human and environmental factors. See the illustration in appendix D, Defined Interval Operations Concept, to this report. Also see appendix E, Time-based Versus Distance-based Intervals During Assigned Interval Operations, to this report.

Under a DI management task, air traffic controllers maintain separation responsibility while assigning pilots a DI task. This reduces air traffic controller workload and enables the air traffic controller to undertake other tasking while increasing airspace capacity. The ARC finds that air traffic controllers and pilots are willing to accept the DI concept because it maintains traditional pilot and air traffic controller roles, and holds pilots accountable for compliance with a DI clearance and air traffic controllers accountable for separation.

The ARC finds DI management would—

- Increase throughput (visual meteorological conditions (VMC) throughput in IMC) and recapture some of the lost throughput because of IMC. System design criteria, performance requirements, and minimum operational performance standards (MOPS) for the avionics and related systems must be appropriate for this level of operation in the reliability, availability, and integrity areas. The requirements are significantly more stringent for this type of operation (and more costly to develop and implement) than for the enhanced situational awareness types of applications (for example, traffic situation

awareness, traffic situation awareness for visual approach, and airport traffic situation awareness).[4]

- Increase capacity, resulting in more efficiency in en route and oceanic domains (see appendix F, Oceanic Interval Management, to this report).
- Increase throughput by managing the wake hazard based on actual risk at the time of the operation.
- Improve efficiencies particularly in the terminal airspace by reducing the effects of compression in varying environmental conditions.

The ARC also finds DI management would—

- Reduce ATC complexities and provide optimized throughput by modifying air traffic controller tactical workloads using the delegation of DIs to the flightdeck.
- Reduce frequency congestion.
- Increase arrival rate to runway occupancy limits.
- Provide repeatable and predictable arrival rates.

The ARC notes DI tasking will require tighter parameters than those currently in use by air traffic controllers and require the use of a CDTI with indications and alerts on the flightdeck to allow the pilot to safely monitor the task. In addition, the air traffic controller will need ground-based tools for indications and alerting to the status of the FIM–DI operation.

The ARC finds the FAA should prioritize the implementation of DI management as follows:

1. In VMC,
2. In an oceanic environment,
3. For arrivals bounded by current separation standards, and
4. For arrivals bounded by a new risk-based inter-arrival spacing criteria.

Recommendation 3a: The ARC recommends the FAA classify the majority of ADS–B In applications previously classified as DS using the alternative concept of DI. The CAVS and CEDS applications will continue to be classified DS.

Recommendation 3b: The ARC recommends the FAA work with the appropriate regional and international standards bodies to harmonize the use of DI.

[4] Retrofitting avionics only designed to "situational awareness" criteria to the level necessary for this type of operation may be very difficult.

Recommendation 4a: The ARC recommends the FAA allow for the use of a distance metric for IM applications as decision support tools are developed for transition to time-based separation intervals because air traffic controllers are familiar with working from distance-based intervals.

Recommendation 4b: The ARC recommends the FAA work with the appropriate regional and international standards bodies to harmonize uses of distance-based and time-based intervals.

Recommendation 5a: Building on today's current separation standards while maintaining the traditional roles and responsibilities of the pilot and air traffic controller, the ARC recommends the FAA develop and transition to a risk-based DI criteria.

Recommendation 5b: The ARC recommends the FAA use the following phased approach to roll out and transition to a full-fledged DI operation within the NAS. However, the ARC finds oceanic DI management would not require a phased implementation because of its unique operational environment of procedurally separated airspace.

1a. Apply DI in VMC with IFR separation, as defined by current separation standards[5] (applied to applications 6a, 6b, 6c, and 6d, as defined in section 3.3 of this report).

1b. Apply DI in IMC with IFR separation, as defined by current separation standards (applied to applications 6a, 6b, 6c, 6d, FIM–S, and FIM–DI, as defined in section 3.3 of this report).

2a. Apply DI in VMC with DI separation standards, as defined by current separation standards (applied to applications 8c, 8d, 8g, 8h, and FIM–DI for CSPO, as defined in section 3.3 of this report).

2b. Apply DI where DI standards are used to runway occupancy limits (applied to applications FIM–S, FIM–DI, and FIM–DI for CSPO, as defined in section 3.3 of this report).

3. Include continued evolution of concepts wherein traditional legacy ATC separation standards evolve into a multidimensional safety-based analysis of operational relationships. See appendix H, Defined Interval, to this report.

[5] See appendix G, Planned Final Approach Speed During Defined Interval Operations, to this report.

Recommendation 5c: The ARC recommends the FAA develop a standardized national policy for approval of DI applications administered through the operators certificate management offices.

Recommendation 5d: The ARC recommends the FAA develop DI separation standards and third-party identification using risk-based analysis.[6] See appendix I, Phraseology and Third Party ID, to this report. The ARC finds this will allow for evaluating acceptable proximity standards with the adoption of new technology such as ADS–B, CDTI, and/or improved air traffic controller and pilot decision support tools.

[6] This should include the dynamic and four-dimensional minimum and maximum boundaries to be based on risk from collision and wake vortex encounters based on proximity management.

3.3 PRIORITIZED APPLICATIONS

The ARC notes operational demonstrations of SURF–IA (US Airways), ITP (United Air Lines, Inc.), and FIM–S and CAVS (United Parcel Service of America, Inc.; US Airways; and JetBlue Airways) are in various stages of maturity and will result in more mature policy guidance and equipment standards. These demonstrations are supported by several avionics manufacturers, airframe original equipment manufacturers, and the FAA. Additionally, the ARC finds the required equipment standards, certification guidance, and operational approval guidance are not sufficiently mature to enable widespread manufacture of avionics and implementation of ADS–B In applications other than those directed toward situational awareness and discussed in RTCA DO–317, technical standard order (TSO) C–195, and Advisory Circular (AC) 20–172.

Recommendation 6: The ARC recommends the FAA use these demonstration projects to mature the equipment standards, aircraft certification guidance, and operational approvals necessary for NAS-wide ADS–B In implementation.

Recommendation 7: The ARC recommends the FAA aggressively focus on developing Safety and Performance Requirements (SPR) MOPS for ADS–B In applications using CDTI to fully unlock the technical and system-wide potential of ADS–B In and to aid in reducing business case risk.

The ARC assigned priorities to the most promising ADS–B In applications by order of maturity, operational impact, and safety improvements (see table 2).

Recommendation 8: The ARC recommends the FAA focus funding on accelerating the development of equipment standards, certification guidance, operational approval guidance, ground automation for the applications, and any necessary policy adjustments to enable operational implementation of the 10 applications listed below (and in table 2 of the report) in priority order (with targeted completion date[7]):

1. CDTI-Assisted Visual Separation (CAVS) (FY 2012 using ADS–B Out legacy equipage targets and FY 2013 additionally using TIS–B targets);

2. Flight-deck-based Interval Management–Spacing (FIM–S) (DI based on current separation standards, to include merging of different traffic streams while increasing arrival throughput) (FY 2015);

3. Traffic Situation Awareness with Alerts (TSAA) (FY 2013);

4. Oceanic In-Trail Procedures (ITP) (FY 2013);

5. CDTI-Enabled Delegated Separation (CEDS) (ending in a visual approach) (FY 2016);

6. Ground-based Interval Management–Spacing (GIM–S) with Wake Mitigation (Establish provisioning by calendar year (CY) 2013, ADS–B Out Link MOPS by CY 2015, ADS–B In platform MOPS by CY 2015, GIM–S with Wake Mitigation at core airports by the end of CY 2018);

7. Flight-deck-based Interval Management–Defined Interval (FIM–DI) (Operational trial by FY 2017 with a push to be operational 2 years following completion of the trial);

8. FIM–DI for Closely Spaced Parallel Runway Operations (CSPO) (FY 2017);

9. Oceanic Interval Management (IM) (FY 2015); and

10. Airport Traffic Situation Awareness with Indications and Alerts (SURF–IA) at airports with surface multilateration system (FY 2017).

[7] The targeted completion date means the completion of equipment standards and certification guidance, operational approval guidance, and any other items necessary for operational implementation in the NAS by the end of the FY identified. The date does not include time required for design, development, integration, testing, and certification of new capabilities on "in-production" aircraft with subsequent availability of service bulletins for retrofit. Other original equipment manufacturer business factors may drive the availability of equipment on in-production and retrofit aircraft that meet these standards.

With respect to some of the less mature applications[8] the targeted completion dates assume an aggressive funding approach by the FAA with respect to flight trials, operational evaluations, and safety. With regard to the schedule, the ARC has taken into account the maturity level but believes the FAA can meet the targeted completion dates with the right level of funding.

[8] CEDS, GIM–S with Wake Mitigation, FIM–DI, FIM–DI for CSPO, and SURF–IA.

Table 2—Prioritized ADS–B In Applications

Priority Rank	Application	Targeted Completion Date (FY unless otherwise noted)	Justification	Is the application in the FAA's funded baseline[9]
1	Cockpit Display of Traffic Information (CDTI)-Assisted Visual Separation (CAVS)[10]	2012 using ADS–B Out legacy equipage targets and 2013 additionally using Traffic Information Service–Broadcast (TIS–B) targets	The ARC finds CAVS can produce near-term ADS-B In benefits, can be conducted in conjunction with existing visual arrival and departure clearances, and will not require any additional infrastructure or modification to air traffic control procedures. The FAA has indicated to the ARC that the ARC-desired dates for CAVS can be supported from a regulatory perspective.	No. However, the FAA has indicated to the ARC that CAVS can be implemented with current FAA resources.
2	Flight-deck-based Interval Management–Spacing (FIM–S)[11] (defined interval based on current separation standards, to include merging of different traffic streams while increasing arrival throughput)	2015	The ARC concurs with the FAA's current program plans for this application, which reflect a date of 2015 for National Airspace System-enabled GIM–S/FIM–S.	Yes
3	Traffic Situation Awareness with Alerts (TSAA)	2013	The ARC notes the date is aligned with current FAA schedules.	Yes
4	Oceanic In-Trail Procedures (ITP)	2013	The ARC notes the date is aligned with current FAA schedules.	Yes

[9] See figure 12 below.
[10] See appendix J, CEDS Concept of Operations, to this report.
[11] This application was reviewed with respect to sub-applications in the benefit-cost analysis in section 3.4.1 of this report, and includes the following sub-applications:

- 6a Interval Management–Spacing (IM–S) Metering; or Merge into En Route Flow,
- 6b IM–S during Arrival and Approach–Standard or Optimized Profile Descent (OPD) Arrivals,
- 6c IM–S during Departure Operations, and
- 6d IM–S Dependent Runway Operations (Parallel or Crossing Runways)

Priority Rank	Application	Targeted Completion Date (FY unless otherwise noted)	Justification	Is the application in the FAA's funded baseline[9]
5	CDTI-Enabled Delegated Separation (CEDS) (ending in a visual approach)[12]	2016	The ARC finds the application needs additional work, including a better understanding of the roles for both pilots and air traffic controllers and a change to separation standards.	No
6	Ground-based Interval Management–Spacing (GIM–S) with Wake Mitigation[13]	Establish provisioning by CY 2013 ADS–B Out Link minimum operational performance standards (MOPS) by CY 2015 ADS–B In platform MOPS by CY 2015 GIM–S with wake mitigation at core airports by the end of CY 2018	The ARC developed a notional schedule for the work and key milestones to be achieved to develop this application.	No
7	Flight-deck-based Interval Management–Defined Interval[14] (FIM–DI)[15]	Operational trial by 2017 with a push to be operational 2 years following trial completion.	This requires a new dynamic separation standard and is a fundamental change to operations.	No

[12] See appendix J to this report.
[13] See section 4.4.4, Case Study on Wake Mitigation.
[14] This application was reviewed with respect to sub-applications in the benefit-cost analysis in section 3.4.1 of this report, and includes the following sub-applications:

- 8a IM–DS (now DI) Metering, or Merge into En Route Flow;
- 8b IM–DS (now DI) during Arrival and Approach–Standard or OPD Arrivals;
- 8c IM–DS (now DI) during Departure Operations;
- 8d IM–DS (now DI) Dependent Runway Operations (Parallel or Crossing Runways);
- 8e IM–DS (now DI) Oceanic
- 8f VMC CDTI Enabled Delegated Separation (CEDS) for single runway arrivals (which is now called CAVS);
- 8g IMC CEDS for single runway arrivals;
- 8h CEDS for departures; and
- 8i CEDS for arrivals to closely spaced parallel runways.

[15] FIM–S based on new separation criteria developed through a detailed risk analysis of ADS–B In applications that improve arrival and departure throughput for airports.

Priority Rank	Application	Targeted Completion Date (FY unless otherwise noted)	Justification	Is the application in the FAA's funded baseline[9]
8	FIM–DI for Closely Spaced Parallel Runway Operations (CSPO)[16]	2017	The ARC finds this is the easiest variation of the paired approach Application Integrated Work Plan application 10 and should be implemented in the second phase of FIM–DI applications.	No
9	Oceanic Interval Management (IM)	2015	The ARC finds additional international coordination beyond ITP is required to deploy this application.[17]	No
10	Airport Traffic Situation Awareness with Indications and Alerts (SURF–IA) at airports with surface multilateration system[18]	2017	The ARC concurs with the FAA's current program plans for this application, which reflect a date of 2017.	No

[16] FIM–DI for CSPO is an evolution of AIWP application 10.
[17] See appendix F to this report.
[18] The FAA introduced the opportunity of using TIS-B targets for the deployment of some ADS–B In applications in the near-term (see 75 FR 30173). However, while the SURF-IA integrity requirements (NIC, SIL, and SDA) are met by rule compliant ADS–B Out avionics, TIS-B does not currently broadcast a non-zero NIC. Specifically, SURF, per the new standard, needs NACv≥2, but mitigations exist that permit a reported NACv of 1 for qualifying targets. "The Operational Performance Assessment (OPA) concludes that a Source Integrity Level (SIL) of 1xE-04 to 1xE-05 is required per hour. Navigation Integrity Category (NIC) bounds are not required but proposed as means to assure the appropriate integrity level. Surveillance and integrity requirements are the same at all airports." In addition, TIS-B does not provide flight ID and the target volume around the ownship is limited. The FAA is currently investigating the requirements and costs to provide NIC as part of the TIS-B message to facilitate the early deployment of SURF-IA.

Recommendation 9: The ARC recommends the FAA delay work on the following applications list in AIWP version 2 until the applications listed in recommendation No. 8 are fully mature. The ARC finds these applications' use in the NAS is less defined and would require significantly more resources.

- Self-separation,
- Flow corridors,
- DS crossing and passing,
- Independent closely spaced routes, and
- Independent closely spaced parallel approaches.

Recommendation 10: The ARC recommends its continued efforts to further define FIM–DI for CSPO.

With regard to the FAA identifying ADS–B integrated collision avoidance as an AIWP application, the ARC notes the future of the Airborne Collision Avoidance System (ACAS) is important work and warrants priority in the FAA's planning. The ARC is providing additional general recommendations about the development of ACAS later in this paper, but defers to separate activities about ACAS in forums such as RTCA SC–147.

Recommendation 11: The ARC recommends the FAA develop policy, equipment standards, certification guidance, operational approvals, procedures, and ground automation to allow maximum use of retrofit hardware and software. The ARC finds full implementation of ADS–B In applications may be significantly delayed if there is not a viable retrofit solution.

Recommendation 12: In January 2011, the FAA provided a briefing to the ARC regarding program development and funding to support ADS–B In applications. Based on the information from that briefing as supplemented by the work of the ARC, the ARC recommends the FAA—

- Continue funding and development of GIM–S to initial operational capability. The ARC finds the GIM–S tool is required in the ATC automation for successful FIM–S and FIM–DI implementation.
- Amend the AIWP to be consistent with table 2 above.

3.4 BUSINESS CASE

Working group 3, consisting of representatives from air carriers, GA, manufacturers, and the FAA, met frequently during the duration of the ARC to evaluate the operational and economic prospects for ADS–B In implementation. Using the Boeing Decision Analysis Tool, the working group identified a set and sequence of application bundles and created a benefit-cost analysis for air transport and GA user groups. See appendix K, Benefit-Cost Analysis, to this report for a full discussion of the analysis.

3.4.1 Air Transport Business Case

The ARC's benefit-cost analysis is predicated on and highly sensitive to a limited set of criteria and assumptions. In particular, the air transport business case analysis represents a national overview and includes estimates of all air carriers' operations combined into one model. The business case should not be used as a proxy for individual operators because each air carrier's business case may vary considerably based on its network, fleet profile, and current/future business model.

The analysis was structured from the perspective of a NAS user and only considered benefits and costs that could accrue directly to operators. Accordingly, the ARC did not consider public benefits as they are not part of an operator's financial assessment for equipage decisions. For example, the ARC omitted any benefits related to passenger value of time and any consideration of the external costs related to potential reductions in greenhouse gas emissions.[19] Moreover, the ARC did not account for any financial impact to the FAA, both as regulator and ANSP.

The ARC assumed no execution risk and also assumed ADS–B In applications will be fully fielded across the NAS. The ARC viewed delay reductions and their cost implications as a proxy for monetizing enhanced capacity, and assumed the fuel price was $3 per gallon. The real discount rate was set at 15 percent, reflecting the higher cost of capital and risks borne by commercial air carriers, and air carriers were assumed to require a 3-year payback period. Regional air carriers were not fully considered in the analysis.

Operational dates for the various ADS–B In applications are notional and subject to change, all of which can materially impact the timing of benefits and subsequent benefit-cost analyses. One critical decision point that drove materially different results was whether to assume benefits growth was either linear[20] with the rate of equipage or a square[21] of equipage.

Based on the limited criteria and assumptions, the ARC's benefit-cost analysis offered a positive return on investment (net present value greater than zero), but the end results did not meet the industry's payback criteria. In the best case scenario where the ARC assumed benefits were

[19] ADS–B In applications offer the potential for NAS operators to improve their fuel efficiency and reduce greenhouse gas emissions; this has been monetized in the benefit-cost analysis in the form of fuel savings. Social benefits such as reduced pollution and health improvements have not been considered in the ARC analysis.
[20] Linear, in the context of benefits and equipage, means benefits are accrued proportionally to the percentage of the fleet that is ADS–B In-equipped.
[21] Square, in this context, means benefits are accrued at a square of the ADS–B In equipage (so if 50 percent of the fleet is equipped, 25 percent of the total possible benefits are achieved.)

linear in relationship to equipage, the air carrier industry business case only closes after 18 years (2028) with a net present value of $481 million. Assuming benefits are square, the net present value declines to $36 million and the business case closes after 20 years, in 2030. The ARC found payback criteria can be met for forward fit in year 2025 or later, when benefits are linear with equipage, but not for retrofit.

For some air carriers, incentives will be required to close any business case for ADS–B In equipage. Given the observed payback periods and potential operational risks involved with any ADS–B In program, incentives are critical to reducing the return on investment period by compressing the gap between cost outlays and accrued benefits. Incentives tools for consideration are either operational (for example, best-equipped, best-served) and/or financial (for example, NextGen equipage fund) in nature, and are politically and operationally challenging to implement. However, without incentives, the average air carrier seeking a 3-year payback period will not equip until 2025 and beyond. Even then, air carriers will need convincing evidence (through trials) that the benefits will be achieved as projected.

Recommendation 13: The ARC recommends the FAA research efforts to identify and validate a range of financial and operational incentive options that can be targeted toward airspace users and mitigate risks.

At this point, the benefit-cost analysis does not offer a convincing case for ADS–B In equipage, whether achieved voluntarily or through mandates. Additional research, trials, and assessments are needed to validate key cost inputs and benefit-cost assumptions and to improve the credibility of the current and any subsequent analyses. As it stands today, there is too much uncertainty surrounding these critical areas to garner widespread air carrier support for ADS–B In equipage. The FAA currently relies on outdated cost inputs that are inflated to current year values from 2002/2003 levels for use in its rulemaking activity.[22] These values appear to understate costs as compared to current information and subsequently understate potential ADS–B In benefits to operators. From an operator perspective, one means of improving credibility and confidence is to structure additional trials and future analyses at the local level where ADS–B In will be implemented incrementally over time; all current work has been identified at the national level. Future work should focus on improving equipage cost estimates as operators are hesitant to make any equipage decisions when ADS–B In production is lacking and when specification and certification standards remain in flux. The ARC performed little to no analysis of regional air carriers even though they operate a material portion of total flights at major hub airports throughout the country because the ARC was unable to obtain sufficient information to do the required analysis.

[22] See two FAA documents: *Economic Values for FAA Investment and Regulatory Decisions, A Guide*, October 3, 2007, and *Economic Information for Analysis*, March 16, 2011.

Recommendation 14a: The ARC recommends the FAA focus on improving benefit-cost analyses by developing better inputs and local-level analyses to help improve credibility within the operator community.

Recommendation 14b: The ARC recommends the FAA support further field trials to validate key assumptions and identified benefits. In particular, the FAA should pay special attention to the relationship between ADS–B In benefits and equipage rates.

Recommendation 14c: The ARC recommends future FAA activities take a close look at ADS–B In and how it will intersect with regional carrier operations.

Recommendation 14d: If benefits are not linear with ADS–B In equipage (there will be a mix of equipped and non-equipped aircraft), the ARC recommends the FAA explore air traffic controller tools and procedures to overcoming mixed equipage barriers to obtain full benefits for the application. The industry business case indicates a substantial positive change in present value when moving from square to linear benefits.

Recommendation 14e: The ARC recommends the FAA accelerate the development of avionics specification and certification standards as operators begin to overhaul their aircraft fleets and seek to reduce any uncertainty in their fleet decisionmaking process.

Recommendation 14f: The ARC recommends the FAA undertake significant efforts to develop international standards after the benefits are also established as achievable and operationally implementable.

Recommendation 14g: At this time, the ARC does not support an equipage mandate because of the benefit uncertainty. Accordingly, the ARC recommends the FAA clearly demonstrate that equipage benefits are indeed both achievable and operationally implementable in a cost-effective manner, including operations in a mixed equipage environment. A follow-on ARC activity might then conclude that an ADS–B In mandate could become a viable alternative.

3.4.2 General Aviation Business Case

The mid to low-end GA aircraft owner faces a marginal business case based on current equipage costs. Based on the benefits of FIS–B and Situational Awareness applications, the payback period is 6 to 12 years for ADS–B In equipage. It will cost aircraft operators an estimated $6,000 to $12,000 per aircraft for a panel mount display, including installation costs, to implement ADS–B In (this does not include ADS–B Out); the business case would be marginal because hull values of many existing GA aircraft may not justify this additional investment.

A more affordable solution would use a portable display that has been qualified as a Class 1 electronic flight bag, such as a tablet computer, and an uncertified ADS–B receiver to provide the desired functionality. Based on current industry offerings, this solution can be implemented

for under $2,000 nonrecurring and provide FIS–B functionality, but likely only will support AIWP application 1, Basic Situational Awareness. It does enhance pilot situational awareness for weather and traffic.

Since the ADS–B traffic is broadcast using absolute Global Positioning System (GPS) coordinates, it is important that the display has a reliable ownship position. Therefore the aircraft GPS position source should be used even with an uncertified receiver/display combination to avoid the potential for misleading traffic information. This should also make it possible for the receiver to safely eliminate ownship ghosts from the traffic display.

Over 74,000 GA aircraft can enable situational awareness applications because they already have non-TSO–C195 traffic or multifunction displays and can display traffic through a software change and some other minor work. For these aircraft, it is estimated it will cost $2,000 to $4,000 per aircraft to make the required changes. The business case for this segment of the GA community is reasonable or can be considered to be positive. The ARC provides a review of and two recommendations about the use of non-TSO–C195 displays in section 4.1, which will provide significant savings to the GA community with respect to enabling ADS–B In.

With a slight change in FAA policy during the transition period leading up to the ADS–B Out rule mandate of January 1, 2020, there could be incentives to the GA community highlighting the benefit of ADS–B technology by allowing continuous uplink of TIS–B and ADS–R information on the UAT link. Allowing the GA community to take advantage of the situational awareness benefits of traffic and weather to the cockpit without having to transmit will showcase the significant benefits of ADS–B technology. It will also encourage GA operators to make the investment needed to ultimately equip with rule-compliant ADS–B Out and displays to continue to take advantage of the ADS–B In capabilities post January 1, 2020.

The GA community recognizes the overarching FAA goal of having everyone operating in the airspace encompassed in the ADS–B Out rule mandate to participate in the system effective January 1, 2020. However, the GA community could greatly benefit from and be incentivized to equip with ADS–B Out through early situational awareness benefits recognized by TIS–B, ADS–R, and FIS–B information during the transition period through January 1, 2020. Statistics obtained from AOPA member surveys indicate that GA pilots invest in technologies that save lives, and make flying easier and more enjoyable. The rapid and nearly universal equipage with GPS navigation is an excellent example the ARC finds should be a model for other safety technologies and services, including ADS–B.

Providing continuous uplink of the TIS–B and ADS–R over UAT would allow users to take advantage of relatively low cost options for receiving critical traffic and weather information, thus building a level of trust in the technology. In addition, there are safety benefits from having increased situational awareness tools at a significantly lower cost (for example, uncertified receive-only devices) during the transition period until the mandate becomes effective. Many of the available low-cost options would allow users to display this situational awareness data on portable tablet devices with minimal investment. Operators who are making this minimal investment today recognize the enhanced safety benefit of the ADS–B In data but are only receiving a portion of the benefits that could be offered if TIS–B and ADS–R services are available continuously. These operators who equip with receive-only UATs and display the data

on portable devices benefit from delaying the larger investment of ADS–B Out until there are lower cost certified ADS–B Out avionics on the market. In the meantime, they are building trust in the technology and are receiving benefits ADS–B In data offers to GA.

Currently, the FAA's TIS–B and ADS–R services are only available to aircraft transmitting ADS–B Out information. The result is that pilots not equipped with ADS–B transceivers are restricted from accessing essential traffic proximity information that would otherwise be available if the ADS–B service broadcast all available TIS–B and ADS–R traffic continuously. Experience with ADS–B and TIS–B for nearly a decade confirms that continuously broadcasted TIS–B is beneficial and valuable (for example, Anchorage terminal airspace) to GA operators.

Limiting TIS–B may be appropriate for the 1090 ES ADS–B system because the FAA is carefully managing frequency spectrum demand and working to ensure performance is adequate. However, the UAT frequency spectrum is not expected to have the same congestion challenges.

A risk to implementing this recommendation is it removes one incentive for aircraft owners equipping with certified ADS–B Out systems before the 2020 mandate. One of the reasons the FAA developed client service volumes for TIS–B and ADS–R was to encourage early ADS–B Out equipage. Currently, the TIS–B and ADS–R services can be used by lower cost uncertified receivers and tablet devices on aircraft with certified ADS–B Out equipage. Giving aircraft owners the option of receiving all ADS–B In traffic functions without ADS–B Out will reduce the demand for ADS–B Out avionics, potentially slowing down the introduction of lower cost certified ADS–B Out solutions.

The ARC notes that in those areas that do not currently have ADS–B coverage but are likely to have significant light aircraft traffic, "receive only" aircraft will not be visible to each other, whereas those transmitting on the UAT frequency will be seen by all aircraft with UAT receivers. See recommendation No. 17 below for further discussion on extension of ADS–B coverage to these areas.

With a configuration change in the ground infrastructure, pilots equipped with receive-only UAT ADS–B systems would have immediate access to safety and efficiency benefits enabled from TIS–B and ADS–R. The change also accelerates NextGen for GA, and enhances safety and utility during the transition period leading up to the January 1, 2020, ADS–B Out mandate.

Although costs to modify the UAT TIS–B and ADS–R ground infrastructure are unknown, if executed now those changes could be standard on the remaining ground stations.

One of the current limitations with the FAA's plan for traffic and weather coverage provided over UAT ADS–B In is the lack of traffic and weather information on the surface and in the traffic pattern at some GA airports. Because of the dual link decision, ADS–R is required where there is mixed 1090 ES and UAT equipage, a situation envisioned at every GA airport. The expansion of ADS–R coverage to more GA airports could also enable the use of the SURF and SURF–IA applications by GA pilots to reduce runway incursion risks.

In addition, most GA aircraft are less weather-tolerant and cannot fly over or around weather the way transport category aircraft can, and they often do not have the systems to avoid or cope with hazardous weather conditions, such as ice. The availability of FIS–B weather information at low

altitudes (below radar-coverage) will increase the weather situational awareness for GA pilots that equip with ADS–B In, further incentivizing ADS–B equipage.

Recommendation 15: Because the cost of the changes to allow for continuous uplink of current TIS–B and ADS–R data could be a limiting factor to implementing the ARC recommendation for continuous uplink on UAT, the ARC recommends the FAA conduct a full analysis of recommendations 16 and 17 and share the results with the ARC before June 2012.

Recommendation 16: The ARC recommends the FAA provide continuous uplink, while not requiring ADS–B Out, of the TIS–B and ADS–R over the current UAT link only (not the 1090 ES) starting today through the ADS–B Out mandate of January 1, 2020, to allow users to recognize and take advantage of this situational awareness benefit of ADS–B In.

Recommendation 17: As a result of the need for greater traffic and weather information to improve the GA business case, the ARC recommends the FAA expand ADS–R and FIS–B service volumes and associated ADS–B infrastructure to improve coverage at GA airports and low altitude airspace.

See appendix K to this report.

3.4.3 DOD Viewpoint Paper

The ADS–B ARC has received input from the U.S. Department of Defense (DOD), which is conceptually and strategically in alignment with the other NAS operators on the ARC and reflects a continuity of thought regarding ADS–B In across the entire community:

> The DOD recognizes that ADS–B In technology could deliver some benefits to properly equipped users, and the value of those benefits is directly related to the operational construct (i.e., location, type of operation, capacity constraints, etc). Some of the ADS–B In applications are mature and could result in increased safety margins and improved aircrew situational awareness. However, the more sophisticated applications that may provide the greatest benefits are at an immature stage and require further research and development.
>
> The DOD inventory of over 14,000 rotary, fixed wing, and unmanned aircraft is comprised of over 100 aircraft types each having their own distinctive operating profile. Some military missions are very similar to civil operations and fly in locations where the benefits are concentrated, while a larger proportion operates in a manner and location with limited benefits. Additionally, the costs to modify and integrate ADS–B In into the DOD inventory will be considerable, given the complexities, differences and sheer volume of DOD aircraft. DOD's initial assessment is that a positive business or safety case to equip with ADS–B In will likely not be proven for the majority of DOD fleets.

The DOD concluded that an ADS–B In mandate encompassing all DOD aircraft is not necessary, due to the expected costs exceeding the benefits. Any FAA mandate must accommodate mixed-equipped DOD aircraft, ensuring DOD aircraft retain access to routes, airspace, and airports required to test, train, and operate in support of the National Defense mission. DOD will continue to explore ADS–B In equipage for specific airframes where benefits and/or increased safety is provided, and will continue to conduct analyses on the possible synergies of ADS–B In and military specific applications. The DOD recognizes the potential benefits for ADS–B In technology, and supports the FAA as they continue to develop these capabilities to increase safety, efficiency, and capacity within the NAS.

3.5 CERTIFICATION AND POLICY DEVELOPMENT

3.5.1 ADS–B Positioning Sources

3.5.1.1 Background About Current Performance Requirements

The ADS–B Out ARC recommended the FAA base the ADS–B performance requirements on the existing capability of the fleet as expected to exist in 2020.

The requirements for position accuracy performance have specifically focused on surface applications. The Airport Surveillance Applications–Final Approach Runway Occupancy Awareness (ASA–FAROA) application became the focus of the NPRM because it was viewed as the primary driver of required performance (NAC_P of 9 (estimated position uncertainty (EPU)<30 m)) and Wide Area Augmentation System (WAAS)-like positioning requirements. Because of the expected performance of the fleet during the near term and the ASA–FAROA application being primarily oriented toward the airport surface and runway environment, the ADS–B Out ARC recommended the FAA establish NAC_P of 8 (EPU<92.6 m) as the threshold for rule compliance. In making this recommendation, the ADS–B Out ARC accepted that some applications would have reduced benefit or not be deployable during the near term, with surface applications specifically cited.

The ADS–B Out ARC responded to numerous comments about the NPRM's proposed NIC and NAC_P requirements and its inference that augmented GPS was the only known means through which required position accuracy and integrity could be achieved.[23] Based on a detailed review of various expected constellations, the ADS–B Out ARC provided a set of recommendations[24] to the FAA about position performance, including recommendation Nos. 14, 16, 17, 22, and 23.

[23] See 72 FR 56956: "Presently, GPS augmented by Wide Area Augmentation System (WAAS) is the only navigation position service that provides the level of accuracy and integrity (NIC, NAC_P, and NAC_V) to enable ADS–B Out to be used for NAS-based surveillance operations with sufficient availability."

[24] ADS–B Out ARC recommendation No. 14, in pertinent part, states "[t]he FAA should specify the following performance requirements for DO–260A and DO–282A according to domain application as follows: […] For performing [Airport Surface Situational Awareness (ASSA)] and FAROA in the terminal area and surface of the 35 [Operational Evaluation Partnership (OEP)] airports [a] NAC_P and Continuity Greater than or Equal to—9 for 95 percent per hour (the continuity for NAC_P>9 requires future FAA analysis) [and] 8 for 99.9 percent per hour." Recommendation No. 16 states "[t]he ARC recommends that the FAA not apply vertical position accuracy requirements associated with NAC_P=9 for surface applications. The ARC also recommends altering the definition in DO–260A and DO–282A for a NAC_P=0 to remove the vertical; accuracy requirement if the aircraft is on the surface. The ARC acknowledges that altering the definition of NAC_P-9 for surface applications would require international coordination and harmonization." Recommendation No. 17 states "[t]he FAA should advocate national policies that explicitly allow for the use of non-U.S. positioning sources, like Galileo, as part of the infrastructure to meet aviation performance requirements." Recommendation No. 22 states "[t]he 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 states "[t]he FAA should specify two continuity requirements for the surface situational awareness applications (for example, [ASSA]). The first requirement is approximately 95 percent per hour (to be verified by FAA analysis.) for horizontal position accuracy of NAC_P>9. The second requirement is 99.9 percent per hour for a horizontal position accuracy of $NAC_P \geq 8$."

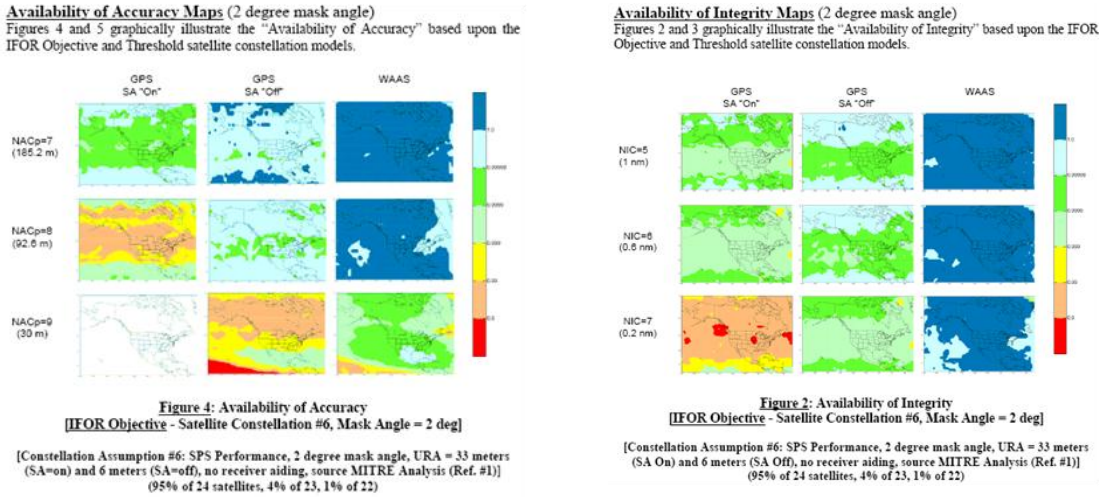


Figure 5—Availability of Accuracy and Integrity from ADS–B Out ARC Report

A more detailed review of GPS performance implications regarding availability can be found in the ADS–B Out ARC task 2 report, appendix Z, Signal In Space Availability Discussion, submitted to the FAA on September 26, 2008.

The FAA published the final ADS–B Out performance requirements in 14 CFR § 91.227, which reduced the NAC_P from $NAC_P \geq 9$ (navigation accuracy ≤30 m) to $NAC_P \geq 8$ (navigation accuracy ≤92.6 m) based on recommendations from industry through the ARC.

There are, however, clear benefits to operators who equip with augmented GPS, as the FAA is expected to exempt WAAS-equipped operators from having to conduct a preflight availability determination. Operators who retain GPS selective availability (SA)–Aware or other types of GPS installations would be required to conduct a preflight assessment.

The ARC remains concerned about a requirement for preflight availability determination and will review the pertinent AC when it is published and provide the FAA with additional comments as necessary.

3.5.1.2 Issues with Existing Fleet Capability

As a component of showing compliance with the ADS–B Out regulation, operators have to make an assessment of their aircraft's capability to meet the requirements in § 91.227. A number of issues exist with the existing fleet, including aircraft not equipped with GPS sources (such as flight management system (FMS) or inertial reference system (IRS)), GPS position sensors that are not SA–Aware (such as those that cannot provide required accuracy to support the application or may not have sufficient availability),[25] and lack of ADS–B Out latency characterization. Some manufacturers are also exploring equipage offerings that would leverage SA–On Global Navigation Satellite Systems (GNSS) coupled with inertial navigation system capabilities to enable aircraft to achieve the required performance parameters, such as a system design assurance (SDA), to address this limitation with the SA–On GPS performance.

The Air Traffic Management Advisory Committee (ATMAC) ADS–B working group looked into opportunities to leverage existing legacy avionics for both air-to-ground and air-to-air surveillance, which included a review of GPS capability.[26] The ATMAC recommendations were submitted in 2010, and since then the FAA has identified in-service issues with ADS–B Out transponders, stating that "some existing equipment, both ADS–B Out radios and GNSS position sources, do not transmit valid position bounded by integrity."[27]

3.5.1.3 Evolution of GNSS Capability in the Fleet

The ADS–B Out ARC envisioned a natural evolution the GNSS constellation's performance that would drive the existing SA–On equipage in the U.S. air transport and GA fleet[28] to an SA–Aware or better performance over the next decade. The events that would drive the evolution of onboard position capability include fielding of a dual civil frequency (L1, L5) GPS constellation, deployment of Galileo, upgrades to satellite-based augmentation systems (SBAS) around the world, and the deployment of ground-based augmentation systems (GBAS).

Beyond the near-term timeframe, when most air transport operators will likely be equipped with legacy GPS, the emerging capabilities of GNSS are expected to drive operators to equip with better performing avionics capabilities such as dual frequency GNSS. This will provide an opportunity to make the position accuracy requirement, and other performance requirements driven by the aircraft's GNSS capability, more stringent than the requirements of § 91.227.

The ADS–B Out ARC believed the evolution to more stringent performance could be achieved when the above positioning system improvements are implemented through an amendment to § 91.227(c)(1) as a "catch-up" rulemaking activity when the capability of the fleet exceeds the new requirement (such as $NAC_P \geq 9$) for all or a portion of the NAS.

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[25] As an example, AC 20–165, appendix 2, figure 10 indicates predicted rule-compliant ADS–B Out availability is only 89.0 percent, which means aircraft dispatch capability may be limited.

[26] See appendix L, Legacy ADS–B Out Avionics, to this report.

[27] The ARC specifically responded to this issue at the October 2010 meeting (see Issue Paper—Legacy ADS–B Avionics and In-Service Issues) and recommended monitoring of equipment and targeted AD action. A copy of the ARC issue paper is included under appendix L to this report.

[28] MITRE estimates 90 percent of the U.S. air carrier fleet is SA-On. The U.S. GA fleet has significant GPS equipage levels. The ARC obtained data from one GA avionics manufacturer, which has fielded more than 60,000 GPS receivers that are TSO-C129a. Approximately 12,000 of these units are discontinued and have no direct upgrade path.

An alternative to this approach would be to "proactively" drive the performance of the fleet by introducing a regulatory requirement before such date, driving operators to dual frequency GNSS, SBAS, or GBAS, depending what is most suitable for their type of operation and desired capability.

3.5.1.4 Use of Mitigations to Address Shortcomings in Near-Term Performance

In addition to the expected evolution of GPS performance and operators voluntarily equipping to meet certain position accuracy performance requirements, opportunities exist to mitigate the lack of performance among operators and achieve performance needed for certain applications.

Exploratory work is underway to identify mitigations that can address the discrepancy between minimum rule compliant performance and the needs of surface and other applications.

The ARC was provided a detailed briefing by MITRE[29] about the inventory of mitigations and alternative surveillance techniques being explored as potential solutions to the discrepancy between minimum rule performance and the needs of certain applications. This briefing included an overview, based on work already underway at MITRE, of expected costs, possible implementation timelines, and any impact on ground equipment or other aircraft equipment. The different options are identified in table 3.

Table 3—Overview of Possible Mitigations and Alternative Surveillance as Identified by The MITRE Corporation

Mitigations
Requalification for Selective Availability (SA)-On Traffic Based on Ownship Horizontal Dilution of Precision[30]
Requalification for low navigation accuracy category for position (NAC_P) Traffic Based on Knowledge of Surface Features[31]
Requalification for low NAC_P Traffic Based on Comparison with Known Ground Sensor Position[32]
Requalification for low NAC_P Traffic based on Knowledge of Ionospheric Disturbance Status[33]

[29] Overview of Mitigations Concerning Qualification of ADS–B OUT Rule Compliant (NAC_P 8) Targets for Surface Applications, presented by Peter Moertl to ADS–B In ARC working group 2, April 25, 2011.
[30] Given ownship's knowledge of the geometric quality factor of the GPS satellites in view, and the geometry's higher quality than a given threshold, SA-On traffic may be qualified for SURF applications, but likely not applicable for SURF–IA due to alerting and higher performance requirements (see RTCA DO–322, appendix D).
[31] Compare traffic positions of otherwise unqualified traffic (such as $NAC_P<9$) with runway and taxiway location information to determine if traffic is sufficiently accurate for application.
[32] The difference between known and reported ground sensor position allows traffic qualification or position correction.
[33] Ground monitoring equipment determines if the current level of ionospheric activity impacts GPS position accuracy at a given airport. The level of activity is encoded and transmitted in an uplink message to aircraft at the airport.

Alternative Surveillance
Alternative Traffic Surveillance Source Using Wide Area Augmentation System (WAAS)/Satellite-Based Augmentation System (SBAS)
Alternative Traffic Surveillance Source Using Dual Frequency Global Positioning System (GPS)
Alternative Traffic Surveillance Source Using Local Area Augmentation System (LAAS)/Ground-based Augmentation System (GBAS)
Alternative Traffic Surveillance Source Using Multilateration/Airport Surface Detection Equipment, Model X/Traffic Information Service–Broadcast (TIS–B)[34]

The mitigations and alternative surveillance sources all provide possible opportunities to address the existing fleet's inability to achieve higher accuracy and integrity than required by § 91.227 to support applications such as Airport Traffic Situational Awareness with Indications and Alerts (SURF–IA, AIWP application 4) and likely Paired Closely Spaced Parallel Approaches (AIWP application 10).

3.5.1.5 Case Study: Deployment of SURF–IA at Airports with Surface Multilateration Capability

SURF–IA provides an opportunity to enhance runway safety through an ADS–B In application. There is broad interest in the application, including recommendations from the National Transportation Safety Board (NTSB) that runway incursion mitigation through alerts to the flightcrew should be developed.[35]

3.5.1.5.1 Background About SURF–IA

The SURF–IA application was subject to operational trials by Aviation Communications and Surveillance Systems (ACSS) and Honeywell in 2009 that expanded the FAA's and industry's understanding of the application, but also identified two key technical challenges to the deployment of the application, both related to message reception: line-of-sight and signal dropout. These issues were identified to the ARC at its July 2010 meeting, after which the FAA asked the ARC, as part of its initial task to endorse continued development work, to review the SURF–IA application and provide guidance on the application's development. The ARC, at that time, recommended the FAA "make it a priority to resolve the issues identified during the SURF–IA demonstration, such as line-of-sight interference and ADS–B dropouts."[36]

[34] The FAA has introduced the opportunity to use TIS–B targets for the deployment of some ADS–B In applications in the near term (see 75 FR 30173). However, while the SURF–IA integrity requirements (NIC, SIL, and SDA) are met by rule-compliant ADS–B Out avionics, TIS–B does not currently broadcast a non-zero NIC, but is expected to provide this capability soon. Additionally, TIS–B does not provide flight ID and the target volume around the ownship is limited. The ARC has not undertaken work to determine which applications would benefit from TIS–B, but speculates that applications such as Traffic Situational Awareness Basic (AIRB), Airport Situational Awareness including with Indications and Alerts (ASA–FAROA, SURF, and SURF–IA), and Traffic Situational Awareness with Alerts (TSAA) would be enabled by TIS–B with further opportunity for CAVS, FIM–S, and CEDS.

[35] See NTSB Safety Recommendations A–00–66.

[36] See ADS–B In ARC task 1 endorsement letter, November 1, 2010.

In addition to the two technical challenges identified through the trials, the ARC also recognizes the implications of the ADS–B Out performance requirements,[37] as they limit the runway configurations where the SURF–I application can be practically deployed.

3.5.1.5.2 Status of Line-of-Sight and Dropouts

The ARC received a detailed briefing from the FAA in May 2011 about the status of the FAA's work to address the two technical issues raised in the ARC's task 1 letter, both of which are and will continue to be subject to additional evaluations by the FAA past the ARC's task 2 final report in September 2011.

The working group was pleased with the progress the FAA has made to better define the two technical issues, including steps to quantify which of an identified set of 104 airports[38] are likely to experience issues with line-of-sight and to look for resolutions to the line-of-sight problem.

For example, approximately two-thirds of the top 100 U.S. airports are affected by crossing-runway scenarios, of which 52 are expected to have line-of-sight issues, and 37 of the 104 experience line-of-sight issues at least 5 percent of the time. These line-of-sight issues include a range of problems, such as late alerts for certain configurations and scenarios. The ARC noted, however, that the FAA has not evaluated this data and the scenarios against runway incursion scenarios to determine the degree of mitigation the deployment of SURF–IA, with some line-of-sight issues remaining, would achieve.

Similarly, the FAA is evaluating potential issues and mitigations for dropouts such as receiver sensitivity adjustments, dual antenna reception, rebroadcast on the same link, and airport wide area network. This evaluation will continue to support the next phase of the SBS program through 2011.

Recommendation 18: The ARC is pleased to see the progress made by the FAA to better define and analyze the SURF–IA technical issues involved in line of sight and dropout, and recommends the FAA continue development work to fully resolve both the line-of-sight problem and the dropout problem.

Recommendation 19: With regard to evaluating line-of-sight, the ARC recommends the FAA assess the mitigation that would be achieved by deploying SURF–IA even with existing line-of-sight problems based on the FAA's runway incursion data; that is, if a "partially functioning SURF–IA applications were deployed at those specific airports where there were events, to what degree would alerts have been issued and with what degree of delay."

[37] § 91.227.

[38] Surface Activities, presented by David E. Gray, SBS program office, to ADS–B In ARC working group 2, May 3, 2011. The list of 104 airports includes a combination of the OEP–35 airports, airports equipped with ASDE–3 and ASDE–X, the 50 busiest towers, and the 100 busiest airports.

Recommendation 20: If the FAA elects to move forward with a "partially functioning" SURF–IA application, the ARC recommends the FAA fully assess the human factors implications of that approach. The ARC noted there are specific concerns with pilots starting to rely on a system that may not give them what they are expecting at all times.

3.5.1.5.3 Status of Addressing Fleet Performance

As discussed earlier, the ADS–B Out ARC expended significant resources in responding to comment regarding the required performance for ADS–B Out-equipped aircraft in the NAS.

The FAA, through the Runway Safety Office, is also funding work at MITRE to address the problem of the minimal fleet capability post-2020 being baselined at NAC_P of 8, even though the SURF–IA application is expected to require NAC_P>9 for many configurations.

While the SURF–IA application was initially expected to be a quickly achievable opportunity for early deployment,[39] the setting of NAS performance post-2020 at NAC_P of 8 remains an impediment to deploying SURF–IA even if the line-of-sight and dropout problems are resolved.

In place of NAS-wide deployment of SURF–IA, the use of multilateration at ASDE–X sites using target information rebroadcast on TIS–B to enhance the accuracy and integrity of the aircraft has emerged as a viable solution to address the performance requirements. Multilateration is also a solution to the line-of-sight and dropout problems discussed earlier.

Recommendation 21: Surface multilateration will be available at 44 airports in the NAS and could provide for a fully functioning SURF–IA application at these airports. While additional research and development will be required, the ARC finds the SBS office should fully fund the development work of NAC performance mitigations, making it a high priority in concert with addressing line-of-sight and dropout problem activities.

The ARC's review of § 91.227 performance requirements on ADS–B In applications, with a specific review of the SURF–IA applications, has resulted in recommendations in four areas.

First, with regard to the option of revisiting the requirements in § 91.227 for ADS–B Out, the ARC identified three options:

- No change: Do not change the required performance in § 91.227 for ADS–B airspace (for example $NAC_P \geq 8$).
- Voluntary with long-term catch-up rule: Monitor the performance of the NAS with respect to the ability of aircraft to exceed the requirements of § 91.227 and initiate rulemaking for more stringent requirements when a threshold portion of the fleet meets or exceeds new requirements.

[39] SURF–IA has AIWP maturity ranking 4, which states: "[c]oncept is well developed; identified research in progress; simulations conducted; detailed feasibility and Cost-Benefit Analysis exists."

- Drive enhanced performance by 2020: Initiate rulemaking to drive more stringent performance than required by § 91.227 before 2020, which would re-baseline the NAS compared to the recommendations of the ADS–B Out ARC, such as raising the performance requirement to for example $NAC_P \geq 9$.

The ARC's consensus is to support the conclusions of the ADS–B Out ARC, which established the requirements in § 91.227 at a level that operators can practically and cost-effectively achieve. There is, however, recognition that a long-term opportunity exists to raise the performance of the NAS, but the ARC endorses the "no change" option at this time.

> **Recommendation 22:** The ARC recommends the FAA maintain its current direction, which is to not initiate rulemaking to raise the position accuracy or integrity performance requirements in § 91.227 (the ADS–B Out rule).

Second, with regard to the ability to deploy the SURF–IA application specifically in the near- to mid-term environment and with recognition of the constraints in § 91.227, the ARC finds there is a pragmatic way forward.

The FAA should initially focus on airports with multilateration, which shows a high degree of promise not only in addressing the line-of-sight and dropout problems, but also in providing the necessary position accuracy for target aircraft to permit a fully functioning SURF–IA application. This was initially discussed by the ARC in its task 1 endorsement letter to the FAA.[40] As part of this focus, the FAA may benefit from determining the risk reduction (the number of runway incursions prevented) by deploying this ADS–B In application at these 44 airports.

Deploying the applications at the multilateration airports would include expending required resources in the near term that would lead to a SURF–IA MOPS. The ARC views SURF–IA as a priority application that should be available to operators who elect to equip with ADS–B In capability in the midterm.

> **Recommendation 23a:** The ARC recommends the FAA analyze the rate of pilot deviation type runway incursions at the 44 airports where the SURF–IA ADS–B In application is initially implemented to assess the application's benefits.
>
> **Recommendation 23b:** The ARC recommends the FAA undertake a benefit-cost assessment for expanding surface multilateration to support SURF–IA at non-multilateration airports where runway incursion events are prevalent or may be likely.

[40] See ADS–B In ARC task 1 endorsement letter, November 1, 2010, p. 6, in appendix M, ARC Recommendations on FIM–S, IM–DS, and SURF–IA to this report.

Recommendation 23c: The ARC recommends the FAA fund the required research, operational evaluations, and development work to complete validated MOPS and any related guidance to deploy SURF–IA at airports with multilateration capability by 2017.

Third, to address the non-multilateration airports (those airports outside the 44 planned to have this surface capability) in the NAS in the near- and mid-term, the ARC finds there is an opportunity to assess SURF–IA at GA airports. It is reasonable to assume that at GA airports a large portion of the fleet will either comply with the ADS–B Out mandate by using their existing WAAS navigator as the position source or upgrade to WAAS capability as part of their installation of ADS–B Out rule compliant avionics. The result will be that a majority of traffic will likely exceed both the position accuracy and integrity requirements of § 91.227. As discussed in the task 1 endorsement letter,[41] the ARC finds the FAA should undertake a separate study to determine the opportunity to deploy SURF–IA at GA airports with the study addressing expected fleet capability for position accuracy and whether known issues such as signal drop-out and line-of-sight would be factors at typical GA airports.

Recommendation 24: The ARC recommends the FAA undertake a study to determine the opportunity to deploy SURF–IA at GA airports with the assumption that the majority of the activity at the airport will be with aircraft that are WAAS-equipped and with consideration of known technical issues such as signal drop-out and line-of-sight.

Finally, with regard to the development of alternative surveillance sources, the ARC notes that dual frequency GNSS is approaching a point at which the FAA, as well as the broader international community, should begin to consider developing deployment standards. Dual frequency GNSS was discussed generally in the ADS–B Out ARC report as one opportunity for operators to enhance their aircraft capability for not only surveillance, but also performance-based navigation.

Dual frequency GNSS provides promise for not only NAS-wide, but worldwide position accuracy and integrity performance. As such, the ARC finds the FAA should start planning for the development of standards for dual frequency GNSS to be available as an option for operators in the next decade.

Recommendation 25: The ARC recommends the FAA assess the readiness of using dual frequency and multi-constellation GNSS to support surveillance and navigation needs and provide a detailed overview of the way forward for dual frequency GNSS to the ARC by spring 2012. At that time, the ARC may exercise its discretion to provide further recommendations about dual frequency GNSS and ADS–B In to the FAA.

[41] Id. at p. 7.

3.5.2 Operational Approvals

The ARC notes the significant administrative burden that goes into operational approvals. This was discussed at length by RTCA Task Force 5. The ARC generally discussed the need to ensure streamlining of the process for ADS–B In operational approvals; otherwise its NAS-wide deployment will be difficult to achieve, especially for smaller operators.

The ARC may exercise its discretion and provide the FAA additional guidance about operational approvals for ADS–B In applications by the end of its charter in June 2012.

4.0 TECHNICAL RECOMMENDATIONS

4.1 NON-TSO–C195 ADS–B DISPLAYS

The ARC looked into issues related to ADS–B traffic data on non-TSO–C195 displays and a proposed compliance path. AC 20–172 describes one acceptable means of installing ADS–B In equipment. AC 20–172 only covers the installation of systems that comply with TSO–C195 and include a TSO–C195 CDTI. TSO–C195 references the minimum performance standards in RTCA DO–317.

4.1.1 Existing Traffic Display Symbology

Many certified panel-mount traffic displays installed on 14 CFR part 23 aircraft and 14 CFR part 27 helicopters do not hold TSO–C195. These displays show traffic information from Traffic Collision and Avoidance System (TCAS) I (TSO–C118), Traffic Advisory System (TAS) (TSO–C147), TIS(–A) (RTCA DO–239), and Capstone-based UAT ADS–B/TIS–B (TSO–C154) systems and often hold partial TSOs (C118, C147, C113, or various combinations of these) for the traffic display functionality. Examples of existing traffic displays include Garmin 430/530 variants and multifunction displays (MFD), Bendix/King MFDs, and Avidyne MFDs, which have a combined installed equipment base likely in excess of 74,000 aircraft.

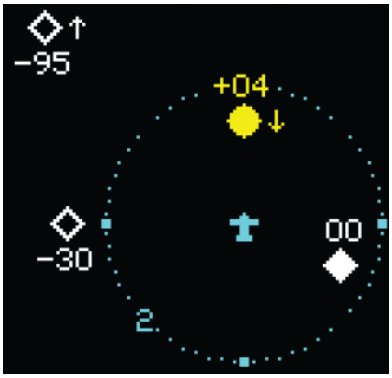

Figure 6—TCAS I/TAS Symbology

Most of these displays use TCAS I symbology for traffic, with yellow circles for Traffic Advisories, filled white or cyan diamonds for Proximate Advisories, and hollow diamonds for Other Traffic (see figure 6 above). Each traffic icon also displays the relative altitude in hundreds of feet and a trend arrow if the traffic is climbing or descending at a rate greater than 500 fpm. Directionality may be provided in the form of a barb for displays designed to show TIS(–A) traffic (see figure 7 below). Various altitude filters and declutter levels have also been provided, as well as traffic identifier symbology.

Figure 7—TIS/TIS–A Symbology

MFDs displaying Capstone-based UAT ADS–B/TIS–B traffic use other symbology such as those shown in figures 8 and 9 below.

Figure 8—Capstone ADS–B/TIS–B Symbology (Unselected)[42]

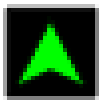

Figure 9—Capstone ADS–B/TIS–B Symbology (Selected)

4.1.2 Existing Traffic Display Characteristics

These displays are not expected to comply with TSO–C195 in the future for two reasons. First, many of these displays are legacy products not actively upgraded by the manufacturer to add new functionality. Adding a new TSO would involve a TSO "Major" project, which manufacturers are not expected to undertake. Second, these displays were never designed to be fully compliant with the TSO–C195 CDTI requirements.

[42] Top-row symbols are ADS–B targets, middle-row symbols are TIS–B targets, and the bottom-row symbol is a surface vehicle (such as a plow, sweeper, or service vehicle). Cyan symbols are airborne, brown symbols are on-ground, and yellow symbols indicate the target has an alert.

The requirements for a TSO–C195 CDTI are in RTCA DO–317 section 2.3 as amended by TSO–C195 appendices 1 and 2. Non-TSO–C195 traffic displays are not required to display air/ground status or traffic directionality under their existing TSO(s). Additionally, the latency, display range, declutter, and system status requirements of TSO–C195 are not required to be met under their existing TSO(s). Most TCAS I and TAS displays use an ARINC 735 interface, which does not include all of the required data for a TSO–C195 CDTI.

Because AC 20–172 requires a TSO–C195 display, there is no written guidance from the FAA that allows installation of equipment running TSO–C195 ADS–B In ASAS applications using displays that do not hold TSO–C195 in order to show traffic information.

4.1.3 Use of Non-TSO–C195 Displays for ADS–B In ASAS Applications

Because of the number of non-TSO–C195 panel-mount certified displays currently installed in aircraft, an opportunity exists to provide ADS–B In traffic information from the Traffic Situation Awareness–Basic application to pilots in those cockpits in an affordable manner through the use of these unmodified traffic displays. One potential configuration involves a TSO–C195 Airborne Surveillance and Separation Assurance Processing (ASSAP) that supports the Traffic Situation Awareness–Basic application (Class C1) installed with an ARINC 735 output that emulates a TCAS I or TAS system using the other traffic (non-traffic advisory or proximity alert) symbology. The ASSAP may be part of a 1090 ES mode select (Mode S) transponder with 1090 Receive capability, a UAT transceiver, or some other ADS–B system. The non-TSO–C195 traffic display would then be configured for TCAS I/TAS/TIS(–A) and would display ADS–B In traffic information, without some data such as ground track and air/ground status. The traffic display may alternatively be configured for Capstone UAT ADS–B/TIS–B and use non-RTCA DO–317 symbology.

These displays would be for situational awareness of surrounding traffic only (like the Traffic Situation Awareness–Basic application) and could not be used for ADS–B-enabled procedures, such as Enhanced Visual Approach or ITP. While the ASSAP may perform all functions of the Traffic Situation Awareness–Basic application, the non-TSO–C195 display would not comply with all requirements of the Traffic Situation Awareness–Basic application.

The TSAA ADS–B In application may also benefit from the use of non-TSO–C195 displays. However, TSAA symbology is not defined at this time, so it is premature to make any recommendations related to TSAA and non-TSO–C195 displays.

Manufacturers do not envision non-certified portable ADS–B In equipment connecting to panel-mount certified displays to display traffic information. However, certified TSO–C195 ASSAP systems may output data to non-certified portable displays.

4.1.4 Use of Non-TSO–C195 Displays for Previously Approved Traffic Functions

Additionally, some non-TSO–C195 CDTI equipment was installed on part 25 aircraft used in part 121 operations, including some equipment developed by UPS AT (now Garmin AT). The equipment was initially approved for Enhanced Visual Acquisition for Traffic Situational Awareness. In order to keep this previously approved equipment operational, some future changes or minor enhancements may need to be made to the systems, such as additional

source-failure indications when displaying ASSAP traffic data on a display that previously had only one source of traffic data. The ASSAPs connected to these non-TSO–C195 CDTIs may be upgraded to comply with TSO–C195, but such upgrades may be cost-prohibitive, and the CDTIs still perform the previously approved traffic functions and applications. The ability to continue supporting these non-TSO–C195 CDTIs through minor changes without getting TSO–C195 is desired.

The financial benefits to enabling the display of ADS–B traffic on non-TSO–C195 displays is further discussed in the benefit-cost section of this paper.

The ARC provides the following recommendations to enable the use of non-TSO–C195 displays for ADS–B In traffic data:

Recommendation 26: The ARC recommends the FAA provide guidance that specifically allows installations of TSO–C195 and subsequent ADS–B In ASSAP systems with non-TSO–C195 traffic displays that use existing TCAS I/TAS/TIS(–A) and Capstone-based UAT ADS–B/TIS–B symbology for situational awareness of surrounding aircraft. It should be clear that minor changes or enhancements may be made to previously approved traffic functionality on displays without requiring equipment to be made fully compliant with TSO–C195 requirements. The ARC finds this approach suitable for GA aircraft.

Recommendation 27: The ARC recommends the FAA provide guidance that specifically allows the continued use of previously certified and operationally approved non-TSO–C195 ADS–B In CDTI with previously approved symbology but limited to previously approved traffic functions and applications. It should be clear that minor changes or enhancements may be made to previously approved traffic functionality on displays without requiring equipment to be made fully compliant with TSO–C195 requirements. The ARC makes this narrow recommendation for specific existing air carrier aircraft.

4.2 Hazard Classifications for ADS–B In Applications

The ARC attempted to consolidate various hazard level determinations for applications being considered by the ARC and make a recommendation for accommodating applications with early ADS–B In avionic architectures. The hazard levels, also known as hazard categories or failure classifications, describe the impact of either missing or misleading data provided by that application. The five possible hazard levels are: No Safety Effect, Minor, Major, Hazardous (Severe), and Catastrophic, as defined by FAA AC 23–1309–1D, AC 25–1309–1A, and SAE International (SAE) Aerospace Recommended Practices (ARP) 4761. The hazard levels then lead to different design or development assurance levels for avionics in the aircraft. The hazard levels can also lead to different aircraft avionics architecture mitigations such as redundant equipment. For the purpose of this discussion, the hazard level is based on the probability of misleading information, not on FAA safety levels or application availability requirements.

Table 4—SAE ARP 4761 Failure Condition Severity Table Augmented with AC 23.1309–1D

Probability[43] (Quantitative)	**Per Flight Hour**				
	1.0	**<1.0E–3**	**<1.0E–5**	**<1.0E–7**	**<1.0E–9**
Probability (Descriptive)	Federal Aviation Administration (FAA)	Probable	Improbable		Extremely Improbable
	Joint Aviation Authority (JAA)	Frequent / Reasonably Probable	Remote	Extremely Remote	Extremely Improbable
	FAA (AC 23.1309–1D)	Probable	Remote	Extremely Remote	Extremely Improbable
Failure Condition Severity Classification	FAA (part 25)	Minor	Major	Severe Major	Catastrophic
	JAA (and AC 23.1309–1D)	Minor	Major	Hazardous	Catastrophic
Failure Condition Effect	FAA & JAA	- Slight reduction in safety margins - Slight increase in crew workload - Some inconvenience to occupants	- Significant reduction in safety margins or functional capabilities - Significant increase in crew workload or in conditions impairing crew efficiency - Some discomfort to occupants	- Large reduction in safety margins or functional capabilities - Higher workload or physical distress such that the crew could not be relied on to perform tasks accurately or completely - Adverse effects on occupants	- All failure conditions which prevent continued safe flight and landing
Development Assurance Level	SAE ARP 4754	Level D	Level C	Level B	Level A
	FAA AC 23.1309–1D	Level D	Level D (communications, navigation, and surveillance equipment in Class I and II) Level C	Level D (CNS equipment in Class I and II) Level C (Class I–III) Level B (Class IV)	Level C (Class I and II) Level B (Class III) Level A (Class IV)

[43] The probability (and thus assurance level) is reduced for Class I–III part 23 aircraft per AC 23.1309–1D.

TSO–C166b 3.b states "For 1090 MHz ADS–B and TIS–B receiver subsystems, we consider an un-annunciated failure that provides onboard applications with incorrect reports a major failure condition … A failure resulting in loss of function defined in paragraph 3a of this TSO is considered a minor failure condition." TSO–C154c includes similar text.

TSO–C195 for ADS–B In applications 3.b states:

> Failure of the function defined in paragraph 3a of this TSO has been determined to be a major failure condition for malfunctions causing the display of hazardously misleading information in airborne aircraft and aircraft on the ground greater than 80 knots. Failure of the function defined in paragraph 3a of this TSO has been determined to be a minor failure condition for malfunctions causing the display of hazardously misleading information in aircraft on the ground less than 80 knots groundspeed. Loss of function has been determined to be a minor failure condition. Develop the system to, at least, the design assurance level equal to these failure condition classifications.

TSO–C195 is for situational awareness applications (traffic situational awareness, airport traffic situational awareness, and traffic situational awareness for visual approach), but will be updated to address additional applications as they are deployed in the NAS.

With these TSO statements, it is unclear how any ADS–B In systems, other than the SURF–IA application, could have anything less than a Major hazard level. The most critical applications have a Hazardous hazard level.

The ARC found that several of the more advanced applications[44] may provide an opportunity for accelerated deployment with avionics and avionic architectures that support the Major hazard level classification, but the applications are in some of the existing documentation identified in the Hazardous category. In many cases the applications identified by the ARC (see table 2) have an opportunity to be differentiated between Major and Hazardous implementation. The ARC notes by restricting the operational environment in which some applications (such as runway separation and aircraft separation) are used, those applications could be included with other applications with a Major hazard level, allowing operators access to more applications resulting in cost-effective retrofit installations and accelerated benefits. The same MOPS, perhaps with different equipment categories, could cover both Major and Hazardous versions of the application.

[44] Possibly applications identified in AIWP version 2 as IM–S Dependent Runway Operations (6d), IM–DS Dependent Runway Operations (8d), CEDS for Arrivals to Closely Spaced Parallel Runways (8i), Paired Closely Spaced Parallel Approaches (10), Independent Closely Spaced Parallel Approaches (11), Delegated Separation–Crossing (12), Delegated Separation–Passing (13), Flight-deck-based Interval Management–Delegated Separation with Wake Risk Management (14), Flow Corridors (16), and Self Separation (17).

Recommendation 28: The ARC recommends the FAA, as part of any research and development work directed toward applications, assess the benefits of splitting applications into a two-phased deployment plan that would enable near-term benefits from avionics at a Major hazard level and far-term benefits from avionics at a Hazardous hazard level. The ARC finds this may further facilitate retrofit and early deployment of these applications.

4.3 Data Comm Implications on ADS–B In Application Deployment

The deployment of data communications (Data Comm) in the NAS will have an impact on how several ADS–B In applications can be deployed during the near- and mid-term. The ARC took the opportunity to review the most current information about the Data Comm program schedule with the goal of determining potential impacts, including delays in the Data Comm program schedule.

4.3.1 December 2010 Schedule for Data Comm Support to ADS–B In Applications

As of December 2010 (when the most recent Terms of Reference for RTCA Special Committee 214 (SC–214) were approved by the RTCA Program Management Committee), Data Comm support in segment 1 of the FAA program (operational in 2017) for ADS–B In applications was scoped to be the following:

- Support for the ITP application. This support has been codified, for oceanic operations, in change 1 to RTCA DO–306, approved in March 2011, assuming Future Air Navigation System (FANS) 1/A avionics, in which binary messages are packaged in character format for transmission over the Aircraft Communications Addressing and Reporting System (ACARS) network using ARINC characteristic 622.
- Support for those Interval Management applications whose Data Comm requirements could be articulated and validated by November 2011. This effort has subsequently been targeted by RTCA SC–186 (ADS–B) to develop application-specific Data Comm support, using the Aeronautical Telecommunications Network (ATN) and Very High Frequency Data Link Mode 2 (VDL2), for the range of IM–Spacing operations.

Specific Data Comm support for any additional ADS–B In applications would be implemented in segment 2 of the Program (then planned to be operational in approximately 2023). Such additional ADS–B In applications might otherwise be earlier supported by digital Data Comm only through: (1) use of Data Comm message formats developed for the segment 1 package, to the degree such formats can be applied; (2) use, in a manner mutually agreed by cognizant airborne platforms and ATC ground systems, of "free-format" messages communicated using segment 1 infrastructure; or (3) use, in a manner mutually agreed by airborne platforms and ATC ground systems, of existing ACARS infrastructure.

4.3.2 April 2011 Changes to Data Comm Program Schedule

At the April 11–15, 2011, RTCA SC–214 Plenary in Berlin, the FAA announced a change to the Data Comm program schedule. Both Tower and En Route data link services to aircraft equipped with FANS 1/A and 1/A+ avionics that can receive the VDL2 link protocol are scheduled to be provided in 2015 and 2018, respectively. Upgrades to the ground infrastructure to also fully support the ATN with VDL2 as the link-level protocol are planned, but the FAA is vetting the timing of these upgrades.

From an ATN perspective, this schedule change essentially involves merging what had been work packages 1 and 2 of the program, with the merged work packages producing implementation of a renamed ATN baseline 2 in a manner harmonized with European Data Comm efforts. In its April 2011 announcement to RTCA SC–214, the FAA projected that ATN avionics supporting this renamed ATN baseline 2 (formerly ATN baseline 3) would become commercially available in 2025.[45]

In light of this schedule change, the FAA is no longer requesting approved RTCA standards for ATN data link messages by the end of 2011 to support what previously was termed segment 1 of the program. Appropriate adjustment to RTCA SC–214 schedules is anticipated in the near future.

4.3.3 Impact of Data Comm Program Schedule Slips

Any absence or delay of FAA Data Comms ground infrastructure support for the applications listed in section 4.3.1 above can be mitigated, where possible, by the use of air/ground voice communications. This is clearly feasible for the ITP application and several initial FIM–S applications (for example, applications requiring basic initiation elements such as planned final approach speed and FIM initiation clearance without IM Turn Intercept Point; basic execution elements such as IM Operation Initiation and Continue Spacing; and basic Termination elements such as ATC Termination and Flight Crew Termination). For these initial applications, the schedule change in the FAA Data Comm program discussed in section 4.3.2 above may be inconvenient but will not prevent the applications from having initial operational implementation.

However, as IM applications with increased complexity are attempted, particularly in high-density airspace, workload issues are likely to arise with the reliance on air/ground voice communications, particularly for the air traffic controller. More advanced ADS–B In applications may involve communicating an amount of information large enough to require Data Comm to ensure accurate pilot and air traffic controller communications and acceptable workloads. Assuming slippage in schedule of FAA Data Comm program implementation of the renamed ATN baseline 2 ground infrastructure until 2023, a likely result of the April 2011 schedule change discussed in section 4.3.2 above, the enabling of these types of ADS–B In applications will be directly impacted unless—

- An FAA Data Comm infrastructure is available in the airspace of interest through which mitigation (2) discussed in section 4.3.1 can be employed using 2015/2018 infrastructure capabilities with VDL2, or
- Mitigation (3) of section 4.3.1 can be employed.

Integration of digital Data Comm into the implementation of such ADS–B In surveillance applications will be required, perhaps with the use of digital Data Comm parameterized, for early implementation, by air traffic density or the amount of information required by the ADS–B In application.

[45] The FAA has provided further guidance to industry about the potential deployment dates (e.g., "2022" in place of "2023" above) in a communication by Deputy Administrator Michael Huerta to the RTCA NextGen Advisory Committee on July 29, 2011, but they are not specifically discussed here.

4.4 ADS–B OUT

4.4.1 Introduction and Objectives

The ARC undertook a detailed review of the evolution of ADS–B Out capabilities in the U.S. fleet, with respect to the requirements established in the rule for ADS–B link, as well as performance of the position system on the aircraft.

The initial subsection reviews the legacy ADS–B Out equipage with respect to installed equipment and its issues in the environment before the effective date of the rule. It identifies existing opportunities for leveraging existing legacy ADS–B Out equipage to obtain early benefits before 2020; identifies issues that need to be addressed to facilitate early ADS–B In benefits; and makes recommendations on issues that need to be explored further through analysis and action by the FAA and industry.

In addition, the ARC provides an overview of the baseline ADS–B Out environment as invoked by the regulation published by the FAA in May 2010, based on input from the ADS–B Out ARC, as well as the constraints introduced by the ADS–B Out ARC recommendations with respect to the deployment of ADS–B In applications. The ARC lays out the pros and cons of a notional first evolution of ADS–B Out (such as the yet-to-be-defined RTCA DO–260C/282C link MOPS) to enhance or enable specific ADS–B Out or ADS–B In applications such as wake-enabled GIM–S or FIM–S.

4.4.2 ADS–B Out Equipage Environment Through January 1, 2020

Until 2020, the deployment of ADS–B In applications must be done in consideration of the equipage capabilities of all aircraft in the flight environment. The deployment of ADS–B In must consider three mixed equipage types before 2020: (1) ADS–B Out-equipped aircraft, but with variations in the installation and avionics equipment capability; (2) aircraft not equipped with ADS–B Out; and (3) aircraft not equipped with transponders. This subsection will focus on aircraft equipped with various levels of ADS–B Out avionics and those not ADS–B Out-equipped, but with other transponder capabilities that support TIS–B.

The ATMAC ADS–B working group looked further into the existing legacy equipment and noted that a number of the over 8,000 RTCA DO–260 installations are not squitting useful or accurate information. Analysis conducted in support of the ADS–B Out ARC task 1 report in 2008 indicates that approximately 2,000 of the RTCA DO–260 installations would be ready to meet requirements for NRA, including possibly Acceptable Means of Compliance (AMC) 20–24,[46] without significant changes for example, via a service bulletin.

[46] The airworthiness installation and operational AMCs adopted by Canada and Europe that allow use of RTCA DO–260 equipment for NRA operations.

Table 5—Estimated Overview of Various Equipage Already in Operation in the NAS in Mid-2011 with Regard to ADS–B Out[47]

Ver. / Link	1090 MHz		978 MHz UAT	
0	RTCA DO–260~	8,000+	n/a	0
1	RTCA DO–260A	1,300	RTCA DO–282A	1,170
2	RTCA DO–260B	0	RTCA DO–282B	0

Since the ATMAC recommendations, the FAA has also identified some in-service issues with ADS–B Out transponders in that "some existing equipment, both ADS–B Out radios and GNSS position sources, do not transmit valid position bounded by integrity."[48] Other issues include the lack of ADS–B Out latency characterization.

In spite of these technical issues, the ARC finds there is interest among operators to create opportunity for early or increased benefits from ADS–B In by enabling deployment of applications that use non-rule compliant ADS–B Out equipage-based version 0 and 1 avionics as well as GPS that may not meet the stringent performance of the ADS–B Out rule, but still meet the requirements of the specific application as target aircraft.

While ADS–B In applications are ultimately intended to be deployed in an environment where the target or coupled aircraft has rule compliant avionics, there are opportunities for mitigations to be introduced that will enable deployment (in some cases phased) of ADS–B In applications before an ADS–B Out rule compliant operational environment.

4.4.2.1 Recommendations Previously Provided to FAA About Legacy ADS–B Out Avionics

Due to the interest from the operator community in leveraging current onboard equipment to achieve early benefits from ADS–B Out and In applications, industry worked with the FAA through the ATMAC ADS–B working group to recommend a strategy for achieving benefits from ADS–B by building on existing equipage.[49]

There are several possible iterations of target aircraft equipage, including RTCA DO–260, accepted by the FAA under AMC 20–24 with a GPS SA–On as well as a compliant transponder (RTCA DO–260B) with a GPS SA–On, the latter of which would allow the air carrier to delay the investment decision for GPS, but bring the aircraft into compliance for the transponder and installation.

[47] This is not an exhaustive list, but includes data from Dimension International–Honeywell (7,996), Alaska Capstone phases I and II, Embry–Riddle Aeronautical University, University of North Dakota, Helicopter Association International, Rockwell Collins, and Garmin (RTCA DO–260A).
[48] The ARC specifically responded to this issue at the October 2010 meeting (see Issue Paper—Legacy ADS–B Avionics and In-Service Issues) and recommended monitoring of equipment and targeted AD action. A copy of the issue paper is included under appendix L to this report.
[49] The ADS–B working group in 2010 conducted a detailed review of the issues that exist with legacy ADS–B Out transponders. A copy of this review including some expanded material related to more recent FAA guidance as well as flight test findings is included in appendix L, Overview of Issues with Legacy Equipment, to this report.

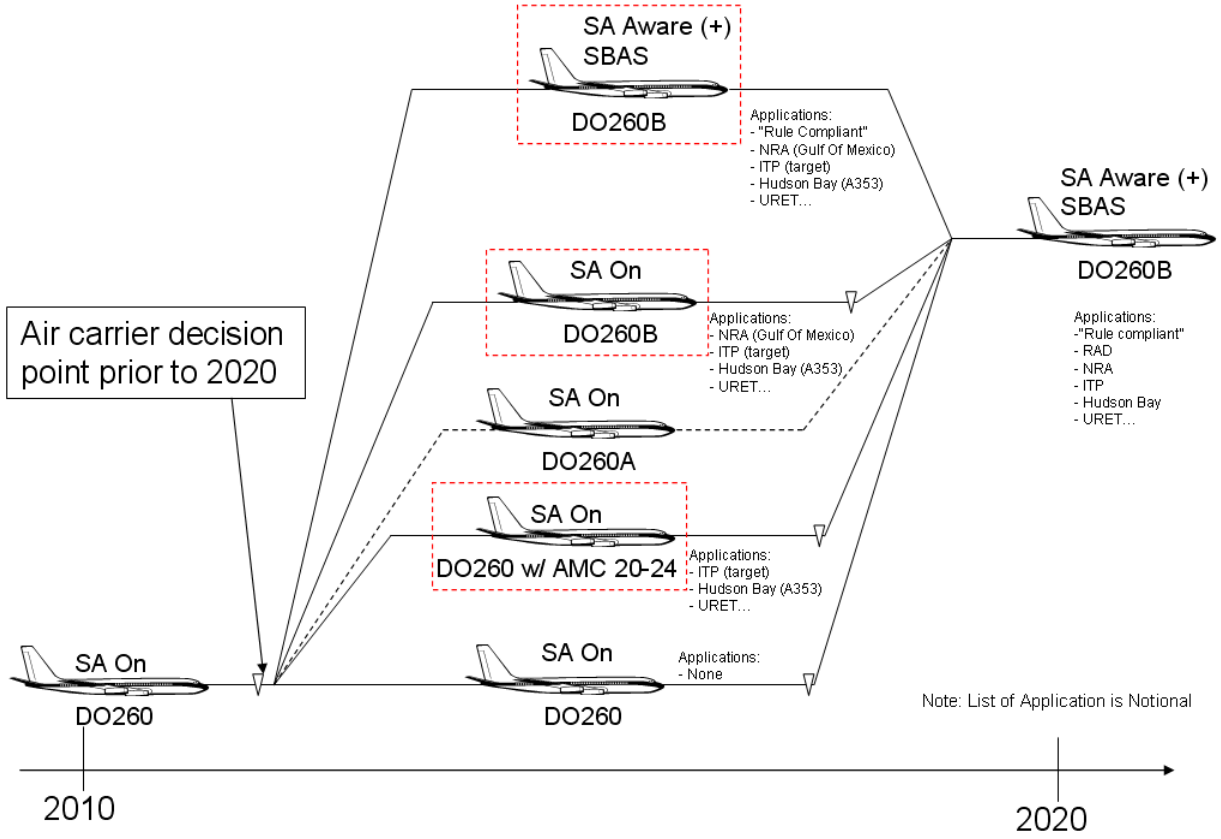

Figure 10—Potential Upgrade Paths for Operators to Change from Current Equipage to Rule Compliant ADS–B Out and Position Source Capabilities[50]

The ATMAC provided two recommendations (Nos. 1 and 6) of relevance to the ARC at its August 4, 2010,[51] meeting, provided here for reference with the FAA's responses. Additionally, background about legacy ADS–B Out avionics is included in appendix L to this report.

[50] This chart provides notional upgrade paths for an air carrier that elects to upgrade its aircraft capability for ADS–B, but not fully comply with the requirements of the 2020 ADS–B Out mandate immediately. Additional background is available in the ATMAC report. The ATMAC used the terminology "SA–Aware (+)" to describe operators that elected to equip their aircraft with SA–Aware GNSS that was enhanced by some other capability such as tightly coupled with IRS. The graph intends to communicate that the 2020 end state is "SA-Aware (+)" or SBAS.
[51] ATMAC ADS–B working group, Use of ADS–B Equipment Before 2020 and Transitioning Legacy ADS–B Equipment to Meet FAA's Mandate (Interim Report), July 26, 2010.

ATMAC recommendation No. 1: The FAA should undertake an alternatives analysis for operators to obtain Non-Radar Airspace (NRA) benefits on specified routes through early equipage with (1) rule compliant avionics as well as with (2) legacy ADS–B transponders with approved installations (such as AMC 20–24) or (3) rule compliant transponder but a position source performance that does not meet the requirements of 14 CFR § 91.227(c) with an acceptable availability. The FAA should also identify dates by which specific ADS–B routes will be available in NRA airspace in the Gulf of Mexico, off the East Coast, and connecting with the North Atlantic Track System and possibly in other airspace to facilitate operators making an informed decision about the timing for obtaining benefits.

FAA response to recommendation No. 1: The FAA [will] perform an alternatives analysis to determine optimal NRA routes for aircraft equipped with rule compliant avionics. The FAA continues to work with the previous ATMAC ADS–B Work Group to review the usage of non rule compliant aircraft for ATC separation services. For example, the review of [Select] Availability (SA) on DO–260B installs may find interim use in NRA or ITP applications.[52]

The FAA concurs with publishing the planned dates for developing NRA routes. As a part of the FAA's Flight Plan, the Surveillance and Broadcast Services (SBS) program office has had a goal to develop and update a performance-based route strategy paper. The program office continues to mature the paper to include inputs from the aviation community and to correspond with the ground infrastructure deployment. The next iteration of the paper, which will include timeline information, will be complete in June 2011.

In addition, the program office is working with carriers to upgrade aircraft to be rule compliant, which will accelerate the use of the routes. The FAA will communicate estimated route availability dates to the NextGen Advisory Committee (NAC).

ATMAC recommendation No. 6 (also referred to as No. 8 due to edits by RTCA): The FAA should continue to evaluate new ADS–B In applications for the applicability of target aircraft with the various types of legacy equipment, including through the use of mitigations when appropriate.

FAA response to recommendation No. 8: We [the FAA] concur with this recommendation. New ADS–B In applications are being evaluated by the ADS–B In Aviation Rulemaking Committee (ARC).

The extensive deliberations within the ATMAC resulted in the above recommendations that encourage the FAA to evaluate each future ADS–B In application against legacy ADS–B Out avionics including GNSS.

The ARC agrees with the ATMAC's recommendations, but it is important that the practical implementation factors be fully considered, including the need for ATC and automation to maintain awareness of different transponder version numbers and the existence, at least in the

[52] Letter from Administrator Babbitt to ATMAC Chairman Dickson, October 27, 2010.

near term, of ADS–B Out installations in which either ADS–B Out radios or GNSS position sources do not transmit valid position bounded by integrity. Concerns were raised by the ATC community about procedures needed by the air traffic controllers to differentiate different version numbers of the ADS–B Out avionics.

The FAA does not plan to have a feature as part of the automation through which the air traffic controller would be shown the version numbers of the ADS–B Out avionics.

The ARC reviewed the Safety and Performance Requirements for Interval Management and the ITP policy memo's approaches to legacy avionics. With regard to ITP, the aircrew must verify that ITP criteria continue to be met after receiving an ITP clearance and before executing the operation. The air traffic controller maintains separation responsibility, but accepts information derived from avionics on board the requesting in-trail aircraft to determine whether ITP criteria are met.[53] With regard to IM, the air traffic controller is required to assess whether all aircraft involved have appropriate equipment. The flightcrew then maintains spacing from the target aircraft using ADS–B In, while both aircraft are under positive control by the air traffic controller.[54]

However, the ARC notes that, depending on the particular application, the ADS–B In airborne system may need to maintain awareness of the version numbers to apply appropriate mitigations.[55]

Finally, it should be noted that legacy ADS–B Out avionics and installations have not been evaluated against the stringent latency requirements prescribed by the ADS–B Out rule. As an example, Boeing conducted extensive latency analysis of specific multi-mode receivers to determine ability to meet compliance with AMC 20–24 for Hudson Bay operations. If operators want to take advantage of expanded targets for ADS–B In airborne and ground applications, latency is one of the factors that must be evaluated or mitigated to facilitate the use of legacy avionics.

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[53] FAA ITP Interim Policy and Guidance Memorandum, May 10, 2010, section 1.0, states "ATC retains procedural separation responsibility throughout the operation, but accepts information derived from avionics onboard the aircraft to determine whether ITP criteria are met. If all criteria are met, ATC issues the ITP procedural clearance. Upon receipt of the clearance, the flightcrew verifies that all criteria are still met prior to executing the clearance. The flightcrew continues to be responsible for the operation of the aircraft and conformance to its ATC clearance."

[54] In RTCA DO–312, Safety, Performance, and Interoperability Requirements Document for the In Trail Procedure in Oceanic Airspace (ATSA–ITP) Application, section 3.3.2, identical wording is used as in the ITP policy memo stating that "ATC retains procedural separation responsibility throughout the operation, but accepts information derived from avionics onboard the aircraft to determine whether ITP criteria are met. If all criteria are met, ATC issues the ITP procedural clearance. Upon receipt of the clearance, the flightcrew verifies that all criteria are still met prior to executing the clearance. The flightcrew continues to be responsible for the operation of the aircraft and conformance to its ATC clearance." And RTCA DO–328, Safety, Performance, and Interoperability Requirements Document for Airborne Spacing—Flight Deck Interval Management (ASPA–FIM), section A.3.2 specifies that "[w]hen verifying that the IM applicability conditions are met, the controller assesses whether the aircraft involved have appropriate equipment."

[55] With respect to UAT, the "UAT MOPS Version" within the link's Mode Status Element is RTCA DO–282B, section 2.2.4.5.4.5; for 1090 ES; the "ADS–B Version Number" subfield within the Aircraft Operational Status Message is RTCA DO–260B, section 2.2.3.2.7.2.5; and the broadcast element 54 indicates the link version for the automation system.

4.4.2.2 Issues Identified for ADS–B In Applications in an Operational Environment (Airspace) Where Some Aircraft Have No ADS–B Equipage

The mixed equipage environment provides inherent challenges for NextGen deployment of several different technologies. In the case of non-equipped aircraft, the SBS program will provide TIS–B targets broadcast to aircraft before complete equipage within that airspace to provide traffic information to ADS–B-equipped aircraft.[56]

4.4.2.3 Description of Mitigations for Legacy ADS–B Link[57]

To enhance early benefits leading to increased adoption of ADS–B In equipage, the ARC encourages the FAA to explore opportunities for all applications to display and use version 0 and 1 aircraft that are broadcasting appropriate integrity and accuracy values.

> **Recommendation 29:** The ARC recommends the FAA permit the use of legacy equipment on an application-by-application (or version number-by-version number) basis if the application is envisioned to be enabled in the NAS before 2020.

The deployment of ADS–B In against the full range of target aircraft can be achieved through the use of mitigations. For example, ITP has been permitted with earlier versions through the use of TCAS range validation. The ARC notes that any mitigation allowing the use of version 0 messages for more critical applications (for example, FIM–S) would improve the business case in the near- and mid-terms, and should be explored. The primary opportunity for mitigation of legacy ADS–B Out equipage is TCAS range validation.

The TCAS range validation function could be used to increase the performance of airborne ADS–B In applications such as FIM–S and CEDS and increase the availability of targets qualified for the operations. TCAS range validation may also be required for ASEP–IM and other more advanced ADS–B In applications. TCAS range validation is a requirement for ITP to qualify target aircraft broadcasting RTCA DO–260 or RTCA DO–260A.[58] Similarly, the UPS trial of FIM–S (also known as Merging and Spacing) as well as CAVS require TCAS range validation.

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[56] The FAA expects the TIS–B "system to support four of the five initial ADS–B In applications. The FAA acknowledges that future ADS–B In applications may require improved representation of the position integrity metrics. With the SIL and SDA changes incorporated in DO–260B and DO–282B and possible changes to future versions of DO–317, the FAA plans […] to evaluate the usefulness of the broadcast of integrity parameters from TIS–B." 75 FR 30173.

[57] Some of the text in this section is based on the October 2010 ARC Legacy Equipage In-Service issue paper provided to the FAA at that time, which can be found in appendix N, ARC Recommendation on Legacy Equipment, in this report.

[58] See p. 6, Interim Policy and Guidance for Automatic Dependent Surveillance Broadcast (ADS–B) Aircraft Surveillance Applications Systems Supporting Oceanic In-Trail Procedures (ITP), AIR–130, May 10, 2010, which states that "TCAS-derived relative position information must be used, if available, to validate the reported ADS–B position integrity of Reference Aircraft with legacy transponders . . . However, ADS–B aircraft may be displayed on the CDTI IAW RTCA DO–317 for the Enhanced Visual Acquisition application […] without position integrity."

ACAS interrogations have a distance accuracy of about 35 feet[59] with high integrity and very low latency. Because the most critical FIM–S calculation of speed is based on the distance to the target and the safety and reliability of those operations is based on the integrity of that calculation, active interrogation would have the largest benefit against low-accuracy and integrity ADS–B targets (such as FMS-only and legacy RTCA DO–260 installations), ADS–R targets and TIS–B targets. Basically, with TIS–B (which would require a change to the TIS–B envelope for the FAA implementation), an FIM–S aircraft could perform IM against all non-equipped aircraft, an immediate and significant benefit increase. Active interrogation would also compensate for position error and latency and increase integrity in rule-compliant ADS–B targets. It can also provide continuity during GPS outages.

The following are the effects of active interrogation[60] with no change in current TCAS systems (fusion of along-track distance with ADS–B and ADS–R surveillance sources):

- Compensate for ownship position errors.
- Compensate for target position error and latency errors.
- Raise integrity levels.
- Determine the suitability of the version 0 or 1 information for use in the intended application.
- Spoofing mitigations.

The following are the effects of active interrogation on TIS–B targets (no change to TCAS but requires a change to the FAA TIS–B "hockey puck" for delivery of TIS–B that would require ground automation knowledge of FIM aircraft and target aircraft pair):

- Compensate for ownship position errors.
- Compensate for target position error and latency errors.
- Raise integrity levels.

The Extended Availability Risk Mitigation Plan (RTCA DO–322, ATSA SURF, annex D) significantly extends the availability of traffic surveillance for applications such as ATSA SURF and ATSA SURF I, thus providing immediate and early benefits of traffic situational awareness on the airport surface.

Recommendation 30: The ARC recommends the FAA include TCAS range validation as part of the evaluation (flight trials and operational evaluations) of ADS–B In applications deployed before 2018 to enable deployment in an environment with legacy ADS–B Out avionics.[61]

[59] ACAS range accuracy is specified in RTCA DO–185B (independent of transponder effects) to be no worse than 35 ft per RTCA DO–185B, par. 2.2.2.2.3.
[60] Note active interrogation using ACAS does not have spectrum implications.
[61] The year 2018 was selected by the ARC as a suitable point at which the limited remaining time before the 2020 rule effective date was small enough that the FAA should instead focus resources on developing ADS–B In applications focused only on rule-compliant ADS–B Out avionics.

4.4.3 ADS–B Out Equipage Environment After January 1, 2020

After January 1, 2020, aircraft operating in Class A, B, and C airspace, certain Class E airspace, and other specified airspace will be required to carry equipment compliant with the requirements laid out in the final regulation published by the FAA in May 2010 describing equipage requirements and performance standards including the carriage of avionics for the 1090 ES broadcast link or the UAT broadcast link.[62] Rule-compliant ADS–B Out installations are for the purpose of this paper referred to as "baseline ADS–B Out" equipage.[63]

The ADS–B Out equipage capability in the NAS after 2020 will mostly avoid mixed equipage issues (such as unequipped aircraft or aircraft equipped with legacy equipment) for operations in rule airspace. However, some limited governmental operations may be necessary in ADS–B Out airspace without broadcasting ADS–B Out, because of operational security concerns. This in itself will facilitate an environment for the wider deployment of ADS–B In applications that depend on all aircraft within a specified airspace.

4.4.4 Possible Evolution of ADS–B Out Equipage and Opportunities for Additional Message Sets

The ARC was specifically instructed to provide recommendations to the FAA for an ADS–B In strategy in consideration of the ADS–B Out avionics specified in § 91.227.[64]

The FAA ADS–B link MOPS invoked in the rule published in 2010 is currently the latest version of the standards as referenced in TSO–C166b (1090 ES) and TSO–C154c (UAT). These performance standards are updated from those proposed in the original NPRM in 2007 and incorporate changes that address public comments, the recommendations of the ADS–B Out ARC, and further requirements developed by the FAA and industry during finalization of the updated standards.

The direction from the FAA was specific and pointed to the existing regulation; however, research and development efforts are underway for applications that would require more data or higher performance in § 91.227.

Since the publication of the updated TSOs and final rule, the RTCA Special Committee responsible for the standards continues to evaluate the potential for additional message sets or requirements to be included in the MOPS in support of adding ADS–B applications to those that were standardized at the time of the 2009 MOPS update. Advocates of particular potential ADS–B applications—most noticeably those involving aircraft intent information and approach speed, wake vortex-related information, and position accuracies beyond that specified in the final rule (certain potential ADS–B applications on or near the airport surface)—have urged the development, between 2012 and 2017, of further updates to the link MOPS.

[62] See amendment 314 to 14 CFR part 91.
[63] Baseline ADS–B Out equipage is defined in § 91.227 and installed in accordance with AC 20–165.
[64] See ADS–B In ARC charter, section 4, which states, in pertinent part, "this ARC's recommendations should provide clear definition on how the community should proceed with ADS–B In, while ensuring compatibility with the ADS–B Out avionics standard defined in Title 14 of the Code of Federal Regulations §§ 93.225 and 93.227."

In particular, a review of the AIWP (as conducted by working group 1) points to wake information as one opportunity to provide additional ADS–B Out message data to either enhance or enable applications such as AIWP 14, FIM–DS with Wake Risk Management, and en route traffic flow management applications. RTCA SC–206 is developing an Operational Services and Environment Definition for a number of wake-related applications. However, there is concern within the ARC that any expansion to include wake information as part of the ADS–B Out message set would have a negative impact on rate of equipage. The ARC, however, notes wake information will primarily add value when provided by larger aircraft that generate significant wake. As a result, the risk from this discussion on equipping small aircraft, such as part 23 type certificated piston engine powered aircraft, is low because they could be exempt from expanding their data set to include wake. Part of the community believes there would be benefit if any aircraft broadcast information because that would enable ground and airborne systems to more accurately develop wing, temperature, and eddy dissipation rate (EDR) profiles for the airspace of interest because of the increased frequency of observations. While this may be true, the cost of expanding the requirement to all aircraft as opposed to just large air transport category aircraft is likely prohibitive. As part of any analysis involving a decision to expand the ADS–B Out information to include wake, it would be essential that the FAA determine the type and size of aircraft for which wake data provided through ADS–B would add value to the different ADS–B In applications such as AIWP 14.

Additionally, Final Approach Speed is an ADS–B Out parameter viewed by a portion of the aviation community as potentially improving the performance of terminal area ADS–B applications that involve ADS–B-supported IM in the terminal area, including for some applications that need to determine the safe wake separation that will be required on final approach.

Aircraft intent information additional to that in the current link MOPS has long been discussed in connection with, for example, Trajectory Operations and Airborne Conflict Management. The relative roles of ADS–B and two-way digital Data Comm links to support these applications remains to be determined.

Case Study for Wake Mitigation

In table K.2 of appendix K to this report, the ARC business case analysis for ADS–B In applications shows that one-third of the projected 2025 benefits of ADS–B In for air transport operators come from improved IM with wake risk management. The application of wake risk management to IM, using wake-related information from aircraft, is the top-ranked application, from a benefits perspective, in the analysis.

The transmission of wake-related parameters from aircraft enables a number of future air-ground applications and air-to-air ADS–B In applications. In table 2, the ARC has focused its recommendations on one of these applications, termed “GIM–S with Wake Mitigation.” In this application, enhancements to the GIM–S platform will allow wake-related information from aircraft to be used to provide intervals adjusted to improve ground-based IM. This could reduce the added wake turbulence separation down to current radar separation standards. This focus by the ARC has assisted in the formulation of an aggressive but achievable timeline for implementing initial applications using wake-related information transmitted from aircraft. An early step in the timeline is the specification of how aircraft need to be provisioned to transmit

wake-related information to support not only GIM–S with Wake Mitigation, an air-to-ground application of ADS–B Out transmitted parameters, but also a more complete set of future air-ground and air-to-air applications. The ability to provision aircraft for these applications as soon as possible will permit operators to implement the provisioning as part of equipping for the ADS–B Out rule.

This case study presents a set of wake-related parameters from aircraft, some of which are not provided in the ADS–B Out message set specified in the ADS–B Out rule, which will support not only GIM–S with Wake Mitigation but also a broad set of air-ground and air-to-air wake-related applications. The ARC finds ADS–B Out is an excellent candidate delivery mechanism for these additional parameters and presents its rationale. Accordingly, the case study then discusses how the parameters could be transmitted, for example, on the 1090 ES ADS–B data link, including a brief discussion of 1090 ES capacity issues (spectrum congestion), with several ARC recommendations in this regard. The case study concludes with the presentation and discussion of a notional timeline for GIM–S with Wake Mitigation implementation. The ARC provides several recommendations with respect to critical path items in the timeline.

The risk of introducing a new ADS–B Out standard that includes wake vortex mitigation parameters and the inevitability that this new standard will slow down ADS–B Out equipage must be balanced against the loss of the potential benefits that aircraft-generated wake data would provide to the NAS, as documented in appendix K.

The ARC is aware the choice of delivery mechanism for wake-related parameters from aircraft is a much-discussed issue. The ARC understands RTCA SC–206 has been tasked to develop AIS and meteorological (MET) SDA recommendations by March 2012, and that, per the Terms of Reference for RTCA SC–206, dated December 8, 2010, "recommended alternatives for AIS and MET data delivery architectures" will be provided. This case study assumes transmission of wake-related information from aircraft using ADS–B Out will be one such recommended alternative.

> **Recommendation 31:** The ARC recommends the FAA provide a briefing to the ARC on the results of the RTCA SC–206 analysis of alternative delivery architectures for AIS and MET data, and the FAA's view of this analysis, in the second quarter of 2012.

The ARC notes much of the data needed to support wake-related applications, such as position and velocity information, are already being transmitted using ADS–B Out at rates exceeding those necessary for ground-based wake vortex mitigation applications. Adding the wake parameters specified in table 6 below to ADS–B Out will also enable air-to-air use of ADS–B In for visualization of a wake-free zone on the primary flight display or heads-up display, giving flightcrews the confidence they need to accept reduced wake vortex spacing criteria. Air-to-air use of ADS–B In for depiction of a wake-free zone will likely be the "stressing case" for determining the required data update rate. A shared aircraft and ground infrastructure solution is likely to maximize the benefits from IM with wake risk management.

Background and Overview of Needed Wake-Related Parameters

The meteorological parameters needed for long-term wake vortex mitigation include wind, temperature, and EDR. Additional useful aircraft parameters include aircraft type, gross weight, and flap setting. Crosswind-based vortex mitigations could be enabled with only the wind data.

Wake turbulence researchers in the United States, Europe, and Russia have identified essentially this same set of input parameter requirements for real-time wake modeling purposes. If provided, this set of data elements would enable both mid-term (by 2018) and far-term (beyond 2020) wake solutions envisioned by the NextGen and SESAR programs. This is the so-called "perfect" set of data for which general scientific agreement exists that real-time predictions of the transport and decay of aircraft wake vortices can be developed if the data elements in table 6 can be obtained from the wake-generating aircraft.

An extremely important aspect of this data set is that successful near- and mid-term applications can be developed if only subsets of these data elements are available. For example, if aircraft weight is not available but aircraft type is known, conservative predictions of wake vortex strength can be based on maximum landing or maximum takeoff weights.

Some elements of the "perfect" data set (position and velocity reports and pressure altitude) are already broadcast in standard ADS–B reports. It is not necessary to rebroadcast data elements contained in other ADS–B messages as long as the existing broadcast rate meets or exceeds the timing requirements for advanced wake solutions. For example, broadcasts of static barometric pressure may not be required as it can be derived from the pressure altitude contained in a current ADS–B message.

An entire class of wake turbulence solutions reliant on crosswinds to remove wake turbulence from the path of trailing aircraft could benefit substantially from winds and aircraft positions delivered through the ADS–B data link. The minimum ADS–B data set required to support crosswind wake turbulence applications could consist of as little as wind speed, wind direction, pressure altitude, and aircraft position, speed, and heading as shown in table 6.

Only wind speed and direction would need to be added to the RTCA DO–260B/DO–282B ADS–B message set to support these applications. The operational benefits of a crosswind-based solution could be significant, but near the ground these solutions would deliver benefits only when the required wind criteria are met. In the en route environment, simple crosswind-based solutions could potentially be used in all-weather to ensure lateral offsets for wake avoidance are always flown to the upwind side of the wake generating aircraft's track.

The ability to accurately predict wake vortex behavior is a key component of most future NextGen and SESAR wake turbulence solutions. A "practical" minimum ADS–B-delivered data set (as opposed to the "perfect" data set discussed above) that preserves the ability to model wake turbulence in real time for both ground-based and cockpit-based applications is identified in table 6 below.

Once again, aircraft position, speed, heading, and pressure altitude are already available through existing ADS–B messages. The aircraft emitter type from which aircraft type information can be gleaned is also currently provided. A direct broadcast of aircraft type data is under

consideration within the ADS–B community for several reasons, including wake vortex applications. Aircraft type is a suitable alternative for aircraft weight for wake vortex applications. Potentially competitive sensitive aircraft weight data would then not need to be broadcast. For wake turbulence applications, the highest priority data elements are wind speed, wind direction, EDR, and temperature.

For ground-based wake turbulence applications, the aircraft type or aircraft weight data field and the pressure altitude data field could be eliminated, as these applications could access current networks of flight information to obtain aircraft type and altitude. Ground automation also has the benefit of acquiring and collating data from many sources other than ADS–B Out, and may be able to calculate the necessary parameters with sufficient precision to create an accurate wake model which would allow closer separation standards than are allowed.

With this minimum data set, most of the potential pool of wake turbulence benefits could be captured using ground-based or cockpit-based wake turbulence applications. Uncertainty buffers would be required if aircraft weight is not provided and no information is available to anticipate airspeed changes by leading aircraft. These buffers would necessarily detract from the benefits achievable, but not significantly.

Table 6—Different Wake Parameter Configurations That Each Would Enable Different Assessment of the Aircraft Wake for ADS–B In Applications

Wake Parameters	Perfect Set	Practical Minimum	Minimum
Wind Speed	X	X	X
Wind Direction	X	X	X
Static Temperature	X	X	
Static Barometric Pressure	X		
Aircraft Type	X	X (or weight)	
Pressure Altitude	X	X	X
Aircraft Position	X	X	X
Aircraft True Airspeed	X	X	X
Aircraft Heading	X	X	X
Aircraft Weight	X	X (or type)	
Atmospheric Turbulence (eddy dissipation rate)	X	X	
Aircraft Configuration (such as flap setting for potential future applications)[65]	X		

[65] The addition of aircraft configuration data provides information to more accurately determine when lead aircraft airspeeds will be changing so effects such as compression on final approach may be anticipated. These configuration data are not required for real-time modeling of the far-field wake vortices that are operationally significant.

The identified data set in table 6 as a practical minimum would enable a number of ADS–B In wake applications as well as ADS–B Out-enabled ground applications.

ADS–B is an Excellent Candidate Medium for Transmitting Wake-Related Parameters from Aircraft

The fully coordinated air/ground dynamic pair-wise wake turbulence separation systems envisioned for NextGen and SESAR operations require near-simultaneous air-to-ground and air-to-air exchanges of real-time data. The data required includes both aircraft position and velocity data as well atmospheric data. The NextGen and SESAR concepts also require a ground-based infrastructure to distribute the data to stakeholders and decision makers who can take operational advantage of opportunities to reduce separations. The ADS–B system is built to provide such data-sharing capabilities and is therefore an obvious candidate data link to enable future NextGen and SESAR wake solutions.

The following characteristics make the ADS–B system a prime candidate for the data link to enable NextGen and SESAR wake turbulence solutions using wake-related information from aircraft. The ADS–B system—

- Will be deployed and operating in time to support mid-term capacity-enhancing wake turbulence solutions already in development.
- Is already certified to collect and distribute data that can be used for aircraft separation purposes. The current ADS–B system complies with the FAA's safety management system requirements for systems involved in providing separation services. Most existing data links do not meet these requirements.
- Is already provisioned to broadcast many of the data elements needed to enable future wake solutions. Relatively few additional parameters broadcast at low rates would enable significant capacity benefits through reductions in required wake turbulence separations. Use of aircraft conducting routine operations in the NAS as real-time sources of weather data was among the originally envisioned uses of the Mode S 1090 ES. A significant body of existing literature can be leveraged to establish minimum performance standards.
- Is by design capable of meeting the near real-time data latency requirements needed to enable dynamic pair-wise separations, particularly for air-to-air applications.
- Will automatically provide the aircraft position and velocity data needed for future pair-wise wake turbulence separations.
- Provides the national (and potentially international) ground infrastructure required to distribute data to stakeholders and decision makers who can take operational advantage of opportunities to reduce wake separations.
- Can simultaneously support both air-to-ground and air-to-air data transmissions essential to developing coordinated air/ground wake solutions. A broadcast data link is preferred due to the complexities of determining which proximate aircraft are relevant to an end user and the enormous network bandwidth required to simultaneously provide high update rate context-sensitive data to each aircraft operating in the NAS.

- Can, in concept, enable both air-to-ground and air-to-air wake turbulence mitigations at all major airports and most areas of the NAS with one-time investments to enhance ADS–B data link capabilities and the supporting ADS–B ground infrastructure.
- Could potentially enable local benefits wherever needed worldwide through the installation of standardized ADS–B ground receiver stations that are relatively easy to deploy.

The baseline RTCA DO–260B and RTCA DO–282B documents already contain an example of ADS–B Out parameters needed to potentially enable future NextGen and SESAR wake vortex mitigation applications. Several of the parameters required to enable future wake solutions (for example, aircraft position, aircraft velocity, pressure altitude, and emitter category) are already broadcast in current ADS–B messages. Air Reference Velocity is a current ADS–B message element that may be broadcast when ground velocity is not available. Eight of the data elements needed for future wake applications have assigned ARINC data labels. The remaining three parameters are already in operational use on some aircraft, although standard data labels have not yet been assigned.

Latencies in the receipt of data needed to enable future wake solutions on the order of minutes would be disqualifying for the real-time air-to-air applications under consideration. It would not be possible to correlate expected wake lifetimes with specific wake-generating aircraft at specific locations. The relevant timescale for wake turbulence mitigations is defined by wake vortex lifetimes and the distances traveled by participating aircraft while wake turbulence avoidance is a consideration. In highly turbulent atmospheres, wakes may decay quickly, sometimes in as little as 40 to 60 seconds, even for heavy aircraft. Realizing the maximum benefit from future air-to-air wake avoidance applications will therefore require transmitting data affecting wake movement (such as wind speed and direction) every few seconds and parameters affecting lifetimes more frequently than once per minute. Current ADS–B system requirements for broadcast rates of ADS–B surveillance data (such as position and velocity reports) to mitigate the potential for collisions must be met when reduced aircraft separations are applied.

Transmission of Wake-Related Parameters in the ADS–B Out Message Set

Many formats can transmit ADS–B Out information with wake vortex mitigation parameters. An example of one possible structure can be found in the meteorological squitter application defined in RTCA DO–260B, appendix V. The first, format 1, contains the highest priority data elements for enabling appendix V applications (wind, temperature, pressure, and average EDR) and is suggested to be sent every 10 seconds from each equipped aircraft—an increase of 0.1 squitters per second per aircraft. This is a very low transmission rate compared to that of other ADS–B Out messages on 1090 ES. The second additional squitter proposed contains additional data elements that would enhance the performance of appendix V applications. The format 2 squitter adds data elements such as aircraft weight and configuration and also includes non-wake-related data such as humidity, icing, wind shear, and microburst hazards that are useful for other applications. It is suggested to be sent at a lower rate than format 1, once every 20 seconds. In the case of severe or hazardous meteorological conditions, the rate of format 2 squitters would be increased to once every 10 seconds, interleaved with format 1 squitter. The increased rate would last for a period of 24 seconds after the event that triggered it, then the aircraft would resume broadcasting only format 2 at the lower rate of once per 20 seconds.

Other potential techniques are possible to transmit the "practical minimum" data set or the "minimum" data set as described in table 6 without affecting the squitter transmission rate. These include the possibility of adding these parameters to existing squitters, such as the Flight ID squitter. It may be possible to include all of the "minimum" set of data, and possibly the entire "practical minimum" set of data using such techniques, without affecting the squitter transmission rate.

The 1090 MHz aviation spectrum hosts several applications whose performance is vital for ATC operations. Some examples of such ATC applications include TC beacon sensors (ATC radar beacon system (ATCRBS) and Mode S), ACAS, ADS–B (1090 ES), and multilateration surveillance. Hence, any new application seeking to employ the 1090 MHz spectrum must be carefully designed to ensure it does not adversely impact these existing systems both now and in the future as the ATC environment evolves and changes.

Because of spectrum congestion concerns on 1090 MHz, ICAO has levied a requirement that no more than 6.2 extended squitters per second average, measured over a 60-second period, be broadcast by any aircraft using 1090 ES for ADS–B Out. The proposed meteorological squitter application would require a change in maximum allowable squitters per aircraft from the current 6.2 per second average over a 60-second period to a normal rate of 6.35 average per second and an occasional increase to 6.4 average per second for short periods.

As has been briefed to the ARC by the 1090 MHz Spectrum Congestion Mitigation Project, a number of techniques to significantly reduce the usage of current 1090 MHz applications are under consideration, and several are being implemented. Among these are removal of the "Terra Fix" from Mode S sensors, use of hybrid surveillance in ACAS, a reduction in the number of radars as part of implementing ADS–B, and replacement of some older ATCRBS ground sensors with monopulse or Mode S sensors.

Other advanced techniques such as phase modulation (see section 4.4.5.3 below) have the potential to dramatically increase the available data bandwidth of the 1090 MHz spectrum. Phase modulation itself could more than triple the capability of 1090 ES ADS–B Out to transfer data, thus enabling many more valuable applications.

The 1090 MHz aviation spectrum is a vital resource that must be protected. This spectrum is a shared resource among several critical applications. Any proposed new user of the 1090 MHz spectrum must not overuse or interfere with existing services on the channel. Known paths and techniques to mitigate 1090 MHz spectrum usage may enable new applications such as meteorological squitter to successfully share the 1090 MHz channel for the foreseeable future.

Recommendation 32a: The ARC recommends the FAA investigate the possibility of adding either the minimum (Wind Speed, Wind Direction, Pressure Altitude, Aircraft Position, Aircraft True Airspeed, and Aircraft Heading) or practical minimum (Wind Speed, Wind Direction, Static Temperature, Aircraft Type, Pressure Altitude, Aircraft Position, Aircraft True Airspeed, Aircraft Heading, Aircraft Weight, and Atmospheric Turbulence (EDR)) set of data to the 1090 ES by reformatting existing squitters to support ADS–B wake-related applications.

Recommendation 32b: The ARC recommends the FAA confirm, through its 1090 MHz Spectrum Congestion Mitigation Project, the two low-transmission-rate extended squitters of RTCA DO–260B, appendix V that support wake-related applications can be added to the ADS–B Out message set without unacceptable impact to 1090 MHz spectrum congestion.

Recommendation 32c: If the FAA confirms the RTCA DO–260B, appendix V squitters that support wake-related applications can be added to the ADS–B Out message set, the ARC recommends the FAA coordinate with ICAO to increase to the current maximum transmission rate of 6.2 squitters average per second per aircraft to 6.4 squitters per average per second.

Recommendation 32d: Should the FAA not be able to confirm that the RTCA DO–260B, appendix V squitters can be added to the ADS–B Out message set, the ARC recommends the FAA consider multiple parameter transmission paths, including the use of new broadcast technologies such as phased modulation, to service the data needs of ground-based and air-to-air wake-related applications.

Implementation of GIM–S with Wake Mitigation as an Initial Wake-Related Application

The schedule chart below presents a notional, aggressive timeline for deploying GIM–S with Wake Mitigation as an initial major wake-related application in the NAS. The remainder of the case study discusses several aspects of this schedule in detail. The ARC emphasizes that the approach taken in the timeline is to permit, as rapidly as possible, operators to provision aircraft so that, with a software upgrade of ADS–B avionics, wake-related parameters can be transmitted from the aircraft using ADS–B Out. An operator could then choose whether to provision an aircraft for wake-related applications as part of early implementation of rule-compliant ADS–B Out. The ARC notes the importance of reducing provisioning risk—and the consequent for the 2013 aircraft provisioning specification to be detailed and complete.

STEPS	CY 2012	CY 2013	CY 2014	CY 2015	CY 2016	CY 2017	CY 2018	CY 2019	CY 2020
PROVISIONING									
Establish EDR algorithm (includes assemble crew and set a deadline; if not reached, will move on without it).	complete by end of year	Q1 definition/ decision							
Establish provisioning specification (includes appropriate interface specifications, concept of use and clearly defined parameters/results, determination of aircraft integration issues) (with OEMs)).		end of year							
STANDARDS									
Develop link MOPS (*possibly complete earlier than 2015*).									
Develop platform MOPS (DO 317) (air-to-ground application (*tentative changes*) and air-to-air visualization of wake-free zone).									
FAA ACTIVITIES									
Receive written FAA management commitment (*Note: this is a separate but parallel step, starting with the ARC recommendation (key decision for the JRC*)). FAA come to JRC decision on ground-based wake application.		end of year							
Perform GIM-S with Wake operational trial.					end of year				
Perform SRMD process						end of year			
TRIALS									
Run trials and validate MOPS and application.						end of year			
IMPLEMENTATION AND DEPLOYMENT									
Make software drop.							end of year		
Equip aircraft.									
Deploy in the NAS at 30 core airports (includes air traffic controller training, operational procedures (Pat Z)).									

working time
completion

NOTE: Schedule is not dependent on completion by ICAO of its ongoing wake categorization effort.

Figure 11—GIM–S with Wake Mitigation Timeline

Recommendation 33: The ARC recommends the FAA establish a GIM–S with Wake Mitigation implementation program consistent with the schedule in figure 11 above.

Provisioning the Aircraft for GIM–S with Wake Mitigation

A key element of the timeline in figure 11 is the development, by the end of 2013, of a provisioning specification for the transmission of wake-related parameters from aircraft.

To evaluate the maturity level of the wake data parameters used to populate the potential ADS–B Out squitters identified in RTCA DO–260B, appendix V, section V–4, the following criteria are used:

- Current availability of data on modern FMS-equipped air transport category aircraft, and
- The existence of a standardized parameter identification definition (ARINC label).

Of the parameters identified in RTCA DO–260B, appendix V, section V–4, for wake, ATM, and MET applications, the following were the highest priority parameters added to currently broadcast parameters to support air-to-ground and air-to-air ADS–B In applications that use the wake data. Only these parameters are evaluated:

- Wind parameters (Wind Speed, Wind Direction),
- Temperature (Static Temperature), and

- Atmospheric turbulence (EDR[66]).

As identified in table V–5 of RTCA DO–260B, appendix V, multiple sources of the wind and temperature data are currently on the aircraft, with the caveat that the sources are compliant with the appropriate ARINC standard. For example, Wind parameters are available from the FMS if the system is compliant with the ARINC 702 standard. Wind parameters are also available from an ARINC 704-compliant IRS. Table V–5 also identifies current standard ARINC 429 label definitions for the wind and temperature data parameters.

No standard source is currently available on the aircraft to provide EDR data, although a number of fleets in Europe, Asia, and the United States calculate EDR and transmit this data in meteorological reports via data link. A number of algorithms that compute EDR are available, but no standard defining the performance requirements of such an algorithm. Also, no standard parameter definition (ARINC label) exists for EDR. To enable the availability of the EDR parameter, standards development will be required to establish the performance of EDR algorithms considering existing available aircraft data parameters, systems to host the algorithm, and standard label definition for reporting the data.

Recommendation 34: The ARC recommends the FAA establish performance standards for EDR computational approaches by the end of 2012, consistent with the timeline for implementation of GIM–S with Wake Mitigation presented above.

Recommendation 35: The ARC recommends the FAA immediately initiate the necessary activities to, through appropriate standards bodies, standardize EDR data value encoding and label definition to support figure 11's timeline provisioning specification completion date of 2013.

Recommendation 36: The ARC recommends the FAA further mature its operational concepts for wake vortex mitigation to support development of an aircraft provisioning specification for wake applications by the end of 2013. The ARC finds the completion date of 2013 will permit early adopters of ADS–B Out to provision for this capability and later activate the capability with a software change to ADS–B avionics. This would minimize the risk of having to open up the aircraft for additional wiring in favor on a more limited change to the aircraft equipage

[66] EDR is a measure of atmospheric turbulence. Atmospheric turbulence level affects how quickly a wake vortex will decay (more turbulence results in faster decay).

Assurance, Certification, and Approval for Use of Aircraft-Transmitted Wake

Real-time, aircraft-centric wake mitigation solutions will require FAA certification. The safety arguments embodied in a safety case for such an aircraft-based or aircraft-centric system will be the responsibility of the applicant proposing use of such a system. While the FAA has reviewed no aircraft-centric wake mitigation systems, it has approved several operational changes within the past 3 years involving wake standards or wake mitigation concepts designed to safely increase airport capacity or introduce new aircraft into the operational fleet. The safety arguments for aircraft wake standards or wake mitigation operational procedure changes are based largely on non-real-time analysis of ground-based wake and weather observations using Light Detection and Ranging (LIDAR), wind lines, and dedicated meteorological stations. The safety arguments for these concepts extend the interpretation of the observed data using wake behavioral models or wake vortex impact models to assess the effect of a wake encounter on aircraft.

Significant research and development has been accomplished in the United States, Europe, and Russia to define requirements and build and test prototypes for real-time, aircraft-based wake mitigation systems. These aircraft-based systems fall into two main categories: those for wake avoidance, and those that rely on acceptably safe levels of wake encounter.

Wake avoidance concepts require real-time information primarily on the winds where the wake generator aircraft operates (as well as the generator aircraft type) so follower aircraft can predict wake vortex transport and decay. The required science for wake avoidance is largely embodied in the Wake Turbulence Mitigation for Departures (WTMD) system mentioned below. Once a minute, the WTMD system predicts crosswinds in the departure path valid for 5 minutes. An airborne wake avoidance system will need to predict three-axis winds valid for 90 to 180 seconds every 15 to 30 seconds. The WTMD wind forecasting algorithm operates comfortably in a standard desktop computer; prototype aircraft-based wake avoidance concepts require minimal computer resources.

A wake mitigation concept that provides indicators of safe wake encounter requires the wind and aircraft type information of the wake avoidance system, but also needs information on atmospheric turbulence and stratification to calculate wake vortex decay. Considerable research and development resources have been invested in developing and maturing real-time wake vortex predictors. The FAA Flight Standards Service (AFS) is presently identifying the "best of the best" of these wake vortex models to define a Flight Standards Wake Vortex Model, which will be used in FAA analyses and made available to the avionics community.

In addition to the real-time wake vortex predictor, an acceptably safe level of wake vortex encounter is required. AFS is developing such a standard to quantify acceptably safe wake encounters, a critical component of any airborne wake mitigation concept that relies on distance (or time) as a means of mitigating wake encounter effects. AFS plans to have a standard ready for industry comment by 2013 and available for use in 2014.

The time required for approvals of the wake standards or wake mitigation operational concepts listed below varies from less than 1 year (for the B787) to more than 8 years (for the A380). As the FAA Aviation Safety organization becomes more familiar with the wake observation systems, the wake behavior models, and the wake influence models, the time for approval has decreased.

In the past 3 years, the FAA has approved safety risk management documents (SRMD) for the following aircraft:

- B757–200/B757–300: The SRMD successfully argued that wake strength with time is the same or less for the heavier (>255,000 lb maximum certificated takeoff weight) 757 variant based on wake science. This established wake measurements and predictions as a robust means to establish safety of a proposed change. The outcome of this SRMD was to place all 757 variants in the same category. A change the weight boundary between the FAA Large and Heavy to 300,000 lb to align with ICAO Heavy/Medium boundary was also made.
- B787: The SRMD shows that the B787 (all models) is safely categorized as a Heavy aircraft, both as a leader and as a follower (potentially encountering a wake from a Heavy leader). Wake vortex decay and wake vortex encounter models were used in this SRMD. This established a relative means to compare the safety of a wake encounter for a new aircraft (Boeing 787) with those presently in the operational fleet and is relevant for an airborne wake mitigation system that relies on acceptably safe levels of wake vortex encounter.
- B747–8: The FAA accepted an ICAO-compliant safety case for the wake category recommendation provided to ICAO Air Navigation Bureau. The B747–8 is a Heavy wake category aircraft. This safety case analyzes ground-based LIDAR data on final approach, and uses wake models to extend the measured data into other flight phases. Wake impact models were used in this safety case to support the argument that the B747–8 can operate safely as a Heavy while following other Heavy aircraft.
- A380–800: The FAA is working with Airbus and the European regulatory authorities to revise the present A380–800 wake turbulence separation standards. These standards presently impose an additional 2 nmi separation for all aircraft following the A380. The Airbus approach to reduce the wake standard involves flight tests of deliberate wake encounters, analyzed with a number of wake vortex models, to show the effect of the A380 vs. a present Heavy aircraft (A340–600) on a Medium class aircraft (A321) and a Heavy aircraft (A300–600). While the FAA is open to wake standards revisions based on this data, the work is ongoing, and as such, has not accepted any wake separation revisions.

The FAA has also approved several SRMDs or ICAO-compliant Safety Cases for Operational Changes. These approvals include:

- FAA Order 7110.308, CSPR 1 ½ nmi Dependent Stagger. Approved for eight airports presently, with two to three additional airports added each year. The SRMD is based on ground-based wake vortex observations, processed in non-real time. The SRMD derives models of wake behavior from wake observations to extend the applicability of the observations to additional airport and meteorological conditions.
- WTMD. Uses a wind-forecasting algorithm to predict favorable crosswinds that support reduction in time between Heavy aircraft departures on downwind runways for CSPO. The WTMD SRMD is approved by the FAA, and WTMD is in procurement cycle. The WTMD SRMD uses observed data, wake models, and wind forecasting models. The wake and wind models are relevant for aircraft-centric wake avoidance concepts.
- Recategorization Phase I (Recat Phase I). This is a Static, six-category wake vortex operational concept. An ICAO-compliant safety case was delivered to the ICAO Wake Turbulence Study Group for review in March 2011. Final ICAO recommendations to the member states are expected in early 2012. The FAA has accepted the safety arguments in the ICAO Recat Phase I safety case. The safety case uses data-driven models for the wake decay and relies on projected wake circulation strength at specified distance as a measure of system safety. These are relevant for an aircraft-centric wake mitigation system involving acceptably safe levels of wake encounter.

Recommendation 37: The ARC recommends the FAA target completion of an SRMD for GIM–S with Wake Mitigation by the end of 2017.

Transmission of Wake-Related Information from Aircraft, ADS–B Data Link Standards, and Rulemaking—Potential Paths

The FAA tasked the ARC with providing feedback to the agency about developing a strategy for ADS–B In deployment in the NAS. One of the focal points of the strategy is the evolution of the ADS–B Out link standard beyond the regulatory standard identified in § 91.227 for RTCA DO–260B/DO–282B-compliant equipment.

As discussed above, a potential benefit pool would go unrealized if wake is not added to the ADS–B Out data set (or an alternative delivery medium) as either mandated parameters or standards are identified for those operators who would elect to equip their aircraft voluntarily to provide wake data by way of the ADS–B link.

The proposal to add wake-related parameters to the ADS–B Out message set can be addressed in several ways:

- Do nothing: This option would remove the opportunity for realizing the wake application's benefit pool through deployment on the ADS–B link.

- Voluntary equipage: Move quickly to mature the research, standards, and operational procedures for using wake to permit operators to voluntarily add ADS–B Out avionics where wake is enabled as part of their upgrade to meet the ADS–B Out mandate in 2020. Trailing aircraft, equipped for ADS–B In wake applications, could use aircraft providing wake data to conduct the wake application operations and conduct "normal operations" against target aircraft not equipped with the new standard.
- Voluntary equipage with catch-up rulemaking after 2020: This option would be similar to voluntary equipage, but include planning for a follow-on "catch-up" rulemaking to mandate a later version of the link standard (RTCA DO–260C/DO–282C) through an amendment to § 91.227 for certain aircraft types (such as large transport category aircraft)[67] or airspace (such as the 30 most congested airports).
- Mandate wake parameters to be part of 2020 ADS–B Out mandate: This option has the most significant impact and would require swift development of the RTCA DO–260C/DO–282C standard (the notional standard that would include wake), which would then be followed by rulemaking amending § 91.227 to include wake for certain aircraft types or airspace, completed early enough to permit all affected operators to meet the 2020 deadline.

Recommendation 38: The ARC recommends the FAA develop the GIM–S with Wake Mitigation application with an initial approach of voluntary equipage. The ARC finds as the development of the application progresses and the benefits are better understood, voluntary equipage with the FAA issuing catch-up rulemaking requiring equipage after 2020 may be a possibility, given appropriate consultation with the aviation community.

4.4.5 Availability and Spectrum Impact of Expanded Messages in MOPS

Although many valuable applications may be enabled by additional information content in ADS–B applications, the value of these additional applications must be balanced with the potential spectrum impacts of adding more transmissions on the 1090 MHz link. As was discussed previously in section 4.4.4, there are internationally established limits on the squitter rate for 1090 MHz.

If the additional applications are highly valuable, it may be worth invoking requirements to mitigate spectrum use, such as mandating ACAS with hybrid surveillance, or finding a way to potentially eliminate the use of Mode A and C transponders.[68]

[67] The ARC finds an opportunity may exist to differentiate "small" and "large" aircraft and whether requiring wake data as part of the ADS–B Out message would add benefit. As an example, if the wake parameter requirement was only applied to large aircraft, it would have less impact on the retrofit/forward-fit case and be justified by small aircraft produce minimal (de minims) wake. Alternatively, there may be an opportunity to limit the requirement to air carrier aircraft only or certain airspace; AFS has indicated willingness to segregate ADS–B In airspace, which was not acceptable for ADS–B Out.

[68] By this the ARC does not mean to imply that those operators that elect to equip with UAT to comply with the rule would have additional equipage requirements placed on them at a later time.

A threshold consideration in making further changes to the 1090 ES MOPS is the ability of the 1090 MHz spectrum to support additional transmissions by aircraft to those in the current MOPS, particularly in airspace with high traffic density. The topic of 1090 MHz spectrum saturation in such airspace has been addressed as an urgent matter by the ADS–B Out ARC and the FAA. This "spectrum problem" remains a significant risk to the SBS program and is managed by the FAA on an ongoing basis. Moreover, ICAO has levied a worldwide limit on the numbers of extended squitters that can be broadcast by a single aircraft. Aircraft transmitting all messages in the current MOPS are transmitting at a rate near this limit, and may exceed the limit for a very short period of time under certain circumstances. Therefore, the business case for an ADS–B In application that requires additional aircraft transmissions must be very strong—and stronger than that provided by other applications competing for additional ADS–B Out message fields to those currently provided.

4.4.5.1 Recognized Limits of the 1090 MHz Link

The current 1090 MHz ADS–B RTCA DO–260B MOPS has assigned most of the allowed specified bandwidth of the 6.2 per second ADS–B extended squitters average rate over a 60-second period. This has resulted in an ADS–B system with limited future growth capability to support additional data messages such as trajectory change information (RTCA DO–260B, appendix O), wake vortex and arrival management information (RTCA DO–260B, appendix V), and intended flight path information (FRAC FIM SPR) required for future applications.

The FAA is currently investigating ways to expand the bandwidth on the 1090 MHz link, with options including reducing the overall congestion on the spectrum frequency, allowing more squitters per second, and phased modulation.

4.4.5.2 Reducing Spectrum Congestion

The ADS–B Out ARC asked the FAA to address overall spectrum congestion with work underway inside the agency. Long-term reduced spectrum congestion could allow for increasing the squitter rate above the current 6.2 per second average over a 60-second period, which would enable an expansion of the bandwidth on the link.

The ARC understands that RTCA SC–147 is proposing to embark on changes to the hybrid surveillance and/or TCAS MOPS estimated to substantially reduce the number of interrogation responses on the link by approximately 60 to 80 percent.

Recommendation 39a: The ARC recommends the FAA validate the 60 to 80 percent estimate in the reduction in the number of TCAS interrogation responses.

Recommendation 39b: If the estimate is validated, the ARC recommends the FAA update the hybrid surveillance MOPS and, if warranted, the TCAS MOPS as well.

4.4.5.3 Phase Modulation

The FAA is exploring phase modulation as an opportunity to enhance the transmit data rate in a given bandwidth by applying this modern-day communications method to the existing ADS–B 1090 ES waveform. The additional bandwidth is provided by controlling the phase of the ES waveform instead of the current random phase transmission of pulse amplitude emissions. With 8 phase-shift keying, an additional three 112-bit messages per 1090 ES transmission are available, along with the original 112-bit pulse-position modulation message. This has the potential to provide for up to three times additional "discovered" bandwidth to support future growth capability while avoiding any new interference to the 1090 MHz link; that is, additional bandwidth without increasing the squitter transmissions that negatively impact the 1090 MHz interference environment. The ARC notes phased modulation is currently covered by several patents or U.S. patent applications assigned to ACSS.

The proposed technique could allow users that require the additional bandwidth to equip without affecting those that do not equip because during normal operations the current fielded 1090 MHz equipment does not "see" the additional three messages provided by the phase modulation.

Initial backwards compatibility testing has been performed by the William J. Hughes Technical Center, EUROCONTROL, and MIT Lincoln Laboratory, and has shown promising results as a viable approach.[69]

4.4.5.4 Increased Bandwidth Uses

Future mid- and far-term uses for ADS–B and other applications (for example FIS–B and aeronautical Data Comm), including the more advanced applications yet to be completely defined, would no longer suffer the current limitations for message data content and message update rates currently in place with the existing 1090 ADS–B system. The following are potential applications of phase modulation:

- Wake Vortex Mitigation. Message content and message update rates can be provided to support advanced air-to-air applications.
- Alternate Position, Navigation, and Timing (APNT Source Authentication, PVT Uplink). For the APNT solution where aircraft computes its position, additional APNT message content and message update rates can be provided for PVT uplink data for each user of the APNT system. No new interference is added to the 1090 environment because the phase modulation PVT information can be provided in the TIS–B and ADS–R messages already being planned for NextGen. Airborne-calculated APNT methods would use similar frequency and phase lock receiving methods required for receipt of phase modulation.
- Additional Data/Bandwidth Needs for Future ADS–B Applications. See RTCA DO–260B appendices O and V for envisioned message content to support future and more advanced ADS–B application needs. Potential use of the additional Data Comm should be considered and mitigated. Some capability provided by this coding technique

[69] See ICAO Aeronautical Surveillance Panel Technical Subgroup Working Paper ASP10–16, dated 11–15 April 2011, for results details.

should be allocated for DOD or military use. This could be done in a fashion similar to the allocation of some Mode S uplink and downlink messages for military use (for example, ultrafiltration/diafiltration (UF/DF)=19 and UF/DF=22).

While work is already underway to address spectrum congestion, no formal program exists to advance phased modulation techniques. The ARC finds phased modulation is one potential method to expand 1090 MHz bandwidth and makes the following recommendations to the FAA.

Recommendation 40: The ARC recommends the FAA continue ongoing work to address 1090 MHz spectrum congestion and determine the mitigations needed, based on expected traffic growth, to enable the range for the expected inventory of ADS–B In applications while also increasing the squitter rate above the current 6.2 per second average over a 60-second period and determine the additional data transmission rate that could be achieved and which applications would be enabled.

Recommendation 41a: The ARC recommends the FAA research, prototype, and demonstrate the phase modulation transmission function to determine its robustness and viability in the current and envisioned 1090 interference ADS–B environment. This includes ensuring backward compatibility with existing receivers that share the 1090 MHz frequency including Mode 5 systems[70] used by the U.S. military, the North Atlantic Treaty Organization, and other allies. The ARC notes the research should include confirmation that the phase modulation does not interfere with Mode 5 systems nor do the Mode 5 systems interfere with the proposed phase modulation. The ARC also notes this backward compatibility and viability with current uses of the 1090 MHz frequency should be ensured before endorsement by the ARC and U.S. Government.

Recommendation 41b: If backward compatibility, viability, and robustness for phased modulation are demonstrated with current uses of 1090 MHz, the ARC recommends the FAA develop applicable ADS–B MOPS requirements and test updates, and support ICAO Standards and Recommended Practices efforts to include the phase modulation Out and In capability within the next RTCA DO–260 MOPS update, and have international agreements in place for use when the MOPS is issued.

[70] Mode 5 is the DOD and NATO replacement for the Mark XII Identification Friend or Foe system. Mode 5 improvements include the transfer of secure, unique platform identification codes, secure Selective Identification Feature codes, and secure 3–D position data. Mode 5 introduces lethal interrogation and response formats to reduce fratricide potential and enable friendly platform response when operating under limited emissions conditions. Mode 5 Level 2 adds an autonomous capability to broadcast position and ID reports (similar to ADS–B). U.S. and Allied forces will employ Mode 5, along with other military and civil modes, during peacetime and in joint operations ranging from crisis response and limited contingencies to major campaigns, defense of the homeland, and civil operations.

4.4.6 Potential Impact of Changes to Link MOPS

An evolution of the ADS–B Out link MOPS would require development work at the technical level within RTCA/European Organization for Civil Aviation Equipment (EUROCAE) technical standards committees. However, beyond the technical work, several policy implications result from introducing a change to the link MOPS at this late stage in the ADS–B program's deployment phase. These include the timing of the operator's equipage decision, the costs incurred to upgrade the equipage and ground infrastructure, and the impact on international harmonization of equipage.

4.4.6.1 Operators Equipage Decision

One of the primary risks to the ADS–B program is the rate of equipage by the operator community with respect to meeting the ADS–B Out mandate. The first rule-compliant avionics are expected to be available to the market for air transport and GA in late 2011, leaving 8 years to retrofit the U.S. air transport fleet, as well as the business aircraft fleet and a large part of the GA fleet, to ensure airspace access after January 1, 2020. It is estimated that 4,500 air transport aircraft, 30,300 turbine-powered business aircraft, potentially over 14,000 military aircraft, and the majority of the 153,000 certified GA aircraft, as well as other GA vehicles, will be required to install the equipment. These installations will be done based on individual supplemental type certificates (STC), Approved Model List STCs, and, pending required policy changes, field approvals at a rate of 24,000 aircraft per year, which is one of the highest rates of avionics equipage ever undertaken. In addition to these aircraft, non-N-registered aircraft operating in the United States would have to become rule-compliant.

Several members of the ARC are concerned that the risk of a change to the equipment standard (specifically the link MOPS), even when a newer standard is not required by rule, would delay the operator equipage decision, placing some risk on the ability to meet the 2020 deadline. While the notional transition from version 2 (RTCA DO–260B/DO–282B) to version 3 avionics may be possible to achieve on some avionics platforms through a software upgrade, some of the proposed expansion of message information, such as wake-enabled applications, would also require additional input, such as EDR, information from weather-related sensors, possibly aircraft gross weight, and flap setting, as well as more specific intent messages containing trajectory control points.[71] The complete interoperability of version 3 avionics with version 2 avionics would be a requirement set in stone.

The value of applications gained by a change to the link MOPS must outweigh the risk added due to potentially delaying some equipage. Alternatively, the FAA must examine if it is possible to develop a new link MOPS and provide enough advance information on wiring changes to early adopters so the change from RTCA DO–260B to RTCA DO–260C could be a software upgrade. This strategy is a potential mitigation to the potential "slowdown" effect on equipage of introducing a new link MOPS.

[71] See RTCA DO–260B, appendix O, as well as earlier table 6 discussing wake.

4.4.6.2 Upgrade to Ground Infrastructure

Any link MOPS change would likely necessitate a concomitant change in the ADS–B ground infrastructure. Even if ground ATC systems did not require any message fields additional to those in the current MOPS (as is not the case, for example, for several wake-related applications under discussion), the ADS–R function would likely need to reflect new message fields and message sets.

The TIS–B service possibly need not reflect additional message fields and message sets, but any change in position accuracy reporting would need to be reflected.

The update from version 1 to version 2, which is currently underway, will cost the FAA about $3.8 million, or approximately $5,000 per radio subject to the change. The costs for more radios would be higher, but not necessarily a linear increase per radio.[72]

The ARC assumes any decision about a transition would ensure an evaluation of backward compatibility such that version 2 receivers could receive version 2 level of information out of version 3 transmitters, and the ground infrastructure would similarly accommodate both versions.

4.4.6.3 International Harmonization

The United States and Europe are coordinating on requirements for ADS–B for surveillance and ADS–B In to ensure a harmonized approach across the Atlantic. The European draft regulation laying down requirements for Performance and Interoperability of Surveillance for the Single European Sky points to the equivalent to RTCA DO–260B[73] requirements as the standards for Europe. The European regulation is currently planned to introduce mandates in 2015 and 2017 for forward and retrofit respectively.[74]

Considering the time required to initiate and complete the work on RTCA DO–260C, concern exists over introducing divergent requirements for ADS–B in Europe and the United States. Even if the divergent requirements were for non-mandated message fields and message sets, the consequent loss of interoperability should be avoided.

4.4.7 Requirement for Rulemaking

The technical issues related to which messages can be introduced into the link MOPS warrants significant evaluation by appropriate entities, such as RTCA SC–186, including a review of the issues outlined above.

However, under the assumption that the link MOPS are subject to an update to a later version, referred to in the ARC discussion as RTCA DO–260C/DO–282C, the ARC is faced with a strategy decision similar to the one for GPS.

[72] Request for data submitted to FAA July 15, 2011.
[73] See EUROCAE Document 102A.
[74] The European Single Sky Committee has endorsed the forward and retrofit schedule and the Surveillance Performance and Interoperability Implementing Rule was published in August 2011.

In the case of new rulemaking, the ARC expressed concerns about the time it would take from initiation until completion of a rulemaking task to amend § 91.227 with respect to performance. The existing regulation was initiated within the FAA as a Rulemaking Project Record Phase I in April 2006 with the final regulation published in spring 2010. While potentially less involved, any recommendation from the ARC related to amending the required equipment in § 91.227, primarily due to its cost implications and effect on strategy, should be approached with caution.

Recommendation 42: The ARC does not believe there is sufficient maturity in the wake or other potential data that could be added to RTCA DO–260C/DO–282C at this time and recommends the FAA not change the link MOPS requirement in § 91.227 pending additional work discussed above related to wake including consideration whether a rulemaking is required or can be achieved through voluntary means as identified in recommendation No. 38.

4.5 ACAS

RTCA SC–147 has been tasked with delivering a report with recommendations on future collision-avoidance system(s) that would be compatible with ACAS,[75] be more compatible with operations in congested airspace, and integrate ADS–B data effectively while recognizing that the integration of ADS–B In traffic and ACAS traffic on the same display must be considered during safety evaluation. This is a summary of the most likely recommendations that are expected in the report, which is due the fourth quarter of 2011.

The RTCA SC–147 report examines operational and technical performance issues observed in the current ACAS, as well as issues anticipated to emerge in the future as NextGen changes affect the airspace. It explores potential changes to address these issues, and addresses the maturity or readiness of these changes. The report comments on additional research and development that would be required, either to better characterize the issue, to develop solutions, or both.

Both issues and solutions are presented in two major categories:

- Issues affecting the current ACAS and changes that could be made to that system without substantial redesign. These are termed "near-term" changes.
- Issues anticipated in the future, and changes that would require either substantial redesign or that might use entirely new sources of surveillance data. These are termed "far-term" changes.

The near-term changes under consideration include the following:

- Updates to ACAS MOPS to further reduce ACAS use of the 1090 MHz channel, which is shared with secondary surveillance radar and ADS–B/ADS–R/TIS–B/Mode 4 and Mode 5 as well. These updates include efficiency improvements to both the standard ACAS MOPS and the ACAS Hybrid Surveillance MOPS. The RTCA Program Management Committee is considering a request by RTCA SC–147 to incorporate these changes into MOPS in 2012.
- Updates to provide some TCAS collision avoidance protection even when ownship transponder is not operational.

The far-term changes under consideration include the following:

- An entirely new approach to collision avoidance logic is being considered. The expected benefits of the updated logic would demonstrate improvement over the present version in reducing unresolved encounters as well as reducing the number of unnecessary, or so-called nuisance alerts.[76]

[75] This paper focuses only on ACAS (equipment built in accordance with RTCA DO–185B) and does not intend to address TCAS I (RTCA DO–197A) or similar traffic equipment.

[76] Nuisance alerts are defined in AC 25.1322–1, Flight Crew Alerting, as "an alert generated by a system that is functioning as designed but which is inappropriate or unnecessary for the particular function" with additional guidance in section 12 of AC 25.1322–1, with regard to "Minimizing the Effects of False and Nuisance Alerts," and 14 CFR § 25.1322(d).

- The use of ADS–B data is being investigated as an enabler to reduce nuisance alerts when sufficient lateral separation is available. Additionally, ADS–B data may enable horizontal maneuvers as well as the resolution of multi-aircraft encounters using both horizontal and vertical maneuvers.
- Improved logic also is expected to provide compatibility between ACAS and NextGen airspace, which is expected to result in reduced aircraft spacing and should facilitate the integration of manned and unmanned aircraft.

While the ARC discussed providing perspectives and recommendations about the evolution of ACAS as part of the ARC's recommendations to the FAA, it elected to instead defer the evaluation to RTCA SC–147 and not make any recommendations about the future of ACAS at this time as the evaluation work is not yet complete. As such, the ARC finds the work underway by RTCA SC–147 is important and can lead to improved interoperability of ADS−B, ADS−B In, and ACAS. The ARC does recognize that ADS–B In, especially applications that bring aircraft closer together in the terminal environment, will be among the drivers that will force changes to ACAS.

The ARC looks forward to reviewing RTCA SC–147's work product as it becomes available and will make further recommendations about the future relationship between ADS−B In and ACAS at that time. ADS–B data is viewed as an essential component to a future ACAS operation and use that better leverages direct interrogations compared to monitoring of aircraft using ADS–B dependent parameters.

Recommendation 43: The ARC recommends the FAA develop, as a priority, a future collision avoidance system that integrates ACAS and ADS–B as well as considers the operational concepts envisioned in NextGen.

Recommendation 44: The ARC recommends the FAA provide a briefing to the ARC in early 2012 about the FAA's response to RTCA SC–147 recommendations about future collision avoidance systems. At that time, the ARC will consider the impact on ADS–B In and exercise its discretion to provide additional recommendations to the FAA before the expiration of the ARC charter on June 30, 2012.

4.6 SPOOFING

The FAA has recognized the potential for nefarious actors to spoof[77] ADS–B, and has implemented mitigations to address these possibilities in the ground segment of the ADS–B system. While the mitigations used by the ground infrastructure may be sufficient for FAA ATC purposes, these mitigations will have no effect for an aircraft receiving these "spoofed" ADS–B signals. Risk analysis results may dictate the requirement for a method of independent verification by the aircraft for some ADS–B In applications. Currently, range validation is required on several ADS–B In applications for integrity purposes of non-rule compliant avionics. However, this requirement is not expected to be necessary for rule compliant avionics. Early analysis of the need to retain this capability or some other method of independent verification, if necessary, would be advantageous.

Recommendation 45a: The ARC recommends the FAA perform a risk analysis on the susceptibility of ADS–B In to intentional spoofing.

Recommendation 45b: Based on the findings of recommendation 45a, the ARC recommends the FAA provide guidance to manufacturers and operators on any required operational mitigations necessary.

Recommendation 45c: The ARC recommends the FAA brief the ARC on the results of the risk analysis in 45a when completed.

Many factors contribute to the probability that pilots and air traffic controllers could receive different operational pictures. Various filtering, validation, and anti-spoofing techniques can lead to this situation.

Anti-spoofing techniques are one factor that can lead to pilots and air traffic controllers using different representations of the traffic in an area. As currently designed, the ground systems will compare ADS–B Out messages with secondary radar and other techniques to validate the ADS–B signals. If the ADS–B position does not match the secondary radar position or other validation techniques by a pre-determined amount, the ADS–B information will be considered invalid and it will not be sent to air traffic automation. Many of these validation techniques will not be available or may not be currently required by aircraft avionics, and could lead to different operational pictures between the pilot and the air traffic controller.

[77] Spoofing is defined as unauthorized radio frequency transmissions by an unfriendly source pretending to be an aircraft or ANSP and giving credible false or misleading instructions to an aircraft ADS–B In system.

The decision by the FAA to automatically filter from the air traffic controller's display valid aircraft that do not transmit the integrity and accuracy requirements of the ADS–B Out final rule may also contribute to these different operational pictures. If aircraft avionics do not filter valid aircraft that do not meet the ADS–B Out rule requirements required for separation standards, given the current FAA filtering methodology, different operational pictures will result. Automatically filtering spoofed targets in the background may also delay or inhibit the ability to identify spoofed targets that an aircraft may consider legitimate. It is also unclear if ADS–R will rebroadcast spoofed ADS–B Out signals, which could then be received as legitimate targets on the opposite link by aircraft.

Air traffic controllers need to operate from an accurate real-time picture of all aircraft data in the airspace for the safety of all. If the cockpit displays do not filter information in the same manner as ATC automation, the pilot may have a more accurate picture of the traffic in their vicinity than the air traffic controller. This can lead to air traffic controllers providing control instructions the pilot may question, as pilots have a more complete understanding of the surrounding traffic. This could result in the pilot-in-command exercising his responsibility for the safety of the aircraft contrary to air traffic controller instruction, potentially inducing unintended risk. If the aircraft does filter out the information, no one will have the most accurate picture available of the airspace in the vicinity of the pilot's own ship.

Recommendation 46a: The ARC recommends the FAA evaluate the various filtering techniques of ground and aircraft systems because pilots and air traffic controllers may view different operating pictures because of varying filtering and validation criteria.

Recommendation 46b: The ARC recommends the FAA evaluate any risks incurred by aircraft and ground systems generating different traffic depictions, and any effect of automatically filtering valid aircraft that do not meet the ADS–B Out requirements for separation purposes. The ARC expects these evaluations will be part of the standard FAA certification process.

4.7 OWNSHIP POSITION SOURCE

While the ARC was developing its recommendations about a strategy for ADS–B In deployment in the NAS, the FAA published for comment draft AC–20 ADS–B In. The ARC took the opportunity to provide coordinated input to the FAA as part of the public comment process, which closed in February 2011 (see appendix O, Ownship Position Source ARC Comments, to this report, for the ARC's comments).

Following the publication of AC–20–172, the ARC identified one remaining issue related to display of ownship, which was viewed as potentially having a significant impact on near-term deployment of ADS–B In situational awareness application without incurring significant costs to change current aircraft architecture.

The ARC worked directly with the FAA to address these issues. The following section provides an overview of the issues, the discussions with the FAA, and the proposed change to future versions of AC 20–172.

4.7.1 Issue/Background

AC 20–172, paragraph 2.7(c)3 states the following:

> The same position source used to provide own ship data for transmission on ADS–B Out should be used to provide position to the ASSAP equipment. Position sources interfaced to the ASSAP equipment must meet the criteria in AC 20–165. Future applications may require that ASSAP and the ADS–B Out equipment use the same position source. Aircraft manufacturers should plan accordingly to prevent extensive redesign. An alternate position source may be used to provide own ship position to the CDTI display, but the accuracy, latency, and display time of applicability requirements still apply (refer to appendix 1). Provide connections in accordance with the manufacturer's installation manual.

AC 20–172 indicates the same position source used for ADS–B Out should be used for traffic processing (ASSAP) for ADS–B In (thus permitting different ownship position sources for ADS–B Out and ASSAP). AC 20–172 further states, however, that the ASSAP ownship position source must meet performance requirements in AC 20–165. (GNSS is the only known position source currently capable of meeting the 0.2 nmi integrity requirement at 10^{-7} per flight hour for 2020 rule compliance). AC 20–172 allows use of an alternate position source for display of ownship position if the source meets the accuracy, latency, and display time of applicability specified in AC 20–172, appendix 1, which does not actually specify accuracy requirements.

Boeing currently uses FMS position for ownship on most of the deployed fleet's navigation displays. The Boeing ASSAP provides absolute latitude and longitude position information for display of traffic on the navigation display. Therefore, any difference between the FMS-generated position and GPS-only ownship position would change the relative position of the traffic relative to the ownship position on the navigation display. It was agreed during the discussion that FMS ownship position is likely to meet the application-specific requirements for

situational awareness and ITP applications; however, FMS position would not meet the AC 20–165 requirement stated in AC 20–172 for an alternate position source for ASSAP. By way of example, the performance requirements in TSO–C195 for ADS–B In situational awareness applications only specify a position integrity requirement of 10^{-3} per flight hour for Visual Separation Approach, which an FMS position source can meet. Boeing indicated a strong desire for the same minimum ownship position source requirements as published in TSO–C195 to be used for both ASSAP and display.

The Airbus ASSAP provides relative position information in the form of range and bearing from ownship for display on the navigation display. Therefore, differences between the FMS generated position and GPS-only ownship position would not change the relative position of the traffic to the ownship position on the navigation display.

4.7.2 Resolution

Boeing and Airbus indicated that CDTI would be displayed only when the FMS is using GPS data as the primary navigation source. If GPS is invalid or has been deselected by the pilot such that the FMS is no longer using GPS (for example, if GPS is not allowed by the local ANSP), then the display of ownship on the CDTI will be removed. The ASSAP will use GPS data from the FMS, but will not source select on GPS side (left or right) based on which transponder is selected and transmitting ADS–B data.

The FAA requested the ARC suggest alternate wording for AC 20–172, paragraph 2.7(c)3.

> **Recommendation 47:** The ARC recommends the FAA revise AC 20–172 from "Position sources interfaced to the ASSAP equipment must meet the criteria in AC 20–165", to "Position sources interfaced to the ASSAP equipment must meet the requirements in TSO–C195, table 2–3". For updates to AC 20–172, the FAA should reference the updated TSO and corresponding table in the new document.

4.8 RESEARCH RECOMMENDATIONS

The ARC found several areas of uncertainty in its activities that future research could fully or partially address. Examples of these areas of uncertainty are generally listed in the ARC report as factors that prevent the assessment of application benefit, cost, or application performance.

Recommendation 48a: The ARC recommends the FAA coordinate amongst the appropriate research organizations the following research activities to further the analyses performed by the ARC and to support mid-term FAA ADS–B In implementation activities:

1. Develop and refine the less mature applications in table 2 through the development of new or expanded concepts of operations and proof of concept exploration though demonstration, simulation, or experimentation. This work is necessary for the FAA and the ARC to better understand the potential costs, benefits, and implementation timelines of the applications.

2. Replicate the nearer term AIWP applications in simulation, and specifically report on benefit metrics of interest to industry operators (such as fleet fuel savings and time savings) and of interest to the FAA on a national level (aggregated fleet fuel savings, carbon footprint reduction, congestion reduction, controller impact, and automation impact). This work is necessary to firm up the applications benefits case including implementation timelines.

3. Investigate mixed equipage environments (specifically the characterization of benefit and the equipage linearity or order of the benefit function to better justify the inclusion, or not, of an equipment mandate for specific applications). This work is necessary to firm up the applications benefits case including implementation timelines.

4. Investigate the suitability of using TIS–B as a surveillance source for specific applications. If TIS–B were to be found suitable, some applications could be significantly accelerated and benefits could be realized much sooner. This work is necessary to firm up the applications benefits case including implementation timelines.

5. Investigate the placement of CDTI and related auxiliary displays in the cockpit (for example, side versus forward field of view) to determine optimal placement of the avionics to ensure maximum usefulness and benefit to ADS–B In applications while also considering the cost and desired timelines of retrofit/forward-fit for the applications. This work is necessary for the FAA and the ARC to better understand the potential costs, benefits, and implementation timelines of the applications.

6. Complete the Third Party Flight ID research, as this is a basic enabler to many of the applications. This work is necessary to firm up CONOPS in support of upcoming operational approvals.

7. Support operational trials and demonstrations via demonstration/trial design, data collection, and analysis. This support is necessary to provide technical expertise for developing, executing, and analyzing the trial/demonstration to ensure the trial goals will be met.

Recommendation 48b: The ARC recommends the FAA ensure the research studies designed specifically in support of the ARC and the FAA should use current ADS–B standards and practices as a baseline for near- and mid-term applications. Hypothetical standards acceptable for longer term research (for example, proposed extensions or not-yet-well-defined conventions such as extended intent data or ideal range/reliability assumptions) may not directly support nearer term applications development and rulemaking.

The ARC stands ready to further advise the FAA on specific research needs and implementation, if the FAA desires that input.

5.0 2010 ARC RECOMMENDATIONS ON FIM–S, IM–DS, AND SURF–IA

The FAA also asked the ARC to make specific near-term recommendations about whether the FAA should continue development work on the following three applications: FIM–S, IM–DS, and SURF–IA. In its November 1, 2010, letter to the FAA, the ARC endorsed the continued development of the FIM–S and IM–DS applications, as well as focused investigation for and refinement of the SURF–IA application. The ARC also provided the FAA several recommendations about the development of each application, including some recommendations that pertain to the FAA's schedule for their deployment. See appendix M to this report for the letter submitted to the FAA.

In response to the ARC's recommendation, the FAA developed a near-term schedule for these applications, shown below in figure 12. The ARC used this diagram as part of its continued work on ADS–B In, and this report amends the ARC's October 2010 recommendation.

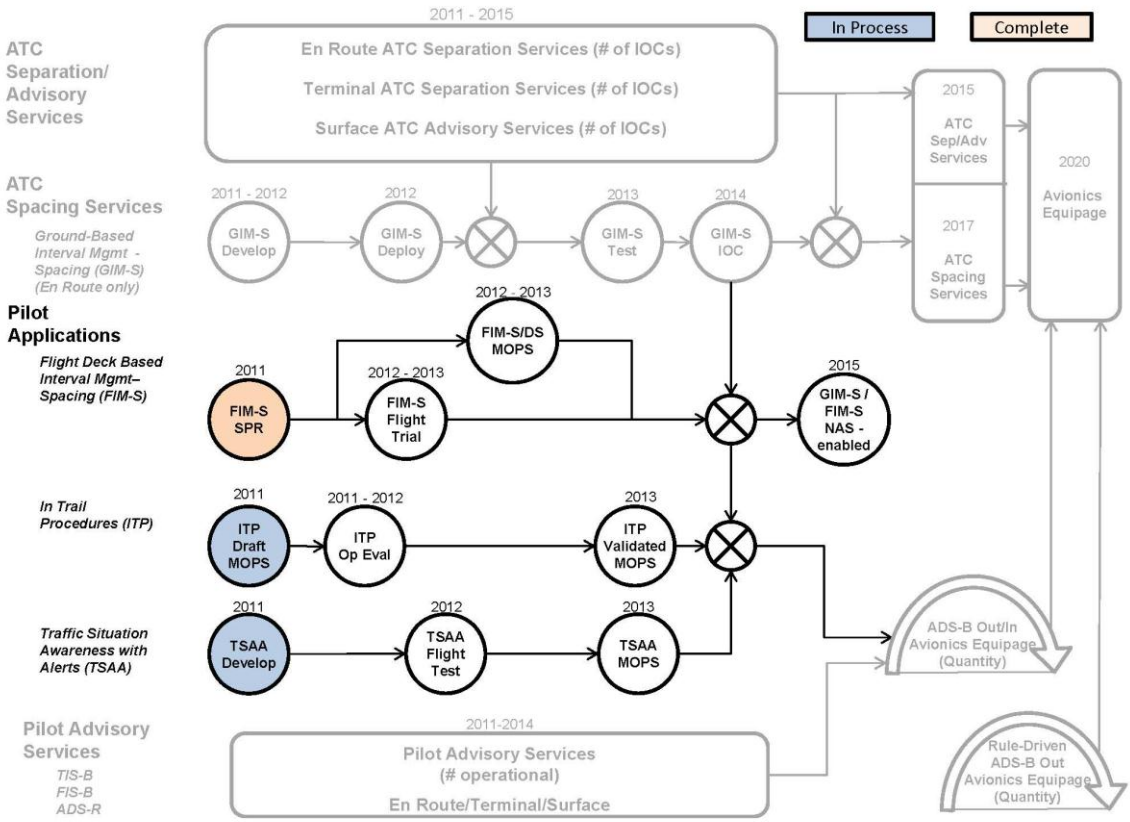

Figure 12—SBS Program Office Update

6.0 RECOMMENDATION ON LEGACY EQUIPMENT

The FAA gave presentations at the August 26, 2010, ARC meeting and the September 2, 2010, working group 2 meeting. The presentations outlined known issues with current 1090 MHz ADS–B Out performance and requested working group 2's input on how to deal with the situation. The ARC provided the FAA with the following recommendations. See appendix N to this report for the full text of the letter to the FAA.

In its November 1, 2010, letter to the FAA, the ARC recommended the FAA should—

- Not make any changes to TSO–C195 to address issues with legacy avionics.
- In the near term, work with involved parties (avionics manufacturers and operators) to address any known in-service issues. Until the problems are adequately characterized by the monitoring system, it is not necessary to modify TSO–C195. When the in-service problems are understood, they can be resolved using existing FAA and industry processes to ensure safe operations. One outcome of these processes could be that the FAA issues ADs.
- In the far term, begin characterizing any observed problems once its monitoring system is in place in mid-2011. One outcome of these processes could be that the FAA issues ADs. However, the ARC finds it is premature to reach this conclusion at this time. See White Paper on Legacy Equipment In-Service Issues in appendix N to this report.

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APPENDIX A—ADS–B IN ARC MEMBERS, SUBJECT MATTER EXPERTS, AND PRESENTERS

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Mr. Tom Hendricks, *Co-Chair*, Air Transport Association of America, Inc. (ATA)

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Mr. John DeBusk, FreeFlight Systems

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Mr. Bob Ellis, Rockwell Collins

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APPENDIX B—ACRONYMS

1090 ES	1090 MHz extended squitter
AC	advisory circular
ACARS	Aircraft Communications Addressing and Reporting System
ACAS	Airborne Collision Avoidance System
ACSS	Aviation Communications and Surveillance Systems
ADS–B	Automatic Dependent Surveillance–Broadcast
ADS–R	Automatic Dependent Surveillance–Rebroadcast
AFS	FAA Flight Standards Service
AIM	Aeronautical Information Manual
AIRB	airborne situational awareness
AIS	Aeronautical Information Service
AIWP	Application Integrated Work Plan
AMC	Acceptable Means of Compliance
ANSP	air navigation service provider
APNT	alternate position, navigation, and timing
ARC	Aviation Rulemaking Committee
ARP	Aerospace Recommended Practices
ASA–FAROA	Airport Surveillance Applications–Final Approach Runway Occupancy Awareness
ASDE–X	Airport Surface Detection Equipment, Model X
ASSA	Airport Surface Situational Awareness
ASSAP	Airborne Surveillance and Separation Assurance Processing
ATC	air traffic control
ATCRBS	ATC radar beacon system
ATM	air traffic management

ATMAC	Air Traffic Management Advisory Committee
ATN	Aeronautical Telecommunications Network
ATO	FAA Air Traffic Organization
CAASD	Center for Advanced Aviation System Development
CAVS	CDTI-Assisted Visual Separation
CDTI	Cockpit Display of Traffic Information
CEDS	CDTI-Enabled Delegated Separation
CFR	Code of Federal Regulations
CONOPS	concept of operations
CNS	communications, navigation, and surveillance
CSPO	closely spaced parallel runway operations
CSPR	closely spaced parallel runways
Data Comm	data communications
DI	defined interval
DME	distance measuring equipment
DO	Document (RTCA)
DOD	Department of Defense (U.S.)
DS	delegated separation
EASA	European Aviation Safety Agency
EDR	eddy dissipation rate
EFB	electronic flight bag
EPU	emergency power unit
EUROCAE	European Organization for Civil Aviation Equipment
EUROCONTROL	European Organization for the Safety of Air Navigation
FAA	Federal Aviation Administration

FANS	Future Air Navigation System
FAROA	Final Approach Runway Occupancy Awareness
FFOV	Forward Field of View
FIM	Flight-deck-based Interval Management
FIM–DI	Flight-deck-based Interval Management–Defined Interval
FIM–DS	Flight-deck-based Interval Management–Delegated Separation
FIM–S	Flight-deck-based Interval Management–Spacing
FIS	Flight Information Service
FIS–B	Flight Information Service–Broadcast
FMS	flight management system
FR	Federal Register
FY	Fiscal Year
GA	general aviation
GBAS	ground-based augmentation system
GIM–S	Ground-based Interval Management–Spacing
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HITL	Human-in-the-Loop
ICAO	International Civil Aviation Organization
IFR	instrument flight rule
IM	Interval Management
IM–DI	Interval Management–Defined Interval
IM–DS	Interval Management–Delegated Separation
IM–S	Interval Management–Spacing
IMC	instrument meteorological conditions

IRS	inertial reference system
ITP	In-Trail Procedures
JAA	Joint Aviation Authority
JRC	Joint Resources Council
LIDAR	Light Detection and Ranging
MEA	minimum en route IFR altitude
MET	meteorological
MFD	multifunction display
MMR	multi-mode receiver
MOCA	minimum obstruction clearance altitude
Mode S	mode select
MOPS	minimum operational performance standards
MORA	minimum off route altitude
MSA	minimum safe altitude
MVA	minimum vectoring altitude
NAC_P	navigation accuracy category for position
NAC_V	navigation accuracy category for velocity
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NextGen	Next Generation Air Transportation System
NIC	navigation integrity category
NPRM	notice of proposed rulemaking
NPV	net present value
NRA	non-radar airspace
NTSB	National Transportation Safety Board

OEP	Operational Evaluation Partnership
OPD	optimized profile descent
PFOV	primary field of view
PO–ASAS	Principles of Operations for the Use of Airborne Separation Assurance Systems
RNAV	area navigation
RTCA	RTCA, Inc.
SA	Selective Availability
SAE	SAE International
SBAS	satellite-based augmentation system
SBS	Surveillance and Broadcast Services
SC	Special Committee
SDA	system design assurance
SESAR	Single European Sky ATM Research
SIL	surveillance integrity level
SOIA	Simultaneous Offset Instrument Approach
SPR	Safety and Performance Requirements
SRMD	safety risk management documents
STC	supplemental type certificate
SURF	Airport Traffic Situation Awareness
SURF–IA	Airport Traffic Situation Awareness with Indications and Alerts
TAS	Traffic Advisory System
TCAS	Traffic Collision and Avoidance System
TDOA	time difference of arrival
TIS	Traffic Information Service
TIS–B	Traffic Information Service–Broadcast

TOD	top of descent
TPID	Third Party Flight ID
TSAA	Traffic Situation Awareness with Alerts
TSO	technical standard order
TTF	traffic to follow
UAT	universal access transceiver
UF/DF	ultrafiltration/diafiltration
VDL2	Very High Frequency Data Link Mode 2
VMC	visual meteorological conditions
VSA	Visual Separation Approach
WAAS	Wide Area Augmentation System
WTMD	Wake Turbulence Mitigation for Departures

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 an 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.

ACAS — Airborne Collision Avoidance System — The internationally accepted term for Traffic Collision Avoidance System (TCAS) II. The ARC uses the term ACAS as opposed to TCAS II where appropriate.

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 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 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 (NAC) for position, NAC for velocity, navigation integrity category, and surveillance integrity level for a given operation. Continuity can take into account the current satellite constellation and power.

Defined interval — An operation in which an air traffic controller maintains separation responsibility while assigning pilots a spacing task that must be performed within defined boundaries. This will enable a range of applications where dynamic interval spacing, closer than that currently allowed by traditional separation standards, may be possible.

Delegated separation — ADS–B application in which the air traffic controller transfers separation responsibility and corresponding tasks to the flightcrew, which ensures that the applicable separation minimums are met.

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 Federal Aviation Administration (FAA)), based on European Aviation Safety Agency Acceptable Means of Compliance 20–24, that the ARC expects will be approved for several ADS–B applications in the National Airspace System. Some DO–260-like equipment is expected to be easily modified to become DO–260-approved.

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 FAA TSO implementing DO–260) and vary from the final DO–260 standard in ways that are manufacturer-specific.

DO–260B — The link standard for transmitting ADS-B data on 1090 MHz per the ADS–B Out rule.

DO–282B — The link standard for transmitting ADS-B data on 978 MHz per the 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 universal access transceivers (UAT) operating on 978 MHz (for low altitude aircraft).

Hybrid surveillance — A technique for 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 TDOA of periodic, uniquely identified transmissions, which can include ADS–B transmissions.

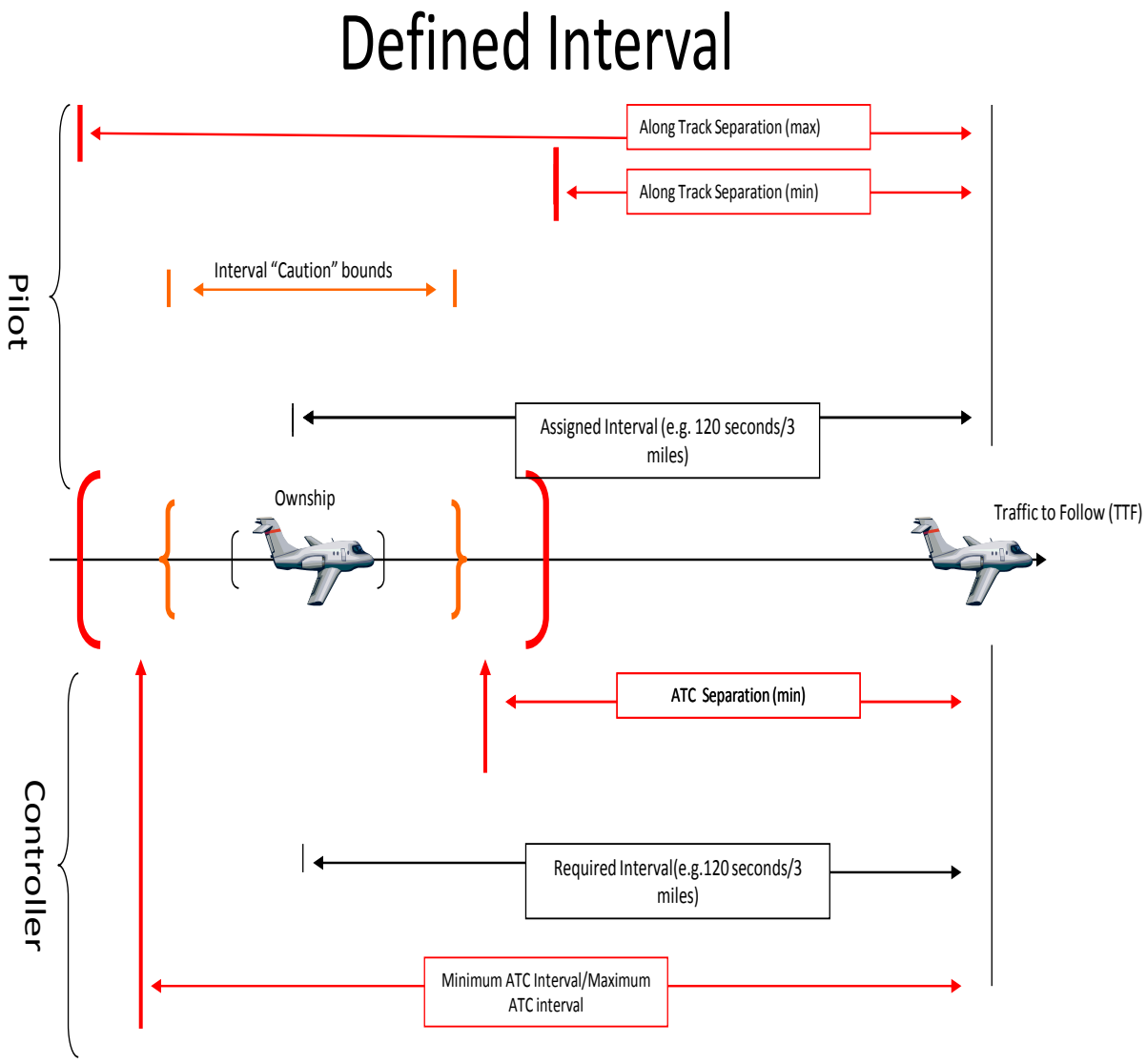
NextGen — Next Generation Air Transportation System. See www.jpdo.gov.

SA–On/SA–Aware — 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–Aware GPS receivers are designed so that no SA-related factors need to be included when estimating the accuracy and/or integrity of the GPS position.

TCAS II — See ACAS above.

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

APPENDIX D—DEFINED INTERVAL OPERATIONS CONCEPT



APPENDIX E—TIME-BASED VERSUS DISTANCE-BASED INTERVALS DURING ASSIGNED INTERVAL OPERATIONS

In general, assigned intervals should be transitioned from distance-based values to time-based values. Time is a better parameter for defined intervals, as a single value of time can be used from top of descent through to the stabilized approach point, and it will account for compression as aircraft slow for approach. It also may be easier to achieve higher throughput levels using the time parameter during strong headwinds, as using ground distance slows the arrival rate because of slower ground speeds on final approach.

United Parcel Service successfully demonstrated Flight-deck-based Interval Management–Spacing from 2007 to 2010, using 145-second intervals consistently from top of descent (TOD) to landing. Aircraft maintained the timed interval throughout the maneuver. The distance between aircraft at TOD was approximately 21–25 nmi and the interval during the approach/landing phase was about 5 nm. Time-based intervals have shown promise of delivering a high degree of repeatable and predictable spacing for interval management, by their very nature accounting for the compression that occurs during the arrival phase of flight. Because time-based intervals account for distance compression during arrivals, they should help solve capacity issues associated with strong headwinds on the final approach segment. To transition to time-based intervals, wake vortex separation criteria need to be defined in terms of time instead of, or in addition to, distance. Also pilot and controller decision support tools need to be designed and optimized to work in a time-based interval world.

Because controllers are familiar with working from distance-based intervals, Interval Management applications should initially allow for the use of distance metric, as decision support tools are developed for transition to time-based separation intervals.

APPENDIX F—OCEANIC INTERVAL MANAGEMENT

Oceanic Interval Management is the application of a new procedure where the flightcrew is assigned the task of maintaining a defined interval (DI) in front of or behind reference traffic on the same or a similar routing in a procedural separation environment. The procedure is similar to the Automatic Dependent Surveillance–Broadcast In-Trail Procedure (ITP), except that instead of transiting the reference traffic's altitude, the aircraft assigned a DI task is assigned to the same altitude as the reference traffic, with the assignment of maintaining a DI with the reference traffic.

The spacing interval is referred to as the "DI distance" and is defined as the difference in distance to a common point on each aircraft's track. When the aircraft are flying identical tracks, the IM distance and the actual distance between the aircraft are the same. In the case where aircraft are on parallel tracks, the DI distance is measured along the track of one aircraft using its calculated position and the point abeam the calculated position of the other aircraft.

If the aircraft is flying an assigned Mach number, the DI distance criteria takes precedence over the assigned Mach number. If the crew is unable to maintain the assigned Mach number and the spacing interval, they should adjust speed as necessary to maintain the spacing interval, and notify air traffic control as soon as practical that they are unable to maintain their assigned Mach number.

The oceanic DI task along with ITP should enable aircraft on oceanic tracks to be at their desired and/or optimum altitude the vast majority of the time.

APPENDIX G—PLANNED FINAL APPROACH SPEED DURING DEFINED INTERVAL OPERATIONS

To gain the most efficiency out of defined interval (DI) operations, the interval between aircraft should be adjusted for known performance differences between aircraft on final approach. For safety and pilot workload reasons, the DI task for pilots must end prior to the stabilized approach point on final approach. From the end of the DI task, aircraft are decelerating based on unique performance differences, and airframe-specific final approach speed rules. The aircraft deceleration performance from the end of the DI operation needs to be characterized, so that inter-arrival spacing can be optimized. Without a well-defined deceleration profile, additional buffers will need to be inserted in the system, causing inefficiencies. Although there are differences between aircraft manufacturers on the philosophy of how they design their aircraft to fly the final approach segment, it is possible to characterize the deceleration performance of all aircraft ahead of time with some knowledge of their gross weight, planned landing flap setting, and the wind field along the final approach path. This information can be used to predict how much compression will occur from the end of the DI task until the aircraft clear the runway after landing. It should be possible to maximize arrival throughput by reducing the inter-aircraft spacing on final approach by using this information.

Recommendation 49: The Aviation Rulemaking Committee recommends the Federal Aviation Administration ask airframe manufacturers to define the deceleration characteristics of their aircraft based on gross weight, flap setting, and wind field conditions so that the flight time from the end of a DI task until the aircraft crosses the runway threshold can be accurately estimated.

APPENDIX H—DEFINED INTERVAL

INTRODUCTION

Reliance solely upon ground-based navigation and surveillance tools is insufficient when advancing the objectives of a next generation transportation system. Federal Aviation Administration (FAA) Next Generation Air Transportation System (NextGen) initiatives are being designed to update the current state of communications, navigation, and surveillance to an advanced state incorporating Global Navigation Satellite System-supported functionality.

Aircraft systems and operator capabilities have capitalized on performance gains and optimization by enlisting many new technologies. The integration of systems and processes that allow optimization of the National Airspace System (NAS) is evolving.

Air navigation service providers (ANSP) including the FAA are making meaningful strides towards a reconciliation of these technologies and the functionality already embraced by aircraft operators. The Automatic Dependent Surveillance–Broadcast In Aviation Rulemaking Committee (ARC) working group 1 recognizes the static application of aged air traffic control separation standards as latent and an impediment to harmonization.

FINDINGS

Recommendation 50: The ARC recommends the FAA adopt a NAS state wherein traditional legacy air traffic control separation standards evolve into a multi-dimensional safety-based analysis of operational relationships. The ARC finds NextGen separation should be governed by circumstance and defined to achieve or maintain an allowable proximity.

A situational relationship would be assignable based on a valuation of risk, specific to a dimensional association, plus traffic management initiatives. Allowable proximity would respect any combination of aircraft, airspace or atmospheric phenomenon. Associations would factor legacy variables that include crew qualifications, aircraft configuration, phase of flight and intent.

Safety of operation dynamics would be predicated on NAS valuations of the introduction, tolerance and mitigation of risk. Collision potential and wake avoidance become benchmarks for instuitionalizing a "defined interval" (DI). Compliance would be gauged against risk rather than standard.

Solution sets of acceptable operations are assigned or applied to maximize runway occupancy, optimized climbs or descents, and optimized cruise performance.

DI would be defined as a situation specific requirement to ensure up to a four-dimensional relationship between a participating aircraft/airship and:

- Another participating aircraft/airship, and or
- Airspace, and/or
- An obstruction, and or
- Wake turbulence.

A DI would be dynamic and accommodate safety-based proximities that vary with time and phase of flight. Participants would transition to/from/between dimensional proximity relationships by design.

To achieve a DI automation would collaboratively determine a relationship in time and at intervals and quantify that relationship. Continuously cross-referenced matrix-derived relationships apply relevant existing and projected risk. Computational valuations would be compared against acceptable risk analysis and solution sets developed and ranked. In an interactive environment Human-in-the-Loop (HITL), sets are weighed for task achievement and assigned. In a "control-by-exception" envisioned environment HITL, application would utilize Automatic Dependent Surveillance–Contract or contract functionality to maximize system state.

As appropriate but fundamentally, DI would place precedence on time relationships as the preferred method of solution.

Incremental adaptation of these "up to" four-dimensional criteria would capitalize on technological advancements in communications, navigation and surveillance capabilities. In keeping with the goals and processes fundamental to NextGen initiatives, the adoption of DI as the premise platform would redefine and reauthorize the relationships between flightcrews and air traffic control.

The roles of both pilots and controllers would be dynamic to the extent that after quantification, the task of achieving, assuring and maintaining a non-risk-adverse operational relationship may be borne by both or either. Maintenance of a DI may be tasked to a properly equipped flightdeck.

> **Recommendation 51:** The ARC recommends the FAA retain responsibility for ensuring separation. The ARC finds the FAA should incorporate exceptions for operations wherein flightcrews are specifically authorized to interval their aircraft to/or on the final approach course in relation to another aircraft or the airport. The ARC envisions that "visual-equivalent" technologies such as Airborne Collision Avoidance System, Cockpit Display of Traffic Information (CDTI), CDTI-Enabled Delegated Separation (CEDS) or Flight-deck-based Interval Management–Spacing (FIM–S) applications should expand the incidence of exceptions.

DI would perpetuate the optimization of air traffic control operations by factoring improvements in surface control, low visibility operations, closely spaced parallel operations, converging and intersecting runway operations. NextGen initiatives would support and enhance arrival/departure optimized procedures including Performance-based Navigation, Time-based Flow Management, Collaborative Air Traffic Management, and environmental and energy sensitive considerations such as the Atlantic Interoperability Initiative to Reduce Emissions and the Asia and South Pacific Initiative to Reduce Emissions.

DI factors user dynamics by incorporating wind speed and direction data to include influenced vertical and lateral track and velocity. DI factors temperature, pressure and situational atmospheric conditions. Aircraft type, weight, configuration and equipage are included in matrix computations. Existing and evolving understandings of wake turbulence prediction and mitigation are supported and factored.

By bridging legacy separation standards, not replacing them, DI is fundamentally adaptive. Accommodating the operational diversity of the NAS is assured. DI is adaptable to any existing or conceived state of the NAS. It is scalable and may be implemented incrementally in concert with the evolutions of CEDS operations, FIM–S, Delegated Approach Spacing and Separation for Instrument Approaches, and Traffic Collision and Avoidance System.

In support of the conceptual process of "best-equipped, best-served," DI provides the flexibility to support increased throughput. Aircraft and aircrews whose technological attributes meet higher levels of sophistication will be assigned DIs that maximize operations by enhancing terminal, en route and oceanic operations. Conversely, those aircraft capable of operations using

only legacy/traditional equipage will be afforded no less than a DI that replicates the safety assurances of current legacy separation standards.

Gate, ramp, and surface operations will respect DI calculations and assigned tasks and will utilize comparative, interactive tower flight data management to maximize system state.

NAS considerations will continue to evolve over time but projections of the integration of unmanned aerial vehicles and commercial space flight operations are accommodated. Restrictions on airspace use as a result of factors these operations present fit the adaptive model. Fundamental Federal Aviation Regulation "see and avoid" considerations that currently complicate unmanned operations will be mitigated against technology and risk.

Aged standards optimized through understanding and technology will provide the opportunity for the NAS to achieve the highest system state efficiency. The commonality of these harmonizations meets an objective of interoperability, and complements International Civil Aviation Organization efforts to provide seamless ANSP services worldwide.

With requirements that baseline through a simple comparative analysis, the FAA will be able to offer commonality of specification that equipment manufacturers will use to enlist capabilities that can be relied upon to be safe, comprehensive and adaptive.

APPENDIX I—PHRASEOLOGY AND THIRD PARTY ID

Third Party Flight ID (TPID) is a required component of many Automatic Dependent Surveillance–Broadcast (ADS–B) In applications.

In an effort to minimize the possible duplication of efforts by various organizations concerning phraseology requirements and TPID associated with ADS–B applications, the Federal Aviation Administration (FAA) is partnering with numerous operators to develop and conduct various ADS–B In demonstrations using TPID. As these programs continue to mature, it becomes increasingly important to develop and implement standard phraseology that will support the operations and lay the foundation for ADS–B phraseology to be adopted into 7110.65, the Aeronautical Information Manual and International Civil Aviation Organization.

The Aviation Rulemaking Committee (ARC) finds the FAA should identify phraseology requirements, challenges, and risks associated with TPID. The ARC finds the FAA should form an appropriately supported Action Team to develop actual phraseology that can be validated through various Human-in-the-Loop analyses.

Recommendation 52: The ARC recommends the FAA develop national policy, procedures, and standards to enable the use of TPID by the end of FY 2012.

APPENDIX J—CEDS CONCEPT OF OPERATIONS

1.0 INTRODUCTION

Cockpit Display of Traffic Information (CDTI)-Assisted Visual Separation (CAVS) and CDTI-Enabled Delegated Separation (CEDS) are a set of procedures in which controllers assign, and pilots accept, separation responsibility from another aircraft in a manner similar to visual separation today to achieve an operational advantage in the National Airspace System (NAS). ADS–B is the underlying technology being used, and the airplane performing the CAVS/CEDS operation must have ADS–B In capability with an appropriate CDTI. For all intents and purposes, this concept of operations (CONOPS) document is focused on air carrier and high-end general aviation (GA) operations.

The basic differences between CAVS and CEDS are:

- CAVS must be conducted entirely in visual meteorological conditions (VMC); CEDS can be initiated in instrument meteorological conditions (IMC)
- CAVS traffic must be initially acquired visually out-the-window and then cross-correlated on the CDTI. CEDS traffic can be initially acquired on the CDTI.

Until such time as significant ADS–B Out equipage exists, the opportunity to perform CAVS/CEDS will be limited. Waiting until the ADS–B Out mandate has been implemented could significantly move the timeline for the adoption of CAVS/CEDS, as well as other ADS–B In applications, far to the right. The use of Traffic Information Service–Broadcast (TIS–B) as a "gap filler" is one potential solution to encourage early benefits. The ability for TIS–B to provide accurate position information for all aircraft in a terminal area, at least at the "Core 30" airports, would greatly enhance the viability of CAVS/CEDS in a mixed equipped environment. Appendix J–5 of this appendix outlines proposed CAVS/CEDS Minimum ADS–B/TIS–B Traffic Data Requirements**.**

> **Recommendation 53:** The ARC recommends the FAA conduct the necessary research and provide the resources to result in the enabling of TIS–B to supplement traffic information to support CAVS/CEDS during mixed equipage operations before the ADS–B Out mandate, at least at the "Core" airports.

The overarching concept of CAVS/CEDS *mirrors* visual separation as it is known today, augmented with appropriate cockpit displays that provide a more complete set of information about the traffic to follow (TTF) aircraft than can be derived from out the window contact. In CAVS/CEDS procedures, pilots are responsible for determining and maintaining safe separation from the assigned TTF aircraft just as in visual separation; controllers are responsible for separation from all other aircraft. CAVS/CEDS operations are modeled on current visual operations and will be developed and implemented by achieving an equivalent level of safety currently experienced. Appendix J–1 of this appendix provides a discussion of the regulations and practices used with respect to visual separation in the current system, and how CAVS/CEDS parallels those requirements. However, CAVS/CEDS is not a replacement for visual operations in the current air traffic system.

Over 10 years of research and development and line operations (See references 1–15) indicate that CAVS/CEDS procedures could be performed in the following operational domains:

- Visual approach
- Single runway instrument approach
- Parallel runway instrument approach
- Instrument departure
- Selected Airspace

Other CAVS/CEDS applications have been identified and could potentially complement other ADS–B In operations as experience is gained. These additional applications would encompass both terminal and en route domains.

This CONOPS provides a framework to enable early, low risk deployment, while providing a path to the more capable applications as operational experience evolves. Some of the capabilities enabled by CAVS/CEDS may include wake risk management with passive tools such as vertical situation awareness.

1.1 CDTI Common Display Elements and Location

For all CAVS/CEDS applications there is a common set of basic display capabilities that support the pilots' tasks associated with delegated separation. These capabilities include—

1. Plan view display of traffic, based on ADS–B In capability
2. Target highlighting, enabling pilot selection of a target to support continuous awareness of a particular target of interest
3. Traffic data on a selected target including—
    a. Aircraft flight ID (if available);
    b. Groundspeed;
    c. Altitude or relative altitude;
    d. Wake category;
    e. Closure rate or differential groundspeed, possibly including a closure trend indicator; and
    f. Distance.
4. Ownship data, including groundspeed, current wind direction and velocity.

A safety analysis of individual applications may indicate that additional capabilities are required for certain operations:

1. Wake situation awareness display, for example, display of TTF altitude history in elevation view.

2. Pilot selectable range alert (auditory and/or visual) to indicate that selected target has reached the selected range. This capability may also provide alerts when closure rate exceeds a selected value.

> **Recommendation 54:** The ARC recommends FAA CAVS/CEDS standards work considers the added value of a passive wake situation awareness display.

Certification and human factors analysis will be necessary to determine available electronic flight bag (EFB) locations that can be approved for CAVS/CEDS operations. Supplemental displays, such as the ADS–B Guidance Display (AGD) will be considered in this analysis when necessary. The FAA Human Factors Design Guide DOT/FAA/CT–96/1 defines Optimum Field-of-View for displays that are well within potential EFB installation locations.

> **Recommendation 55a:** The ARC recommends the FAA accomplish human factors studies to help maximize the usefulness of retrofit EFB installations.
>
> **Recommendation 55b:** If an EFB is installed in a position that is currently acceptable for paper chart display (chart clip), the ARC recommends the FAA also allow it to be acceptable for CAVS/CEDS applications. See Appendix J–4 of this appendix for further information.

1.2 General CAVS/CEDS Procedures

The basic delegated separation task assigned to the pilot is expected to function as today's visual separation, with controllers managing the overall flow of traffic and delegating separation to the flightdeck when it is operationally advantageous to do so. When pilots accept a CAVS/CEDS clearance, they will operate at a safe interval behind TTF and use the CDTI tools to manage the interval. If the flightcrew is unable to maintain a safe interval for any reason (for example, loss of the displayed TTF) they will immediately advise air traffic control (ATC), just as is done today during visual separation operations.

In all CAVS/CEDS procedures ATC retains responsibility for separation as is currently done for visual separation operations. If runway separation is at risk, ATC will issue a go around as required.

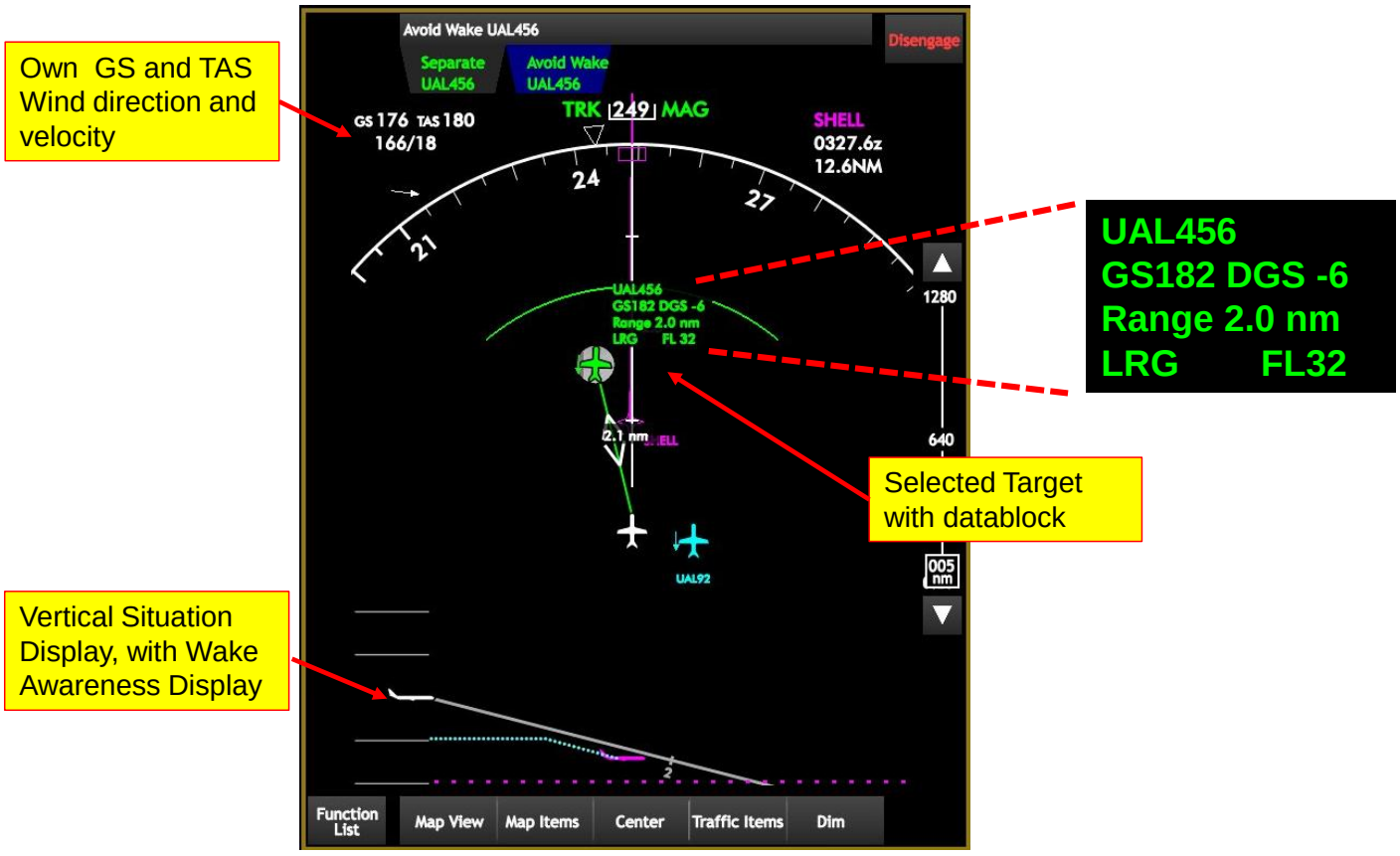


Figure J.1—Example Display used for some CAVS/CEDS applications

2.0 APPLICATION DESCRIPTIONS

CAVS/CEDS consists of the applications as described below. Appendix J–2 of this appendix provides an informal overview of these applications.

Phase I

2.1 CAVS Approach—Single Runway Arrival

CAVS is the simplest CAVS/CEDS operation, enabling pilots to accept separation responsibility from other aircraft with the aid of a CDTI. It is somewhat similar to the Airborne Traffic Situational Awareness for Enhanced Visual Separation on Approach (ATSA–VSA) application specified in RTCA, Inc., Document 314 (RTCA DO–314), Safety, Performance and Interoperability Requirements Document for Enhanced Visual Separation on Approach (ATSA–VSA), in that ownship must remain in VMC. The definition of the Visual Separation Approach (VSA) application in DO–314 states that information provided by the Traffic Display is not a substitute to out the window information and the pilot must maintain visual contact with the TTF Aircraft throughout the VSA application operation. However, fundamental difference between CAVS and VSA is that in CAVS the flightcrew is allowed to use the information provided by the CDTI for the traffic-to-follow (TTF), after visual TTF acquisition and cross correlation on the CDTI, as a substitute for out the window information. Therefore, once the TTF has been acquired by correlating the traffic on the CDTI with a visual acquisition of the traffic out-the-window, the CAVS can continue through the use of the traffic display when the traffic information out-the-window is no longer available (for example, lost in lights during approach at night).

CAVS can be conducted in conjunction with existing visual arrival and departure clearances and will not require any additional infrastructure or modification to ATC procedures.

> **Recommendation 56a:** The ARC recommends the FAA determine if avionics certified for VSA can qualify for CAVS operations.
>
> **Recommendation 56b:** If the FAA finds VSA certified avionics cannot be used for CAVS, the ARC recommends the FAA define the differences.
>
> **Recommendation 56c:** The ARC recommends the FAA conduct an analysis to use TIS–B to support the acquisition and following of the traffic-to-follow aircraft to dramatically improve CAVS benefits during mixed equipage operations.

The CDTI will provide situational awareness and optimize the visual approach; providing the pilots with the ability to more readily and more positively identify TTF, and to help maintain visual separation requirements during day and night VMC.

Operators will develop an approved training program, in accordance with FAA guidelines, to conduct CAVS operations. Techniques for achieving and maintaining appropriate separation with the information provided by the CDTI will be developed by incorporating recommended best operating practices for speed management, spacing and wake avoidance.

Autopilot and/or autothrust/throttle are not required for this application.

Aircraft are not required to be established on an instrument approach procedure or a defined path, such as an area navigation (RNAV) or conventional procedure. However, this does not preclude the use of such procedures during CAVS.

Special phraseology or procedures for ATC and pilots will not be a requirement of CAVS. CAVS will be conducted in conjunction with a visual approach clearance with the same ATC monitoring responsibilities. Using CAVS during arrivals will continue to require that controllers consider aircraft performance in their decision to delegate separation. This would apply to known final approach speed differences as well as runway separation. Once the pilot has visually acquired and accepted a visual approach clearance behind TTF, the pilot may use the TTF aircraft traffic information on the CDTI as a means for maintaining separation while performing a visual approach. As done today with a visual approach clearance, no specific spacing assignments will be made by ATC. The procedure would be applied behind all aircraft weight categories. Flightdeck speed command features of Interval Management will not be required in performing this application.

> **Recommendation 57:** The ARC recommends the FAA incorporate wake turbulence considerations and trajectory closure rate awareness into CAVS operator training programs.

Additionally, air traffic controllers will be expected to manage aircraft spacing and speeds that properly place CAVS aircraft in a position to successfully conduct CAVS operations. For example, do not clear a pilot for a CAVS procedure if the closure rate (overtake speed) is excessive and would require the pilot to take aggressive actions to reduce speed and closure rate. As in current visual approach operations, speed assignment or other typical arrival flow management tasks would continue to be applied to both aircraft, and ownship's pilot would continue to advise the controller if an instruction would lead to an unsafe or uncertain condition.

An approved electronic minimum/maximum distance/time alerting function will help to notify the pilot if the aircraft is within a predetermined distance/time from the TTF and would be programmable by the pilot. If installed, the alerting function would assist with situational awareness, wake avoidance, and would enhance repeatable and predictable CAVS operations. It is important to note this function is not intended to be used in the same functionality as Interval Management–Defined Interval (IM–DI) operations and therefore will not provide aircraft speed guidance to the pilot to acquire and maintain a specific interval.

Knowledge of the TTF aircraft final approach speed could aid pilots in managing spacing to the runway, but is not required. This information may permit CAVS aircraft to set an appropriate minimum/maximum distance/time alerting functions, which could reduce pilot and controller workloads on the final segment of the procedure.

Controllers remain responsible for separation on the runway and will continue to monitor approach spacing in the last segment of the approach to ensure that runway separation is not violated. Controllers also remain responsible for separation with other non-participating aircraft.

Pilots will monitor position of TTF aircraft visually (when in sight) and with CDTI display indications (for example, TTF distance and differential ground speed) and respond as necessary to unexpected behavior by the TTF (for example, failure to decelerate as expected) or system anomalies such as loss of CDTI TTF. Pilot will notify ATC of these unplanned events, just as they do during visual separation operations using out-the-window acquirement.

2.2 CAVS Departure

CAVS Departure will mirror visual separation operations as outlined in FAA Order JO 7110.65T Chapter 3 (for example, 3.10.3). CAVS Departure uses the traffic information from the CDTI to augment out-the-window visual contact with an aircraft to follow and enable pilots to accept separation responsibility from that aircraft.

The CDTI will provide situational awareness providing the pilots with the ability to more readily and more positively identify TTF, and to help maintain visual separation requirements during day and night VMC. As similar to CAVS Approach, the flightcrew is allowed to use the information provided by the CDTI for the TTF, after visual out-the-window TTF acquisition and cross correlation on the CDTI, as a substitute for continuous out the window information. Therefore, once the TTF has been acquired by validating the traffic on the display with a visual acquisition of the traffic out-the-window, the CAVS Departure can continue through the use of the CDTI traffic display when the traffic information out-the-window is no longer available (for example, lost in lights during departure at night). As in CAVS Approach, ownship must remain in VMC during CAVS Departure operations.

Operators will develop an approved training program, in accordance with FAA guidelines, to conduct CAVS Departure operations. Techniques for achieving and maintaining appropriate separation with the information provided by the CDTI will be developed by incorporating recommended best operating practices for speed management, spacing and wake avoidance.

Autopilot and/or autothrust/throttle are not required for this application.

Aircraft are not required to be established on a published departure procedure, such as a RNAV or conventional Standard Instrument Departure procedure. However, this does not preclude the use of such procedures during CAVS Departure.

Special phraseology or procedures for ATC and pilots will not be a requirement of CAVS Departure. CAVS Departure will be conducted in conjunction with a visual departure clearance with the same ATC monitoring responsibilities. Using CAVS during departure will continue to require that controllers consider aircraft performance in their decision to delegate separation. Once the pilot has visually acquired and accepted a visual clearance behind TTF, the pilot may use the TTF aircraft traffic information on the CDTI as a means for maintaining separation while performing a visual departure. As done today with a visual departure clearance, no specific spacing assignments will be made by ATC. Just as in current operations, the procedure would only be applied behind large and small weight category aircraft. Flightdeck speed command features of IM–DI will not be required in performing this application.

ATC assigned speeds, or other typical departure flow management tasks, would continue to be applied to both aircraft, and ownship's pilot would continue to advise the controller if an instruction would lead to an unsafe or uncertain condition.

Pilots will monitor position of TTF aircraft visually (when in sight) and with CDTI display indications (for example, TTF distance and differential ground speed) and respond as necessary to unexpected behavior by the TTF (for example, failure to accelerate as expected) or system anomalies such as loss of CDTI TTF. Pilot will notify ATC of these unplanned events, just as they do during visual separation operations using out-the-window acquirement.

As outlined in section 2.1, an approved electronic alerting function would assist in situational awareness in order to alert the pilot of minimum/maximum distance/time requirements. However, this function is not a requirement for this operation.

Phase II

2.3 CEDS Approach

CEDS Approach will permit sole use of CDTI to acquire and follow traffic in IMC to weather conditions of a ceiling of 1,000 ft and visibility of 3 statute miles, or lower, as appropriate for the particular airport. Once the minimum VMC ceiling is reached the completion of the operation will be identical to CAVS Approach. During initial operational approval the minimum ceiling may need to be higher to allow pilots and the operator to obtain operating experience (for example, initial minimum ceiling 5,000 ft).

Until the aircraft has transitioned to VMC, a requirement for CEDS Approach will include radar vectors when at or above minimum safe altitudes (minimum en route IFR altitude (MEA), minimum obstruction clearance altitude (MOCA), grid minimum off route altitude (MORA), minimum safe altitude (MSA), etc.) or the use of a defined path, such as a RNAV or conventional procedure, that insures obstruction clearance until the aircraft has transitioned to VMC. As weather minimums decrease, the benefits of a defined path increase. A defined path can be achieved by a Standard Terminal Arrival Route that provides lateral guidance to a downwind termination point, or a procedure that terminates at or transitions to an instrument approach procedure. This is illustrated in the following figure:

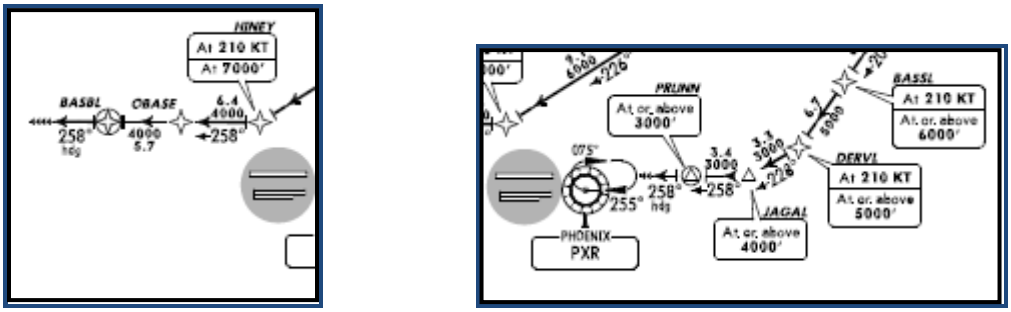


Figure J.2—Downwind Termination Versus Transition to ILS

Since aircraft equipped for CEDS will also be certified with ADS–B Out, the minimum vectoring altitude for these aircraft can be the minimum safe altitude (MEA, MOCA, grid MORA, MSA, etc.). Guidelines and policy will be required to determine the minimum VMC ceiling and visibility for each airport conducting CEDS Approach operations. Appendix J–3 of this appendix provides a basic construct of how the weather requirements are established for visual approaches and some of the factors that can generate surprisingly high ceilings for visual operations, resulting in reduced efficiency.

An approved electronic alerting function may add situational awareness to alert the pilot of minimum/maximum distance/time. This may help insure situational awareness while transitioning through the IMC layer(s) and provide an additional level of safety.

Other tools, such as Vertical Situational Awareness, may be beneficial. Guidance will be established for the use of such additional technology. In all cases, the actual separation provided will be based on pilot judgment, as in visual separation.

CEDS phraseology may be developed and established as standard phraseology for all CEDS operations, if necessary. It may be possible to modify current phraseology to cover visual, CAVS and CEDS operations (for example, Cleared for visual (or CEDS), maintain separation). *Note: A FAA/Industry work group has been formed to research the need for Third Party Identification phraseology and procedures.*

> **Recommendation 58:** The ARC recommends the FAA standards work determine if current phraseology can accommodate CEDS.

In a mixed equipage environment, ATC will need the capability to readily identify aircraft with CEDS capability. Pilots will also have the option to request a CEDS Approach clearance.

CEDS Approach is not intended to mirror or replace IM–DI. In fact, it could provide a transitional platform to IM–DI under certain conditions, such as airports that have attained a level of equipage for CEDS applications, but fall short for IM–DI operations.

In current Optimized Profile Descent (OPD) operations, a high degree of uninterrupted lateral and vertical flight path capability is accomplished with the procedure. When merging streams of traffic converge on one runway, ATC visual separation clearances are the primary tool to maintain maximum runway capacity in VMC. During IMC, OPD operations are frequently interrupted in order to insure minimum vertical, longitudinal, or lateral separation standards. With CEDS Approach applications, OPD operations would benefit from a high degree of uninterrupted flight paths.

In merging flow operations, the aircraft intervals achieved with CAVS or CEDS may be less than what IM–DI may be able to deliver. The ATC Feeder or Final Controller is tasked with merging multiple streams of traffic to a particular runway. Consistent with the issuance of visual clearances today, ATC would issue merging CEDS clearances with acceptable or appropriate merging geometries. Aircraft would fly the profile descent which incorporate altitude and speed constraints. The repeatability and predictability of the CEDS procedures will be comparable to that achievable through visual separation clearances and is expected to result in a consistent level

of spacing to the terminal environment and in close proximity to the airport (downwind) or directly to an instrument approach. In addition, CEDS Approach research suggests that an average of one mile of reduced longitudinal spacing could be achieved between aircraft landing on the same runway, compared to ATC arrival intervals applied in IMC conditions today.[78] CEDS Approach will enable the capability to maintain visual arrival rates in IMC for the final phases of the arrival procedures.

2.4 CEDS CloselySpaced Parallel Runways (CSPR) Approach

CEDS Closely Spaced Parallel Runways (CSPR) Approach is based on CEDS Approach procedures and can be conducted wherever visual or Simultaneous Offset Instrument Approach (SOIA) clearances are provided to CSPRs. Wake avoidance tools may assist in managing spacing.

Initially the procedure would only be conducted behind Large or Small category aircraft.

The procedure will use defined arrival paths and/or instrument approach procedures when aircraft are closely spaced. The CDTI, or primary flight display, would include a vertical situation display enabling pilots to assess and respond to wake concerns as the lateral separation between the TTF aircraft reduces closer to the runways. Pilots would monitor display information and respond as necessary to maintain appropriate wake avoidance behind the TTF on the adjacent approach. Specific additional restrictions may be placed on CEDS CSPR operations as results from on-going studies become available.

2.5 CEDS Departure

CEDS Departure—

- Is similar to CAVS Departure, except it will not require TTF initial visual contact by ownship before CEDS Departure is initiated.
- May require CEDS phraseology.
- May be conducted in IMC with minima established for each facility such that the tower can establish initial visual contact with the aircraft.

CEDS Departure uses the information from a CDTI or related flightdeck displays, for example, an AGD, to enable pilots to accept separation responsibility from a TTF airplane. As they do today when performing visual separation by direct visual contact out-the-window, pilots may use the TTF aircraft traffic information on the CDTI as a means for maintaining separation while performing a CEDS departure. Autopilot and/or autothrust/throttle are not required for this application. As in the current use of visual separation for departures, the procedure would only be used behind Large or Small category aircraft. The duration of such responsibility can be variable, but is typically of short duration, only long enough to establish another form of separation after takeoff, such as diverging headings (15° or greater), lateral separation of at least the radar minimum, or altitude separation as is done today with visual departures. Controllers will continue to manage the departure interval to account for known performance differences, for example providing additional spacing behind a slower accelerating Regional Jet.

[78] ATC delivered separations usually exceed the minima.

2.6 Airspace CAVS/CEDS

Research indicates that other CAVS/CEDS applications are possible that mirror visual separation used in terminal airspace today. Additional applications such as parallel runway and parallel path operations, merging in terminal airspace, and applications in en route airspace are being studied and appear to hold promise. Provisions will be made for accommodating additional CAVS/CEDS applications as operational experience is gained and appropriate research and development is completed.

Recommendation 59: The ARC recommends the FAA write the CAVS/CEDS standards as broadly as possible and take a functional approach to advance CAVS/CEDS to as many applications as possible.

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APPENDIX J–1—VISUAL OPERATIONS AS A FRAMEWORK FOR CAVS/CEDS OPERATIONS

The current requirements of FAA Order 7110.65, Air Traffic Control, Chapter 7 (Visual), section 2, Visual Separation; and the guidance in Aeronautical Information Manual (AIM) paragraph 4–4–14, Visual Separation, provide a basic *framework* for the application of potential CAVS/CEDS procedures. Specific visual separation requirements that seem directly *adaptable* to CAVS/CEDS operations include:

> FAA JO 7110.65T Paragraph 7–2–1 Visual Separation:
>
> Aircraft may be separated by visual means, as provided in this paragraph, when other approved separation is assured before and after the application of visual separation.

For CAVS/CEDS operations, the general ATC requirement for another form of separation before and after the application of CAVS/CEDS would still apply.

> Paragraph 7–2–1 continues:
>
> To ensure that other separation will exist, consider aircraft performance, wake turbulence, closure rate, routes of flight, and known weather conditions. Reported weather conditions must allow the aircraft to remain within sight until other separation exists. Do not apply visual separation between successive departures when departure routes and/or aircraft performance preclude maintaining separation.

Using CAVS/CEDS during arrivals and departures would continue to require that controllers consider aircraft performance in their decision to delegate separation. This would apply to known final approach speed differences as well as acceptable separation between departures when issuing the takeoff clearance. Additional spacing should be provided when climb or acceleration performance differences between successive departures is known. For CAVS operations, the paragraph 7–2–1 requirement that weather must allow aircraft to remain in sight will apply. CEDS procedures would not require such conditions and in fact could be performed in IMC.

For pilots, the AIM provides additional guidance that could be adapted to CAVS/CEDS operations, in lieu of direct visual contact:

> AIM Paragraph 4–4–14 Visual Separation:
>
> a. Visual separation is a means employed by ATC to separate aircraft in terminal areas and en route airspace in the NAS. There are two methods employed to effect this separation:
>
> 1. The tower controller sees the aircraft involved and issues instructions, as necessary, to ensure that the aircraft avoid each other.
>
> 2. A pilot sees the other aircraft involved and upon instructions from the controller provides separation by maneuvering the aircraft to avoid it. When

pilots accept responsibility to maintain visual separation, they must maintain constant visual surveillance and not pass the other aircraft until it is no longer a factor.

NOTE−*Traffic is no longer a factor when during approach phase the other aircraft is in the landing phase of flight or executes a missed approach; and during departure or en route, when the other aircraft turns away or is on a diverging course.*

b. A pilot's acceptance of instructions to follow another aircraft or provide visual separation from it is an acknowledgment that the pilot will maneuver the aircraft as necessary to avoid the other aircraft or to maintain in-trail separation. In operations conducted behind heavy jet aircraft, it is also an acknowledgment that the pilot accepts the responsibility for wake turbulence separation.

NOTE−When a pilot has been told to follow another aircraft or to provide visual separation from it, the pilot should promptly notify the controller if visual contact with the other aircraft is lost or cannot be maintained or if the pilot cannot accept the responsibility for the separation for any reason.

For CAVS/CEDS operations the requirement of sub-paragraph a(2), which mandates "constant visual surveillance", may be accomplished by any combination of actual visual contact and information provided by the CDTI. Loss of direct visual contact would not require notification to ATC if the CDTI TTF is still available and used for the separation task. The "maneuvering" reference in sub-paragraph b, especially with regard to maintaining in-trail separation may be limited to speed adjustment when CEDS procedures are used during instrument approaches. The CEDS display tool set is designed and expected to provide the information required to enable these adjustments to be made by pilots in a timely and safe manner.

The Note in a(2) also suggests natural termination points for CAVS/CEDS Approach responsibility. CAVS/CEDS responsibility would end the same as visual separation operations currently end. For departure operations, CAVS/CEDS would terminate when "the other aircraft turns away or is on a diverging course". Pilot responsibility for wake turbulence separation also applies during CAVS/CEDS operations, for which additional CDTI tools may provide useful information.

The requirement for controller notification of inability to continue the separation task called out in the Note to sub-paragraph b of 4–4–14, will also apply to CAVS/CEDS. For example if a pilot is performing a CEDS Approach operating in IMC using the display to perform the delegated separation task, and a malfunction occurs resulting in a loss of TTF, the pilot must advise ATC as soon as feasible. In this case separation responsibility is handed back to ATC, just as it would be if actual visual contact is lost during a visual approach with visual separation in today's operations.

To summarize, each of these common ATC requirements would apply to established CAVS/CEDS procedures, regardless of the actual visibility existing at the time, and provide a framework for the conduct of CAVS/CEDS across a range of operational domains.

Weather conditions will determine the specific responsibilities assigned to the flightcrew during CAVS/CEDS operations, and will include both visual and normal instrument approach or departure procedures. Controllers retain responsibility for the overall flow of traffic and will use CAVS/CEDS procedures when they will provide an operational advantage. The delegation of separation responsibility is always at the discretion of the controller, and the decision to accept that responsibility is always up to the pilot. In this way CAVS/CEDS operations are collaboration between controller and pilot to achieve operational efficiency in the NAS.

APPENDIX J–2—CAVS/CEDS APPLICATIONS OVERVIEW

This appendix attempts to provide an overview of the CAVS/CEDS applications described in this document in a manner such that those familiar with the history of these applications can distinguish the phases and evolution of the applications.

1. CAVS Approach (Single Runway Arrival CAVS Phase I):

CAVS was originally developed as CEFR in R&D, and is referred to as CEFR in early publications such as references 1–3. It was authorized as CAVS for operational use by UPS (See References 6–9). It requires an initial visual acquisition of the traffic to follow (TTF); then a cross-correlation with the TTF on the CDTI. After that, the TTF may be "lost" visually, but the procedure allows flightcrews to complete the visual approach based only on the CDTI TTF. It does not require new phraseology (although it does not preclude the use of call signs by ATC to point out targets.) It uses the same visual approach requirements as in use today. Ownship always remains in VMC. It does not require ownship to follow an instrument procedure.

2. CEDS Approach (Single Runway Arrival CEDS Phase II)

This phase authorizes sole use of CDTI to acquire and follow traffic to the runway. Until the aircraft has transitioned to VMC, a requirement for CEDS Approach will include radar vectors when at or above minimum safe altitudes (MEA, MOCA, grid MORA, MSA, etc.) or the use of a defined path, such as a RNAV or conventional procedure when below minimum vectoring altitude. This phase may require new CEDS phraseology and enables minima of ≥1000 ft and 3 statute miles visibility for approaches. During initial operational approval the minimum ceiling may need to be higher to allow pilots and the operator to obtain operating experience (for example, initial minimum ceiling of 5,000 ft).

3. CAVS Departure

Initial visual acquisition by crews; then CDTI cross correlation by crews; then CDTI-based separation. Initial runway separation (for example, 6,000 ft and airborne) is provided visually by ATC. Ownship remains in VMC.

4. CEDS Departure

Initial visual acquisition by crews is not required; initial acquisition on CDTI alone is acceptable; and continued separation based on CDTI alone. Initial runway separation is provided by ATC. Ownship does not need to remain in VMC after initial conditions are satisfied.

5. CEDS CSPR Approach

CEDS CSPR Approach is envisioned to develop in two stages. In stage I, it is used in conjunction with SOIA simply to enable a more robust application of SOIA, where the

CEDS CDTI provides crews with the ability to formulate a wake strategy well before visual acquisition, removing uncertainty in the ability of sustaining the SOIA operation and providing more predictability for controllers to repeatedly issue SOIA clearances.

In stage II, CEDS CSPR Approach is envisioned to constrain approach geometries such that crews are provided with a more benign geometry in which to proceed in a CSPR approach. An initial 1.5 NM separation, and Large aircraft leading, are examples of such restrictions.

6. Airspace CAVS/CEDS

Airspace CAVS/CEDS is the place where all other CAVS/CEDS applications are captured. Numerous such CAVS/CEDS applications that mimic or parallel visual operations have been identified and more are expected to be desired both by ATC and the operators, as experience is gained with CAVS/CEDS. CAVS/CEDS for merging and crossing in terminal airspace, and en route airspace are examples of two CAVS/CEDS applications documented in research.

APPENDIX J–3—CONSIDERATIONS FOR ESTABLISHING VISUAL APPROACH MINIMUMS AND CRITERIA

There are numerous factors and considerations that drive and determine the minimum weather requirements used for visual approaches at each air traffic facility. As a baseline, ceiling requirements are 500 ft above the minimum vectoring altitude (MVA). Numerous airports are impacted by Class B airspace constraints and vertical separation requirements for parallel runways.

The following examples will better illustrate:

- The MVA for Airport A is 2500 ft, so the Visual Approach (VA) minimums are technically 3000 ft.
- The floor of the Class B is 3500 ft, which drives the minimums up another 500 ft to 3500 ft from the MVA requirement.
- In order to get aircraft below the cloud deck for the visual, 500 ft is added, so 4000 ft becomes the ceiling minima.

Using the same set of circumstances, Airport A has parallel runways. The standard vertical separation of 1000 ft is used between parallel traffic until aircraft are cleared for the visual approach.

- This now raises the VA ceiling to 5000 ft.
- 500 ft is added for the cloud deck and 5500 ft becomes the minima.

If Airport A conducts triple parallel arrivals, the ceiling can drive up to as high as 8000 ft before maximum utilization of VMC arrival rates can be achieved.

CEDS operations can clearly augment visual approaches by enabling controllers to conduct visual-like approaches in reduced weather minima. Incremental phases of reducing the weather requirements could result in operational enhancements for the NAS.

APPENDIX J–4—EQUIPAGE REQUIREMENTS FOR CAVS/CEDS

This section provides general equipage requirements and considerations for CAVS/CEDS.

EQUIPAGE REQUIREMENTS

Certification and human factors analysis will be necessary to determine available EFB locations that can be approved for CAVS/CEDS operations. Supplemental displays, such as the AGD should be considered in this analysis when necessary. Advisory Circular 20–172 "Airworthiness Approval for ADS–B In Systems and Applications" states that an installation in the forward field of view (FFOV) (14 CFR §§ 23.1321 and 25.1321) will provide the best situational awareness and support subsequent upgrades to other ADS–B applications. These regulatory paragraphs state each flight, navigation, and powerplant instrument for use by any required pilot during takeoff, initial climb, final approach, and landing must be located so that any pilot seated at the controls can monitor the airplane's flight path and these instruments with minimum head and eye movement. The FAA Human Factors Design Guide DOT/FAA/CT–96/1 defines Optimum Field-of-View for displays that are well within potential EFB installation locations.

- Range Advisory Alerting – provide an advisory to the flightcrew when a defined minimum distance range to traffic-to-follow is reached on a FFOV display (auxiliary guidance panel or primary flight displays).
- Traffic Computer – provides the ADS–B In traffic processing and an ARINC 735B Display of Traffic Information File (DTIF) interface to the CDTI.
- Traffic Select/Couple – provide selection and coupling of traffic-to-follow when performing CAVS/CEDS.

EXAMPLE AIRCRAFT RETROFIT EQUIPAGE ARCHITECTURE

The architecture shown in figure J–4.1 was derived from an existing installation on a United Parcel Service of America, Inc., Boeing 757/767 aircraft. This architecture is envisioned to support the CAVS/CEDS application.

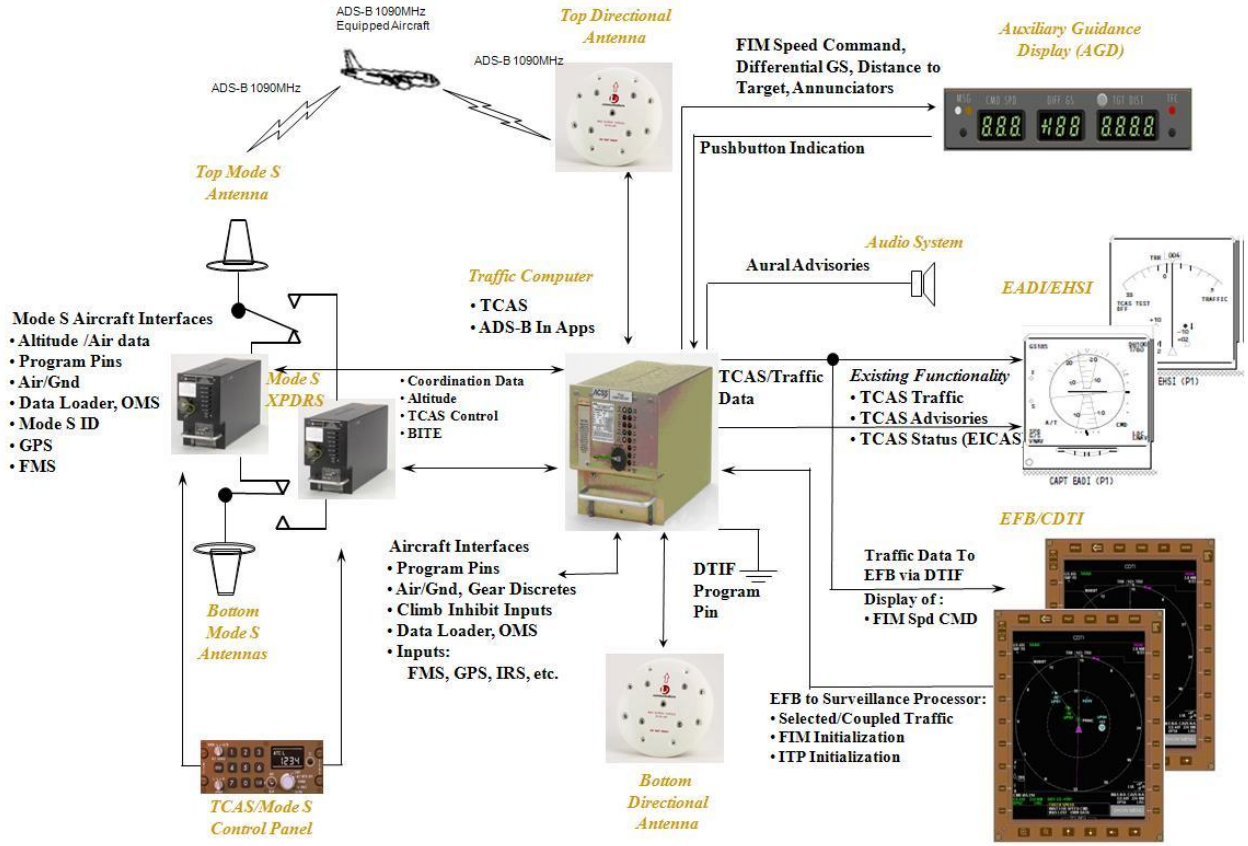

Figure J–4.1—Example CAVS/CEDS Aircraft Equipage Architecture

The architecture shown in figure J–4.1 consists of the following components:

Class 3 EFB (figure indicates Dual but only single is required) – Host the following functions:

- CDTI hosted on Class 3 EFB (side display) (Note that some retrofit installations could use mini multi-function display with same features.)
    - Integrated display of ADS–B and Traffic Collision and Avoidance System (TCAS) Traffic
    - Application Controls hosted on Class 3 EFB
    - Traffic Select/Couple
    - ADS–B In System Status Advisory Messages

- ARINC 735B DTIF interface to Traffic Computer

Auxiliary Guidance Display (AGD) in FFOV (Single):

- Speed Guidance (Not applicable for CAVS/CEDS, intended to support Flight-deck-based Interval Management–Spacing (FIM–S)/IM–DI)
- Distance to coupled traffic
- Differential ground speed
- Visual caution/warning alerts/advisory annunciators (for example, CAVS/CEDS Range Advisory, system status, etc.)

Traffic Computer (Single):

- ADS–B In processing (ADS–B Receive, Airborne Surveillance and Separation Assurance Processing (ASSAP)) and applications integrated into TCAS
- A735B DTIF interface to EFB/CDTI
- Aircraft State Data Interfaces to Traffic Computer (Global Positioning System (GPS), flight management system (FMS), etc.)

Since the EFB/CDTI is installed in the flightdeck side panels (side display) and not in the FFOV, an Auxiliary Guidance Display (AGD) is used to provide the pilot with ADS–B In application data required in the FFOV. It is mounted below the mode control panel as shown in figure J–4.2.

Figure J–4.2—AGD FFOV Installation Example

The AGD provides distance and differential ground speed to the traffic-to-follow to support applications such as CAVS/CEDS operations.

Two annunciators (white and amber) are provided on the AGD to indicate to the flightcrew that an application status system advisory (for example, range alert, etc.), or system failure (for example, ADS–B fail, etc.) message is available on the CDTI for review. An additional annunciator (red) exists on the AGD is used in conjunction with aural alerts, to notify the flightcrew of situations that require immediate pilot awareness and immediate pilot action.

APPENDIX J–5—PROPOSED CAVS/CEDS MINIMUM ADS–B/TIS–B TRAFFIC DATA REQUIREMENTS

The following traffic data requirements are based on the requirements associated with UPS CAVS application:

- Flight Identification (required for CEDS, if available for CAVS)[4]
- Position Latitude/Longitude
- Navigation Accuracy Category for Position (NAC_P): $NAC_P \geq 7$ (0.1 nmi, 95 percent)
- Pressure Altitude
- Velocity
- Navigation Velocity Accuracy[79]: $NAC_V=1$ (10 m per second, 95 percent)
- Navigation Integrity Category (NIC)[3]: NIC≥6 (0.6 nmi)
- System Integrity Level (SIL)[3]: SIL≥2 (1E–05)
- System Design Assurance[80]: SDA≥2 (1E–05), provided via Version 2 ADS–B/TIS–B

Additional traffic data parameters to enhance the operation:

- Emitter Category[4]

Note: The current draft of RTCA DO–317A identifies the following accuracy, integrity, and design assurance data requirements for VSA as follows:

- Navigation Accuracy Category: $NAC_P \geq 6$
- Navigation Velocity Accuracy: $NAC_V=1$ (10 m per second, 95 percent)
- Navigation Integrity Category: NIC≥6
- System Integrity Level: SIL≥1 (1E–03)
- System Design Assurance: SDA≥1 (1E–03)

[79] Currently set to zero by TIS–B service. Position message Type Code set to unknown NIC.
[80] Currently not supported by TIS–B service on 1090 MHz link. SDA and SIL Supplement not provided by TIS–B.

APPENDIX K—OPERATOR BUSINESS CASE ANALYSIS

1.0 Analysis Objectives and Document Overview

Working group 3 was chartered with looking at benefits and costs for the Automatic Dependent Surveillance–Broadcast (ADS–B) In Aviation Rulemaking Committee (ARC). The working group focused on the following objectives:

- Develop a sequence of application bundles that maximize benefit-cost. (See section 5.2 of this appendix.)
- Provide data for stakeholder to make decisions in regards to equipping for ADS–B In. (See section 3 of this appendix.)
- Help the Federal Aviation Administration (FAA) identify a strategy that maximizes the return on investment for ADS–B In. (See section 5 of this appendix)

This appendix is structured as follows:

- Section 1: Analysis Objectives and Document Overview: Identifies the objectives for working group 3 in the ADS–B In ARC and provides an overview to this document.
- Section 2: Decision Hierarchy: The decision hierarchy identifies decisions that have already been made, strategic decisions that need to be made, and tactical decisions that can be made later. The Decision Hierarchy is a tool to help frame a decision problem.
- Section 3: Business Case: Identifies the business case for GA operators and air carriers to equip for ADS–B In.
- Section 4: Lessons: Identifies specific lessons working group 3 gathered throughout the analysis process.
- Section 5: Strategic Decisions: Provides recommendations for the three strategic decisions identified for ADS–B In.
- Section 6: Next Steps: Recommends next steps from a benefit-cost /business case perspective.

2.0 DECISION HIERARCHY

A decision hierarchy is tool to frame a decision problem. Decisions are categorized into three categories:

1. Policies: Decisions already made.
2. Strategies: Decisions we need to make now.
3. Tactics: Decisions that can be made later.

2.1 Policies

"Policies" are decisions already made that do not require any further analysis and that stakeholders have agreed to. Sometimes they are unstated assumptions that need to be documented. Policy, in this context, is a label that does not necessarily imply the usual definition of policy in Washington, DC. Working group 3 identified the following policies:

- AIWP Applications 1, 2, 3, and 5 are early applications the FAA has already committed to.
- Efforts will be made to make equipage and procedures globally interoperable.
- ADS–B Out (260B) will be mandated in year 2020.
- ADS–B In mandate, if any, will occur no earlier than 2020.
- Continue implementing applications as they are available.
- Implement a strategy to validate the business case for the high-value applications that apply to most operators.
- Incentives for equipage may vary by airport or region (including flight level) depending on operational needs.
- "Walk before you run" approach–Flight-deck-based Interval Management–Spacing (FIM–S) must be deployed and trialed before high-value Cockpit Display of Traffic Information (CDTI)-Enabled Delegated Separation (CEDS) applications and Interval Management–Delegated Separation (IM–DS) applications.
- Need to define Best-Equipped, Best Served (we will let others define that).
- The FAA needs a streamlined process to approve applications currently outside bounds of current policies and procedures.

2.2 Strategies

Given these policies and the focus on ADS–B In implementation in the NAS, the following strategic decisions need to be made:

- What mandates and incentives are required for a successful ADS–B In implementation?
- What is the ideal bundling/sequencing strategy in terms of rolling out ADS–B In applications?

- Which airports should have the highest priority in terms of implementation?
- What changes in the ADS–B Out rule should be implemented?
- What additional changes policies and procedures do we need to implement for a successful ADS–B In implementation?

2.3 Tactics

Given these strategic decisions, the following tactical decisions will need to be decided later on, once the strategic decisions are agreed to: Where and with whom will we conduct trials to develop and validate applications?

3.0 BUSINESS CASE

This section describes the business case for ADS–B In for NAS users. The primary focus is on airlines and GA operators. The business case for these two stakeholders will be described in detail.

3.1 Airline Business Case

3.1.1 Background

Airlines typically make a decision avionics equipage decisions across their fleet of aircraft. So, if they make an equipage decision for their B737 NG, they are typically making that decision across their entire fleet of B737 NG aircraft, including any new deliveries that are already in the business plan. This requirement for fleet commonality ensures that every B737 NG pilot is familiar and knows what to expect operationally regardless of the tail number they are assigned on a given day.

3.1.2 Assumptions

The following are the assumptions for the airline business case[81]:

- Passenger value of time is not included in the benefits calculations.
- ADS–B Out is mandated in year 2020.
- Future operations are based on the FAA Terminal Area Forecast.
- Baseline airport capacities are based on The MITRE Corporation's Future Airport Capacity Task 2 (FACT 2) study.
- The fuel cost was assumed to be $3 per gallon.

3.1.3 Business Case Inputs

Based on Air Transport Association of America, Inc. (ATA) inputs, airlines typically have the following business case requirements:

Payback Period = 3 years

Discount Rate = 15 percent

Benefits included = Airline Direct Operating Costs

Other Criteria = "System" benefits are not included[82]

[81] The ARC's benefit analysis did not consider credit for passenger value of time or assess the final benefit of reducing greenhouse gas emissions as part of the benefit-cost analysis as these are not part of operator's financial assessment for equipage decisions.

[82] System benefits are benefits that accrue to other flights due to connectivity issues (passenger, flightcrew, cabin crew and aircraft).

3.1.4 Airline Influence Diagram

To conduct the analysis of the air transport industry, an influence diagram was constructed to identify the key variables and the interdependencies between those variables. The influence diagram is a visual representation of the spreadsheet model used to calculate the cash flows associated with the industry analysis. Figure K.1 below is a simplified version of the complete influence diagram for the problem. To simplify the influence diagram, timing elements were excluded.

There are three node types in the influence diagram:

- The Hexagon (the net present value node) is the value node and represents the objective that is being maximized. There is one value node in an influence diagram.
- Double ovals are deterministic nodes. These are nodes whose values are calculated based on input from other nodes.
- Single ovals are uncertain nodes. These are nodes that represent the uncertain inputs into the model and become bars on the tornado diagram. (See section 3.1.7 Results in this appendix.)

There are basically two major elements to the model:

- On the cost side is the avionics investment, which is a function of the cost per aircraft and the number of aircraft that will be equipped. Costs are broken into Forward Fit, Retrofit In Production and Retrofit Out of Production because costs and the equipage percent vary depending on which category is being equipped. (Forward fit is the cheapest to equip and will be equipped the most.)
- On the benefits side the application benefits are broken into five components:
    - Situational Awareness applications (1–5),
    - CDTI-Assisted Visual Separation (CAVS) for single runway arrivals,
    - FIM–S applications,
    - Flight-deck-based Interval Management–Delegated Separation (FIM–DS) applications, and
    - Wake Delegated Separation (DS) application.

The benefits are impacted by the ADS–B In equipage percent, the ADS–B Out equipage percent, and the Equipage Factor (whether benefits are linear or square with equipage and whether there is a minimum equipage required).

One of the uncertainties not explicitly captured is the benefit growth rate for each set of applications. This is a major uncertainty and is implicitly captured in the analysis below by putting an uncertainty on the benefits in 2011.

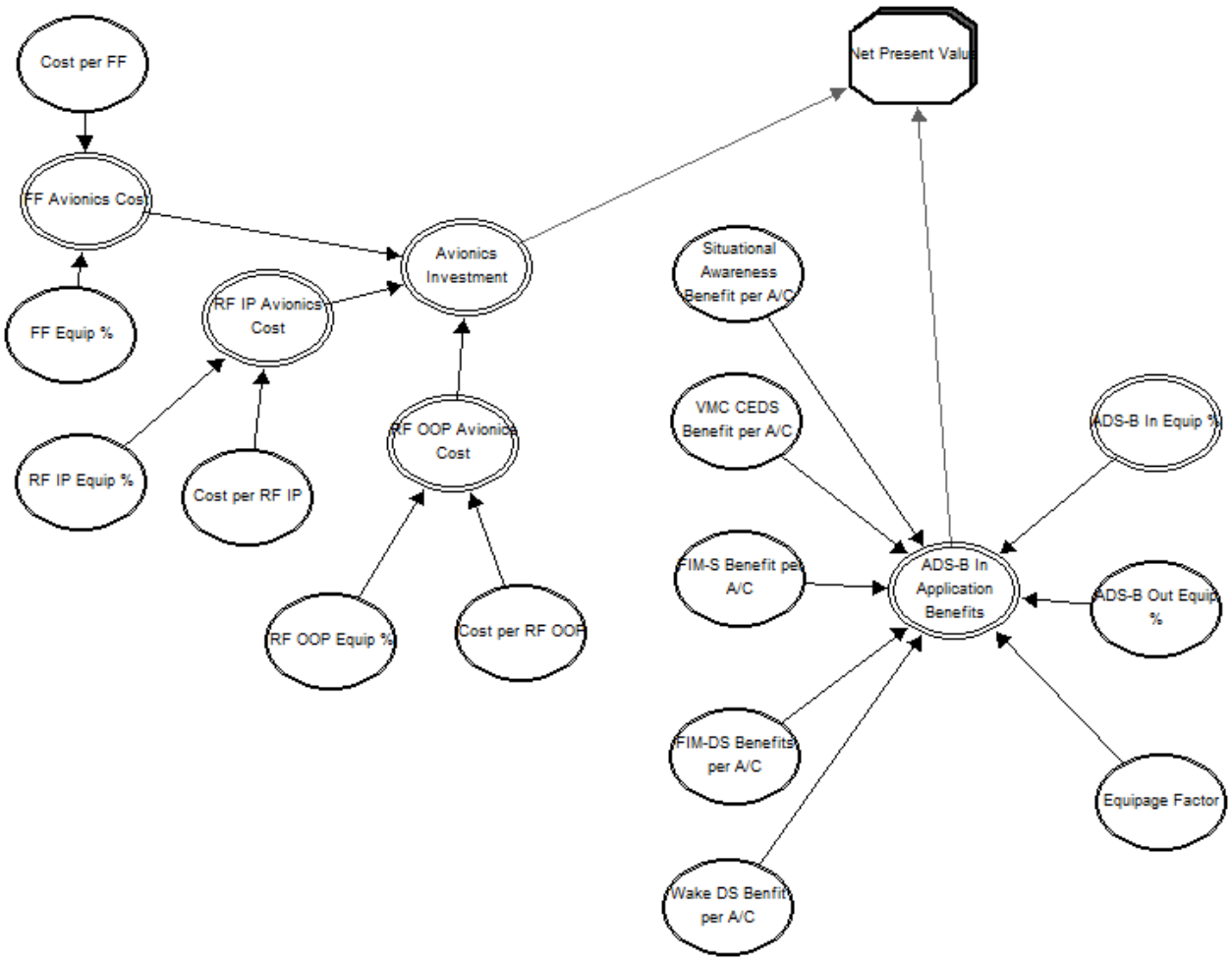

Figure K.1—Air Transport ADS–B In Influence Diagram

3.1.5 Data Inputs

Equipage costs vary depending on the capability of the avionics and whether the avionics is forward fit, retrofit for aircraft still in production, or retrofit for aircraft that are out of production.

Equipage Costs: MCR worked with Boeing and Airbus to update the avionics equipage cost estimate. Costs were assessed for three categories of aircraft: Forward fit, retrofit of in production aircraft, and retrofit of out-of-production aircraft. In addition, the equipage costs were segregated into near-term, mid-term and far-term architectures, depending on the applications enabled. For the purposes of computing the benefits and costs, the ARC has focused on a mid-term architecture in terms of both benefits and cost. The costs below assume a Primary Field of View (PFOV) Display.

Table K.1—Air Transport Equipage Costs

Architecture Scenario	Applications Supported	Forward Fit	Retrofit In Production	Retrofit Out-of-Production
Near-Term	Situational Awareness: 1, 2, 3, 4, 5	$130K–$290K	$270K–$425K	$490K–$700K
Mid-Term	Spacing and Delegated Separation: 6, 8	$360K–$445K	$535K–$890K	$625K–$1040K
Far-Term	Advanced Applications: 9, 10, 11, 12, 13, 14, 16, 17	$430K–551K	$640K–$1075K	$763K–$1221k

ADS–B Out Equipage Curve

Benefits accrued for ADS–B In applications are dependent on ADS–B Out equipage. Since the U.S. ADS–B Out (RTCA DO–260B) mandate does not come into effect until 2020, it is anticipated that benefits accrued are reduced in the 2010 to 2020 time frame when there will be partial ADS–B Out equipage. The following assumptions were made in the derivation of the ADS–B Out equipage curve for the U.S.-registered air transport fleet, as shown in figure K.2 below. Note that regional carriers were not included in this projection.

- Fleet growth is based on 2011 Boeing Current Market Outlook (CMO).
- U.S. ADS–B Out (RTCA DO–260B) mandate for forward fit and retrofit will be effective in January 2020.
- European ADS–B Out (RTCA DO–260B) mandate for forward fit and retrofit will be effective in January 2015 and December 2017, respectively.
- Initial (through 3Q 2014) RTCA DO–260B retrofit will be limited to operators who are active participants of ADS–B trials.
- Retrofit for twin aisle airplanes will begin in 2014 in anticipation of the European ADS–B Out retrofit mandate. While it is understood that not all twin aisle U.S.-registered airplanes will penetrate European airspace, operators tend to maintain fleet commonality and as such are assumed to retrofit their entire twin aisle fleet early.
- Retrofit for single aisle airplanes will not begin until 2016 in anticipation of the U.S. ADS–B Out mandate. While it is understood that some U.S.-registered single aisle airplanes will penetrate European airspace, they constitute a minority and are assumed to be flown in the NAS only.
- Forward fit will begin for all airplanes by 4Q 2014 in anticipation of the European ADS–B Out forward fit mandate.
- Combined industrial capacity for RTCA DO–260B-compliant equipment production and MR&O retrofit rate is capped at 20 percent of the total U.S.-registered fleet per year.
- ADS–B Out equipage reaches 100 percent by 2020 due to the U.S. ADS–B Out mandate.

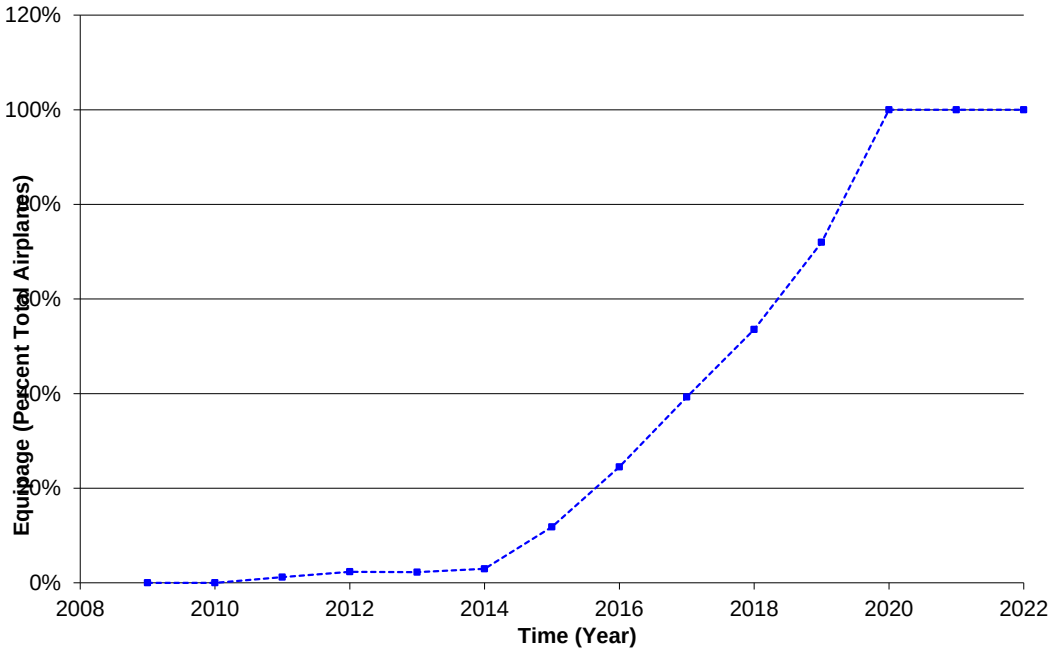

Figure K.2—Air Transport ADS–B Out Equipage Curve

IOC and Rollout Years

In order to compute how benefits will accrue over time, working group 3 asked the FAA to provide a schedule for when applications will be implemented and over what time period. Most of the dates are an educated guess at this point in time, a very few are FAA commitment.

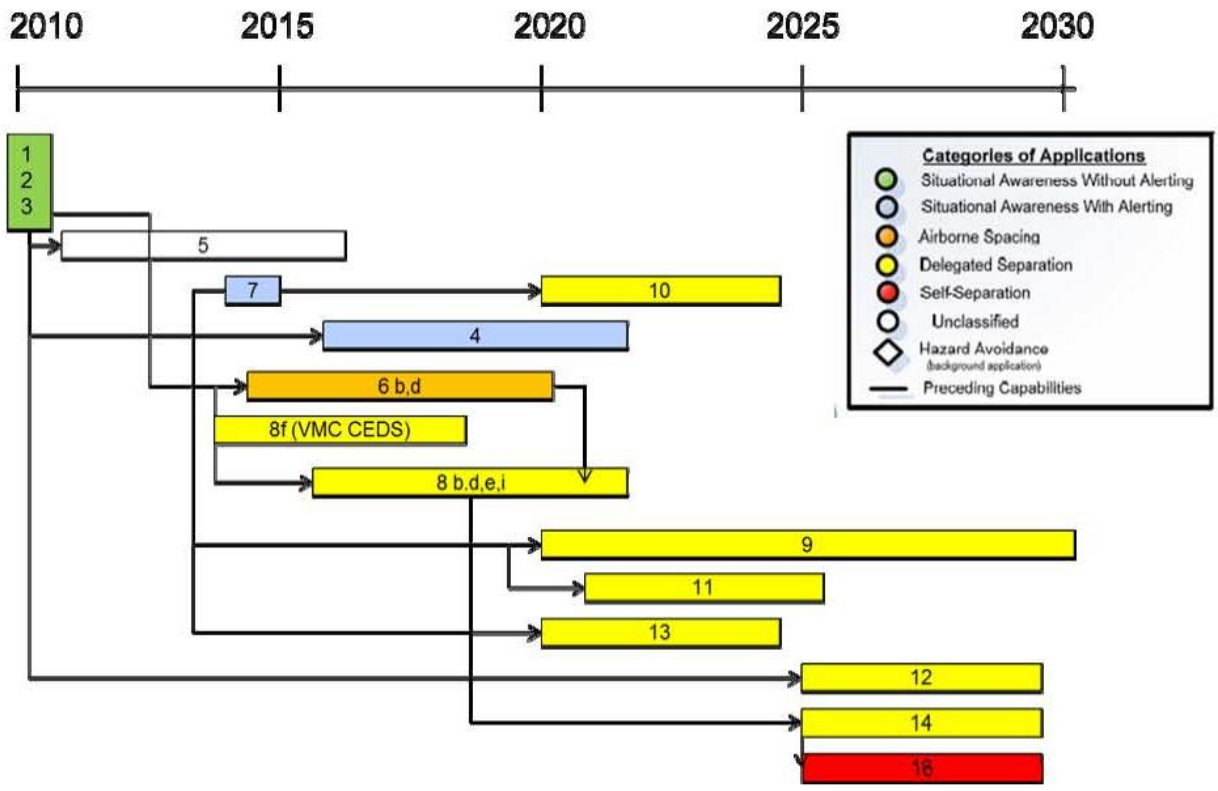

Figure K.3—Application Sequencing and Timing Chart

Application Benefits in 2025 with Full Equipage

The table below identifies the applications and the benefits to the Air Transport industry. The numbers assume 100 percent ADS–B Out and ADS–B In equipage and are sequenced in terms of decreasing benefit. The year 2025 was chosen to calculate these benefits because it is approaching the year (2028) when it is optimal to retrofit aircraft with ADS–B In equipage (see figure K.5) and the business case for equipping both forward fit and retrofit is starting to approach the desired 3 years.

Table K.2—Air Transport ADS–B In Application Benefits

Application No.	Application	2025 Air Transport Benefit	Annual Benefit per A/C	2025 % of Total Benefit	Cumulative Benefit %
14	IM–DS with Wake Risk Management	$536M	$60,819	33%	33%
8b	IM–DS during Arrival and Approach-Optimized Profile Descent (OPD) Arrivals	$378M	$42,891	23%	55%
8f	CDTI-Assisted Visual Separation (CAVS) for single runway arrivals	$149M	$16,907	9%	65%
8d	IM–DS Dependent Runway Ops	$108M	$12,255	7%	71%
6b	IM–S During Arrival and Approach-OPD Arrivals	$101M	$11,460	6%	77%
10a	Closely Spaced Parallel Approaches (New Runways)	$82M	$9,304	5%	82%
2	Traffic Situation Awareness for Visual Approach	$65M	$7,375	4%	86%
10b	Closely Spaced Parallel App (Current Runways)	$58M	$6,581	4%	90%
4	Airport Traffic Situation Awareness with Indications and Alerts	$55M	$6,241	3%	93%
5	Oceanic In-Trail Procedures (ITP)	$35M	$3,971	2%	95%
6d	IM–S Dependent Runway Operations	$32M	$3,631	2%	97%
8e	IM–DS Oceanic	$18M	$2,042	1%	98%
3	Airport Traffic Situation Awareness	$14M	$1,589	1%	99%
11	Independent Closely Spaced Parallel Approach	$10M	$1,135	1%	100%
8i	CEDS for arrivals to closely spaced parallel runways	$7M	$794	0%	100%
Total			**$186,996**		

A few conclusions can be drawn from this table and knowledge of the associated applications:

- 83 percent of the benefits ($154,000 annually in 2025) will come from delegated separation and closely spaced parallel runway applications (14, 10, and 8). These applications will likely require a PFOV display.
- 9 percent of the benefits ($16,000 annually in 2025) come from situational awareness applications (1, 2, 3, 4, 5). These applications can be enabled through an electronic flight bag (EFB) or other side display.
- The remaining 8 percent of benefits ($14,000 annually in 2025) come from spacing applications. It is possible a Side Field of View Display or Forward Field of View display (not Primary) would be sufficient for these applications.
- There is no single application that can close the business case for avionics on its own.

- The annual benefit per aircraft is highly impacted by where the aircraft flies. Aircraft flying into congested airports such as Hartsfield-Jackson Atlanta International (ATL) and McCarran International (LAS) will accrue much larger benefits than those flying into less congested airports.
- The benefits climb significantly from 2018 to 2025 as airports become more congested. In 2018, the annual benefit per aircraft is $98,000. (This assumes 100 percent ADS–B Out implementation and 100 percent implementation of all applications, neither of which is expected in 2018, so the actual value per aircraft will be less).
- There is extra risk associated with applications 14 (Instrument Meteorological Conditions (IMC) CEDS with Wake Risk Management) and 10 (Closely Spaced Parallel Approaches (CSPA)). RTCA DO–260B as currently specified will not meet the requirements for 14 and may not meet the requirements for 10, depending on how it is implemented.
    - Application 10a: Higher navigation performance may be required, depending on the approach taken and new runways will be required to achieve the benefit.
    - Application 10b: Higher navigation performance may be required, depending on the approach taken.
    - Application 14: Wake parameter required in ADS–B Out message set.

Missing Applications

There are a number of Air Transport applications whose benefits have not been quantified. These applications are listed in table K.3.

Table K.3—Applications Whose Benefits Have Not Been Quantified

Number	Name
6a	IM–S Metering or Merge into En Route Flow
6c	IM–S during Departure Operations
8a	IM–DS Metering or Merge into En Route Flow
8c	IM–DS during Departure Operations
8h	CEDS for Departures
9	Independent Closely Spaced Routes
12	Delegated Separation—Crossing
13	Delegated Separation—Passing
15	ADS–B Integrated Collision Avoidance
16	Flow Corridors
17	Self Separation

Applications 6a and 8a (Metering or Merge into En Route Flow) have not been quantified yet due to technical challenges related to the interaction with several other NextGen planned programs in the en route environment including improvements to En Route Automation Modernization Conflict Probe and Datalink Communications.

Applications 6c and 8c (Departure IM) may provide some benefit at departure fixes, however, it is expected other planned NextGen improvements (for example, RNAV departure fanning) may mitigate much of the current issue that these applications address.

Application 8h is currently calculated as part of the applications 8f and 14.

Applications 9, 12, 13, 15, 16, and 17 are considered longer-term applications that will not be implemented until beyond 2020 (or later) and likely will not impact ADS–B In equipage decisions prior to 2025.

3.1.6 Implementation Scenarios

As noted above, the annual savings calculated assumes implementation of all the applications. There are several different scenarios that could occur. The table below lists four possible scenarios and the annual savings per year in 2025:

Table K.4—Air Transport Implementation Scenarios with Benefit Implications

Scenario	Requirement	Annual Savings per Aircraft in Year 2025 (Cumulative)
1	Baseline ADS–B Out	$110,292
2	Add Wake Parameter	$171,111
3	Increase Navigation Performance to accommodate CSPA (10b)	$177,692
4	Construction of new runways (10a)	$186,996

These numbers assume a) no minimum equipage is required for benefits and that b) benefits are linear with equipage, and c) the applications is fully implemented across the NAS. The annual savings listed in the table above are cumulative.

3.1.7 Results

Annual Benefits per Aircraft by Calendar Year

The chart below shows the annual benefits per aircraft per calendar year. It takes into account the rollout schedule for the various applications and the ADS–B Out equipage curve. There is currently no consideration of equipage critical mass in the computation; that is, that benefits potentially will not be achieved until 20 percent to 40 percent of the fleet are equipped. One implicit assumption in this chart is that the benefits accrue evenly to all aircraft. In actuality, these are the average savings across all air transport aircraft. The actual savings will vary depending on aircraft size and weight, the degree to which the aircraft is flying to capacity congested airports, and the degree to which the aircraft is flying Oceanic routes and getting ITP and DS–Oceanic benefits. Some key insights from these curves are the following:

- The benefits are very low in the years 2010 to 2019. (In 2019 the annual value per equipped aircraft is $34,000.)
- The benefits ramp up significantly from 2019 to 2021. This is the timeframe when ADS–B Out equipage is climbing but also the time when the high value IM–DS applications are being implemented.

- The benefits per year continue to grow, but not as significantly through the remainder of the analysis. This benefits growth is due to the increased value of additional system capacity over time.
- The full implementation year is denoted by the crosses on the two curves. For the RTCA DO–260 B apps, the full implementation year is 2023. For all apps, the full implementation year is 2028, when IMC CEDS is fully implemented assuming a 2025 Wake Parameter requirement for all ADS–B Out aircraft.

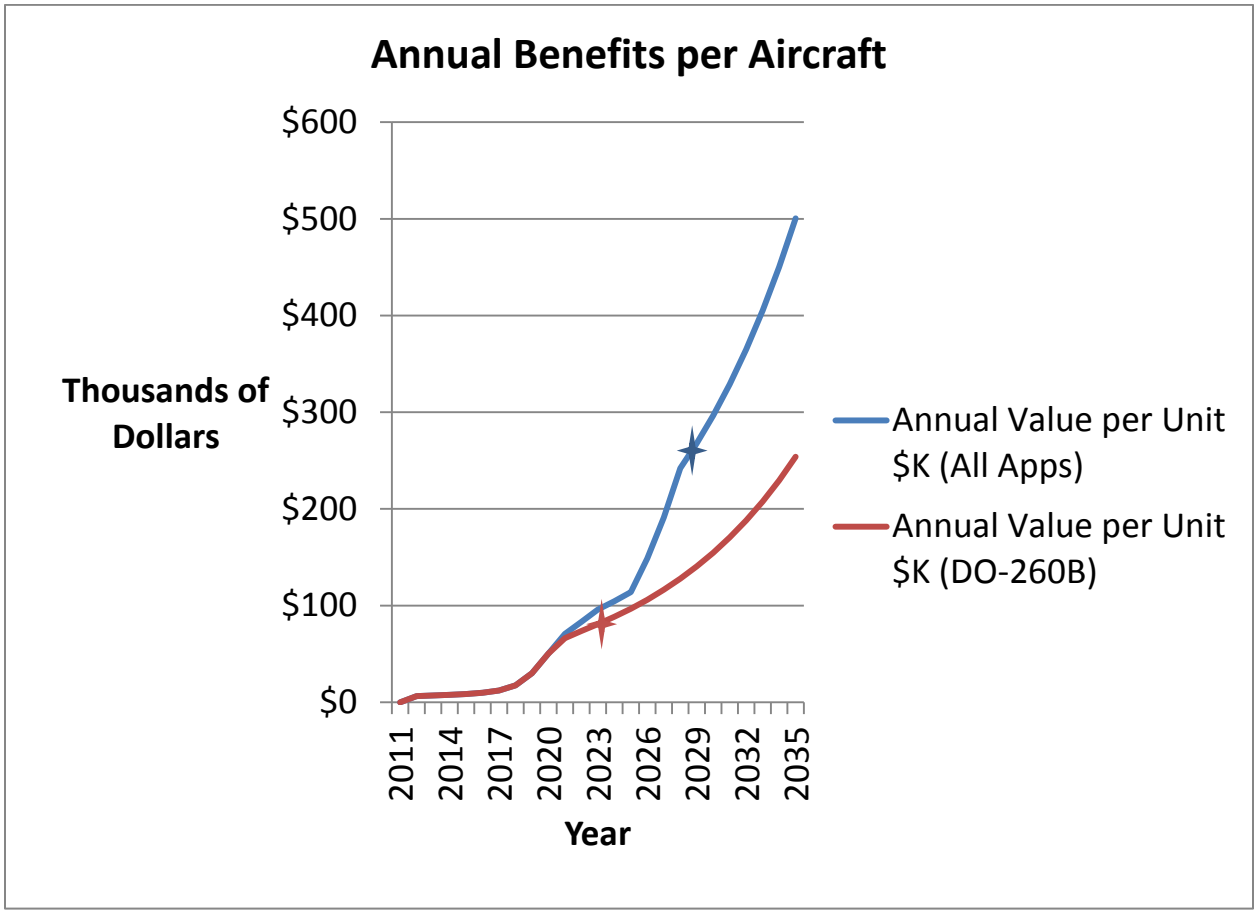

Figure K.4—Air Transport Annual Benefit per Aircraft (denotes applications fully fielded)

Note that this chart assumes that all benefits accrue equally to all aircraft. Aircraft that fly to congested airports (see table K.12) will get benefits more quickly and aircraft that fly to airports that are not congested will get benefits more slowly.

Benefits Present Value per Aircraft by Calendar Year (through 2035)

The chart below shows the Present Value per equipped aircraft for equipping with ADS–B In, with assumed life through 2035. Another key assumption in this chart is that benefits are linear with equipage and there is no critical mass of equipage required. Given these assumptions, the

chart shows the peak time to equip is year 2028 for the linear equipage curve, when the present value per aircraft is $770,000 per aircraft. For the square equipage curve, the peak time to equip is 2029 with a present value per aircraft of $480,000 per aircraft. (This particular date and number is very sensitive to the speed of equipage). The implication of this chart is that airlines should wait until 2028 or 2029 to get the maximum return on their investment for retrofitting aircraft. Some of the direct and indirect factors that drive the optimum year to these years are the following:

- The applications are fully fielded across the NAS
- All aircraft are ADS–B Out equipped due to the mandate in 2020
- Congestion is starting to significantly increase the value of capacity-creating and capacity-driven applications
- Applications have a track record so airlines will better know what their return will be and can more accurately predict the business case

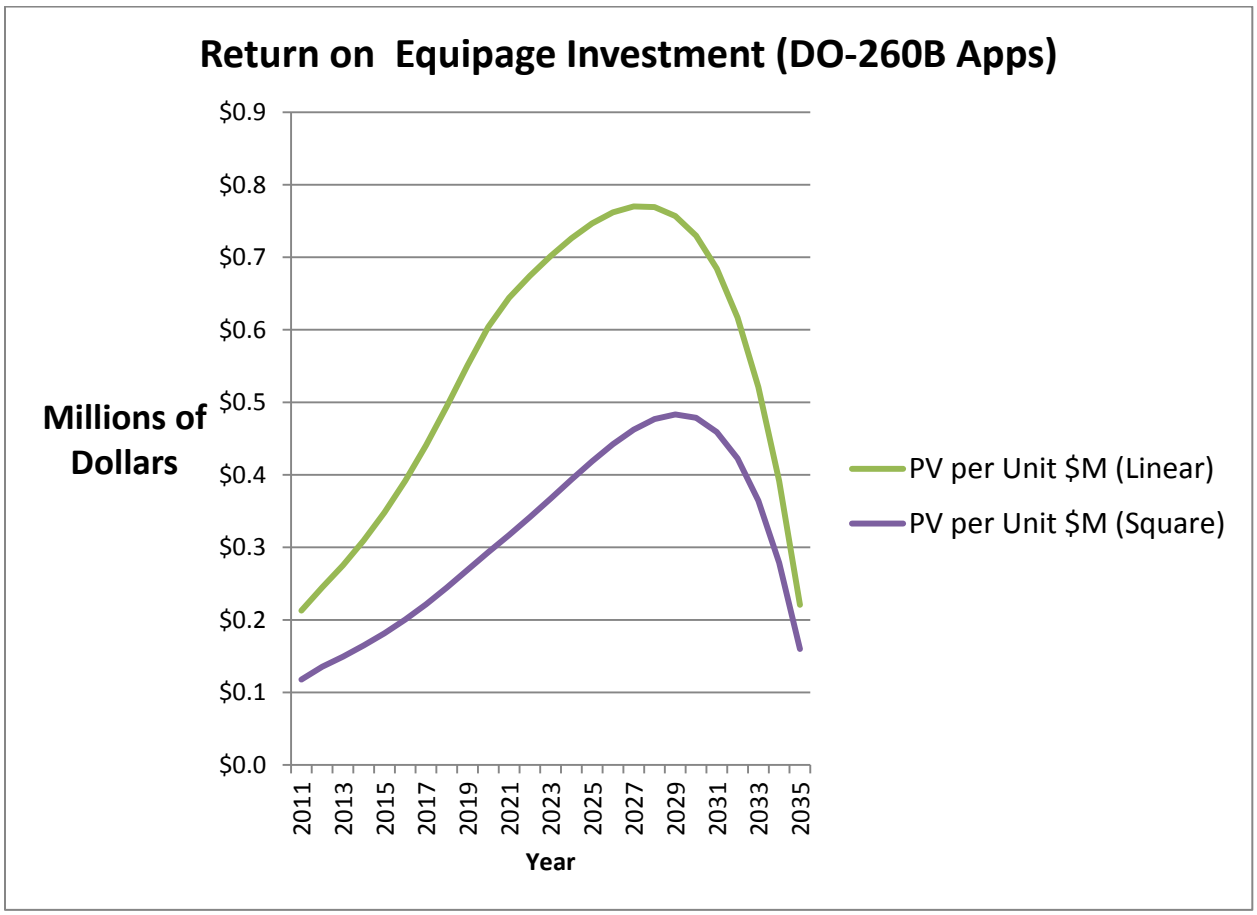

Figure K.5—Optimal Time to Equip: Aircraft Retiring in 2035 (RTCA DO–260B Apps Only)*

*Assumes aircraft life through 2035.

Industry Deterministic Sensitivity Analysis

An analysis of the air transport industry business case was conducted. The following general assumptions were used:

- Discount Rate = 15 percent discount rate
- 2011 dollars
- Start Year = 2011
- Final Year = 2035

The base case scenario assumed an 80 percent equipage rate for forward fit, 50 percent for retrofit in production and 0 percent for retrofit out-of-production. (See figure K.6 below) The business case is run through 2035 and uses 2011 dollars and a 15 percent discount rate which approximates the 17.5 percent discount rate that air transport uses for retrofit equipage business cases (assumes about 2.5 percent inflation.)

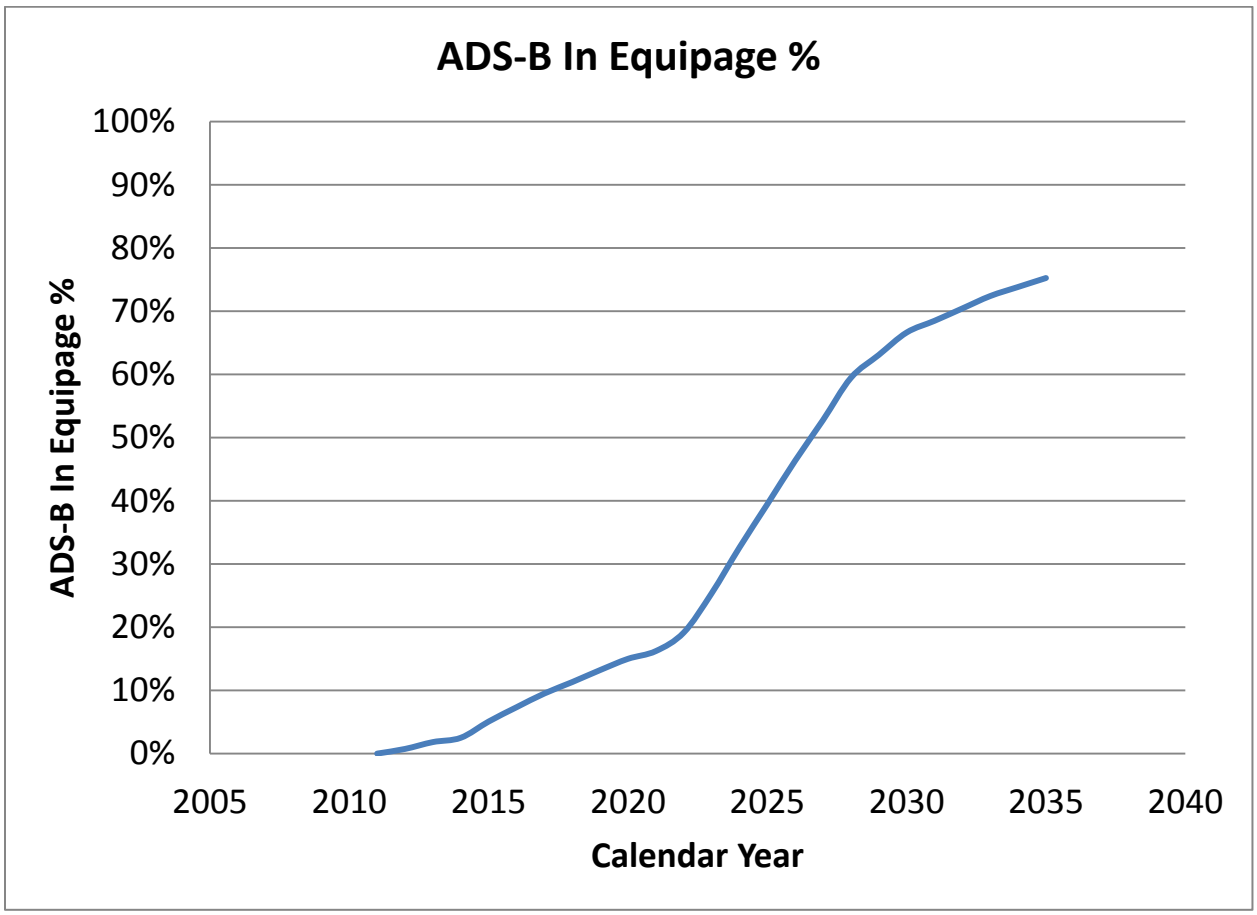

Figure K.6—ADS–B In Equipage Percent

The ADS–B In Equipage curve above assumes PFOV equipage that supports all of the applications listed in table K.2. The following assumptions were made in the base case:

- 80 percent of new deliveries are equipped with ADS–B In.
  - Airbus deliveries are equipped starting in 2012.
  - Boeing deliveries are equipped starting in 2015.
  - Regional deliveries are equipped starting in 2020.
- In Production aircraft are retrofit from 2023 to 2029, and 50 percent of those aircraft will be retrofit with ADS–B In. In Production aircraft are any aircraft still in production at year 2023, based on the MITRE fleet forecast.
- There is no retrofit for Out of Production aircraft.

Two scenarios were run. In the first scenario, benefits are achieved as a function of the square of equipage percent for the Wake, FIM–DS and Spacing applications. In the second scenario, benefits are achieved linear with equipage for those applications. In both cases, there is a minimum equipage requirement for those applications.

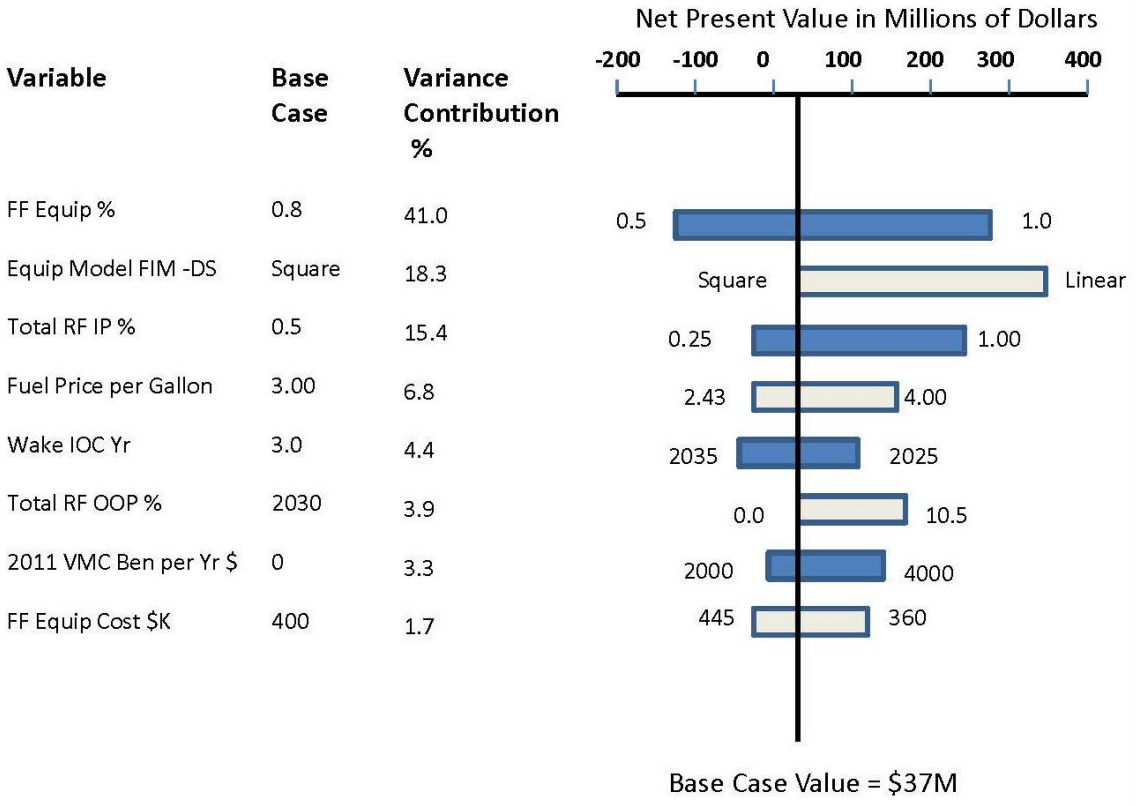

Figure K.7—Air Transport Industry NPV Analysis: Square Equipage Assumption

The base case results show a net present value of $36 million. The biggest uncertainty is Forward Fit Equipage percent and then the equipage model for FIM–DS applications. The sensitivity analysis shows that if equipage were linear with equipage, the NPV would be $481 million. The analysis shows that increasing equipage for Forward Fit, Retrofit In Production and Retrofit Out of Production will increase the business case significantly. This business case shows that while the business case may not meet airlines traditional payback periods for equipage, it will meet airlines discount rate requirements for equipage. The payback period for the industry business case is 20 years.

The analysis above was re-run assuming benefits are linear with equipage for FIM–DS applications. The results are shown below.

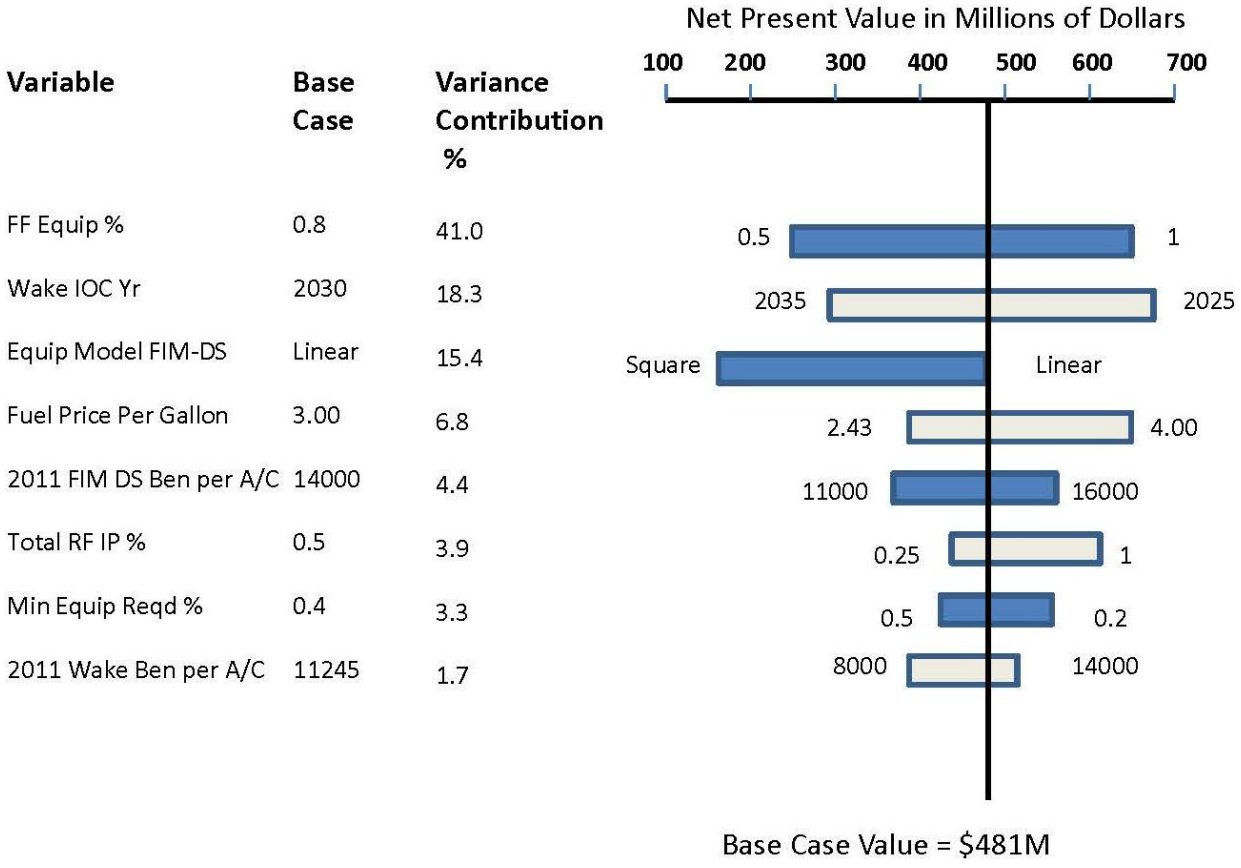

Figure K.8—Air Transport Industry NPV Analysis: Linear Equipage Assumption

The results show a net present value of $481 million and payback period of 18 years.

3.2 General Aviation Operators Business Case

3.2.1 Background

General Aviation (GA) aircraft operators fall into two categories: high-end GA operators, who typically equip more aggressively than the airlines do because they put more weight on access and reducing flight time; and mid- to low-end GA operators, who have less incentive to equip and are primarily seeking improved safety and access. The analysis below focuses on the mid- to low-end GA operator.

3.2.2 Assumptions

The following are the assumptions for the GA business case:

- ADS–B Out is mandated in year 2020,
- Future operations are based on the FAA Terminal Area Forecast,
- Baseline airport capacities are based on the MITRE Future Airport Capacity Task 2 (FACT 2) study, and
- ADS–B In benefits are assumed to be linearly correlated with ADS–B In equipage (not a square of equipage).

3.2.3 Business Case Criteria

The following criteria were used for the GA business case:

- Payback Period = Not applicable
- Discount Rate = Not applicable
- Benefits included = Safety Only
- Other Criteria = Access and fuel
- Other Criteria = Avionics cost threshold of $1,500

3.2.4 Inputs

Equipage Costs

For low-end to mid GA aircraft, four GA aircraft equipage scenarios have been identified. The scenario depends on the data source (Universal Access Transceiver (UAT) or 1090) and the Display (legacy display or TSO–195 compliant display). UAT gives the aircraft FIS–B, but does not provide access to airspace above FL180 or international flying. (UAT also requires continued transponder carriage and integration.) The legacy display (that is, non-TSO–C195) saves those aircraft owners $5,000 to $10,000 per aircraft, but may not allow the aircraft to use some applications, such as Application Integrated Work Plan (AIWP) Version 2 application 7, Traffic Situation Awareness with Alerts.

The cost for the new display is also sensitive to whether it is a portable display or flat panel mount. The costs below assume flat panel mount displays. A portable, or Class 1 EFB, would be a cheaper solution that would provide traffic, weather and situational awareness, but may not

support all applications. Similarly, other portable EFB solutions may have a cost advantage compared to flat panel mount displays in the cockpit, but may be limited in part by their location in the cockpit.

Table K.5—Mid- to Low-End GA Avionics Cost Scenarios

Data Source	Display	Incremental Cost	Apps Enabled	Description
UAT	Legacy Display with Existing Qualified Positioning Source	$5K–$10K	1, 2, 3 and partial FIS–B.	Over 74,000 potential units. Cost includes ADS–B Out.
UAT	New Display and New Qualified Positioning Source	$10K–$20K	1, 2, 3, 4, and 7. Complete FIS–B.	Provides new TSO–C195 qualified display. Cost includes ADS–B Out.
1090	Legacy Display with Existing Qualified Positioning Source	$5K–$15K	1,2,3. No FIS–B.	Over 74,000 potential units. Cost does not include Mode S transponder.
1090	New Display and New Qualified Positioning Source	$15K–$25K	1, 2, 3, 4, and 7. No FIS–B.	Provides new TSO–C195 qualified display. Cost does not include Mode S transponder.

As shown by Table K.5, the ARC's non-TSO–C195 enabling policy (see section 4.1 of report) establishes the opportunity for savings of close to $500 million for the general aviation fleet to become ADS–B In capable for applications 1, 2, 3 and partial FIS–B.

A lower cost solution would be to use a portable tablet computer (such as, an iPAD) as the display by qualifying it as a Class 3 or, if obtaining power through the aircraft, Class 2 EFB. Presumably, this solution would eliminate or minimize installation costs and provide an alternative to installed displays. One identified solution has the following costs, which amount to $1,700 non-recurring and $99 recurring fee:

- Tablet Display = $499
- ADS–B In Received = $950
- Extension Antenna = $60
- Software = $99 purchase, $99 annual fee

This solution provides FIS–B and also supports other non-FIS–B applications. This solution, however, does not enable or support any of the applications identified in the AIWP, but enhances the pilot's situational awareness for weather and traffic.

IOC and Rollout Years and Application Benefits

The applications, rollout years, and savings across the GA fleet assuming 100 percent equipage (230,000 aircraft in 2011) are listed in the table below.

Table K.6—GA Application Benefits, IOC and Rollout Years

App. No.	Application Name	Ann Savings 2011 $M	IOC	Rollout Years		
				Low	Med	High
1	Traffic Situation Awareness–Basic	$10	2010	0	3	0
7	Traffic Situation Awareness with Alerts	$37	2013	0	0	0
3	Airport Traffic Situation Awareness	$0	2010	0	3	0
4	Airport Traffic Situation Awareness with Indications and Alerts	$1	2017	3	5	6
FIS–B	Flight Information Services–Broadcast	$192	2012	0	1	0

The FIS–B benefits calculate the savings based on cost savings (specifically accidents avoided). For those aircraft that get FIS–B today, one could argue that the benefits should be the avoided subscription costs, but for simplicity, the ARC has chosen to evaluate benefits based on cost savings.

ADS–B Out Equipage Curve

For the purposes of this analysis, we will assume an ADS–B Out equipage curve similar to the air transport equipage curve shown in section 3.1.5 in this appendix. In actuality, aircraft that do not fly in transponder airspace will not equip, but this does not impact the savings per aircraft computation.

3.2.5 Results

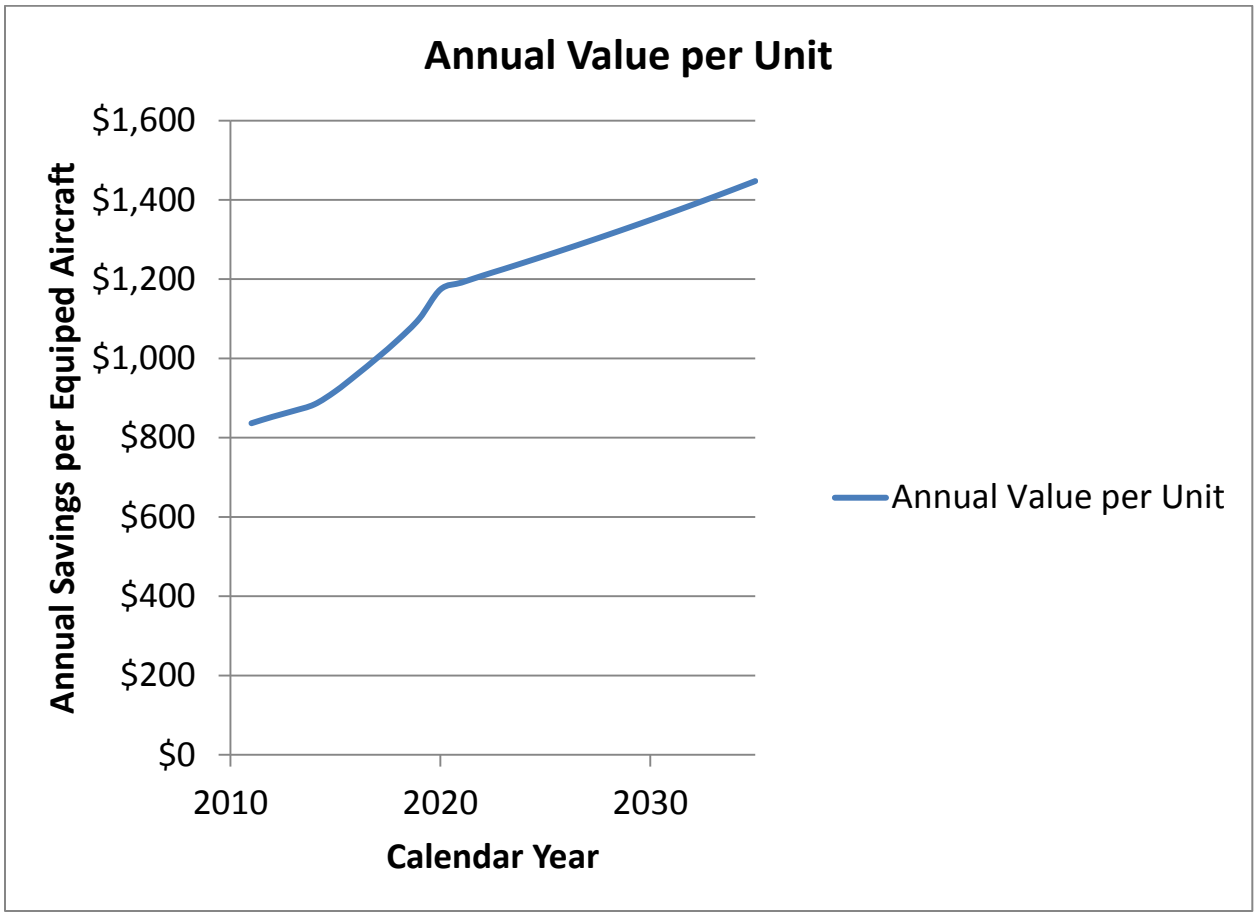

Figure K.9—GA Annual Benefits per Aircraft

GA aircraft will peak at about $1,050 benefit per aircraft per year. These benefits are calculated based on safety benefits. No attempt has been made to quantify the benefits based on access or fuel savings. According to the RTCA, the primary equipage criteria is the cost of equipage, with a $1,500 limit. So given that the cost of equipage will exceed $10,000 for a UAT new display and $5,000 for a UAT existing display, it is unlikely low-end GA will equip. High-end GA however, may see enough benefits in terms of fuel savings, increased on time arrivals, etc., that will help them close the business case, but insufficient data to analyze their business case is available at this time.

Payback Period

The annual savings per equipped aircraft (figure K.9) was used to calculate the Present Value per Aircraft for an aircraft with a life through 2035 and using a discount rate of 7 percent and assuming 1.5 percent inflation.

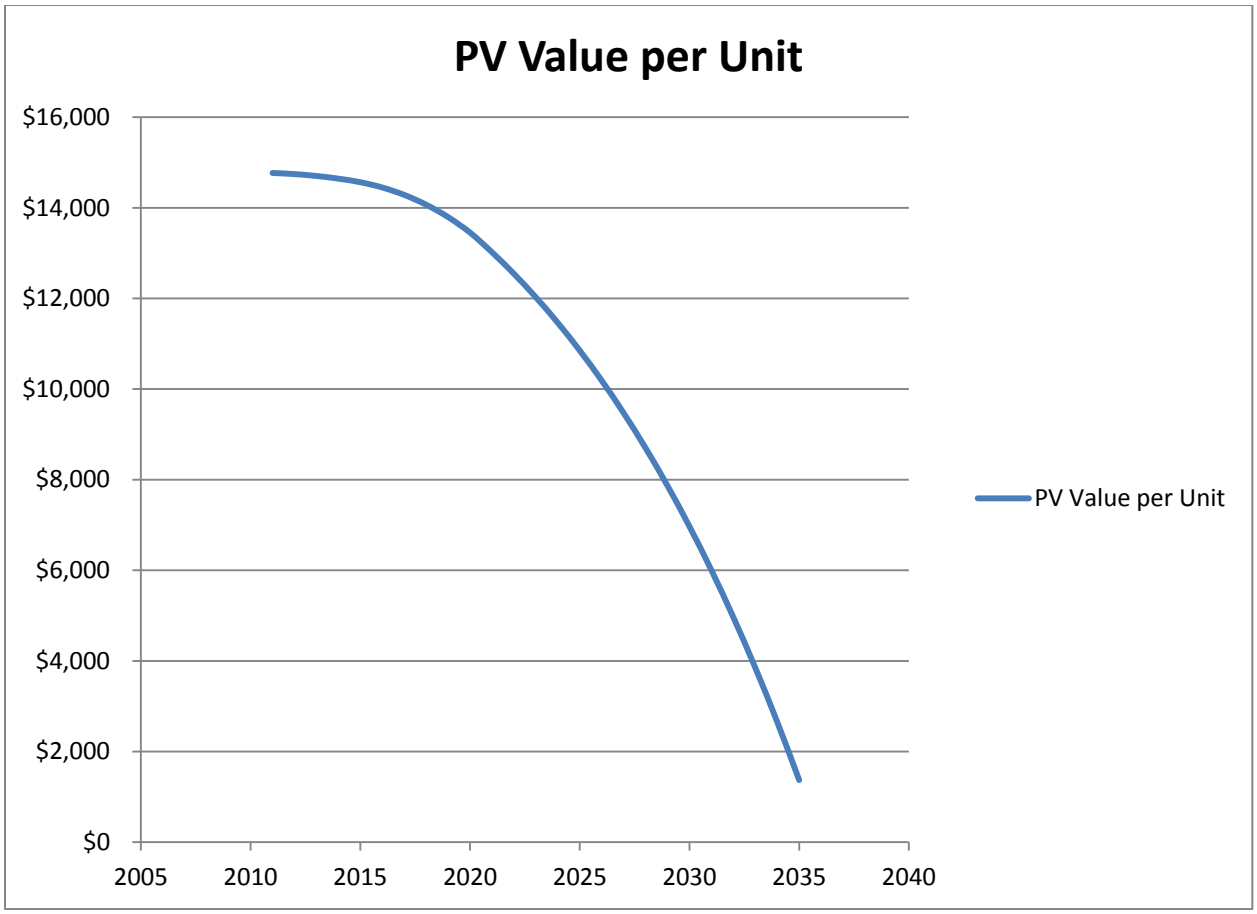

Figure K.10—Present Value of Benefits for GA Aircraft through 2035

The chart above shows that an aircraft owner equipping ADS–B In in 2011 will have a Present Value of about $12,000.

The table below captures the likely equipage decision for the equipage scenarios above. The benefit present value is adjusted for partial or missing functionality. Based on these results, only the UAT Legacy Display presents a potentially strong business case. The business case will depend largely on how much FIS–B benefits are delivered. If no FIS–B benefits are delivered, the business case is $2,000; if 100 percent of the benefits are delivered, the business case is $15,000.

Table K.7—Likely Equipage Decisions[83]

Equipage Scenario	Equipage Cost	Applications Enabled	Estimated PV of Benefit	Likely Equipage Decision
UAT Legacy Display	$5K–$10K	1, 2, 3 and partial FIS–B.	<$15K	Might equip
UAT New Display	$10K–$20K	All: 1, 2, 3, 4, and 7. Complete FIS–B.	$15K	Unlikely to equip
1090 Legacy Display	$5K–$15K	1,2,3. No FIS–B.	$2K	Will not equip
1090 New Display	$15K–$25K	1, 2, 3, 4, and 7. No FIS–B.	$2K	Will not equip

3.2.6 High-End GA Avionics Costs

The ARC concentrated on the mid-low end GA business case and the Air Transport business case. It did not pursue the high-end GA business case, but we did review the AIWP cost estimates for high-end GA.

The AIWP 2.0 identified costs for high-end GA, which is captured in the table below. Generally, the figures in the table are in line with other efforts to assess the cost of high-end avionics. The exercise last year (driven by the stimulus debate) pointed to high-end GA (jets) incurring a cost of approximately $125,000 average for ADS–B In with the assumption that 40 percent of business jets will elect dual EFB (like) solution while 60 percent will elect single EFB (like) solution, which may be a Multi-Function Display. At $125,000, the cost estimate fits into the higher end of the cost range ($23,000–$143,000). Based on that analysis, it is unclear how the $23,000 cost was arrived at.

Regarding ADS–B Out, the costs estimates seem low, as the requirements force a NAV position upgrade for pretty much everyone. The cost for ADS–B Out was identified as $128,000 split between ADS–B Out transponder upgrade ($68,000) and new ADS–B Out Nav Position Upgrade ($60,000).

Table K.8—AIWP Avionics Cost Estimates for High-End GA

Avionics Enabler	High-End GA Unit Cost
ADS–B Out	$16–$53K
CDTI (Ground Only)	$23–$143K
CDTI (Ground) with Surface Indications/Alerts	$23–$143K
CDTI (Air-Ground)	$23–$143K
CDTi (Airborne with Conflict Detection)	$23–$143K
Along-Track Guidance with CDTI	>$23–$143K
Deconfliction Guidance with CDTI	>$23–$143K
Paired Approach Guidance and Alerting with CDTI	>$23–$143K

[83] The statements “might equip,” “unlikely to equip,” and “will not equip” are only in the context of the positive versus the negative business case.

4.0 KEY LESSON

4.1 Impact of Mixed Equipage is Unclear on ADS–B In Applications

One of the big uncertainties in the ADS–B In business case, is how much benefit will be delivered when there is a mixed equipage environment. Prior to 2020, the fleet of ADS–B Out equipped aircraft will be less than 100 percent and ADS–B In equipage will be less than that. In 2020, the ADS–B Out Mandate is effective and presumably 100 percent of the fleet will be ADS–B Out equipped. It is unclear how quickly ADS–B In equipage will grow after 2020. ADS–B In equipage is voluntary at this time and retrofit for out-of-production aircraft does not appear to close, while the business case for retrofit in production appears marginal.

One school of thought says that mixed equipage increases controller workload resulting in the controllers "missing" Spacing and Delegated Separation opportunities. The table below assesses the impact of mixed ADS–B Out and mixed ADS–B In equipage on ADS–B In benefits.

Table K.9—Impact of Mixed Equipage on ADS–B In Operations

Application Type	Surveillance Requirements	Impact of Mixed ADS–B Out Equipage	Impact of Mixed ADS–B In Equipage
Situational Awareness	TIS–B Sufficient	No Impact	No controller involvement, so no impact.
Spacing	TIS–B Sufficient	No Impact	Higher workload for Spacing than DS, because controller still retains separation responsibility. Benefits will be less than linear.
Delegated Separation	Requires ADS–B Out	Non-linear, even if the tool is good. Probably want to wait until full ADS–B Out Equipage.	Need a critical mass (20–50%) of ADS–B In Equipage, assuming full ADS–B Out equipage, to start operations. Then, benefits are non-linear with equipage, because some pairings will be missed due to workload.

The basic conclusion is that when controllers are working in a mixed ADS–B In equipage environment, opportunities for Spacing or Delegated Separation operations will be missed because of higher workload and therefore the benefits will be less than linear with equipage. The thought is that the benefits will be somewhere between linear and a square of the equipage rate. The graph shows the impact of mixed ADS–B In equipage on benefits depending on whether benefits are linear, square, or linear but require some critical mass of equipage for achieving benefits. These are notional curves that define three different potential scenarios. The shape of the benefits versus equipage curve may change depending on the application. It is felt that for situational awareness applications, benefits will accrue linearly with equipage and that if indeed benefits are not linear with equipage for some applications, the delegated separation applications will be impacted the most.

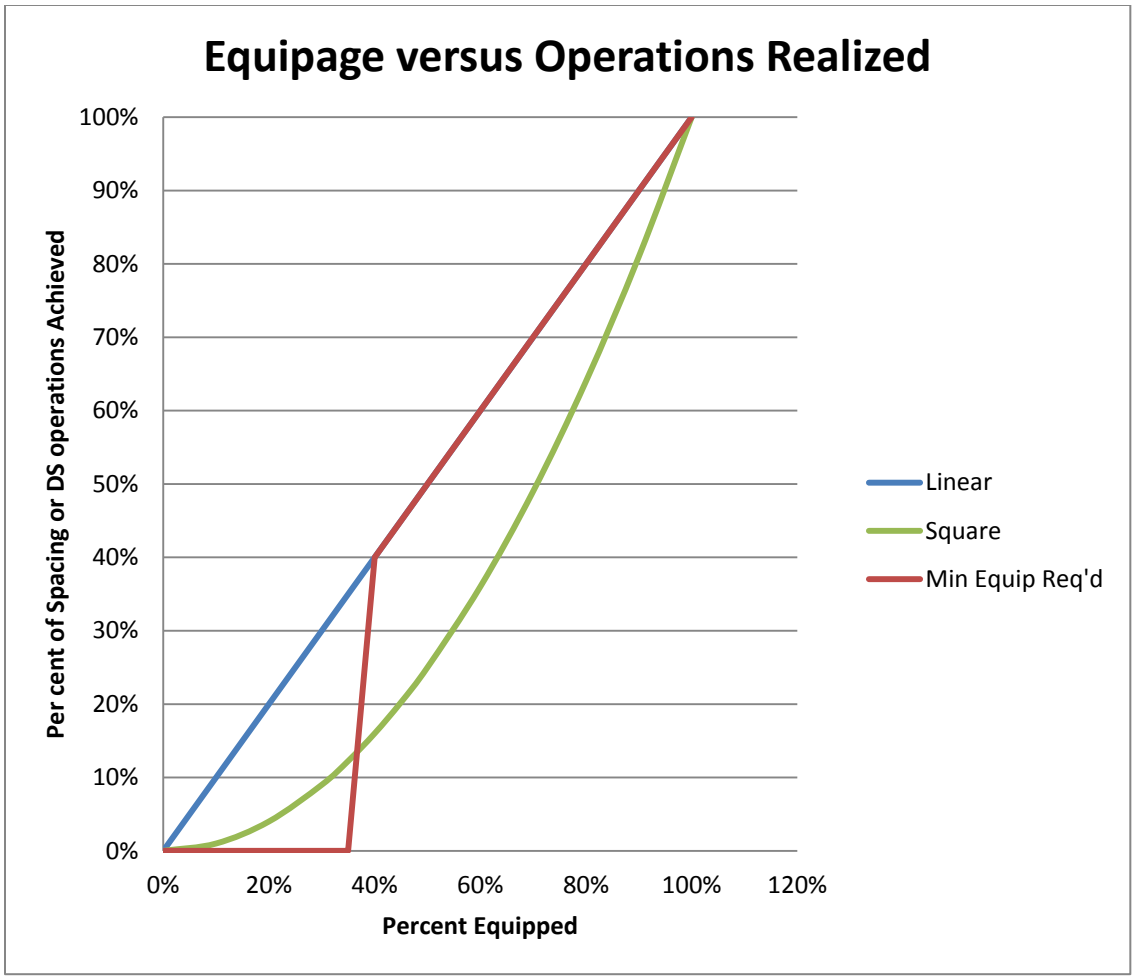

Figure K.11—Mixed Equipage Impact Scenarios

Another school of thought is that benefits are nearly linear with equipage and simply depend on the ratio of equipped aircraft and non-equipped aircraft and the performance of the equipped aircraft in terms of spacing relative to the non-equipped aircraft.

> Arrival Rate = ADS–B In Equip percent * FIM Interval + (1 – ADS–B In Equip percent) * Non-FIM Interval

4.2 Airlines' Desire for Commonality Across Fleet Poses Risks for Equipage

The business case for Forward Fit is the strongest business case for the airlines. However, given the airlines' desire for fleet commonality, they will likely look at the business case across a fleet, instead of for a set of deliveries. Airlines' desire for fleet commonality is based on both maintenance and operations issues as well as crew training issues. In the ideal fleet, a trained flightcrew can operate any aircraft in the fleet because of fleet commonality.

Training was not considered directly in the business case. However, some analysis was done and it was concluded that training costs would amount to about 1 to 5 percent of the avionics non-recurring cost per airlines and would require about 12 months to implement across an airline.

So while the business case for a new A320 or 737 NG delivery may close for forward fit delivery in isolation, if the airline has a large fleet of aircraft already that require more expensive retrofit, they may choose to forego equipage altogether because the fleet business case does not close.

4.3 PFOV Displays Are Required To Get the Bulk of Benefits for Air Transport

Fully 83 percent of the benefits will come from Delegated Separation applications. Delegated Separation applications will require PFOV equipage and Spacing applications may require PFOV equipage. For Air Transport, only $19,000 per year comes from Situational Awareness applications that are clearly enabled by Side Field of View equipage. This implies that ADS–B In will not pay for Side Field of View Equipage without help from other applications using the equipment.

4.4 AIR TRANSPORT ADS–B IN EQUIPAGE EXPECTATIONS

Given the current status of the business case, broad equipage is unlikely.

Through 2025, equipage will likely be concentrated on—

a. Deliveries of aircraft relatively new to the fleet (so that the fleet-wide business case does not require more expensive retrofit) such as the B787, B747–800, A350, and A380.

b. Airlines with high percentage of operations at Hartsfield-Jackson Atlanta International Airport (ATL), John F. Kennedy International Airport (JFK), and LaGuardia Airport (LGA), where benefits per operation will be three times or greater than the U.S. airport average and, therefore, will reduce payback periods significantly. Incentives and/or mandates are opportunities to improve the business case and raise air transport ADS–B In equipage totals.

4.5 REGIONAL(GEOGRAPHIC) MANDATES

One of the options identified by the team was to implement a regional mandate, especially at the capacity-constrained airports, to reduce the overall cost of equipage. Unfortunately, regional equipage mandates do not appear to be practical from an Air Transport perspective:

- Airlines are reluctant to have a sub-fleet of aircraft and have to manage which aircraft they use at which airport.
- Given assumption 1, the problem is that at ATL, the airport which provides 28 percent of the overall benefit, for only 6 percent of the total operations, just about every major airline flies there.

For GA operators, regional mandates can provide benefit. GA aircraft owners can presumably avoid the top 5 or 10 airports and fly to secondary airports to avoid expensive equipage mandates, should they be implemented.

4.6 FLEET COMPOSITION IN 2025

In 2025, the U.S.-registered fleet[84] composition will be:

- 3,455 aircraft Forward Fit Opportunities (40 percent)
- 2,852 aircraft Retrofit In Production (32 percent)
- 2,506 aircraft Out-of-Production (28 percent)

The fleet composition is important to determine the percent of aircraft likely to equip with ADS–B In. Forward fits are the cheapest to equip, then retrofit in production and finally retrofit out-of-production.

Forward Fit Opportunities are opportunities to Forward Fit aircraft with ADS–B In. It is assumed Airbus aircraft are eligible for Forward Fit in 2012, Boeing aircraft in 2015, and all others in 2020.

In 2035, only 9 percent of the fleet will be Out-of-Production (967), as 1437 aircraft will be retired from that category.

[84] U.S.-registered fleet included aircraft registered to U.S. airlines. It excludes aircraft owner by foreign carriers that take off and land in the NAS for a portion of their flights.

5.0 STRATEGIC DECISIONS

5.1 Mandates and Incentives

Background

In the Air Traffic Management (ATM) arena, equipage mandates are typically implemented to address either a safety concern (for example, Traffic Alert and Collision Avoidance System (TCAS)) or for the greater good of the system (for example, ADS–B Out). The ideal ATM enhancement is attractive enough that system users equip voluntarily because they see a business case to equip and no mandates are required.

Incentives are used to enhance the business case. The ideal incentive has a tangible and quantifiable return on investment for equippers so that the incentives can be adequately considered in a business case. Incentives can be used to convert a marginal business case to a positive business case.

This section addresses working group 3's recommendations for Mandates and Incentives.

Mandate Versus Incentives for ADS–B In

Working group 3 agreed that if benefits are linear with equipage, then no mandate is required because airlines get essentially immediate return on investment—they do not have to wait for others to equip. However, if benefits are a square of equipage, a mandate needs to be considered. In that case, 50 percent equipage will result in only 25 percent of the benefit.

Critical Mass of Equipage May Be Required

There is separate concern that interval management spacing and delegated separation applications may require a critical mass before implementation. For instance, some think it is unlikely to conduct a spacing application or delegated separation application if equipage is less than 20 to 30 percent. Several options have been identified to address this concern:

1. Mandate ADS–B In Equipage on all aircraft.
2. Mandate ADS–B In equipage for all newly delivered aircraft beyond a certain date.
3. Provide incentives through the NextGen Equipage Fund.
4. Provide incentives through implementation of best-equipped, best-served operations.
5. Provide favorable treatment on new slots created as a result of ADS–B In Equipage.

Air Transport is reluctant to implement Option 1, a mandate for ADS–B In Equipage on all aircraft, due to a limited amount of investment capital and competing investment opportunities and a business case with a lot of risk still to be addressed and mitigated.

Option 2, a mandate for forward fit of ADS–B In equipage, is more attractive than a system-wide mandate for ADS–B In equipage. However, airlines are reluctant to implement ADS–B In operations on a sub-fleet of aircraft due to training and fleet management issues, so it may not fully achieve the objective of establishing a critical mass of equipage. But it will make the business case easier to close for equipping the entire fleet.

Option 3, the NextGen Equipage Fund[85], is attractive because it addresses two airline concerns: (1) The availability of capital at low interest rates and (2) that operations meet the performance and business case expectations that FAA suggests. With the NextGen Equipage Fund, airlines that see a positive business case can equip early in anticipation of benefits. If the business case is not met, then they pay a reduced or lower cost, depending on the detailed implementation of the NextGen Equipage Fund. This is an ideal approach to addressing the "first third" equipage problem inherent in so many equipage business cases, because it substantially reduces the risk associated with early equipage. Once the critical mass of equipage has been implemented and the applications are proven, the NextGen Equipage Fund is no longer necessary.

One variation on Options 2 and 3 might be that the NextGen Equipage Fund is available only for retrofit of aircraft older than a certain year and that eligibility for the fund requires that the airlines forward fit all new aircraft deliveries with ADS–B In. This will ensure that most leasing companies and airlines will take all new deliveries with ADS–B In installed, so they can get access to the NextGen Equipage Fund and pushes a small part of the risk to the airlines. If NextGen equipage funds are limited, the NextGen Equipage Fund could be targeted to only early equippers (the first 30 to 40 percent) and late equippers would pay their own way.

Option 4, Best-Equipped, Best-Served, would give preferential treatment to equipped aircraft. For instance, one option being discussed would be to give priority service to equipped aircraft that were put in a holding pattern, rather than First-Come, First-Served. This strategy is neutral to overall benefits but transfers benefits from unequipped users to equipped users who are presumably creating overall benefit to the system by creating system capacity.

Option 5, favorable treatment on new slots, has some promise in that the benefits are tangible and quantifiable. The downside is constructing a fair and equitable way of distributing slots depending on airlines' equipage.

All of these options can be difficult to implement both politically and operationally.

Closing the Business Case

Based on typical airline equipage business case metrics (3 year payback period), without incentives, the business case for any equipage, even forward fit, will not close prior to 2025. Based on results to date, the business case for retrofit post-2020 will be difficult to close.

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[85] The NextGen Fund is structured to address the needs of commercial aircraft operators, private sector investors, avionics suppliers, and the FAA. This is achieved using innovative financial structures that are augmented by "Best-Equipped, Best-Served" contractual commitments that create shared risks, returns, and accountability for all stakeholders. The purpose of the fund is to encourage early equippers who incur higher costs and higher risk than late equippers.

The question for the industry is what incentives are required to push the business case over the tipping point, sufficient to get critical mass for IM–S and IM–DS applications and sufficient for airlines to equip new deliveries and retrofit in production aircraft. The NextGen Equipage Fund, depending on the terms, could be used to help airlines pay for equipage and shorten the payback period that airlines require for making an equipage investment.

Summary of Findings

At this time, the ARC does not support an equipage mandate, but a mandate discussion might be considered only after it has been clearly demonstrated to the satisfaction of the user community that equipage benefits are indeed both achievable and operationally implementable in a cost effective manner within a mixed equipage environment, and an ARC activity concludes that a mandate makes sense. Only after this is reached should mandates be considered under the following conditions:

- Equipage is not linear with equipage and/or there is a minimum equipage required to get benefit.
- The FAA has researched controller tools and automation that could make equipage linear with benefit and not found anything that will work both technically and economically.
- Given those conditions, the air transport stakeholders still prefer that other tools be used to encourage equipage: Subsidies, risk sharing (for example, NextGen Equipage Fund or something similar), tax breaks, preferential treatment, etc. If those have been deemed insufficient, a mandate can proceed.
- Prior to a mandate, benefits from the top applications in terms of benefit need to be validated through trials.
- Ideally, the mandate year would coincide with the optimal year to equip for air transport.
- A targeted mandate (for example, Forward Fit only) is preferred to a system-wide mandate. Ideally, those aircraft that get the best return on investment, based on both benefit and cost, would be targeted.

Mandates are generally undesired by the air transport industry because it does not take into account the decisionmaking status at each airline such as financial status, availability of capital and competing investment opportunities, and the airline-specific benefits and costs of ADS–B In.

5.2 Bundling and Sequencing

Background

Another decision considered was the bundling and sequencing of applications. In the AIWP 2.0, 17 applications were identified. Applications were generally sequenced by maturity, equipage requirements, and from least risky to most risky. The ideal sequence would be to implement those applications that provide the maximum benefit with the minimum equipage and overall investment first and then proceed.

Overall Application Sequence

In general, the application sequence suggested by the AIWP makes sense. Applications can be sequenced into the following major phases:

Table K.10—Air Transport Application Sequence

Phase	Description	Equipage Requirements	AIWP Applications
1	Situational Awareness	CDTI	1,2,3, 5, FIS–B
2	Situational Awareness with Alerting	Indication and Alerting	4, 7
3	Spacing and Delegated Separation	PFOV CDTI with along-track guidance	6, 8
4	Advanced Applications	Add conflict detection	9, 10, 11, 12, 13, 14, 16
5	Self Separation		17

Phase 1 includes applications that provide situational awareness. Applications 1, 2, 3, and 5 are already being implemented by the FAA. The basic equipage requirement is CDTI and it is assumed the aircraft is already equipped with ADS–B Out.

Phase 2 adds alerting to the Situational Awareness applications. Application 4 (Surface IA) may require increased navigation performance beyond the current ADS–B Out rule and application 7 adds alerting to the initial situational awareness applications in application 1.

Phase 3 adds IM Spacing and DS applications. These applications add requirements for a PFOV display and Along-Track Guidance. At this point, applications 6 and 8 provide over 80 percent of the overall benefits to the air transport industry.

Phase 4, the Advanced Applications, adds conflict detection as a requirement. Benefits have not been estimated for applications 9, 12, and 13. Application 14 benefits have been quantified. Application 15, ADS–B Integrated Collision Avoidance has been eliminated as a separate application and so it is no longer listed. (Application 15 would basically re-architect TCAS to integrate it with ADS–B Out).

Phase 5, Self Separation, besides the technical risks, introduces potential political risks and has a great deal of research and risk-reduction required prior to implementation.

Phase 3 Application Sequence

The Phase 3 sub-applications are as follows, sequenced in order of benefits in year 2018 (Benefits assume 100 percent ADS–B In and ADS–B Out Equipage):

Table K.11—Air Transport Phase 3 Applications

Number	Name	2018 $M
14	IMC CEDS	$204M
8b	IM–DS during Arrival and Approach—Standard or OPD Arrivals	$158M
6b	IM–S during Arrival and Approach—Standards or OPD Arrivals	$52M
8f	VMC CEDS	$51M

Number	Name	2018 $M
8d	IM–DS Dependent Runway Ops	$34M
6d	IM–S Dependent Runway Ops	$13M
8e	IM–DS Oceanic (NATOTS only)	$4M
8i	CEDS for closely spaced parallel runways	$1M

This set of sub-applications can be grouped into the following major applications, listed in order of annual direct (no Passenger Value of Time) air transport industry value in 2018:

1. IMC CEDS ($204 million)
2. IM–DS ($192 million)
3. IM–S ($68 million)
4. VMC CEDS ($51 million)
5. IM–DS Oceanic (NATOTS only) ($4 million)
6. CSPR CEDS ($1 million)

Working group 3 agreed to the following constraints regarding sequencing:

- IM–S comes before IM–DS to help reduce technical and implementation risk.
- VMC CEDS comes before IMC CEDS to help reduce technical and implementation risk.
- CSPR CEDS and IM–DS Oceanic have small returns and may not provide an overall return on investment.
- VMC CEDS is the least risky application.
- IMC CEDS is the riskiest application. In addition, it requires a change to the ADS–B Out message set to include wake parameter information.

Based on perceived risk and value, the suggested sequence for applications 6 and 8 is as follows:

1. VMC CEDS (2016)
2. IM–S (2018)
3. IM–DS (2020)
4. IMC CEDS (2025): IMC CEDS requires a change to the message set to add the wake parameter. Given the mandate for RTCA DO–260B is in 2020, it would probably require at least 5 extra years to upgrade to RTCA DO–260C. A mandate for this will require an updated business case.

Regional Sequence

Another consideration in rolling out ADS–B In will be the airport sequencing. Benefits were computed on a per flight basis for applications 6, 8, and 10. (Spacing, Delegated Separation and Closely Spaced Parallel Runways.) Airports are ordered in terms of total benefits in 2025 in the table below. The magnitude of benefits for each airport is driven primarily by a) the number of operations and b) the benefit from decreasing capacity constraints at that airport. The operations assessment takes into account planned airport. The analysis includes consideration of future planned improvements documented in "Capacity Needs in the National Airspace System 2007–2025", also referred to as the FACT 2 study.

The benefits resulting from the delay model do not accrue equally across the NAS and vary considerably by airport. The following table gives a good idea of the variability; however, we believe more credence should be given to the NAS-wide values than the airport-by-airport results. The model was originally validated on a NAS-wide basis; the delay at any one airport does not represent the same level of precision/confidence as the NAS-wide result. Also, the model represents a network and the process of assigning flight delay savings to a particular airport without double-counting involved some judgment calls by the analyst that may not tell the entire story.

Table K.12—Airport Benefits Analysis

Rank	Airport	Total (min)	2030 Ops	Daily Min Saved	% of Total Benefits	Cum Benefit	% of all Ops	Cum % of all Ops	Benefit to Average Ratio
1	ATL	13.4	1311	17567	28%	28%	6%	6%	4.6
2	JFK	9.9	805	7970	13%	41%	4%	10%	3.4
3	LAS	5.5	984	5412	9%	49%	5%	14%	1.9
4	PHL	6.1	804	4904	8%	57%	4%	18%	2.1
5	LGA	8.8	388	3414	5%	63%	2%	20%	3.0
6	SFO	3.9	626	2441	4%	67%	3%	23%	1.3
7	LAX	2.2	998	2196	4%	70%	5%	28%	0.8
8	EWR	3.3	580	1914	3%	73%	3%	30%	1.1
9	CLT	1.8	963	1733	3%	76%	4%	35%	0.6
10	IAD	2.3	749	1723	3%	79%	3%	38%	0.8
11	IAH	1.9	905	1720	3%	82%	4%	43%	0.7
12	BWI	3.7	434	1606	3%	84%	2%	45%	1.3
13	SEA	2.4	506	1214	2%	86%	2%	47%	0.8
14	MDW	2.6	401	1043	2%	88%	2%	49%	0.9
15	PHX	1.3	645	839	1%	89%	3%	52%	0.4
16	ORD	0.5	1350	675	1%	90%	6%	58%	0.2
17	DTW	0.9	688	619	1%	91%	3%	61%	0.3
18	MSP	0.9	676	608	1%	92%	3%	64%	0.3
19	FLL	1.2	476	571	1%	93%	2%	67%	0.4
20	BOS	1.1	457	503	1%	94%	2%	69%	0.4
21	DEN	0.5	998	499	1%	95%	5%	73%	0.2
22	SAN	1.3	321	417	1%	95%	1%	75%	0.4
23	MCO	0.8	506	405	1%	96%	2%	77%	0.3
24	DFW	0.4	949	380	1%	97%	4%	82%	0.1
25	DCA	1	307	307	0%	97%	1%	83%	0.3
26	TPA	0.8	360	288	0%	98%	2%	85%	0.3
27	MEM	0.5	526	263	0%	98%	2%	87%	0.2
28	SLC	0.5	510	255	0%	98%	2%	90%	0.2
29	PDX	0.6	378	227	0%	99%	2%	91%	0.2
30	CLE	0.8	282	226	0%	99%	1%	93%	0.3
31	STL	0.6	266	160	0%	99%	1%	94%	0.2
32	PIT	0.8	178	142	0%	100%	1%	95%	0.3
33	MIA	0.2	581	116	0%	100%	3%	98%	0.1
34	CVG	0.5	222	111	0%	100%	1%	99%	0.2
35	HNL	0.2	301	60	0%	100%	1%	100%	0.1
AVG		**2.9**							

In summary, the top 6 airports ATL, JFK, LAS, PHL, LGA and SFO provide 67 percent of all the benefits with only 23 percent of the total operations.

The average savings per operation across the top 35 airports is 2.9 minutes. The final column computes the ratio of the savings per operation at the designated airport relative to the average savings per operation. So, for example, an aircraft flying to ATL would expect 4.6 times the average aircraft savings for those operations. It is interesting to note that only eight airports have a better than average savings per operation: the top six airports listed above and EWR and BMI.

The working group found the priority of the application categories, at a high level, should be as follows:

1. Situational Awareness,
2. Situational Awareness with Alerting,
3. Spacing and Delegated Separation,
4. Advanced Applications with Conflict Detection, and
5. Self Separation.

The working group also found within the Spacing and Delegated Separation applications, the order of the applications should be as follows:

1. CAVS,
2. IM–S,
3. IM–DS, and
4. IMC CEDS.

Recommendation 60: The ARC recommends the FAA prioritize the applications as follows, in terms of airport implementation:

1. Hartsfield-Jackson Atlanta International Airport (ATL),
2. John F. Kennedy International Airport (JFK),
3. McCarran International Airport (LAS),
4. Philadelphia International Airport (PHL),
5. LaGuardia Airport (LGA),
6. San Francisco International Airport (SFO),
7. Los Angeles International Airport (LAX),
8. Newark Liberty International Airport (EWR),
9. Charlotte Douglas International Airport (CLT), and
10. Washington Dulles International Airport (IAD).

5.3 Avionics Requirements Beyond the Current ADS–B Rule

Another strategic decision area considered by working group 3 is changes to the ADS–B Out Rule. Some of the applications will not be feasible with the current implementation of the ADS–B Out Rule, so changes to the rule need to be considered.

The three applications that might require changes in the ADS–B Out Rule are as follows:

- Application 4: Airport Traffic Situation Awareness with Indications and Alerts;
- Application 10: Paired Closely Spaced Parallel Approaches; and
- Application 14: IM–DS with Wake Risk Management.

Higher Navigation Performance

Both applications 4 and 10 require a NIC and NAC beyond the current rule. Other applications like RNP, will drive airlines toward a higher Navigation performance, but from an ADS–B In perspective the business case to mandate a higher NIC and NAC for navigation is marginal.

According to the current business case results, in year 2020, application 4 will return the average aircraft about $3,000 in benefit and application 10 will return the average aircraft $10,000 in benefit. This would not warrant a mandate for higher navigation performance by itself. However, in conjunction with other navigational upgrades such as RNP, SBAS, and GBAS there may be sufficient navigation performance to meet the requirements.

Changes to the Message Set To Add a Wake Parameter

Application 14 requires an addition to the message set to add a Wake Parameter.

The benefits distinction between IM–DS and IM–DS with Wake Risk Management is still being conducted at the time of writing this article, so no definitive conclusion can be made.

One option that could be considered would be to mandate for only the busy airports, in this case ATL and JFK, and perhaps LAS, PHL, and LGA. These airports conduct only 20 percent of the operations in the NAS. However, experts have stated that a change mandated at the New York airports is equivalent to implementing a NAS-wide mandate.

Recommendation 61: The ARC recommends the FAA make no changes to the ADS–B Out rule at this time.

Recommendation 62: The ARC recommends the FAA monitor other NextGen improvements to determine if a business case for mandating higher Navigation Performance can be made.

Recommendation 63: The ARC recommends the FAA conduct further research to determine whether incorporation of the wake parameter into the ADS–B Out message set is warranted.

5.4 Portfolio[86] Perspective Is Required

Ongoing aviation community efforts (by the RTCA BCPMWG and the ADS–B In ARC BCWG) are assessing various components of NextGen-related avionics as a series of independent capabilities.

There is a growing recognition that the subject NextGen capabilities interact at the operational level; and that these operational interactions are both synergistic and competitive. Benefits assessed at the independent capability level are at risk of understating some benefits and overstating others.

It is more broadly understood that the subject capabilities rely upon common components in the aircraft; whose costs cannot be readily allocated to those discrete capabilities. Cost assessments that address them as independent capabilities are at risk of understating some costs and overstating others.

Recommendation 64a: The ARC recommends the FAA implement a NextGen portfolio activity that looks at all the proposed investments from a portfolio perspective and identify potential cost synergies, benefit overlaps, and other portfolio interactions.

Recommendation 64b: Once these operational and technical interactions are better understood, the ARC recommends the FAA look at the collection of applications across the portfolios and make sure they make sense together and they do not cause conflict in their implementation.

The ARC finds the RTCA NextGen Advisory Council appears to be the appropriate forum to address these NextGen avionics portfolio considerations and provide recommendations to the FAA and other aviation stakeholders.

Substantiation:

Realizing NextGen operational and business objectives will require substantial investments in avionics capabilities. The U.S. aviation community is engaged in two activities investigating the business case considerations regarding these investments:

- The ADS–B In Advisory Rulemaking Committee (ARC) is tasked to assess industry business case considerations for the range of ADS–B In capabilities defined in AIWP v. 2.0. This tasking is being undertaken by their Business Case Working Group (BCWG) (working group 3).

[86] A portfolio is a set of investment opportunities competing for the same source of capital.

- The RTCA NextGen Advisory Council (NAC) is tasked (tasking allocated to the Business Case and Performance Metrics Working Group (BCPMWG)) to assess industry business case considerations, using available research results, for—

    - Performance-based Navigation (PBN) (RNAV and RNP–0.3 with RF Legs),

    - ADS–B Out (per the ADS–B Out Mandate), and

    - ATC Data Link Communications (FANS–1/A+ and ATN Baseline 1, both over Mode 2).

The shared uses of avionics components necessitate some understanding of the portfolio considerations of these investments.

- Costs to design, acquire, and install these components should be assessed jointly to avoid double counting of common expenditures; and, to identify integration and installation synergies.

    - Positioning, navigation and timing (PNT) functions provided through GPS are needed by all the capabilities.

    - Changes to flight management systems (FMS) are needed by some ADS–B In, PBN, and data link capabilities.

    - Primary navigational displays are needed by PBN and ADS–B In capabilities.

- Benefits arising from the use of these components should be assessed jointly to avoid double counting of common benefits; and, to identify synergies arising from joint use of capabilities:

    - ADS–B In, PBN, and data link capabilities each claim to enable optimized profile descents; but the joint effects of their various combinations have not been assessed.

While the desirability of a comprehensive portfolio assessment is clear, the current ongoing activities have real constraints that limit their ability to do so:

- Tasking guidance to the activities identified above is explicitly limited in their scope to assessing discrete capabilities rather than their joint effects.
- The fundamental research on the joint benefit effects of capabilities needed to conduct the assessments has not been done; these industry activities are not scoped to conduct such research.
- Assessments of component commonality and integration impact have not been conducted.

These considerations should be captured as scope limitations in the deliverables of the above activities.

6.0 NEXT STEPS

Recommendation 65: The ARC recommends the FAA take the following next steps for the benefit-cost analysis:

1. Mixed Equipage Benefits Impact: If possible, establish whether benefits are linear with equipage, or square with equipage, or something else. This uncertainty has major implications regarding whether to equip, whether mandates are required, etc. This can be done through expert interviews, trials, simulations, etc. The ARC could not come to consensus on this issue.

2. Updates to FAA provided monetary value: Accurate data inputs are a prerequisite to any solid and credible analyses. The ARC recommends that the FAA invest resources in maintaining a current set of economic criteria to be used as the basis for any benefit-cost analyses. The FAA currently uses two documents: "Economic Values For FAA Investment And Regulatory Decisions, A Guide", October 3, 2007 and "Economic Information for Investment Analysis", March 16, 2011.[87]. These documents rely on cost inputs that are less than relevant today given material changes experienced by all user groups. For example, aircraft operating costs for air carriers and GA rely on values set from 2002 and 2003 respectively that have been inflated over time to 2010 levels. Given the plethora of data which is both reliable and current, the FAA has the opportunity to improve data quality and should do so without hesitation.

3. Equipage Cost Synergies: Identify if any of the identified equipage costs will be required for other NextGen programs or other new features that the airlines are pursuing. This can reduce the true cost incurred for ADS–B equipage. One scenario is that operators are considering upgrading CRT displays to LCD displays for 757/767 aircraft. This would cover part of the cost for upgrading to ADS–B In.

[87] Of particular note are two critical cost variables that will have a material impact on any benefits calculations. FAA suggests that an average fuel price of $2.43 in FY 2011 be used from 2011 to 2031. While precision is difficult to reach when establishing a price over 20 years, it is worth noting that the current U.S. Department of Energy forecast for jet fuel price shows $3.01 per gallon in 2011 and $3.09 per gallon in 2012. Moreover, with respect to direct operating costs (DOC) for airspace users (which is at the heart of any benefits calculations as time and cost savings are a proxy for monetizing benefits stemming from enhanced capacity) FAA has simply taken outdated cost values and inflated them to current year values using the consumer price index; the FAA took actual Air Transport DOC values from 2002 and inflated them to 2011 estimates. This methodology is faulty at best, especially when considering the plethora of cost data that is both current and readily available.
Using the FAA's methodology as an example, we know that 2002 direct operating costs for passenger carriers who operated an Airbus 320 were $2,829 per block hour, which would translate into $3,430 in 2010 using CPI. By contrast, the actual 2010 value was $3,883, 13 percent higher than the inflation adjusted estimate. If costs ultimately translate into benefits, the FAA would be understating the benefits in its calculations.

4. Top Five Application Benefits: The top five applications contribute 77 percent of the total benefits. Three of the next applications in the list require higher Navigation Performance than specified in the RTCA DO–260 B mandate. Focus on the top five applications in terms of additional data gathering to increase confidence in the results. Develop credible ranges of possible benefits in order to conduct a meaningful sensitivity analysis. Conduct trials, simulations, experiments, etc. to reduce the uncertainty on key benefit assumptions and increase stakeholder confidence in benefits estimates.

5. Capacity Sensitivity Analysis: A majority of the benefits in the air transport business case come from increases in capacity. When modeling capacity increases, adjustments to the traffic forecast are made when delay reaches unacceptable levels. Flights may be cut or re-distributed to less busy times in the day. The bottom line is that modeling benefits from increased capacity is an art and not a science. A sensitivity analysis should be done around these assumptions to determine the impact of these assumptions and how conservative or aggressive the current analyses are.

6. Equipage percent: The benefit-cost analyses are highly sensitive to the equipage assumptions which are highly sensitive to incentives and to the degree to which operators believe the business case.

APPENDIX L—LEGACY ADS–B OUT AVIONICS

The following are excerpts from the Air Traffic Management Advisory Committee (ATMAC) Automatic Dependent Surveillance–Broadcast working group report submitted and accepted by the ATMAC at its August 4, 2010, meeting.

> The FAA established a 2020 effective date for ADS–B "Out" performance-based airspace.[88] The rule contains requirements for operators in specified airspace to be equipped with certain avionics[89] with required performance. The rule's performance requirements will drive operators' decisions with respect to Global Positioning System (GPS) equipment installation and upgrade in advance of the January 1, 2020 deadline.
>
> In parallel to the final rule, the FAA published equipment installation and operational guidance Advisory Circulars (AC) 20–165 and AC 90–ADSB (draft) that identify one way by which aircraft manufacturers and operators can ensure that ADS–B equipment is properly installed and used.
>
> Legacy ADS–B equipment is in operation on a number of air transport and general aviation aircraft. For the purpose of this paper, legacy ADS–B equipment includes DO–260, DO–260A, or DO–282A[90] avionics manufactured and / or installed prior to the FAA's publication of the ADS–B "Out" final rule and prior to the development of FAA installation guidance. Legacy equipment also includes GPS positioning sources that cannot meet the requirements of AC 20–165 or which performance is unlikely to achieve necessary position accuracy and integrity performance requirements with needed availability.
>
> Today there are numerous airline and general aviation operators who have voluntarily elected to equip with ADS–B based on previous equipment standards including through the Alaska Capstone program; to enhance safety in flight training at Embry-Riddle Aeronautical University and University of North Dakota; to facilitate and demonstrate more efficient operations at United Airlines, UPS, and US Airways; to provide surveillance in Non-Radar Airspace (NRA) in the Gulf of Mexico through MOU with the Helicopter Association International; and to meet the NAV Canada Hudson Bay initiative per OpsSpec A353. Analysis conducted in support of the ADS–B Aviation Rulemaking Committee (ARC) Task 1 report indicates that approximately 2,000 of the DO–260 legacy avionics installations would be ready to meet requirements for non-radar

[88] See 14 CFR 91.225.

[89] In December 2009 the FAA published updated Technical Standards Orders (TSO) for 978 MHz UAT (DO–282B / TSO–C154c) and 1090 MHz (DO–260B / TSO–C166b) based on guidance from the ADS–B ARC and work done by RTCA SC–186. The DO–260B MOPS is expected to be recognized as the internationally harmonized avionics standard for ADS–B "Out" equipment.

[90] An overview of the changes made to the different versions of equipment for 1090MHz ADS–B (DO–260) as well as 978MHz ADS–B (UAT) is included in Appendix A. Issues with the legacy ADS–B transponder equipment is outlined in further detail in Appendix B.

airspace including possibly AMC–20–24[91] without significant changes such as via a Service Bulletin.

The working group was asked to make its recommendations in the context of RTCA Task Force 5 through which the operator community communicated its desire to take the fullest advantage of existing equipage versus forcing new equipage by operators.

[91] AMC 20–24 is the airworthiness installation and operational acceptable means of compliance adopted by Canada and Europe which allows use of DO–260 equipment for non-radar airspace operations.

SEPARATION IN NON-RADAR AIRSPACE (NRA)

Explanation: The FAA does not plan to accommodate legacy avionics equipment for separation services domestically except for limited operations in Alaska[92] and Gulf of Mexico.[93] However, the FAA has determined that significant benefits exist for high altitude routes in the Gulf of Mexico based on achieving increased capacity and optimal routing. Currently, the benefits are being reviewed and quantified for the non-radar transition airspace abutting the North Atlantic Track System while the business case for the offshore East Coast routes has not yet been developed. The SBS office believes there are benefits in this area due to an increased availability of surveillance and the possibility of additional routes.

The full and optimized use of any of these routes is dependent on the completion of the ground infrastructure rollout, aircraft equipage, and operational procedure development and approvals. The FAA expects the OpsSpec for these operations to be approved in February 2011 and the capability will be fully available in the NAS in 2013. The FAA will implement these routes in three tiers, as equipage drives the capability in the mixed environment:

Low Equipage (0–30 percent), "Better Access to Airspace"

Medium Equipage (30–70 percent), "Dedicated Altitudes"

High equipage (over 70 percent), "Dedicated Routes"

The airline operator community, lead by Air Transport Association (ATA), has indicated a level of interest[94] in obtaining some benefits in non-radar airspace prior to 2020. Several combinations of equipment configurations were identified by the working group that could drive an airline to elect to equip their fleet in order to be authorized to operate in the NRA environment using ADS–B before 2020. These options include:

Upgrading their aircraft to rule compliant avionics that meet the stringent performance needs of the rule which are based on terminal and surface separation standards and performance requirements.

Upgrading their aircraft with rule compliant ADS–B transponders, when available, but postponing the upgrade of the aircraft's position accuracy and integrity capability, the aircraft GPS units, until a time prior to the effectiveness of the 2020 mandate depending on the availability of benefits.

[92] In Alaska, the FAA plans to support the 472 Capstone aircraft equipped with DO–282A. The FAA is accommodating these aircraft because the agency has knowledge of how the installations were made

[93] In the Gulf of Mexico, the FAA use a list of approved DO–260A and DO–282A aircraft that meet the requirements outlined in the April 6, 2009 memorandum from SBS to AIR–130 Automatic Dependent Surveillance Broadcast (ADS–B) Requirements for Separation Services in the Gulf of Mexico.

[94] The ADS–B Working Group conducted a survey of the ATA membership with respect to plans for using legacy equipage and possible opportunities for generating benefits prior to 2020.

Upgrading their aircraft to comply with the Nav Canada requirements for Hudson Bay operations (AMC 20-24).

There are various factors influencing each of the above listed options. To become rule compliant, an operator would incur costs related to installation of rule compliant transponders and new or upgraded GPS (multi-mode receiver "MMR") units for their aircraft. If the FAA provided an option to upgrade only the ADS–B transponders and not the MMRs, an air carrier could potentially meet certain lower performance requirements adequate for NRA in the interim and obtain limited ADS–B benefits using their existing MMRs. Some operators are also obtaining Hudson Bay operational approvals which are based on older transponder standards; however this configuration has several operational issues[95] that would have to be managed through ground or other mitigations.

The ADS–B Working Group notes that for NRA the performance requirements referenced in RTCA Safety and Performance Requirements (SPR) standards are less stringent than 14 CFR 91.227 which is also the case for NRA as approved by the FAA in Alaska.[96] This provides an opportunity for authorizing operations with MMRs that cannot meet the stringent performance of 14 CFR 91.227.

Recommendation: The ATMAC should recommend that the FAA undertake an alternatives analysis for operators to obtain Non-Radar Airspace (NRA) benefits on specified routes through early equipage with 1) rule compliant avionics as well as with 2) legacy ADS–B transponders with approved installations (such as AMC 20–24) or 3) rule compliant transponder but a position source performance that does not meet the requirements of 14 CFR 91.227(c) with an acceptable availability. The FAA should also identify dates by which specific ADS–B routes will be available in NRA airspace in the Gulf of Mexico, off the East Coast, and connecting with the North Atlantic Track System and possibly in other airspace to facilitate operators making an informed decision about the timing for obtaining benefits.

Legacy general aviation avionics[97] may be easier to accommodate for NRA operations since some issues such as the lack of 4096 code are not present. General aviation and also some air carrier operations will benefit from expanded surveillance in low altitude airspace below current radar coverage.

[…]

[95] Hudson Bay operational approvals per A353 are based on EASA AMC 20–24 and DO–260 transponder equipage. Most aircraft are DO–260 equipped that rely on NUC, which is blends integrity and accuracy, and does not provide a 4096 code for which the FAA has not identified clear operational mitigations. Authorizing operation with DO–260 equipment for separation would require the FAA to conduct a Safety Risk Management Document (SRMD) evaluation.

[96] DO–303 SPR NRA sets NIC at 4 and NAC_P at 5 while for Alaska NIC has been approved by the FAA at 5 and NAC_P at 6.

[97] DO–282A and specifically the Garmin GDL–90.

AIR-TO-AIR APPLICATIONS

Explanation: The FAA evaluates each ADS–B application for the applicability of target aircraft with legacy equipment. Individual applications may require mitigation when targets are using legacy equipment. Most air-to-air applications currently approved (Merging and Spacing, CAVS, Enhanced Visual Approaches) and some currently being specified, including In-Trail Procedures (ITP) has used a TCAS integrity and accuracy check to qualify target aircraft broadcasting DO–260 or DO–260A.[98] Situational awareness applications (AIRB) do not require any mitigation.

Recommendation: The FAA should continue to evaluate new ADS–B In applications for the applicability of target aircraft with the various types of legacy equipment, including through the use of mitigations when appropriate.

[98] See page 6, Interim Policy and Guidance for Automatic Dependent Surveillance Broadcast (ADS-B) Aircraft Surveillance Applications Systems Supporting Oceanic In-Trail Procedures (ITP), AIR-130, May 10, 2010 which states that "TCAS-derived relative position information must be used, if available, to validate the reported ADS-B position integrity of Reference Aircraft with legacy transponders, (i.e. DO–260/260A as described in paragraph 2.2.1.1 below. However, ADS-B aircraft may be displayed on the CDTI IAW RTCA/DO–317 for the Enhanced Visual Acquisition application (paragraph 2.2.4.1.2) without position integrity."

APPENDIX M—ARC RECOMMENDATIONS ON FIM–S, IM–DS, AND SURF–IA

November 1, 2010

Mr. Henry P. Krakowski
Chief Operating Officer
Air Traffic Organization
Federal Aviation Administration
800 Independence Avenue SW.
Washington, DC 20571

Ms. Margaret Gilligan
Associate Administrator for Aviation Safety
Aviation Safety Organization
Federal Aviation Administration
800 Independence Avenue SW.
Washington, DC 20571

Subject: Automatic Dependent Surveillance–Broadcast (ADS–B) In Aviation Rulemaking Committee (ARC) — Task 1

Dear Mr. Krakowski and Ms. Gilligan:

The Federal Aviation Administration (FAA) chartered the ADS–B In ARC to define a strategy for incorporating ADS–B In technologies in the National Airspace System (NAS). The FAA also asked the ARC to make specific near-term recommendations about whether the FAA should continue development work on the following three applications: Flight-Deck-based Interval Management-Spacing (FIM–S), Interval Management–Delegated Separation (IM–DS), and Airport Traffic Situation Awareness with Indications and Alerts (SURF–IA).

The ADS–B In ARC endorses the continued development of the FIM–S and IM–DS applications, as well as focused investigation for and refinement of the SURF–IA application. The ARC also provides the FAA with several recommendations about the development of each application, including some recommendations that pertain to the FAA's schedule for their deployment. See attachment for specific recommendations.

We trust this report will be helpful in your decisionmaking process. The ADS–B In ARC will continue to define a strategy for incorporating ADS–B In technologies in the NAS while encouraging international harmonization. We and our fellow ARC members stand ready to help the FAA with any additional tasks as needed.

Sincerely,

Steven J. Brown
ADS–B In ARC Co-Chair
National Business Aviation Association

Thomas L. Hendricks
ADS–B In ARC Co-Chair
Air Transport Association of America, Inc.

Enclosure
Copy to Mr. Doug Arbuckle, ADS–B In ARC Designated Federal Official

Interval Management Applications

As defined in the Application Integrated Work Plan (AIWP) version 2, FIM–S is "a suite of functional capabilities that can be combined to produce operational applications to achieve or maintain an interval or spacing from a target aircraft." Some of the operational applications, such as Sequencing & Merging and Merging & Spacing, are well-developed. For these well-developed applications, research, simulations, trials, detailed feasibility analysis, and cost-benefit analysis have been performed (AIWP Maturity Ranking 4).

As defined in AIWP version 2, FIM–DS, and a companion ground tool to deliver IM-DS, is "a suite of functional capabilities that build upon FIM–S and can be combined to produce operational applications that delegate responsibility for separation of ownship from a target aircraft to the flightcrew." The concept is in development and a research plan exists (AIWP Maturity Ranking 3).

The aviation community recommends continued developmental funding of both suites of functional capabilities.

The ADS–B In ARC recommends the Federal Aviation Administration (FAA) continue work on standards development for both interval management applications. The ARC also encourages the FAA to continue developing operational services and environment definitions for the specific operational applications supported by FIM–S and IM–DS functionality. The FAA should provide the results of this work for use in developing minimum operational performance standards (MOPS).

The ADS–B In ARC also provides the following recommendations to the FAA about the necessary work to mature FIM–S and IM–DS, in accordance with the FAA's current schedule.

- The ARC assumes FIM–S MOPS will be developed by June 2013 based on the FAA's proposed funding levels and the following assumptions:
    - The required datalink Controller-Pilot Data Link Communications (CPDLC) message sets for FIM–S are included in the work plan of RTCA, Inc. (RTCA), Special Committee (SC)–214 as part of its December 2011 deliverables.
    - The FAA conducts required end-to-end system validation, including flight trials, by September 2012 to meet the schedule for MOPS validation. The ADS–B In ARC recommends these trials go beyond the operations conducted in 2007 through 2010 by United Parcel Service at Louisville, Kentucky. Assuming NAS deployment of FIM–S starts in 2015, the FAA should design flight trials to identify and confirm benefits for early adopters in a mixed equipage environment (ADS–B Out[1] and non-ADS–B Out-equipped aircraft).

[1] For the purposes of this paper, ADS–B Out assumes versions 0, 1, and 2.

  - The FAA ensures air traffic control (ATC) automation, such as Ground-based Interval Management–Spacing (GIM–S), is ready to support FIM–S deployment by Fiscal Year (FY) 2014.

- The ADS–B In ARC provides the following recommendations to the FAA about FIM–S:

  - The FAA should continue to request SC–214 include FIM–S CPDLC message sets in the work plan for December 2011 deliverables.

  - The FAA should evaluate the use of legacy ADS–B Out avionics in target aircraft through mitigations such as Traffic Alert and Collision Avoidance System (TCAS) range validation, which is in line with the current interim policy guidance for In-Trail Procedures (ITP). The use of legacy ADS–B Out avionics could help the community realize early benefits.

  - The FAA should continue to rapidly mature other applications that can be supported by a FIM–S cockpit architecture. The ARC assumes retrofit installations will rely on a combination display, using an auxiliary display in the forward field of view (for along-track guidance) and a Cockpit Display of Traffic Information (CDTI) in a forward or side field of view location. Both forward fit and retrofit architectures are assumed to be in the Major function hazard category.

  - The FAA should determine the suitability of auxiliary display guidance information in the primary field of view, traffic information in the side field of view, and a requirement to integrate autoflight capabilities. The ARC believes these factors are a significant driver for operator retrofit costs.

  - Recognizing that IM–DS is an evolution of FIM–S, but not as mature, the FAA should ensure the FIM–S flight trials can support future IM–DS development and flight trials. The flight trials should be conducted to inform the operational definition of associated IM–DS applications.

  - The FAA should accelerate the plan to develop documented requirements supporting required ATC ground automation. The commissioning and deployment of ATC ground automation is a prerequisite to certain FIM–S deployment and operator equipage.

  - The FAA should publish procedures describing the ADS–B In operations well in advance of anticipated operations.

  - The FAA should harmonize the development of the FIM–S application with Europe.

- The ADS–B In ARC believes IM–DS MOPS will be developed by July 2014 based on assumed funding levels and the following assumptions:

  - ATC automation is ready for IM–DS deployment by FY 2015.

  - The concept of operations for IM–DS is at a level of maturity in 2011 to determine whether the work plan of RTCA SC–214 should include additional CPDLC message sets for delegated separation, beyond those required for FIM–S. The ARC notes current FAA planning would result in a mature IM–DS concept of operation in November 2011.

- The ADS–B In ARC provides the following recommendations to the FAA about IM–DS:

  - The FAA should release a draft IM–DS concept of operations for public comment as soon as is practical.

  - The FAA should evaluate the use of legacy ADS–B Out avionics (including ATC transponder, TCAS, global navigation satellite system receivers, flight management systems, and other affected on-board equipage) in target aircraft through mitigations (for example, TCAS range validation), which conforms to current policy guidance for ITP. This consideration could help the community realize early benefits.

  - The FAA should plan for IM–DS flight validations in the FY 2013–2014 timeframe and budgets. The IM–DS flight validations should use lessons learned in the FIM–S flight trials.

  - The FAA should define airborne and ground automation requirements that will support FIM–S and IM–DS, as well as some situational awareness applications and ITP. The ARC hopes these requirements will support a bundled set of applications for interval management deployment.

  - The FAA should determine whether IM–DS deployment would require rulemaking to temporarily delegate responsibilities for separation from the air traffic controller to the pilot. If rulemaking is required, the FAA should ensure this rulemaking is completed by the expected IM–DS entry into service in FY 2015.

  - The FAA should determine if other rules, regulations, and associated guidance would need to be changed to support IM–DS.

Finally, with respect to FIM–S and IM–DS, as well as other ADS–B In applications, the ADS–B In ARC believes the FAA must move quickly to define cockpit display requirements, including required information in the forward/primary field of view (per Advisory Circular (AC) 25–11A). The ARC believes defining the application requirements will improve the business case analysis and provide operators with the necessary confidence in the spacing separation capabilities. The application requirements will also allow manufacturers and operators to better evaluate the bundling of ADS–B In applications (based on avionics architecture and business case equipage decisions).

Airport Traffic Situation Awareness with Indications and Alerting

The ADS–B In ARC reviewed the extensive demonstration work the FAA conducted during FY 2010 for SURF–IA. The ARC believes it is essential the FAA make it a priority to resolve the issues identified during the SURF–IA demonstration, such as line-of-sight interference and ADS–B drop-outs.

The ADS–B In ARC also believes the FAA should identify the role of Traffic Information Service–Broadcast (TIS–B). To enhance the usability of the SURF–IA application at all airports with surface service volume multilateration surveillance systems, the FAA should—

- Modify TIS–B in a manner that it will broadcast all targets in an airport surface service volume. This modified TIS–B should leverage the integrity and accuracy of multilateration systems to enable SURF–IA for all traffic at these airports.

- Maintain this modified TIS–B service in the NAS until alternate means are viable to enable SURF–IA, independently of this new TIS–B service.

The ADS–B In ARC also notes the current NextGen Implementation Plan (NGIP) identifies the development of guidance, including technical standard orders for "surface indications/alerts" by 2012[2]. This schedule is not based on the additional work needed to develop this application. The ARC recommends the FAA re-plan the activity after the issues have been resolved.

After the FAA solves the above-listed problems, the ARC provides the FAA the following additional recommendations:

- Considering the required accuracy for SURF–IA exceeds the accuracy requirement in the ADS–B Out rule, the ADS–B In ARC requests the FAA to evaluate the benefits that can be obtained from SURF–IA with (1) rule-compliant ADS–B Out avionics and (2) rule-compliant ADS–B Out avionics with multilateration and TIS–B airports.

[2] NextGen Implementation Plan, March 2010, appendix A.

- The ARC recommends the FAA undertake a separate study considering equipage with better performance (than the minimum rule-compliant avionics) in the general aviation fleet and the geometry and size of general aviation airports.

- The ARC encourages the FAA to move quickly to evaluate the opportunity for deploying receive-side mitigations to display the necessary accuracy. The ARC also recommends the FAA evaluate the benefits of receive-side mitigations in an ADS–B Out rule-compliant avionics environment.

- The ADS–B In ARC has reviewed the SURF–IA benefits that can be achieved in an environment of rule-compliant ADS–B Out avionics. The ADS–B In ARC recommends the FAA request the RTCA Program Management Committee (PMC) task SC–186 to focus on developing the SURF–IA application in context of rule-compliant ADS–B Out avionics.

- The ARC recommends a phased SURF–IA deployment strategy, starting with early deployment, while using rule-compliant avionics. The ARC also recommends leveraging higher-accuracy performance, when available, while using rule-compliant avionics. The ARC does not recommend any changes to the performance specifications in the ADS–B Out rule.

- The ADS–B In ARC notes that analysis seems to show little benefit for reduced navigation accuracy category for position (NAC_P) requirements by splitting the SURF–IA and SURF–I applications. However, the ARC believes other differences may exist to encourage the applications to be separated, for example, the avionics requirements for SURF–I may be less stringent than those for SURF–IA. The ARC recommends the FAA Aircraft Certification Service determine, as soon as possible, the requirements for SURF–I and SURF–IA regarding the following: (1) CDTI display location; (2) indication and alerting display location; (3) moving map requirements (airport versus runway only); (4) traffic selection implementation; and (5) function hazard category. An example of operational issues that will drive equipment requirements is whether the application will provide a non-directive alert(s) or if the pilot is expected to take immediate action. There is some guidance in the SURF–IA Safety and Performance Requirements (SPR), but it is critical the FAA determine how the alerts are to be handled by the flightcrew.

- The ADS–B In ARC has a general concern that lack of dimensional information describing (1) distance from threshold to runway edge and (2) distance from threshold to runway centerline, could increase the NAC_P requirement. This lack of dimensional information could also decrease the availability to use SURF–IA at airports without airport map data bases. While airport mapping databases (AMDB) are are being developed and deployed around the world and in the NAS, the ARC encourages the FAA to assess the impact of AMDB availability on successful implementation of SURF–IA.

- The ADS–B In ARC believes some of the ADS–B applications are similar and the concept of operations should address the potential overlaps with aircrew guidance and differing performance requirements. Specifically, some of the scenarios evaluated for SURF–IA are very similar to scenarios for other applications. The ARC recommends the FAA evaluate whether overlapping applications pose a risk of conflicting guidance to the flightcrew and incompatible performance requirements. Furthermore, the ARC recommends if a risk is identified, the FAA should request SC–186 to address the issue of overlapping applications. Similarly, the ARC notes it will consider these potential overlaps in its own cost-benefit analysis.

The ADS–B In ARC understands only limited analysis has been done regarding non-fixed-wing aircraft and ground vehicles as targets at an airport where the SURF–IA application is deployed. The ARC recommends the FAA conduct additional analysis about the integration of non-fixed-wing aircraft and ground vehicle operations into the SURF–IA application.

APPENDIX N—ARC RECOMMENDATION ON LEGACY EQUIPMENT

November 1, 2010

Mr. Henry P. Krakowski
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800 Independence Avenue SW.
Washington, DC 20571

Ms. Margaret Gilligan
Associate Administrator for Aviation Safety
Aviation Safety Organization
Federal Aviation Administration
800 Independence Avenue SW.
Washington, DC 20571

Subject: Automatic Dependent Surveillance–Broadcast (ADS–B) In Aviation Rulemaking Committee (ARC) — Response to Request from Aircraft Certification Service

Dear Mr. Krakowski and Ms. Gilligan:

The Federal Aviation Administration (FAA) chartered the ADS–B In ARC to define a strategy for incorporating ADS–B In technologies in the National Airspace System. While working on its first task, the Aircraft Certification Service requested the ARC's input on legacy ADS–B Out avionics equipment. Please find the ADS–B In ARC's recommendation in the attached issue paper.

We and our fellow ADS–B In ARC members stand ready to help the FAA with any additional tasks as needed.

Sincerely,

Steven J. Brown
ADS–B In ARC Co-Chair
National Business Aviation Association

Thomas L. Hendricks
ADS–B In ARC Co-Chair
Air Transport Association of America, Inc.

Enclosure
Copy to Mr. Doug Arbuckle, ADS–B In ARC Designated Federal Official

ISSUE PAPER—LEGACY ADS–B AVIONICS AND IN-SERVICE ISSUES

Background

The Federal Aviation Administration (FAA) gave presentations at the August 26, 2010, Automatic Dependent Surveillance–Broadcast (ADS–B) In Aviation Rulemaking Committee (ARC) meeting and the September 2, 2010, Equipment and Performance Working Group (WG 2) meeting. The presentations outlined known issues with current 1090 MHz ADS–B Out performance and requested WG 2's input on how to deal with the situation.

The FAA stated, "some existing equipment, both ADS–B Out radios and GNSS [Global Navigation Satellite System] position sources, does not transmit valid position bounded by integrity." This means airplanes are transmitting incorrect data with non-zero navigation uncertainty category for position (NUC_P) values, resulting in the display of credibly misleading position information.

The FAA estimated the number of these airplanes to be less than 5 percent of the fleet. The FAA stated, because its monitoring system is not yet in place, the number of airplanes transmitting incorrect data is purely an estimate. It is the ARC's understanding that the FAA's monitoring system is expected to be operational by summer 2011. It was noted, as ADS–B In equipment becomes prevalent, this situation will become unsafe.

The ADS–B In ARC is being asked to respond, by October 2010, with any immediate recommendations affecting Technical Standard Order (TSO) C195, Avionics Supporting Automatic Dependent Surveillance–Broadcast (ADS–B) Aircraft Surveillance Applications (ASA). This TSO includes three situational awareness applications included in version 2 of the FAA Application Integrated Work Plan (AIWP):

1. Traffic Situation Awareness—Basic (TSO application name–Enhanced Visual Acquisition);

2. Traffic Situation Awareness for Visual Approach (TSO application name–Enhanced Visual Approach); and

3. Airport Traffic Situation Awareness (TSO application name–Airport Surface Situational Awareness/Final Approach Runway Occupancy Awareness).

The FAA also plans to revise the TSO to incorporate In-Trail Procedures (ITP) during 2011. The ADS–B In ARC may also provide longer-term recommendations.

The FAA presented four options:

1. The FAA could structure the ADS–B In TSO to disallow all but ADS–B version 2 messages. This, in conjunction with the FAA's installation approval policy, will ensure misleading data is not presented to the flightcrew.

2. The FAA could issue airworthiness directives (AD) against known bad part numbers. This would temporarily allow bad data to be presented on certified ADS–B In equipment. In addition, it may allow unknown bad data to be displayed until the operator becomes rule compliant.

3. The FAA could structure the ADS–B In TSO to require Traffic Collision and Avoidance System (TCAS) validation of ADS–B version 0 and version 1 messages to be displayed. This solution would not work as well for general aviation aircraft without TCAS.

4. The FAA could perform additional rulemaking to prohibit non-interference ADS–B Out installations.

The existing RTCA, Inc., DO–260[1] ADS–B Out aircraft can be broken down into the following categories:

1. *European Aviation Safety Agency (EASA) Approved Means of Compliance (AMC) 20–24-compliant aircraft (ADS–B version 0).* The FAA approved certification of equipment that meets EASA AMC 20–24. The FAA also authorized airplane flight manual updates to allow use of this equipage. These airplanes are thus transmitting valid data, are approved by the FAA, and should be allowed to operate in U.S. airspace.

2. *AMC 20–24-compliant aircraft (ADS–B version 0) with in-service problems.* There is at least one known in-service issue with AMC 20–24 equipage being addressed through standard FAA/industry processes. The FAA suspects there may be other problems, but the FAA currently does not have data to characterize or quantify them. The ADS–B In ARC suggests the FAA characterize the problems once its monitoring system is in place. At that time, in-service problems can be resolved using existing FAA/industry processes to ensure safe operations. One outcome of these processes could be the FAA issues AD(s); however, the ADS–B In ARC believes it is currently premature to reach this conclusion.

3. *Non-AMC 20–24-compliant aircraft.* These aircraft may be broadcasting inertial reference system position with a NUC_P=0, and will be updated to DO–260B-based installations in time for the European and U.S. mandates.

The ADS–B In ARC understands the equipage of concern falls into category 2 AMC 20–24 aircraft (ADS–B version 0) with in-service problems.

[1] DO-260A: Minimum Operational Performance Standards for 1090 MHz Automatic Dependent Surveillance – Broadcast (ADS–B) and Traffic Information Services (TIS–B).

Recommendations

Immediate: The ADS–B In ARC does not believe the FAA should make any changes to TSO C195 to address issues with legacy avionics.

Near-term: The ADS–B In ARC recommends the FAA work with involved parties (avionics manufacturers and operators) to address any known in-service issues. Until the problems are adequately characterized by the monitoring system, it is not necessary to modify TSO C195. When the in-service problems are understood, they can be resolved using existing FAA/industry processes to ensure safe operations. One outcome of these processes could be the FAA issues AD(s).

Longer-term (when monitoring is available): As noted above, the FAA suspects there may be other problems, but data does not exist to characterize them. It is also unknown how many airplanes may be affected. Therefore, the ADS–B In ARC suggests the FAA begin characterizing any observed problems once its monitoring system is in place in summer 2011. At that time, in-service problems should be resolved using existing industry processes to ensure safe operations. One outcome of these processes could be the FAA issues AD(s); however, the ADS–B In ARC believes it is premature to reach this conclusion at this time.

Paper on Navigation Service Provider's Approach to Protect the Air Traffic Control System

Following the presentation of the WG 2 recommendations to the ADS–B In ARC (about resolving issues with equipment that does not transmit valid position bounded by integrity), one of the ADS–B In ARC members presented a paper. The paper outlined the approach of this member's air navigation service provider to protect the integrity of its air traffic control system. This approach includes prohibiting, in Australian airspace, transmission of ADS–B data that does not meet Australia's regulatory requirements (see Civil Aviation Order 20.18) and the use of white and black lists.

WG 2 reviewed the paper and concluded it did not warrant a change to the strategy proposed above by WG 2 at the September 2010 ADS–B In ARC meeting. This conclusion is primarily based on the time required to develop a similar regulation in the United States, particularly given that such a regulation would only have an incremental impact before 2020.

Other General Commentary about Issues with Legacy Equipage (Not in response to the questions from the FAA presented at the September 2, 2010, WG 2 meeting)

WG 2 also takes this opportunity to note, as the FAA begins working on the next version of TSO C195 (which WG 2 understands will take place in 2011), the compliance monitoring function will be available. WG 2 understands the compliance monitoring function will assess the performance of ADS–B version 0, version 1, and version 2 equipment. The compliance monitoring data will enable the FAA to consider mitigations, such as allowing TCAS validation or providing discretion in the TSO.

Such discretion would allow new equipment to ignore version 0 and version 1 messages on an application-by-application basis.

To enhance early benefits leading to increased adoption of ADS–B In equipage, the ADS–B In ARC encourages the FAA to explore opportunities for all applications to display ADS–B version 0 and version 1 aircraft broadcasting appropriate navigation integrity category and navigation accuracy category values. WG 2 believes, going forward, the FAA should permit the use of legacy equipment on an application-by-application (or version number-by-version number) basis. For example, ITP may be permitted with earlier versions through the use of TCAS validation. WG 2 believes it is unlikely Interval Management–Delegated Separation (IM–DS) will be able to use ADS–B version 0 messages. However, WG 2 notes any mitigation allowing the use of ADS–B version 0 messages for more critical applications (for example, IM–DS) would improve the business case in the near- and mid-terms, and should be explored.

APPENDIX O—OWNSHIP POSITION SOURCE ARC COMMENTS

The Automatic Dependent Surveillance–Broadcast In Aviation Rulemaking Committee (ARC) provided the Federal Aviation Administration the following recommended language on ownship position source via e-mail on June, 7, 2011:

> Current wording: "Position sources interfaced to the ASSAP equipment must meet the criteria in AC 20–165".
>
> Proposed wording: "Position sources interfaced to the ASSAP equipment must meet the requirements in TSO C195, Table 2–3".
>
> For updates to AC20–172 (172A, B, etc.) we would reference the updated TSO (C195a, etc.) and corresponding Table in the new document.