TECHNICAL MEMORANDUM
OU/AEC 08-09TM15689/0007-1

REVIEW OF THE AUTOMATIC DEPENDENT SURVEILLANCE-BROADCAST (ADS-B) SYSTEM AND DEVELOPMENT OF ADS-B FLIGHT INSPECTION REQUIREMENTS, METHODOLOGIES, AND PROCEDURES

This report documents a study to develop ADS-B flight inspection requirements and procedures. Additionally, flight inspection aircraft equipment requirements are detailed. The study includes an extensive literature search conducted by the Avionics Engineering Center, aspects of ADS-B Essential Services that should be evaluated by flight inspection, the minimum necessary flight inspection aircraft equipage to perform the mission, and suggested minimum content for recorded airborne data. Documents reviewed include: the Notice of Proposed Rulemaking (Docket No. FAA-2007-29305; Notice No. 07-15), ADS-B/ADS-R Critical Services Specification (Version 1.2), TIS-B/FIS-B Essential Services Specification (Version 1.1), United States Standard Flight Inspection Manual (FAA Order 8200.1C), and others. Proposed flight inspection requirements, methodologies, and procedures for ADS-B Essential Services are presented along with limited discussion of applicability to ADS-B Critical Services. A system description of the ADS-B system and operational use is provided.

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I. INTRODUCTION

The Federal Aviation Administration (FAA) Office of Aviation System Standards (AVN) is tasked with the flight inspection and assessment of navigation and surveillance systems as a means of ensuring that system specifications are met and the systems are safe for use in the National Airspace System (NAS). Deployment of newly installed systems always includes "commissioning" flight inspections and will likely include subsequent periodic, special, or other flight inspection requirements after a successful "commissioning" flight inspection. The FAA's deployment of Automatic Dependent Surveillance – Broadcast (ADS-B) services through an infrastructure developed, installed, operated, and maintained by the FAA's ADS-B service vendor necessitates a review of the ADS-B system, development of new flight inspection requirements and procedures, and identification of commissioning flight inspection activity.

FAA AVN originally tasked the Avionics Engineering Center (AEC) at Ohio University to review and provide commentary on ADS-B and ADS-B services relevant literature, provide proposed flight inspection requirements, methodologies, and procedures for ADS-B services, provide a recommended flight inspection aircraft equipment list, and provide an ADS-B system description and operational use summary. Throughout the course of the review, research, and development of this document, it became necessary to change the scope to focus on developing these items for the ADS-B Essential Services element of ADS-B. As will be discussed, the development of flight inspection requirements for the other element of ADS-B, ADS-B Critical Services, remains to be addressed.

The FAA Surveillance and Broadcast Services Office responsible for ADS-B deployment directed that the first deployment of ADS-B by the vendor be the ADS-B Essential Services for Service Volume 168 (SV-168) in southern Florida. Since no ADS-B Critical Services have been deployed and the system configuration for deployment is not fully developed, it was decided that this report focus on flight inspection of the ADS-B Essential Services. A follow on effort to address the ADS-B Critical Services components and requirements as they are refined and made concrete should be performed.

Thus, this report presents the results of the tasks listed above and conclusions and recommendations for ADS-B flight inspections that may be used to help define flight inspection of ADS-B Essential Services as they become available from the vendor and are accepted by the FAA.

II. BACKGROUND

The ADS-B vendor's deployment of ADS-B ground infrastructure is dissimilar to existing navigational and surveillance aides and presents new concepts of operation in the NAS. This section will provide background information on the current surveillance systems (i.e., radar) as well as research and development of the ADS-B system that is

being deployed. A brief ADS-B system description along with overviews of the operational use, services, and operational evaluations are provided.

The Air Traffic Control (ATC) system relies on information received from radar sweeps by local and national radar facilities. More specifically, the system relies on secondary surveillance radar (SSR) to obtain information about the aircraft in the surrounding airspace. The primary radar returns are "skin paints" or simple reflections of the radar pulse from the aircraft surfaces that are received by the radar facility. The SSR receives information coded on a pulse transmitted from the aircraft when it detects that a radar has "interrogated" or "illuminated" it. This information may contain the aircraft's assigned transponder code (assigned to each aircraft when flying with a flight plan), altitude, and ICAO address (unique identifier for each aircraft) depending on which version of transponder is installed. This additional information helps the ATC personnel track and direct aircraft in their area.

Radar facilities can only observe a portion of the sky at any given time since the radar antenna is continuously rotated, generally completing one revolution (a 360 degree sweep) in less than 15 seconds (depending on the model of radar). Given that the NAS traffic density has significantly increased since the time when radar systems were first deployed, and that avionics technology has advanced during the same time, conventional radar no longer serves as the most efficient source of surveillance information but is still necessary to provide surveillance for non-ADS-B equipped airborne targets.

The Traffic Alert and Collision Avoidance System (TCAS) [1] can provide pilots with airborne collision warning and avoidance information; however, aircraft pilots have not had access to a source of airborne information that can provide real-time continuous situational awareness. While TCAS systems are installed in commercial and corporate aircraft, general aviation has not seen a significant level of fleet equipage. Advances in aircraft avionics capabilities now make it possible for all properly equipped aircraft to broadcast certain information about its location, direction of travel, and other information to other aircraft in the vicinity that are similarly equipped. A reasonable predication is that the other aircraft can then use that information to determine the transmitting aircraft's altitude, position, and direction of flight in relation to their own, providing an immediate increase in the level of flight situational awareness. Different enabling data link technologies were competing to serve this function in the NAS in the late 1990s [2].

In August 1998 the RTCA Free Flight Select Committee issued a report in response to the FAA Administrator's request to assist in defining a restructured Flight 2000 Initiative [2]. The report contained "operational enhancements" obtained from deploying new communication, navigation, and surveillance (CNS) systems along with associated risks and mitigation strategies. Joint government and industry planning for implementation of these new CNS systems was conducted. The FAA Safe Flight 21 Program Office was established to "…focus on meeting the nine operational enhancements…" in late 1998. [2] The FAA made a decision in 2002 [3] to utilize two different data links. The first data link operates at 978 MHz and is known as Universal Access Transceiver – UAT. It serves the general aviation and light corporate aircraft fleet. The second data link

operates at 1090 MHz and is known as Mode-S Extended Squitter – 1090ES and is typically installed on commercial and larger corporate aircraft. These two links are used to provide ADS-B in the United States NAS. These data links will be discussed in the following sections.

The FAA awarded in 2007 a government prime contract with ITT Corporation, White Plains, NY to provide ADS-B services in the NAS. This procurement of navigation support and surveillance services is unique at present in that the FAA is procuring the service only (i.e., signal-in-space) and not the equipment to transmit, receive, process, distribute, etc., the information. Additionally, the implementation of the ADS-B service also differs in that the standard definitions and understanding of service volumes do not directly apply. The signal transmission and reception sites for an ADS-B service volume (e.g., the initial ADS-B service volume SV-168) is a composite of multiple ground stations (11 sites in SV-168). This presents some engineering challenges when considering the commissioning of the services by flight inspection aircraft.

Provision of separation services by ATC requires that the controller and system have knowledge of each aircraft's position, altitude, and direction of flight or intentions. It is critical that each participating ADS-B equipped aircraft's information be received by the ground infrastructure and passed on to ATC in a timely fashion. Traffic statistics from received ADS-B targets can provide some information about the capabbility of the ground infrastructure to receive information. However, it is not sufficient to verify proper reception by the ground infrastructure of an ADS-B message from an aircraft with equipment operating at required minimum operational specifications. The intended use of ADS-B system data in the provision of aircraft separation services by FAA ATC necessitates flight inspection of the system to ensure that the ADS-B signal-in-space (SIS) is present, useable, and safe with aircraft operating at minimum transmission power. Additionally, flight inspection of the SIS can identify areas in the service volume(s) where: interference sources may exist, there is SIS blockage by terrain and buildings, and obstacles (new or temporary) exist in the intended flight operations area, etc. There is no independent monitoring of the ADS-B SIS (i.e., external sampling of the ADS-B SIS broadcast by the ground facilities) as has been the case in previous navigation and landing systems. Without independent monitoring there is no mechanism to evaluate the broadcast signal-in-space and ensure that the ADS-B ground broadcast requirements are fulfilled. Flight inspection of the ADS-B system can verify requirement compliance.

a. ADS-B System Description

ADS-B is essentially "a data link technology that automatically broadcasts selected aircraft information from suitably equipped aircraft" [4]. The ADS-B system is enabled by aircraft avionics that are capable of transmitting the aircraft state vector (position, velocity, time, etc. – commonly referred to as PVT) along with the aircraft identification code and other information (e.g., quality of PVT information) via one of the two accepted data links to aircraft operating within radio reception range and to ground receivers.

The ADS-B avionics equipment typically consists of a data processing unit, a data link transceiver, and a separate or integrated source of position, velocity, and time (PVT) information. PVT information is currently provided solely by GPS (preferably GPS WAAS). Provisions in the specifications allow for use of other PVT systems with equivalent accuracies or in a "degraded performance" mode using PVT systems that can't meet the typical specifications [5][6][7]. Manufacturers of aircraft ADS-B equipment are free to use either an external (e.g., aircraft GPS WAAS, GPS LAAS, Multi-mode receiver, etc.) or internal (e.g., GPS WAAS, or better, receiver built into the ADS-B data link equipment package) source for PVT. [8] Regardless of which option is chosen, a measure of the quality of the PVT information that is transmitted is to be provided. The entire ADS-B system is designed to operate based on availability of GPS time. The ground stations are assigned specific time slots within each second when they are to transmit the necessary information. The airborne systems use GPS time to provide the "time" in PVT thus ensuring that all users are using the same reference.

Proper air-to-air operation does not depend on the presence or operational status of the ground component. However, the receiver portion of the ground based transceiver (GBT) does depend on proper operation of the airborne equipment. The GBT's receive the airborne data and transfer the data to the required service delivery points (SDP). Additional systems may process the airborne data matching the received targets with those provided from FAA radar feeds. This merged data is then used to broadcast Traffic Information Services (TIS-B) to the ADS-B equipped aircraft. Information such as weather radar, meteorological conditions, terminal area forecasts, restricted airspace notifications, and more may be provided as a broadcast Flight Information Service (FIS-B). Additional "value added" services may also be broadcast by the ADS-B service vendor subject to a fee for reception by interested aircraft. Services such as the Traffic Information Service and Flight Information Service are typically broadcast from the ground facilities to all suitably equipped aircraft in the ADS-B service volume. The vendor implementation of the ADS-B services may differ in the way information is broadcast. For example, traffic for a given aircraft is only transmitted if the traffic is within an 18 nautical mile radius.

At this writing, the ADS-B services vendor is in the process of developing and deploying the initial set of GBT equipment in southern Florida for the FAA's key site acceptance test. Additionally, the supporting infrastructure to connect the GBTs and provide interfaces to the FAA SDPs is being deployed. A description of the vendor's actual implementation of the ADS-B ground infrastructure system is not available at this time due to company proprietary considerations. It is expected that, as deployment progresses, some top level information will become available to the general public. The simplified conceptual diagram provided in Figure 1 is loosely based on the FAA implementation of ADS-B for the initial deployment in the eastern US.

Typically, any given aircraft will have only one of the data links installed (e.g., UAT); the question of how to enable that aircraft to "see" aircraft equipped with the other (e.g., 1090) data link must be answered. The decision to operate the ADS-B system using two different data links thus creates a need to provide a sort of "re-broadcast" function within

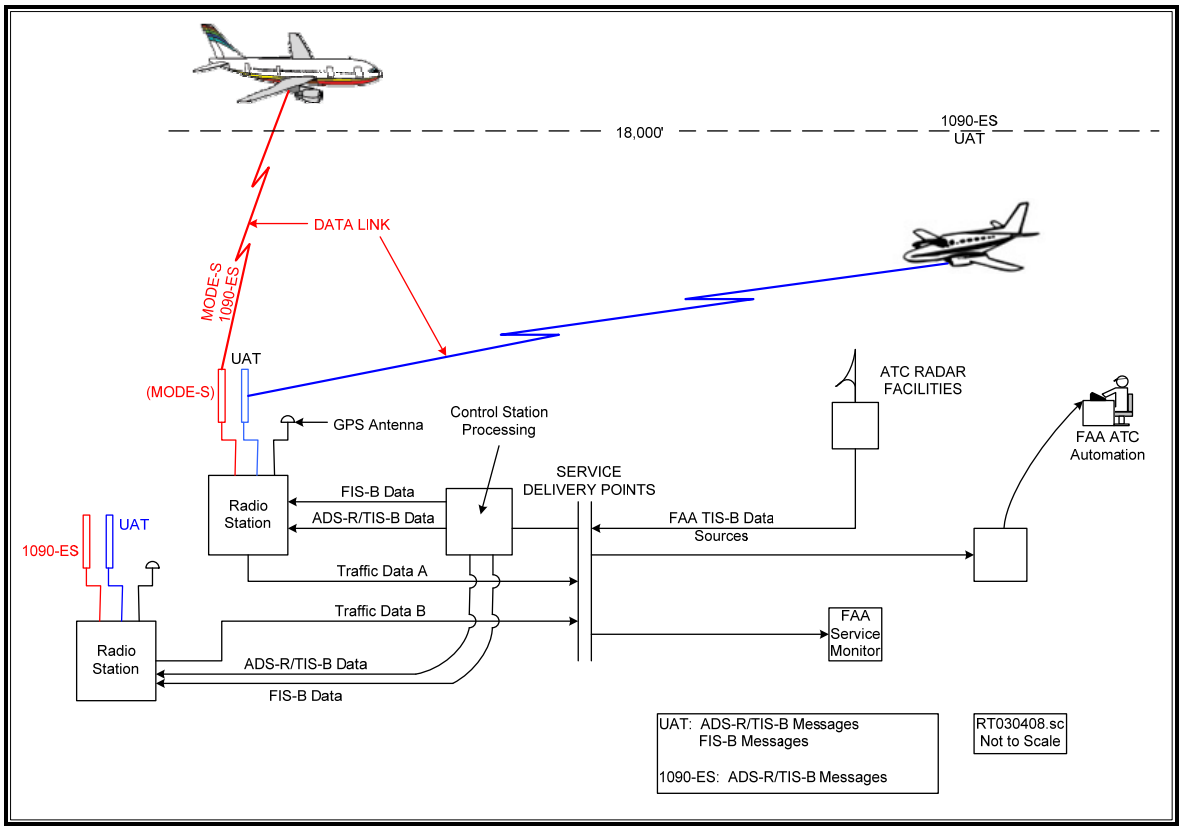

Figure 1. Simplified ADS-B Block Diagram.

the ground infrastructure. This function is implemented in the ADS-B vendor's infrastructure in two phases because of the deployment strategy. These two phases are known as the TIS-B *crosslink* [9] and ADS-B Rebroadcast (ADS-R) Service [3]. While the specific implementation is complicated by aircraft equipage and traffic data transmission management, the essential understanding of this is that if a message is received by the ground infrastructure via the UAT data link, it is made available for "re-broadcast" via the 1090 data link and vice-versa. This enables all aircraft that are equipped with one of the two data links to be capable of receiving and displaying traffic data from either of the two data links.

Figure 2, Figure 3, and Figure 4 are representations of the ADS-B system and of the 1090 and UAT TIS-B data links for aircraft equipped with a single link, dual link (standard configuration), and the dual link flight inspection aircraft. Figure 2 depicts an aircraft equipped with the UAT data link. The ADS-B service receives the UAT position from the aircraft and schedules TIS-B data for transmission to the aircraft. The UAT equipped aircraft will receive TIS-B data for the 1090 equipped aircraft and the Mode-C aircraft that are within its TIS-B service area. The UAT equipped aircraft will also receive the FIS-B data messages sent out via the UAT data link. Figure 2 represents the most common case for aircraft in the NAS where an aircraft will have either the UAT or the 1090 data link but not both

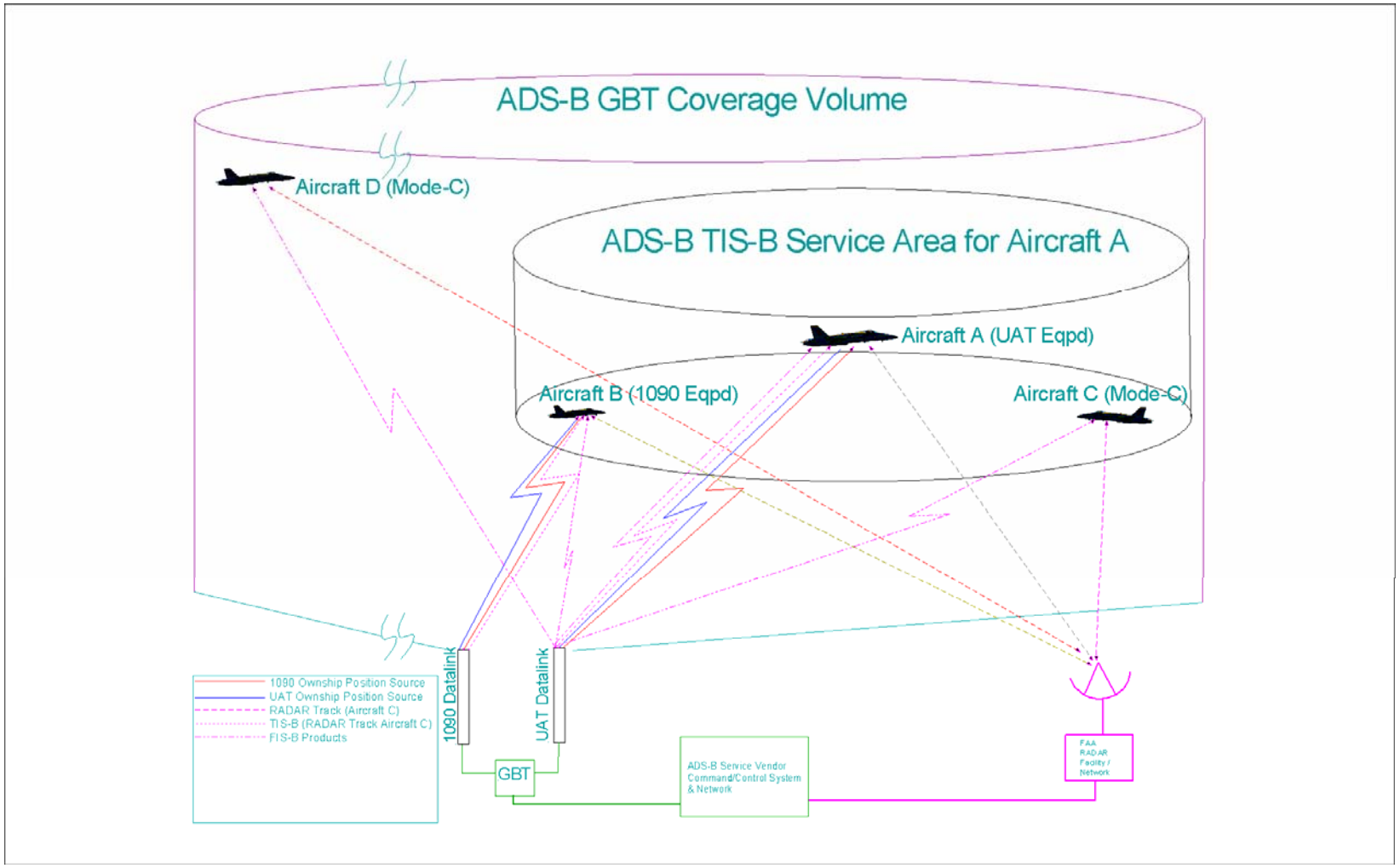

Figure 2. Single Link Equipped Aircraft (Majority of Aircraft in NAS).

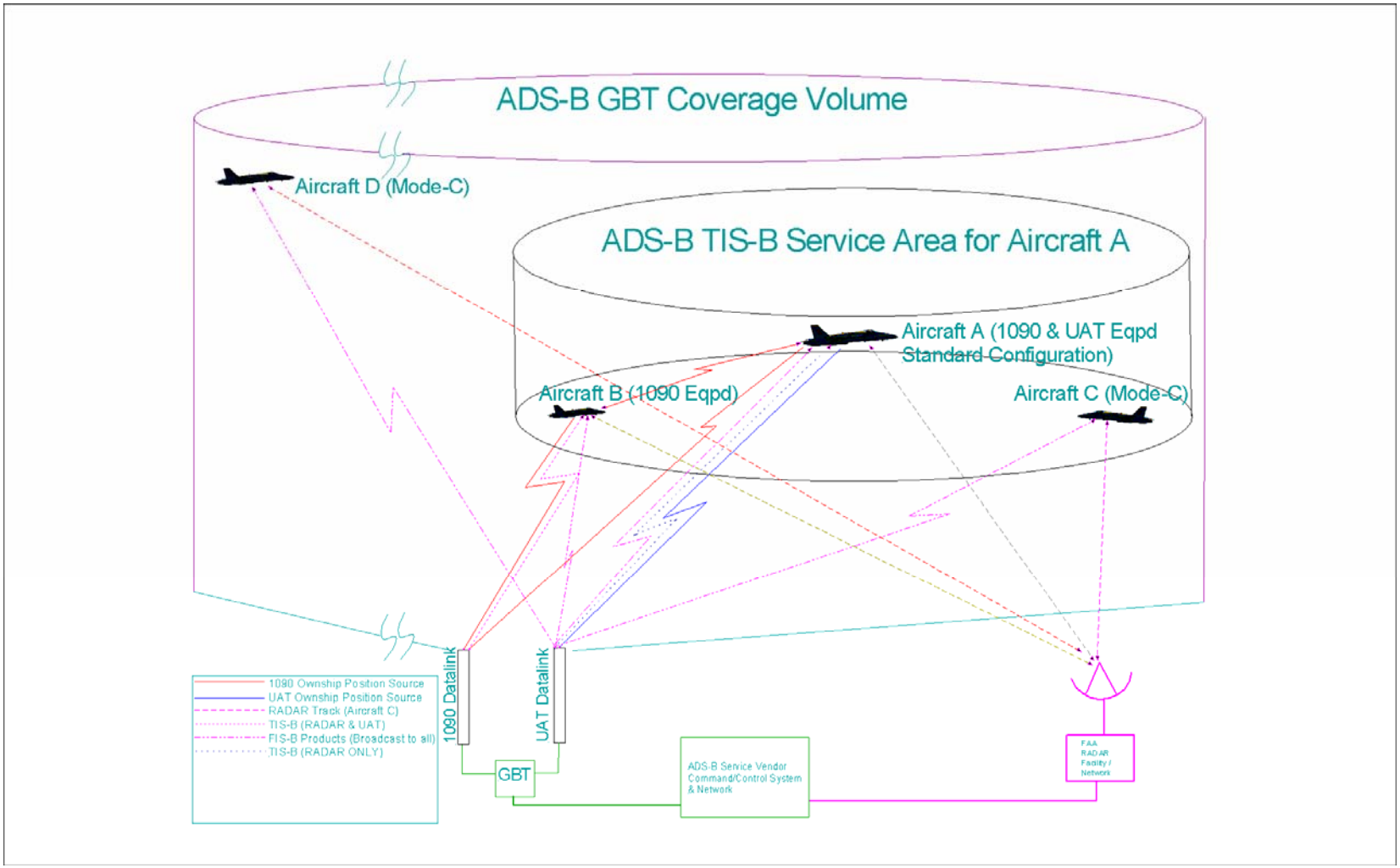

Figure 3. Dual Link Equipped Aircraft - Standard Configuration.

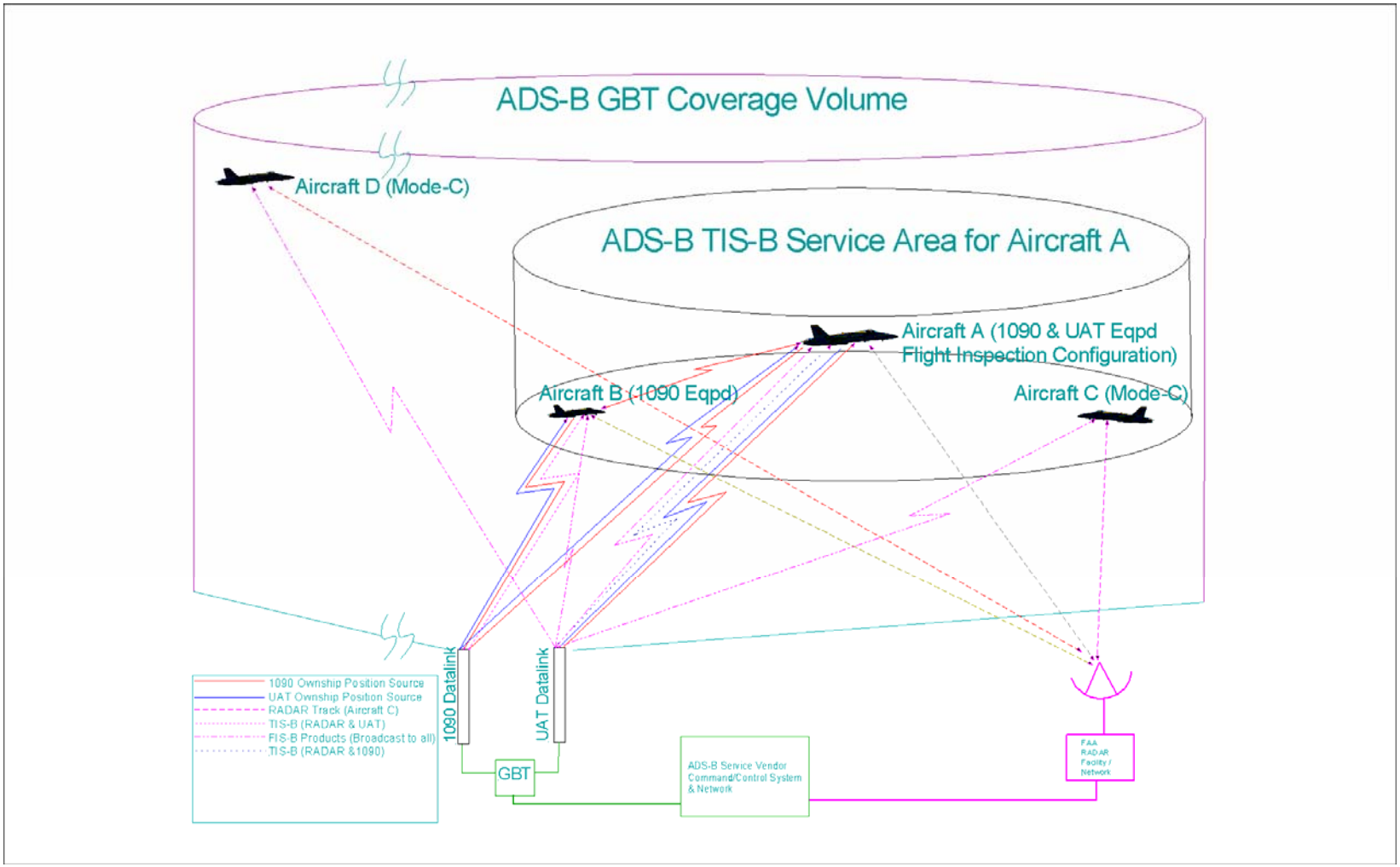

Figure 4. Dual Link Equipped Aircraft - Flight Inspection Configuration ONLY.

In Figure 3, the aircraft at the center of the TIS-B service area is dual equipped (i.e., is equipped with both UAT and 1090 ADS-B data links). This configuration is not likely to occur often within the NAS but is possible. The aircraft in this configuration is recognized by the ADS-B service as dual equipped and will only receive TIS-B messages on the UAT and 1090 links that are from the Mode-C equipped aircraft that are within its TIS-B service area. There will be no TIS-B message from the ADS-B service for any aircraft within its service area that are equipped with either UAT or 1090. This occurs because the ADS-B service has received the aircraft's position via both data links and assumes that the aircraft will receive other 1090 or UAT equipped aircraft's broadcast positions directly (i.e. air-to-air).

Figure 4 represents the case for flight inspection aircraft. It is expected that flight inspection aircraft will be dual equipped with both 1090 and UAT data links. However, configuration of the flight inspection aircraft will be different than any commercial or private dual equipped aircraft. The reasons and mechanisms for this difference will be discussed further in section IV. For purposes of discussion herein it should be understood that the aircraft will be configured such that the ADS-B service will "see" the two data links on board the flight inspection aircraft as originating from "different" aircraft. Because of this configuration, the flight inspection aircraft will receive TIS-B messages from the ADS-B service for all aircraft in its service area. It will receive 1090 and Mode-S TIS-B messages on the UAT data link and will receive UAT and Mode-S TIS-B messages on the 1090 data link. This ability allows a great efficiency gain to be achieved by the flight inspection aircraft over running inspections on the data links separately. Again, it must be understood that only FAA Flight Inspection aircraft and an extremely limited number of FAA contract support aircraft will be permitted to equip in this manner, as there are safeguards that need to be established and implemented for operation of aircraft in this configuration.

b. ADS-B System Operational Use

ADS-B has been deployed and operational in the Ohio River Valley and Alaska since 1999 [2]. The FAA has operated a network of ADS-B GBTs known as "Legacy Broadcast Services", which includes an installation at the Avionics Engineering Center's hangar at the Ohio University Airport. This network has been referred to as the "East Coast Laydown", and has provided both the FAA and authorized users with experimental data and basic services. The procurement of ADS-B services will mean replacement or removal of this "legacy" equipment as the ADS-B service vendor determines optimum placement of GBT equipment for NAS deployment. The Legacy services have been used to support the FAA operational evaluations along with several other test and demonstration activities. Some of these other activities and their use of ADS-B are briefly described in the following sections.

c. ADS-B Services

The FAA has chosen to procure ADS-B services for the United States NAS from an industry vendor [10] instead of incurring the cost of developing and deploying the

necessary infrastructure that is required to operate the ground based portion of ADS-B operations and provide the ADS-B user services. Information from a national network of ADS-B ground based transceivers owned and operated by the ADS-B vendor will be supplied to the FAA for use in air traffic control and other uses. This national network will be used to provide ADS-B user services to the appropriately equipped aircraft.

The national network of ADS-B facilities is slated to be "turned on" according to geographic regions identified by the FAA as ADS-B service (or coverage) volumes. These service volumes are described below. ADS-B services will be implemented in two phases, the first being "Essential Services" or TIS-B and FIS-B data uplink services. The second phase is identified as "Critical Services" and encompasses the interconnection of the ADS-B national network with Air Traffic Control. Both phases are further described below.

1. ADS-B Coverage Volumes and Service Volumes

The FAA is ordering ADS-B Service on a "Coverage Volume" basis. A coverage volume will contain one or more "service volumes". Unlike the traditional navigation aids (Navaids) shown in Figure 5, the service volumes for ADS-B may not be associated with a single ground station. ADS-B service volumes may have multiple GBTs to provide the required ADS-B services coverage. The en-route coverage service volumes are shown in Figure 6. The Segment 1 ADS-B service volumes will be completed during the first phase of deployment to be followed by deployment of the infrastructure for the Segment 2 service volumes.

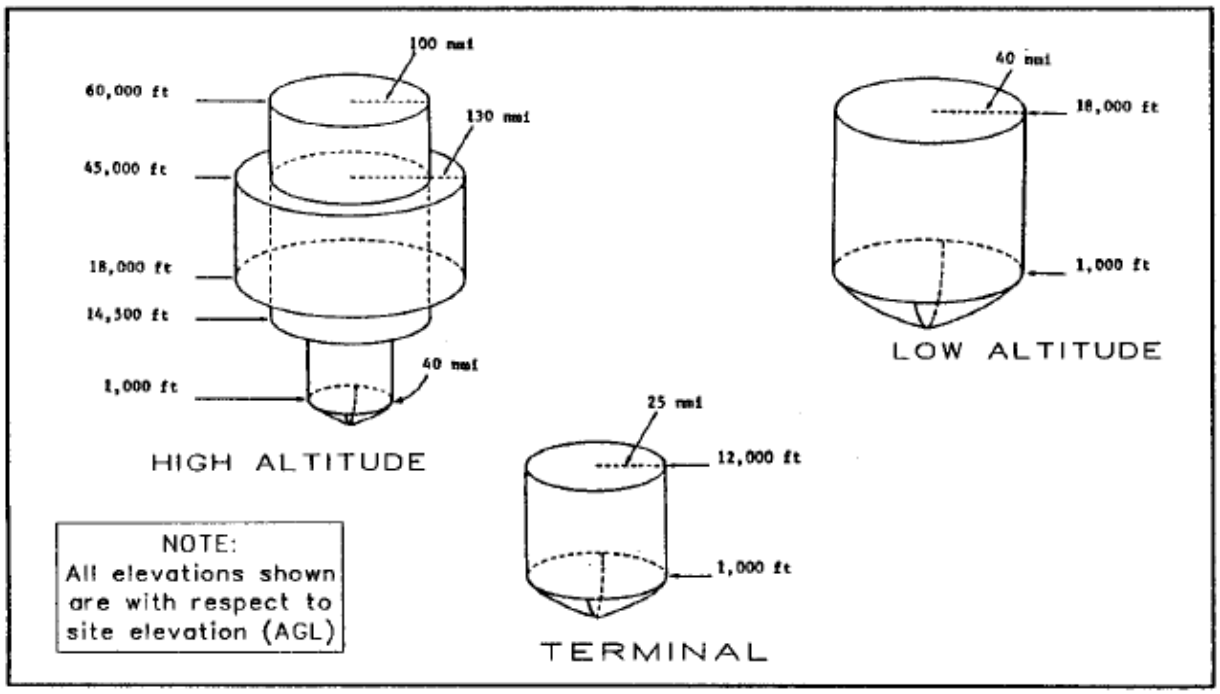

Figure 5. Typical NAS Ground Equipment Service Volumes [11].

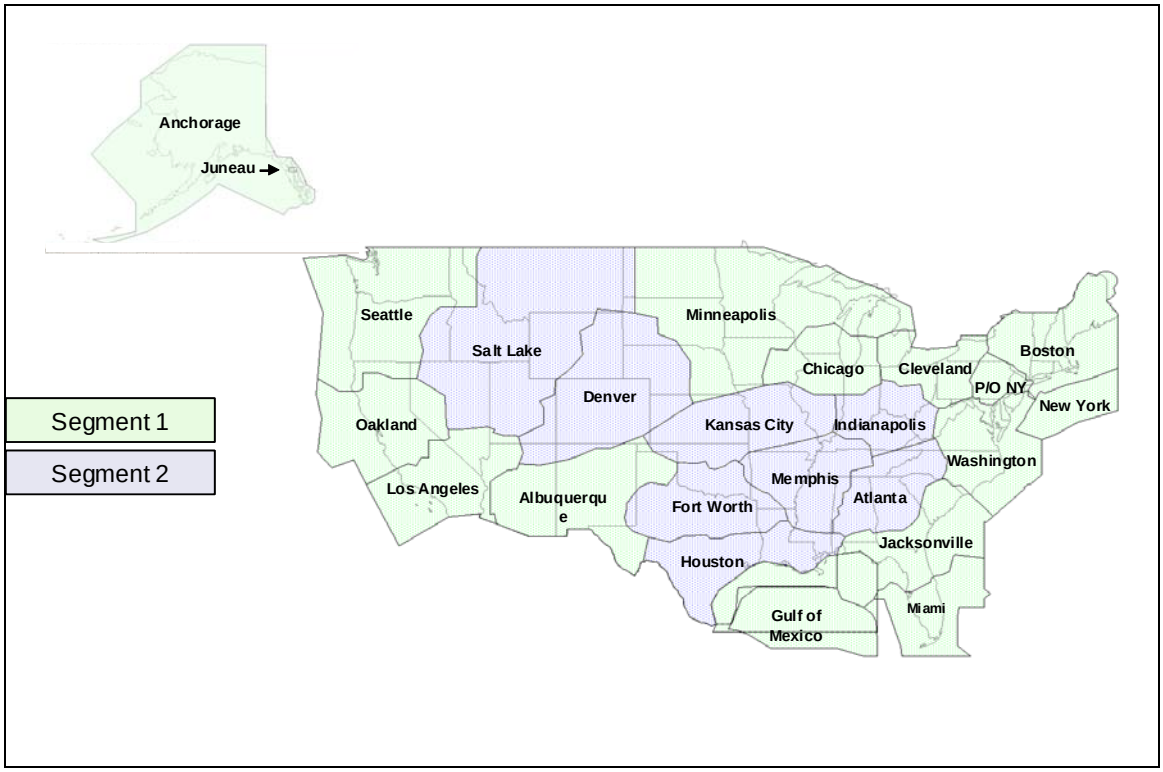

Figure 6. FAA Segments 1 and 2 En Route ADS-B Coverage [12]**.**

For example, the initial Essential Services service volume 168 (see Figure 7) provides coverage for south Florida, and covers over 71,000 square nautical miles. The Miami International Airport (MIA) is located within this service volume. Both the airport surface at MIA will require coverage as will the farthest corners of the service volume. The range between MIA and the furthest point is more than 321 nm. Coverage of this complex scenario by a single GBT at the site (MIA) is not possible, given: radio line-of-sight, constraints placed on the transmission power for both data links (due to proximity to existing radar and communication systems), and requirements to provide low-level or surface coverage at other airports within the same service volume.

2. Essential ADS-B Services

ADS-B "Essential Services" are defined in the document titled "*Traffic Information Service – Broadcast (TIS-B) / Flight Information Service – Broadcast (FIS-B) Essential Services Specification*" [9]. This information is broadcast from the ground facilities and uses data from received airborne ADS-B transmissions, radar tracks, weather stations, FAA flight information services, and other approved information sources. The UAT data link carries both TIS-B and FIS-B messages while the 1090ES link carries primarily TIS-B. These services are the first to be deployed in the NAS and are designed to provide the airborne user with greater information to enhance situational awareness of airborne traffic and flight conditions that could impact flight safety. Vendor implementation of the essential services includes an ADS-R like feature, which is often referred to as "TIS-B crosslink", where received ADS-B messages on a given data link are rebroadcast on the

other data link. The critical services ADS-R requirements do not apply to the TIS-B crosslink, particularly the timing requirements are different.

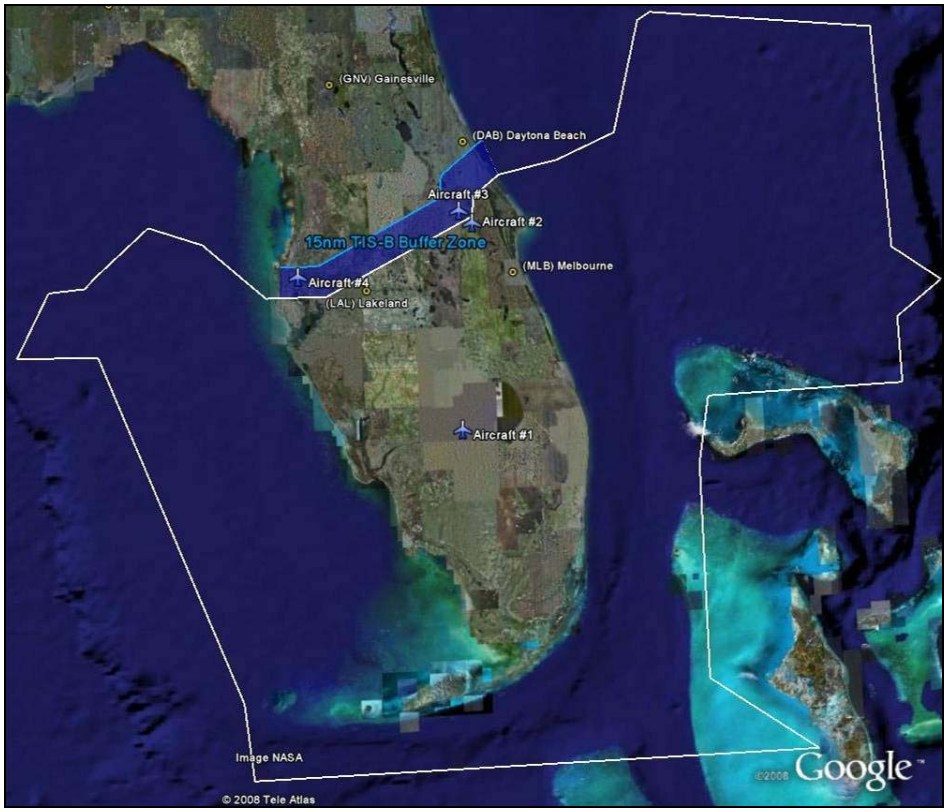

Figure 7. Initial Essential Services Coverage Volume (South Florida SV-168) [12].

AVN and Ohio University personnel have gained valuable experience with the operation and initial performance of ADS-B Essential Services through participation in the FAA's test and evaluation process. AVN flew flight test profiles for the initial service volume (SV-168) located in southern Florida in July and November 2008. Ohio University flew SV-168 flight test profiles in August and November 2008. The November tests were jointly conducted with AVN and Ohio University aircraft (N55 and N200U respectively) during the week of November 10-14. Some of the recommendations in this document are a direct result of the flight crews' (pilot, co-pilot, engineer) involvement in these test programs.

3. Critical ADS-B Services

ADS-B "Critical Services" are defined in "*Automatic Dependent Surveillance – Broadcast (ADS-B) / ADS-B Rebroadcast (ADS-R) Critical Services Specification*" [3]. Critical services are scheduled to become available after the essential services have been deployed, tested, and accepted by the FAA. These services are referenced to the transfer and delivery of ADS-B information between the ADS-B ground equipment and FAA SDP. Critical Services can be understood to mean those services where the ADS-B data

is being supplied to ATC and used to provide aircraft surveillance and separation. ADS-R functionality is also a component of the Critical Services and carries tighter tolerances for the related specification requirements as compared to the TIS-B crosslink.

d. Operational Evaluations

There have been multiple demonstrations and evaluations that either focused on testing and demonstrating ADS-B or utilized ADS-B as an enabling technology as part of a larger aviation related demonstration. First, the Safe Flight 21 Program Office held a series of three operational evaluations in the Ohio Valley area to test and demonstrate the use of ADS-B in various applications. Second, the Alaska Capstone project delivered ADS-B functionality in a trial form to the people of Alaska, making the benefits immediately available to the aircraft in that state. Following success of the OpEvals and Capstone projects, the FAA worked with local and state governments to deploy an ADS-B test bed (the Legacy System) on the east coast of the United States to test and evaluate requirements for a nationally deployed system. A NASA demonstration was held in 2005 at Danville, Virginia that used ADS-B air and ground components as an enabling technology for the Small Aircraft Transportation System.

1. Safe Flight 21

The FAA Safe Flight 21 Program Office held three Operational Evaluations (OpEvals) of key technologies to demonstrate and evaluate systems that would work toward achievement of goals contained in the "Development and Implementation Template for ADS-B and other CNS applications: An Implementation Planning Guide" produced by RTCA. These OpEvals are the result of a cooperative venture between the Cargo Airline Association (CAA) and the FAA [4]. The CAA members were Airborne Express, Federal Express, and UPS. Each of the evaluations involved participants from the FAA, CAA, and other organizations.

The FAA and CAA selected the Ohio River Valley for evaluation of ADS-B technology because each of the three cargo airlines maintained hubs in this region. Airborne Express operated out of Wilmington, Ohio while the Federal Express hub was located in Memphis, Tennessee and UPS based operations at Louisville, Kentucky. A summary of each Operational Evaluation activity in the Ohio River Valley trials follows.

Operational Evaluation I: This evaluation was held in Wilmington, Ohio in July 1999, and was hosted by Airborne Express. This first operational evaluation of ADS-B had two main objectives. The first objective was to assess performance of the three competing data link technologies available at the time: 1090ES, UAT, and VHF Data Link Mode 4 (VDL-M4). The second set of objectives was to assess the use of enhanced situational awareness for see-and-avoid situations, enhanced visual approaches, and, where applicable, for applications to ground surface movement [4].

AEC participated in Operational Evaluation I (OpEval I) with a Tomorrow/UPS-AT avionics ship set installed in the Center's Piper Saratoga aircraft, which is a general aviation aircraft. This avionics set provided both 1090ES and UAT data links. AEC's response time and proximity to the test location in Wilmington resulted in heavy use of AEC's aircraft during the preparation activities as well as participation in the actual Operational Evaluation.

Operational Evaluation II: This evaluation was held at Standiford Field in Louisville, Kentucky and was hosted by UPS in late October 2000. OpEval II focused on ADS-B based approach spacing, departure spacing, and airport surface movement applications (rollout, taxiing, occupied runway, etc.). [4]

Operational Evaluation III: This evaluation was held in Memphis, Tennessee and was hosted by Federal Express in May 2002. Information regarding the final outcome of OpEval III was requested but no response was received.

2. Alaska Capstone

The Alaska region, with its vast expanse, mountainous terrain, and extreme weather provides a challenge to the surveillance of aircraft. Aircraft are used to reach the remote areas in the wilderness and often fly without ATC surveillance or guidance and, in the case of an accident, are left at a great disadvantage during search and rescue operations because of the lack of surveillance services. A surveillance system that would not require the installation of complex radar systems would provide immediate benefit to the aviation community in Alaska.

The Capstone program delivered ADS-B to the State of Alaska to improve aviation safety and efficiency. The program was supported by both industry and the FAA's Alaskan Region and operated from 1996 to 2006. Beginning in January 2007, the FAA integrated the Alaska Capstone program into the FAA Surveillance and Broadcast Services Program Office. The Alaska Office is now known as the SBS Western Service Area Office.

Unlike the Safe Flight 21 program in the eastern United States, where the aviation users purchased their own avionics equipment, the FAA provided avionics equipment for aircraft under the Capstone program. The FAA also installed and operated the ground infrastructure necessary to operate the program. Alaska Capstone reports are now housed under the SBS Western Service website although web search engines still provide results based on a query of "Alaska Capstone".

3. US East Coast Laydown

Following the success of the Ohio Valley trials, the east coast of the United States was developed as an ADS-B test bed in the lower continental United States through cooperation between the FAA and local and state governments. This cooperative effort led to the deployment of a small network of ADS-B GBT sites known as the "east coast lay down". Completion of this network allowed the use of TIS-B and some FIS-B uplink

data in properly equipped aircraft traveling up and down the east coast of the United States. The ADS-B downlink data collected by this network was fed into an operations center located at the William J. Hughes Technical Center where the system was subject to additional testing and evaluation.

4. NASA Small Aircraft Transportation System (SATS)

In the summer of 2005, the Avionics Engineering Center participated in a NASA sponsored demonstration of the results from the SATS program. For five years, NASA worked with government, industry, and universities to develop a small aircraft transportation system. AEC was a member of the Virginia SATS Alliance and performed system integration and installation on the Center's King Air C-90 aircraft and operated this demonstration aircraft for the alliance. The SATS system, utilized ADS-B UAT as part of the overall system designed to benefit smaller aircraft and airports by improving capacity during lower visibility conditions, increasing pilot situational awareness, and enabling the scheduling of aircraft arrivals. Information was transmitted to the aircraft via UAT and other data links containing arrival and departure instructions. Each participating aircraft was then sequenced in to the Danville, Virginia regional airport along a defined route. Each aircraft also had situational awareness of the other participating aircraft via ADS-B and proprietary data links and displays.

III. ADS-B LITERATURE REVIEW

The AEC was tasked to conduct a literature review for ADS-B. This review was not intended to be exhaustive of all information regarding ADS-B but instead provide a summary of the information contained in the documents that were both accessible and relevant to developing FI requirements. What follows are brief descriptions of the contents of each document and summary information from the review process. Some documents such as the Vendor Service Contract were not available to AEC and have not been reviewed. References for all documents are provided in the References section of this report.

ADS-B Notice of Proposed Rulemaking (FAA-2007-29305): The FAA issued the Notice of Public Rulemaking (NPRM), Docket Number FAA-2007-29305; Notice Number 07-15 [13] to gather comments on the proposed *ADS-B Out performance requirements to support Air Traffic Control (ATC) service*. The document presents the plan for "performance requirements for certain avionics equipment on aircraft operating in specified classes of airspace within the United States National Airspace System" [13]. The notice comments on some aspects of "*ADS-B In"* uses and applications in general terms but does not provide details of TIS-B or FIS-B data or services.

The NPRM references the surveillance and broadcast services acquisition documents when commenting on latency requirements for the ground station reception and processing for display to the FAA ATC system. These documents are referred to in the footnote as "*Final Program Requirements for Surveillance and Broadcast Services*, En

Route and Oceanic Services, Air Traffic Organization, Federal Aviation Administration". No date information was provided.

Power output requirements are provided for UAT and 1090ES ADS-B Out equipment. Some requirements from the NPRM are that the UAT is required to meet TSO-C154b with a 16 watt minimum transmit power and the 1090ES ADS-B system must meet TSO-C166a with a minimum output power of 125 watts. Also, the altitude and ATC-assigned transponder codes must be identical for the Mode C transponder, the Mode S transponder, and the ADS-B Out message. Numerous additional requirements for ADS-B message content are provided.

Operational Safety Assessment & Operational Hazard Assessment: These two assessments are combined in one FAA Report Number 010927-01 entitled *Design Analysis Report: ADS-B Operational Safety Assessment* with subtitles of *Operational Services and Environment Definition (OSED)*, *Operational Hazard Assessment (OHA)*, and *Allocation of Safety Objectives and Requirements (ASOR)* [14]. The latest publication date for the copy that has been reviewed is July 15, 2005. It is noted that this publication is an electronic copy and while it has no signatures included or noted, there is no "Draft" or "Preliminary" marking in the document. However, the authors are not confident that this is the final document for ADS-B.

Vendor Service Contract: The Vendor Service Contract was not available for review by AEC as of the writing of this document.

ADS-B/ADS-R Critical Services Specification: ADS-B "Critical Services" are defined in "*Automatic Dependent Surveillance – Broadcast (ADS-B) / ADS-B Rebroadcast (ADS-R) Critical Services Specification*" [3]. This specification provides requirements for ADS-B and ADS-R services that will support critical ATC surveillance applications in the United States NAS. This specification will be applied to the ADS-B services after the TIS-B/FIS-B deployment has commenced and is envisioned as the "next, or second step" in ADS-B service acceptance. Requirements contained in this specification are more stringent than those for essential services, and directed at providing the FAA ATC system with live ADS-B data that may be used to enhance, implement, or replace secondary surveillance radar coverage throughout the NAS.

This specification provides requirements (such as ADS-R update interval, service volumes, latency, service availability, and others) are provided to ensure that the ADS-B ground infrastructure receives, processes, and acts on incoming ADS-B messages, providing the information to the FAA ATC system and aircraft equipped with an ADS-B link different from the originating ADS-B message's data link. Quality assurance tests are defined for the ADS-B and ADS-R services.

TIS-B/FIS-B Essential Services Specification: ADS-B "Essential Services" are defined in the document titled "*Traffic Information Service – Broadcast (TIS-B) / Flight Information Service – Broadcast (FIS-B) Essential Services Specification*" [9]. Provision

of traffic information and flight information to the airborne user via the ADS-B data links is defined.

This specification provides requirements (such as service volumes, coverage volumes, message encoding, and others) for deployment of certain limited ADS-B services to aircraft operators. These services include the TIS-B and FIS-B uplinks. Basic required FIS-B meteorological and aeronautical information products are identified along with data link specific requirements for broadcasting of these products. TIS-B specific requirements such as latency and accuracy are defined.

Others: Additional documents were reviewed for information pertinent to ADS-B flight inspection requirements. These documents are listed in Table 1. Additional Documents Reviewed**.** A brief description is included for each document.

Table 1. Additional Documents Reviewed.

Document	Title / Description
RTCA DO-282A	Minimum Operational Performance Standards for Universal Access Transceiver (UAT) Automatic Dependent Surveillance-Broadcast (ADS-B) [5]
RTCA DO-242A	Minimum Aviation System Performance Standards for Automatic Dependent Surveillance Broadcast (ADS-B) [8]
FAA Order 8200.1C	United States Standard Flight Inspection Manual [15]

IV. ADS-B FLIGHT INSPECTION REQUIREMENTS

Before any system or service can be fully implemented in the NAS, standards and policy must be developed, including flight inspection requirements. Thus, the FAA decision to procure ADS-B services has led to the need to develop ADS-B flight inspection requirements, methodologies, and procedures. FAA Aviation System Standards or AVN is responsible for ensuring "the standard development, evaluation, and certification of airspace systems, procedures, and equipment for customers worldwide" [16]. Flight inspection of the ADS-B system can provide a functional check of the integrity of the ADS-B signal-in-space for all aircraft flying in operational ADS-B airspace by flying the extremities of the desired airspace, probing the airspace while the ADS-B equipment is operating at the minimum output power and receiver sensitivity levels, and recording and observing data products transmitted from the ground infrastructure. Flight inspection ensures that the ADS-B SIS is present, useable, and safe with aircraft operating at minimum transmission power throughout the service volume.

FAA AVN tasked AEC to draw on the Center's experience gained during OpEval I and other ADS-B test experiences, coupled with extensive experience with navigation and landing aid flight inspections, to develop preliminary guidance in preparation for ADS-B flight inspection operations. As previously stated, the scope of this document has changed from an overall ADS-B flight inspection document to one that focuses on the inspection of ADS-B Essential Services. As of this writing, the ADS-B Essential Services have received the *In-Service Decision* from the FAA [17] and are being

deployed in the NAS. The ADS-B Critical Services are expected to follow within the next year. Flight inspection requirements will be addressed once the Service has been initially deployed, tested, and some experience gained with its operation and system requirements.

Flight inspection of ADS-B services (Essential and Critical) presents new challenges since the FAA no longer controls the specifics of the hardware and software that are providing the signal in space. This situation may limit the FAA's insight into the specifics on equipment and software design assurance activities conducted by the service provider and needs to be realized when developing FI requirements. Instead, the FAA is procuring the ADS-B "service" (or availability of the ADS-B signal in space) from a vendor. While future nationwide deployment of ADS-B services will include both "Essential Services" and "Critical Services", only "Essential Services" are presently being deployed. It is these essential services that need to be flight inspected to ensure the services provided throughout the service volume meet the requirements of the vendor's contract. Essential Services are advisory in nature with the pilot maintaining responsibility for visual separation from other aircraft [9][3]. Deployment of the initial ADS-B Critical Services will follow closely with Surveillance and Broadcast Services for ADS-B expected to receive ISD in September 2010 [18].

The first challenge to flight inspection of ADS-B is a clear delineation of responsibility for pre and post-flight functions that are outside AVN's area of responsibility. For example, it is envisioned that ATC provide a list of critical routes and fixes necessary for safe and proper aircraft operations within the subject service volume. Identification of ATC coordination liaison must be provided. Likewise, a liaison with the ADS-B service vendor must be identified for coordination and verification of system status.

Figure 8 presents an overlay of the existing ADS-B service coverage that comprises the FAA's legacy network with the future NAS-wide deployment of ADS-B essential and critical services. Service volume 168, the initial "Essential Service" service volume in southern Florida, is seen in the lower right corner.

The experimental legacy system is not flight inspected; however, the new ADS-B services will be flight inspected at commissioning, and subsequent to commissioning. The next section presents candidate requirements for flight inspection of the ADS-B services. A description of the three types of flight inspection missions is provided. Suggested requirements and procedures for preparation and execution of a mission, as well as analysis of the data are presented. Finally, a suggested minimum aircraft equipage list for data collection and analysis of the ADS-B data links is discussed.

When developing flight inspection requirements for ADS-B, it is important to understand the ground infrastructure that provides the ADS-B service, because the configuration of the infrastructure directly impacts the performance of the resulting service. As an example, it is understood that each GBT can be used to transmit to a participating aircraft. The determination of which GBT to use to transmit to a particular aircraft is accomplished by the ADS-B vendor's ADS-B system software. The software uses

expected antenna transmission patterns, ground terrain, aircraft location, and other parameters to determine the appropriate GBT for transmission. Proper operation of the software depends on valid and correct data, and thus is similar to any other system that is dependent on input data to provide a navigation function (e.g., FAS data block for GPS LAAS, coordinates for electronic approach plates and procedures, etc.).

Figure 9 and Figure 10 depict the differences between the TIS-B service areas of the legacy ADS-B network and the vendor provided ADS-B Essential and Critical Services. The ADS-B Essential Service TIS-B area is defined by the area identified within 18 nmi and +/- 3800' (commonly referred to as the TIS-B "hockey puck") of the aircraft receiving (the "TIS-B client") the TIS-B uplink information. [19] This results in transmission of TIS-B uplink data for only those aircraft that are dissimilarly ADS-B equipped (i.e., no ADS-B equipage or equipped with the alternate ADS-B link) and within the area described above. In the legacy network, TIS-B uplink information is transmitted for all aircraft throughout the received coverage volume.

To ensure that the flight inspection aircraft can efficiently assess the TIS-B uplink function (to include the TIS-B Crosslink functionality described previously), the aircraft should be dual-link equipped and configured for simultaneous link operation. This equipage and configuration is referred to herein as the *flight inspection dual-link configuration*. The caveat is that the 1090 equipment must use the aircraft's proper ICAO address and the UAT equipment must be configured to use a "test" ICAO address.

This configuration will not provide difficulties for the Essential Services but will require additional logic in the ATC systems using ADS-B Critical Services information to prevent the "test" ICAO address (target) from causing self induced traffic alerts (self-alerts) or warnings to the ATC system. Essentially, the "test" ICAO address will cause the UAT signal from the flight inspection aircraft to appear as an additional aircraft at the same location and altitude of the flight inspection aircraft. This logic is proper; however, it should not cause any increase in workload for ATC during flight inspection operations.

An ADS-B Flight Inspection Technical Interchange Meeting (TIM) was hosted by FAA AVN and held at the Mike Monroney Aeronautical Center (MMAC) on December 16, 2008. TIM participants included personnel from the FAA AVN, AJW, AJP, ATO, and AFS organizations, and Ohio University. A summary of the questions and comments taken from the ADS-B TIM notes are provided in Appendix A [20]. During the meeting the mechanism to provide protections against self-alerting due to the presence of dual ICAO addresses from one aircraft was discussed. The consensus reached is that this mechanism should be implemented in the AT system and not in the vendor's ADS-B system. The ADS-B system should pass all information received to the AT system unfiltered in the case of dual-link equipped aircraft (having two distinct ICAO addresses). If a method of self-alert prevention is not used, the complexity and cost of flight inspection more than doubles due to requiring two flights, at a minimum, to achieve what can be accomplished with a single flight when equipped and operated in the flight inspection dual-link configuration.

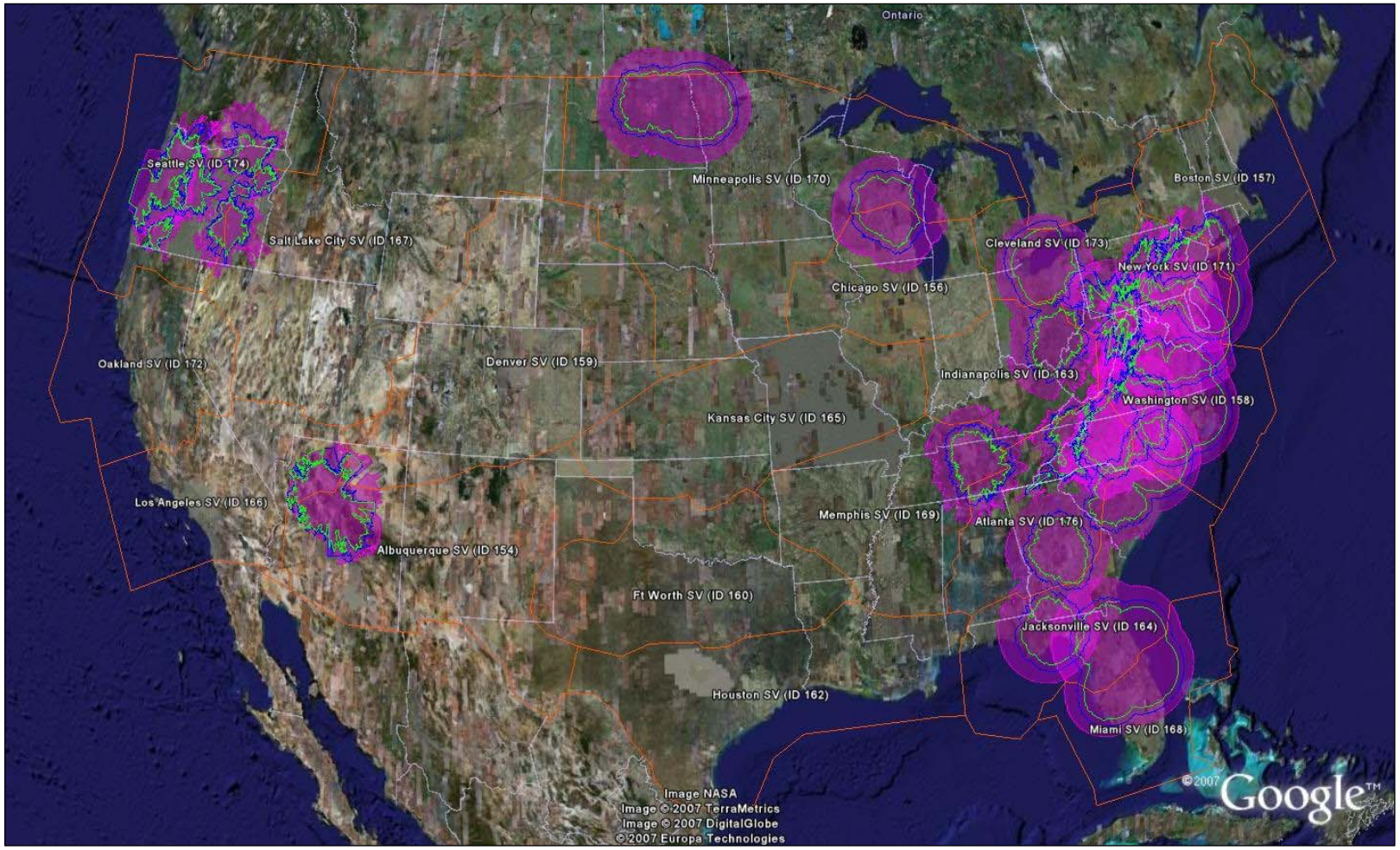

Figure 8. ADS-B Service Volumes and Legacy Systems Coverage [12].

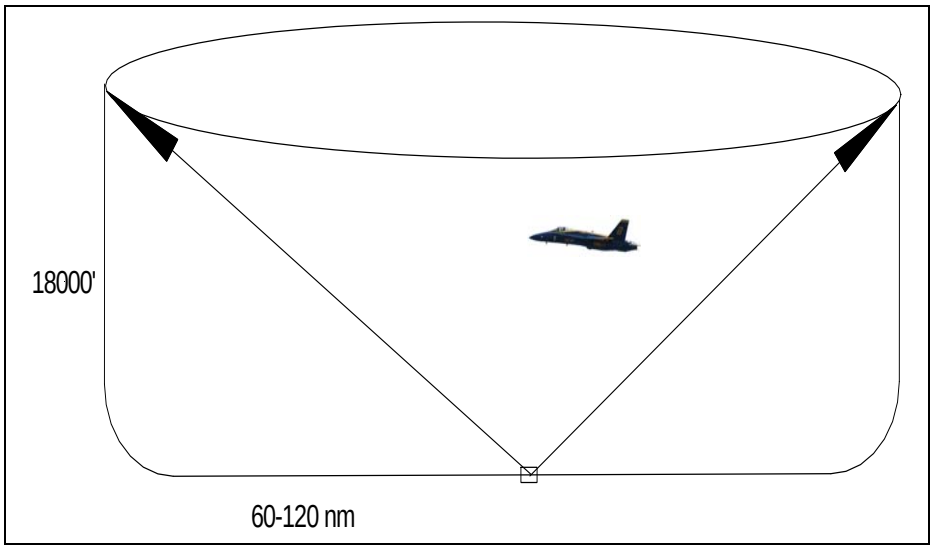

Figure 9. Legacy ADS-B Network TIS-B Service Area.

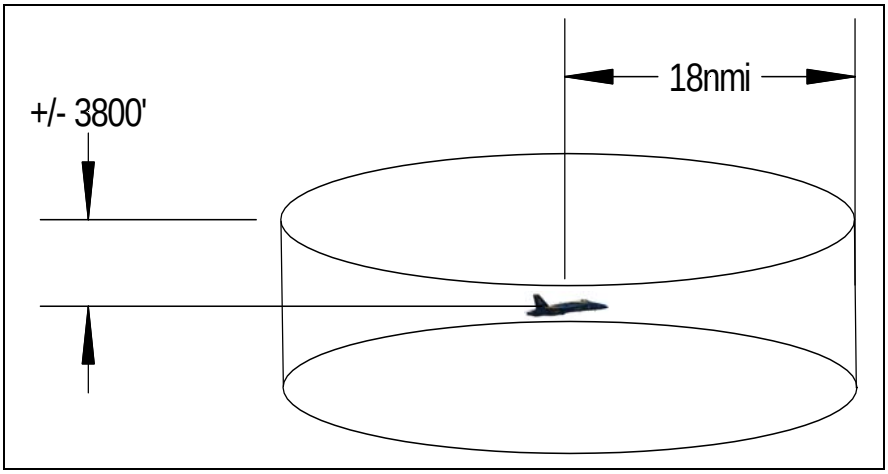

Figure 10. ADS-B Service TIS-B Service Area (as defined for 11/08 flight tests).

During the November 2008 flight tests for SV-168, AVN and AEC aircraft operated in coordination with the test team from the William J. Hughes Technical Center executing a series of tests and flight profiles to determine if several items identified during the August tests had been sufficiently mitigated or addressed [21]. It is suggested that each ADS-B GBT be configured to transmit a unique test target. These test targets would be a good indication of which ground stations are being received provided they are only transmitted from a single, associated station. While the ADS-B system is designed so that only one ground station is used to transmit information to a client aircraft if other ADS-B equipped aircraft are flying in the vicinity of other ground stations, their traffic will be transmitted from the closest ground station and if the flight inspection aircraft is within range it will

receive that TIS-B transmission. Also, FIS-B information is broadcast globally from the ground stations (although it may be disabled if there are no client aircraft anywhere within its coverage – the specifics on how the vendor will handle this situation is not known to the authors at this writing).

During initial analysis of the November 2008 data, a behavior in the target data was noted and, after discussions with the ADS-B vendor, it was determined the behavior is required by the ADS-B contract [22]. This behavior is that once the ADS-B system has associated an ICAO address with a target, the address continues to be assigned to the target once the ADS-B signal is lost as long as the radar track is valid. Once radar loses track, the ICAO assignment is lost. This results in valid ICAO address target track data even when the ADS-B data source has been disabled on the aircraft until the radar track is lost.

A benefit of using 1090 equipment like that supplied in the surveillance processor is that airborne traffic is detected by the TCAS component of the unit and displayed on the same display as ADS-B using different symbology. This additional information can be used for comparison with the TIS-B targets being broadcast by the ground stations. For example, if TCAS targets exist with 18 nmi and +/- 3800' of the flight inspection aircraft there should be corresponding TIS-B targets on at least one of the two (UAT or 1090) displays and possibly on both. If there are TCAS targets detected within the TIS-B hockey puck and there are no TIS-B targets on UAT or 1090 then a problem has been identified.

a. Flight Inspection Types

FAA Order 8200.1C section 4.12 describes a commissioning flight inspection as: "A comprehensive flight inspection designed to obtain complete information as to system performance and to establish that the system will support its operational requirements." Similar statements are found in sections 4.13 and 4.14e for periodic and special inspections [15]. Clearly defining these types of inspections for application to the new ADS-B services is critical. However, a different approach to assessing the coverage over time is proposed for use in place of traditional "periodic" inspections. Suggested commissioning, periodic / autonomous monitoring, and special inspections, as applied to ADS-B en-route "Essential Services" service volumes, are defined in the following paragraphs.

ADS-B Service Volume Commissioning: Commissioning of a new ADS-B service volume for provision of essential services requires a comprehensive flight inspection. Three types of inspections that assess coverage of the ADS-B service within the subject service volume are described in Table 2. These inspections are designed to check coverage at the outer borders of required coverage, coverage along busy air traffic routes, and provide a check of the individual ADS-B GBT antenna coverage pattern and system performance.

The plots in Figure 11 and Figure 12 in are an example of the coverage checks performed by AEC for SV-168 during August and November 2008 [22].

Table 2. Flight Inspection Commissioning Inspection Types.

Commissioning Inspection Type	Description
1	The perimeter (extremes) of the volume shall be inspected for coverage. - Perimeter flights should be inspected at the minimum radar coverage altitude and at 24,000'.
2	Each site associated with the service volume should be checked with an additional profile specifically created to pass-through the interior sections of the site's service volume and fly directly over the transmission facility (GBT). - ADS-B en-route service volumes are expansive and contain multiple GBT sites. Perimeter inspections do not check performance throughout each facility's complete transmission coverage volume.
3	Heavily utilized air traffic routes should be inspected to ensure coverage if not inspected by either the first or second previous types.
All	ADS-B TIS-B Crosslink target latency should be checked when operating in all areas (with special attention to high traffic areas).

ADS-B Periodic / Autonomous Monitoring: Although targets of opportunity will help to alleviate the necessity for closely spaced periodic flight inspections, a need may exist in the first four to five years of ADS-B operation to conduct flight inspections, of the coverage limits on a relatively long periodic cycle. Obstructions, whether man-made or organic, may slowly intrude in the radio line-of-sight. This may degrade performance at the perimeters to a level that falls below requirements. If traffic flow is insufficient in a perimeter area, periodic inspection to monitor ADS-B coverage is also warranted. This inspection need not be exhaustive, as in the case of a commissioning inspection, but may simply involve flight on the perimeter with data recording enabled and monitoring by FAA personnel on the ground to ensure coverage.

However, the long-term preferred method of routine inspection is to equip the FAA AVN aircraft with an autonomous ADS-B monitoring package that will record all pertinent data (raw and processed) from both UAT and 1090 receivers [23]. Then, as the AVN fleet conducts flight inspection missions for other FAA facilities in the NAS, the ADS-B data is recorded and submitted to the appropriate organization for post-flight processing in conjunction with recorded ADS-B ground system data. This post-flight processing provides a degree of quality assurance that the system is operating normally. If the recorded data shows any areas in need of additional inspection a special inspection can be scheduled. This will allow more efficient use of AVN resources than would nationwide periodic inspection of ADS-B. An exception to this alternative method may be needed for inspection of the backup transmitters; however, with proper coordination and scheduling, even the backup transmitters could be checked using the autonomous monitoring capability of the aircraft.

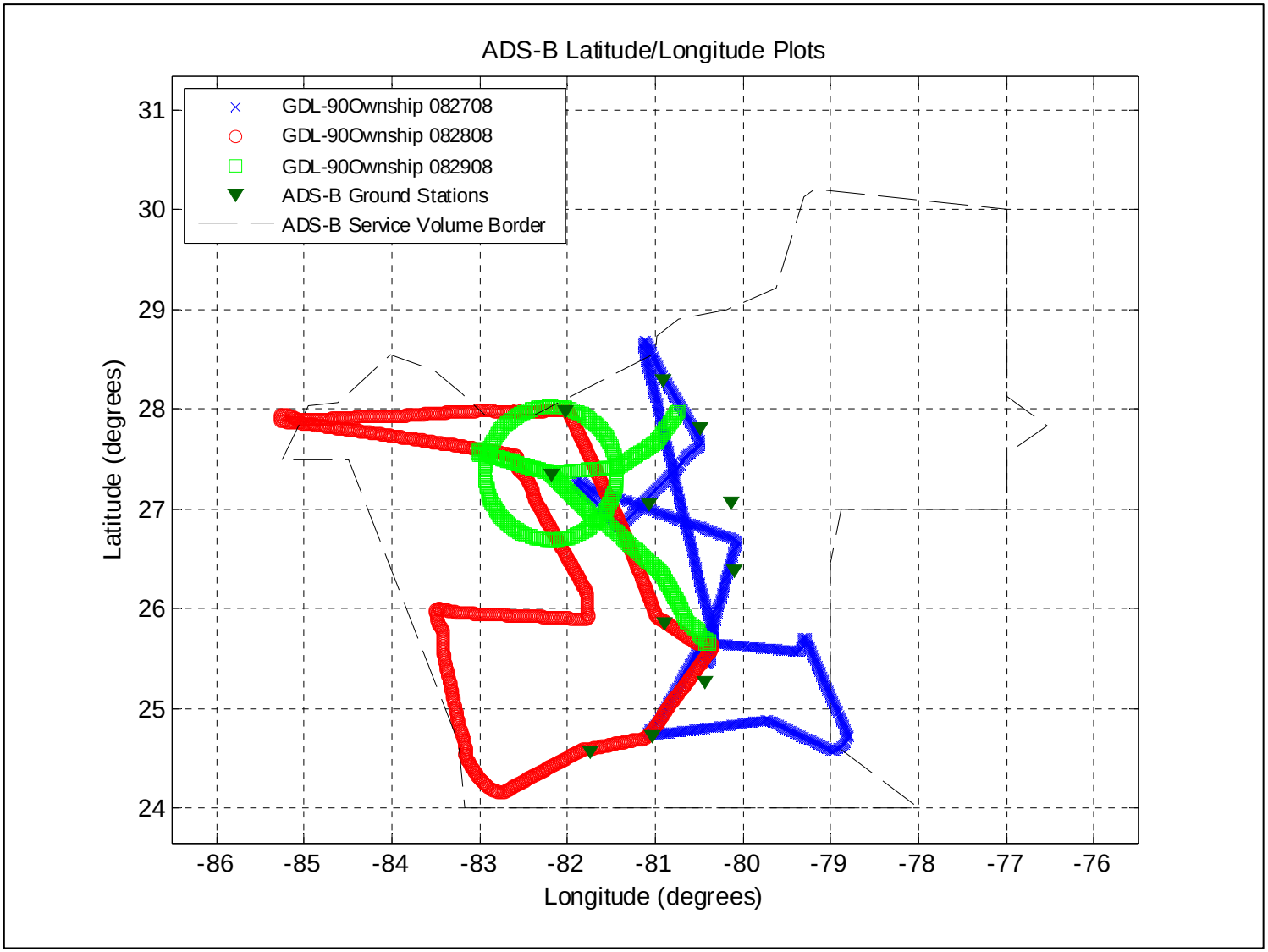

Figure 11. August SV-168 Flight Test Paths.

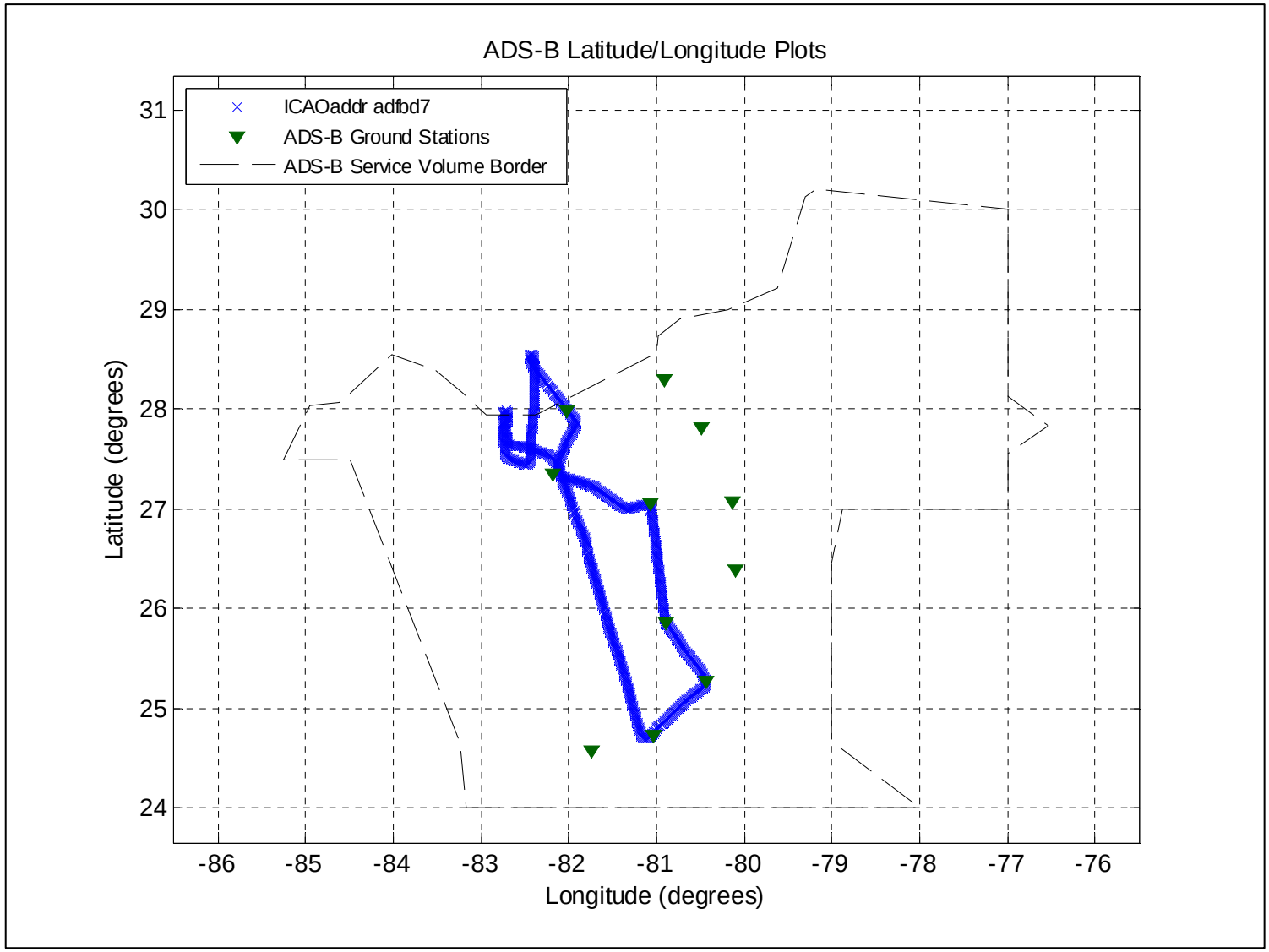

Figure 12. November SV-168 Station Overflight Test Path.

If autonomous monitoring of ADS-B is implemented, a procedure for tracking the status of the monitoring must be established. This should ensure that areas of the NAS with high concentrations of air operations are monitored within acceptable elapsed time limits. Assuming that implementation of autonomous monitoring will occur, it is not necessary to establish periodic inspections at this time. As experience with the ADS-B system is gained the consideration of periodic inspections may be revisited as needed.

ADS-B Special: Special inspections are typically scheduled for events such as a change of major components (either physical or in software) that directly affect the broadcast signal (e.g., antenna, power amplifier, etc.) and cannot be validated by ground test [15]. Any system that supports the NAS should be inspected after a change has been completed and before returning the equipment to service. User complaints about the ADS-B service that have been verified by other user reports may indicate necessity of a special flight inspection. Special inspections for radio frequency interference reports and after accidents may also apply.

If inspection is necessitated by changes at a single ground facility, properly defined orbits may be flown to ensure coverage by the facility under inspection. If more than one facility has been modified or changed, the affected area of the standard service volume perimeter must be flown along with any heavily utilized air routes transiting the facility's coverage area. Any change to software that affects the rebroadcast of ADS-B data may require a flight check in the service volume for its initial deployment if it cannot be checked by ground testing.

b. Flight Inspection Requirements

Flight inspection requirements, methodologies, and procedures have been divided into the following sections: *Preparation* (Table 3) and *Inspection requirements, procedures, methodologies, and data analysis* (Table 4, Table 5, and Table 6). Table 3 contains items that are either already performed as part of a typical flight inspection mission or are new and should be completed prior to dispatch for any ADS-B flight inspection mission and are included here for completeness of this document. *Inspection requirements, procedures, and methodologies* presented in Table 4, Table 5, and Table 6 are for the ADS-B en-route "Essential Services" service volume (e.g., SV-168 in southern Florida).

While most of the requirements below will also apply to ADS-B Critical Services, there may be differences in tolerances or additional requirements. Thus, as the ADS-B program continues deployment and moves toward the capability of providing the "Critical Services", these procedures should be re-assessed. There is no consideration given to terminal or surface service areas in this document (it is possible that surface service areas may be inspected with properly equipped ground vehicles) but should be included in future revisions. *Data analysis* provides guidance on how to assess operation of the ADS-B ground infrastructure and its ability to support the "Essential Services" operational requirements.

Preparation:

Table 3. Flight Inspection Preparation Procedures.

Description	Information / Data Required	Responsible Organization
Obtain definition of service volume to be inspected.	Service Volume corner post coordinates, minimum elevation contours, and service volume ceiling	FAA SBS PO
Obtain location and coverage volume for each GBT supporting the service volume to be inspected.	Coordinates for each GBT GBT coverage volumes	FAA SBS PO / ADS-B Vendor
Confirm that all GBTs and radars supporting the SV are operational.	ADS-B System Status	FAA SBS PO / ADS-B Vendor
Utilize target density data, if available, to identify areas with a sufficient number of low altitude target reports to define low-priority areas for coverage assessments.	Target density data (observed targets of opportunity)	FAA Technical Operations and AVN
Generate service volume boundary flight inspection profiles	Service volume boundary waypoints and altitude requirements	FAA
Generate interior service volume flight inspection profiles, ensuring that each GBT is directly over-flown and sufficiently directly sampled (data from service volume boundary inspection and target density data may be used to maximize flight inspection efficiency)	Profile waypoints and altitudes	FAA
Identify critical service corridors and generate flight inspection profiles to assess ADS-B service in such corridors (determine if boundary and GBT profiles may provide sufficient assessment).	Profile waypoints and altitudes	FAA ATC
Pre-flight: ATC coordination (particularly for air space restrictions)		AVN and Air Traffic Control
Pre-flight: coordinate with ADS-B service provider		AVN and ADS-B Vendor
Pre-flight: equipment calibration and check out procedures		AVN
Pre-flight: confirm upload of ADS-B parameters to flight inspection data collection system (AFIS or other)		AVN
Confirm proper operation of recording / data logging equipment		AVN

Inspection Requirements, Procedures, Methodologies, and Data Analysis:

Table 4. En-route Essential Services Flight Inspection Procedures.

Description	Information / Data Required	Requirement Source	Responsible Organization	C	A/P	S
Conduct ATC briefing to discuss all flight profiles to be performed and finalize profile sequencing based on prevailing traffic, weather conditions, and air space restrictions	Flight profiles, weather, restricted air space	NA	AVN/ATC	●	●	●
Conduct ground facility/service provider briefing to discuss equipment configuration requirements (power alarm limits, others?)	Equipment configuration and status	NA	AVN/ADS-B Service Vendor	●	●	●
The inspection is conducted with both aircraft and ground transmitters at the lowest permitted power levels (similar to radar transponder inspection) to ensure proper reception by ADS-B ground facilities at actual coverage limits.	Power levels and aircraft in-line attenuation / calibrated values		AVN/ ADS-B Service Vendor	●		
Conduct flight inspection along service volume profile - floor	Log all received ADS-B UAT raw data	Essential Services Specification V1.1	AVN	●	●	
	Log all received ADS-B 1090ES data (raw if possible)			●	●	
	Log signal strength data (if equipped)			●	●	
	Perform in-flight quality assurance for data collection process			●	●	
Conduct flight inspection at service volume profile – ceiling[1] (or Max Alt Capable)	Log all received ADS-B UAT raw data	Essential Services Specification V1.1	AVN	1		
	Log all received ADS-B 1090ES data messages (raw if possible)					
	Log signal strength data (if equipped)					
	Perform in-flight quality assurance for data collection process					
Conduct flight(s) along interior GBT profile(s) ensuring over-flight of all transmission facilities	Log all received ADS-B UAT raw data	Essential Services Specification V1.1	AVN	●	●	
	Log all received ADS-B 1090ES data messages (raw if possible)			●	●	
	Log signal strength data (if equipped)			●	●	
	Perform in-flight quality assurance for data collection process			●	●	
Conduct flight(s) along critical service corridor profile(s)	Log all received ADS-B UAT raw data	Essential Services Specification V1.1	AVN	●		
	Log all received ADS-B 1090ES data messages (raw if possible)			●		
	Log signal strength data (if equipped)			●		
	Perform in-flight quality assurance for data collection process			●		
Transfer all data files to removable media	UAT, 1090, and Truth data files	NA	AVN	●	●	●

Notes: 1.) Required for the first service volume only to establish a baseline. If no problems detected subsequent commissioning may defer this test until requested as a special flight inspection due to user complaints.

Table 5. En-route Essential Services - In Flight Performance Validation.

Description	Information / Data Required	Requirement Source	Responsible Organization	C	A/P	S
Verify reception of proper ADS-B TIS-B services	Presence of UAT/1090 targets in TIS-B service area (the hockey puck). There should always be a target for each link that should be the alternate ADS-B link's TIS-B Crosslink report.	Essential Services Specification V1.1, P 3.2.1.1.2.i.	AVN	●	●	
Verify TIS-B Update Interval < 12.1 seconds	Ownship crosslink target uplinks at rate greater than once every 12.1 seconds	Essential Services Specification V1.1, P 3.3.2.11.4	AVN	●	●	
Verify reception of proper ADS-B FIS-B services	Reception and presentation of FIS-B product via UAT and associated display	"Guide to SV List 082908 v3.doc" or current version	AVN	●	●	
Verify received power – UAT only	Output power must provide a field strength of at least 280 microvolts per meter (minus 97 dBW/m2) throughout the Service Volume	Essential Services Specification V1.1, P 3.3.2.11.7.1.3	AVN	●		
Analyze TIS-B traffic to ensure that FI aircraft radar TIS-B is NOT being transmitted[1]	UAT / 1090 ownship should not have a radar TIS-B target "ghost", only alternate link TIS-B Crosslink.	Essential Services Specification V1.1, P 3.2.1.1.2.e	AVN	●	●	
Prepare flight inspection report after completion of flight inspection	Include required records	NA	AVN	●	●	●

Notes:

1.) If other targets exist in FI aircraft's TIS-B service area and ownship position is not received as a TIS-B target this indicates that the TIS-B service has a valid ADS-B position for the FI aircraft and has correlated it with a radar track. TIS-B refers to a radar generated target. If operating in a flight inspection dual-link aircraft an "ADS-B" generated TIS-B target should be present in service volumes that are required to generate them. This parameter may be service volume specific.

Table 6. En-route Essential Services - FAA (non-AVN) Post Flight Data Analysis.

Description	Information / Data Required	Requirement Source	Responsible Organization	C	A/P	S
Verify reception of proper ADS-B TIS-B services	Documented presence of UAT/1090 (partially tested by ADS-R checks below) targets in TIS-B service area (the hockey puck) in collected data for the flight profile. Notate exceptions.	Essential Services Specification V1.1	FAA (non-AVN)	●	●	
Verify reception of proper ADS-B FIS-B services	Documented reception of any FIS-B product via UAT in collected data for the flight profile. Notate exceptions.	"Guide to SV List 082908 v3.doc" or current version	FAA (non-AVN)	●	●	
Analyze TIS-B traffic to ensure that FI aircraft radar TIS-B is NOT being transmitted[1]	Assess recorded UAT / 1090 data to ensure that a "radar generated TIS-B" target was not present during the flight profile. Notate exceptions.	Essential Services Specification V1.1	FAA (non-AVN)	●	●	
Verify ADS-R/TIS-B Crosslink Operation	Verification of ADS-R / TIS-B Crosslink rebroadcast is achieved by ensuring that ownship ADS-B 1090ES positions are rebroadcast via the TIS-B Crosslink and received by the FI ADS-B UAT and vice-versa[2]	Essential Services Specification V1.1	FAA (non-AVN)	●	●	
If multiple GBT equipment exists within a service volume (definite for en-route probable for all other service volumes)	Lat/Lon position broadcast by the GBT for site location should be checked - UAT	Essential Services Specification V1.1	FAA (non-AVN)	●		
	TIS-B site identification should be checked – UAT	Essential Services Specification V1.1		●		
Assess latency of UAT ADS-R position via 1090 is within tolerance	UAT Ownship and 1090 Rx'd UAT time-stamped positions	Essential Services Specification V1.1, P 3.3.2.6	FAA (non-AVN)	●		
Assess latency of 1090 ADS-R position via UAT is within tolerance	1090 Ownship and UAT Rx'd 1090 time-stamped positions	Essential Services Specification V1.1, P 3.3.2.6	FAA (non-AVN)	●		
Prepare flight inspection report after completion of flight inspection	Include required records	NA	FAA (non-AVN)	●	●	●

Notes: 1.) If other targets exist in FI aircraft's TIS-B service area and ownship position is not received as a TIS-B target this indicates that the TIS-B service has a valid ADS-B position for the FI aircraft and has correlated it with a radar track. TIS-B refers to a radar generated target. If operating in dual link aircraft with separate ICAO addresses an "ADS-B" generated TIS-B target should be present. It is also possible that radar may be INOP for some reason, should confirm with ATC. May be SV specific.
2.) UAT and 1090 must have different ICAO addresses with UAT being a "test" address and 1090 the actual aircraft ICAO address.

c. Flight Inspection Aircraft Equipment Requirements

Flight inspection aircraft will require the equipment listed (or equivalent) in Table 7 to accomplish the procedures and analysis suggested in the previous section. Figure 13 shows the equipment used for ADS-B test flights by AEC. The equipment is installed in the Center's King Air C-90B aircraft. Figure 14 shows the MITRE UAT and ACSS "Traffic Display" applications running on two AEC computers. They are interfaced with the Garmin GDL-90 and ACSS Surveillance Processor, respectively.

Table 7. Required Flight Inspection Aircraft Equipment.

#	Quantity	Equipment	Description
1	1	ADS-B Universal Access Transceiver (UAT)	Equipment to transmit and receive information on the ADS-B UAT data link. Current UAT systems are complete with position source and data radio enclosed within one unit. (Must be capable of passing-through received ADS-B messages unaltered)
2	1	ADS-B 1090 MHz Extended Squitter Avionics Suite	Equipment to transmit and receive information on the ADS-B 1090 MHz data link (transponder). Current 1090 systems require additional avionics (surveillance processor) to supply aircraft and position information and to process received data. (Should be capable of passing-through received messages unaltered)
3	1	Data Capture/Analysis Computer(s)	Computer(s) will simultaneously capture data from both data links, perform airborne analysis based on flight profile, and alert the FI crew of observed outages. Need RS-232/422 and ARINC-429 interfaces.
4	1	ADS-B Display	Can be used to verify traffic target reception and some FIS-B uplink data but can not be used to display which GBT is uplinking data for coverage checks or detailed analysis of raw data.
5	1	1090ES Receive Only Unit - Recommended	At present, one vendor manufactures a device which may be used to monitor 1090ES broadcasts. Some agency groups have engaged this vendor to supply equipment for aircraft flight test monitoring. Status of that request is unknown. This unit is not TSO'd.
6	1	UAT Receive Only Unit – Availability Likely	If this product becomes available, when combined with the 1090ES Rx only unit, it may be possible to test the ADS-R functionality while airborne by switching transmitting data links off and monitoring the "off" channel.

At this time, Garmin (UAT) and ACSS (1090) are the only vendors known to offer for sale ADS-B aircraft units for the respective data links. The Garmin unit is certified while the ACSS surveillance processor unit is in development. The other part of the 1090 ADS-B equipment suite is the ACSS Mode-S transponder (XS-950) and it is a certified unit. No aircraft product with the ability to output signal level/strength is available at this time. However, it may be advisable to approach the vendors regarding development of a "flight inspection" version of their equipment to include signal level and other items.

Figure 13. ADS-B Test Pallet in AEC's King Air C-90.

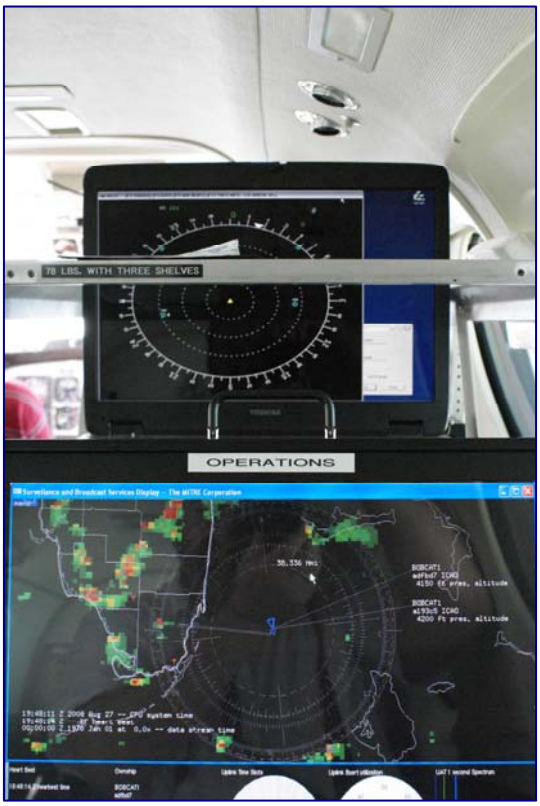

Figure 14. Example ADS-B Displays (Mitre UAT and ACSS 1090).

One such suggested item for a "flight inspection receiver" is for the ACSS surveillance processor. An option to output the "raw" received ADS-B data would be useful for flight inspection because, at present, which transmitting station is responsible for the received data cannot be determined from data available to Ohio University. Absent a flight inspection version of the surveillance processor, it is suggested that a separate 1090 receive-only unit be installed in addition to the surveillance processor if the receive-only unit is capable of outputting/recording the "raw" 1090 message content.

The Ohio University AEC King Air is equipped with the same MITRE UAT Electronic Flight Bag (EFB) software used on the AVN Learjet, and this EFB software records the UAT data in a MITRE format. These files are then converted post-flight for processing. However, the data that is recorded is not the "raw" data stream from the UAT unit but rather a filtered version. The "raw" data stream should also be recorded to ensure a complete data record and provide the ability to reconstruct the output of the receiver.

Similarly, the ACSS surveillance processor on board the AEC King Air outputs traffic information for display on an EFB [24] and is recorded by the AEC data collection equipment. However, traffic information recorded from an ARINC 735B data stream appears to be a subset of the information sent up the 1090 data link may be combined with output of a TCAS

V. CONCLUSIONS AND RECOMMENDATIONS

It has been necessary to divide the study to develop recommended ADS-B flight inspection requirements and procedures into two parts. This first study focuses on the flight inspection required for ADS-B *Essential Services* and provides initial observations on ADS-B *Critical Services*. The separation is necessary because ADS-B Critical Services has not yet been deployed. While the FAA has an *ADS-B Critical Services* specification that provides requirements, the implementation is not complete and thus the actual system "definition" is not available. This impacts the ability to provide specific requirements and procedures for flight inspection similar to that experienced during the development of the flight inspection requirements, methodologies, and procedures for the ADS-B Essential Services contained herein. It is crucial to have a basic understanding of the ground infrastructure when preparing flight inspection requirements. The conclusions and recommendations contained herein are based on information available to AEC as of December 2008.

The FAA (vendor supplied) ADS-B Essential Services provides information to the pilots of suitably equipped aircraft that will enhance their situational awareness through onboard weather information, NOTAMs, and better understanding of surrounding air traffic relative their own aircraft through use of TIS-B. These services require use of a cockpit display. Aircraft that are equipped with only ADS-B "out" equipment will not be capable of utilizing the vendor ADS-B broadcast essential services products; however, other fully equipped ADS-B users will have a GPS based position for the ADS-B "out" aircraft in place of a radar derived position. These services are not used for separation of

aircraft during instrument conditions. Air Traffic Control's use of ADS-B technologies to provide for separation of aircraft will occur with vendor deployment, and FAA acceptance, of ADS-B Critical Services.

The following are the general conclusions and recommendations that are presented based on the study and experience of flight testing the initial Essential Services Service Volume for ADS-B:

1. ADS-B Essential and Critical Services should be flight inspected to ensure that the service contracted by the FAA is present in the associated service volumes and meets contractual performance requirements;
2. No ground-based "over the air" monitoring is performed based on available information;
3. Vendor supplied ADS-B Essential and Critical Services should receive a commissioning flight inspection;
4. Special inspections of ADS-B Essential Services should be driven by items previously discussed in this report;
5. Proper ADS-B system operation while using aircraft with two separate ICAO addresses, dual-link operation, has been demonstrated during flight tests in the first ADS-B Essential Services deployment (SV-168);
6. FAA AT system logic should be implemented in a way that enables the use of ADS-B UAT "test" ICAO addresses onboard AVN flight inspection and other supporting aircraft while operating in dual-link mode such that the "test" ICAO target does not disrupt ATC operations with self-alerts;
7. The broadcast of "test" TIS-B targets from each GBT during flight inspection operations should be requested by the FAA (should be enabled by service volume);
8. Temporary periodic inspections identified by AVN should be conducted for Essential Services until such time that the Flight Inspection Autonomous Surveillance of ADS-B functionality is operational;

FAA AVN has begun preparation for flight inspection of ADS-B and has equipped an aircraft for use in test and evaluation of ADS-B deployment. It is configured as a preliminary installation. The following conclusions and recommendations apply to aircraft equipage in preparation for NAS-wide ADS-B deployment:

9. A function should be developed, either in AFIS or as a standalone program, to compare ownship position vs. crosslinked ownship position to provide in-flight assessment of ADS-B TIS-B crosslink system latency performance;
10. All "raw" data should be recorded for post-flight processing (UAT, 1090, other outputs from equipment, and truth system position and time);
11. Additional AVN aircraft should be equipped with ADS-B capability in preparation for nationwide ADS-B deployment in the next five years;
12. A Flight Inspection Autonomous Surveillance system (or function within AFIS) to continuously monitor and record ADS-B data while on routine flight inspection missions for other navigation aides should be developed;

13. If a Flight Inspection Autonomous Surveillance system is used to continuously monitor and record ADS-B data, a quality assurance process should be implemented that uses the collected data to ensure that effective sampling across the NAS is being achieved; and,
14. UAT and 1090 equipment vendors should be approached concerning development of a flight inspection version of standard equipment (raw data logging, power measurement/control, etc).

This report presents current best engineering understanding of the ADS-B Essential Services and associated flight inspection requirements, methodologies, and procedures based on this understanding. Deployment of the ADS-B system is continuing along a path to ISD for the Critical Services during the second half of 2010. As the deployment continues new understanding of the Critical Services and additional consideration of the Essential Services will follow. This new information will impact flight inspection requirements, methods, and procedures established based on the current state of the ADS-B system. Ohio University has identified the following remaining issues that need addressed as the system is more fully deployed and reaches fully operational status:

1. Internal FAA information related to requirements provided to the ADS-B vendor in the actual ADS-B contract should be obtained and cross-checked against the essential and critical services requirements documents;
2. A follow-on study to complete the flight inspection requirements, methodologies, and procedures development for ADS-B Critical Services and revise/refine the ADS-B Essential Services section should be conducted. The critical services study should build on and maximize use of this study;
3. Planning and scheduling for additional FAA aircraft equipage with the minimum required avionics should begin/continue immediately; and,
4. Mechanisms for direct engineering interaction with the ADS-B vendor should be established to enable development of efficient flight inspection procedures.

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Appendix A.

Selected ADS-B Flight Inspection Technical Interchange Meeting Discussion Points
December 16, 2008
MMAC, Oklahoma City

Master Document Compiled by
Aviation System Standards (AVN)

This Appendix Contains
Questions and Comments Down-Selected by
Ohio University per Relevance to Report Topics

ADS-B Flight Inspection Technical Interchange
Dec 16, 2008
MMAC, Oklahoma City

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Q - Question
C - Comment
A - Answer

From ADSB Requirements Overview:

C. Not sure what requirements were given to ITT
Q. Is this info proprietary?
Q. Has anyone in this group contacted ITT to ask for the spec data?
  A. "No" seems to be the answer.
  A. Possibly use Mr. Paul Pender to contact ITT contract officer.
C. ADS-R isn't required to have same service volume as ADS-B.
Q. What are ADS-R coverage requirements, and how are they different than TIS-B?
  A. The requirements information is published on the SBS ADS-B KSN web site, including "contract letters" modifying the initial contract.
Q. What actions require special inspection?
  C. FI requirements should be based on safety.
C. From the original specifications released in Spring '07, don't understand the coverage requirement for Terminal Domain service volumes, which states: "For ADS-B Services, the floor of the SV must be equivalent to that of the group of radars that provide coverage

in the SV for 98% of the service volume. For the remaining 2%, the floor of the service volume must be at least 500 feet below the MVA closest to that airspace."
For Surface Domain service volumes coverage includes the airport movement area surface up to 200 feet AGL, and all standard and non-standard approach/departure corridors out to five miles from runways and thresholds. TIS-B and ADS-R have 15 NM radius traffic info requirement.

Q. What are the coverage requirements in terms of redundancy?

Q. Do some types of service volumes require reception of at least 2 GBTs?

Q. What are the monitoring requirements?

> **A.** There is no backup requirement – only reliability. We're provided with coverage information. We can get a briefing from the program office for each service volume. Sometimes redundancy is provided by a backup transmitter, other times by overlapping service volumes. "Requirements" is wrong word to use.

Q. What about minimum power requirements?

Q. What is the minimum transmission power for aircraft avionics, and for GBTs?

Q. Will it be necessary for flight inspection aircraft to be able to measure signal strength in terms of power like dBW/m^2, or is being able to receive (at the aircraft) and decode the transmission a good enough indicator of adequate coverage?

Q. What criteria should be used to determine if FIS-B or TIS-B transmissions are acceptable?

Q. Are there flight inspection support requirements in the ITT contract?

From Briefing of OU Draft for Essential Services:

Q. Why flight check?

> **A.** The FAA is buying a service and it needs to be checked for safety's sake. The monitor system doesn't check signal in space.
>
> **A.** Some monitoring capability exists – but not to the degree required –yet. Work has begun on developing level of safety documents.
>
> **A.** We (clarification: ADS-B) can't be used as part of the monitoring, because it's not included in the current contract.

C. FAA AVN not responsible for inspecting air-to-air operations.

C. We need to ensure ITT can accommodate the dual ICAO ident scheme being used for flight inspection.

C. For all the details, see the Ohio University Technical Memorandum OU/AEC 08-09TM15689/0007-1, Review of the Automatic Dependent Surveillance-Broadcast (ADS-B) System and Development of ADS-B Flight Inspection Requirements, Methodologies, and Procedures.

From Responsibilities and Flight Inspection Requirements Discussion:

Q. Who will determine specific flight inspection coverage profile?

> **A.** It was agreed that AVN must be supplied with the necessary information and details.

Q. Who is going to be the point of contact to talk to ITT?

> **C.** We need to be able to confirm the system is up, the system configuration, and also coordinate ITT recording the data during inspection.

Q. Who determines if the inspection is satisfactory?

More coverage questions:

Q. Is the "good low/good high" theory to be considered valid?

Q. How and when should we check backup transmitters?

Q. How and when should we check backup antennas?

> **C.** While it is true that originally, dual UAT transmitters had separate antenna systems; some now share the same antenna.

Q. Should we be checking the facility in reduced RF power?

Q. What about airborne transponder reduced power?

> **C.** All seemed to agree that the system should be tested at minimum power. It shouldn't be necessary to operate the aircraft receiver at minimum sensitivity for a couple of reasons: first, ADS-B only has an ADS-B OUT requirement at this time; and, the principle of reciprocity should allow adequate testing of the ground-aircraft link with the ground system and aircraft both transmitting at minimum power levels.

Q. Is WAAS positioning data from the flight inspection aircraft of sufficient accuracy for test purposes?

> **C.** This is really the wrong question. ADS-B is dependent on the data sent to it by the aircraft, and has no control over the accuracy of that position data. The real question, and thing to check is, how does the "ownship" position sent from the aircraft compare with the position re-broadcast by ADS-B on TIS-B via ADS-R (or the cross-link), and the position ultimately used by ADS-B for critical services (like aircraft separation).

Q. Should a commissioning inspection require all GBTs be operational?

> **C.** This is really an implementation strategy question. ITT may wish to commission Enroute service volumes it knows are going to have more GBTs when follow-on Terminal service volumes are implemented.

C. There is a two day response time for transmitter outages.

Q. Will we need to re-fly coverage when a GBT is out of service?

Q. In this case, should the "hockey puck" be checked?

> **C.** Operators can change configuration anytime, but there will be some safety features.

Q. Will local system configuration be checked on a periodic basis?

Q. Should there be some kind of periodic oversight of configuration control like that carried out by the MSAW QA panel?

Q. When there is no radar coverage in an area, (either due to no radar facilities or a radar outage) does flight inspection we need to verify the controller's ability to identify when the aircraft is over procedure or route fixes, especially those designated "Radar Required?"

Q. Will ADS-B be used in this way?

Q. In GOMEX?

Q. Do we need to check fixed targets, like permanent echoes?

Q. Is this a part of Essential or Critical services?

Q. If there is a change to the software, who decides if a flight inspection is required?

C. It was suggested that the flight inspection would occur during flight testing of the new software before it was used operationally.

Q. Will we get a special set of ICAO codes, to transmit UAT and 1090ES simultaneously?

C. There could be an issue with either (1) the ITT system not being able to tolerate two different aircraft occupying the same place; (2) air traffic automation systems alerting to a traffic conflict.

C. Based on recent tests, the ITT system seems to be able to handle the flight inspection aircraft using two different ICAO codes. <u>For critical services, it will be up to Air Traffic to filter out "flight inspection test ICAO addresses" so conflict alerts are eliminated. It was agreed that any filtering or other solution to this conflict problem should occur at the AT automation level, and not within the ADS-B system.</u>

Q. Will ITT continue to transmit GBT test targets?

Q. Do we need to know which, or how many, GBTs the flight inspection aircraft is receiving at any given time?

C. Currently, we have that capability for FIS-B, but not TIS-B. One solution might be to have each GBT transmit a unique TIS-B target with a unique ICAO address.

Q. Do we need a FIS-B test pattern? Or, can we just check to make sure there is FIS-B information of all the required types?

Q. What role will AOS have in monitoring system configuration?

Q. What are the future flight inspection equipment requirements?

Q. Will a separate laptop be required to record the 1090ES data, vice the UAT data already being recorded?

Q. Could this software be integrated into the flight inspection aircraft's existing computer?

C. Information is needed for determining future Next generation Automated Flight Inspection System (NAFIS) requirements. This includes signing any necessary non-disclosure agreements with ITT.