Benefits and Incentives for ADS-B Equipage in the National Airspace System

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Report No. ICAT-2007-2
August 2007

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ABSTRACT

Automatic Dependent Surveillance – Broadcast (ADS-B) is a technology that can replace secondary surveillance radars and enhance cockpit situational awareness. It also has the potential to enable procedures not possible with current surveillance technology that would increase the capacity of the National Airspace System (NAS) in the US. Certain forms of ADS-B also have the bandwidth to upload weather and airspace information into the cockpit. However, prior to achieving the benefits of ADS-B, operators must equip with the technology. In order to voluntarily equip, owners and operators must receive benefits from the technology that outweigh the cost or receive other incentives. Through an online survey of stakeholders, applications of ADS-B with the strongest benefits to users are identified.   In-cockpit data link offerings are explored in detail, along with a detailed analysis of ADS-B benefits for Hawaiian helicopter operators.   The conclusions of this study are that ADS-B should be implemented in non-radar airspace along with busy terminal areas first to gain the most benefits from non-radar separation applications and traffic awareness applications.   Also, the basis for the US dual ADS-B link decision is questioned, with a single 1090-ES based link augmented with satellite data link weather recommended.

Keywords

Acknowledgements

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List of Acronyms

1090-ES	1090 MHz Extended Squitter
ACSS	Aviation Communication and Surveillance Systems
ADS-B	Automatic Dependent Surveillance – Broadcast
ADS-R	Automatic Dependent Surveillance – Rebroadcast
AGL	Above Ground Level
AIRMET	Airmen's Meteorological Information
ANSP	Air Navigation Service Provider
ARTCC	Air Route Traffic Control Centers
ASDE(-X)	Airport Surface Detection Equipment (-Model X)
ATC	Air Traffic Control
ATCRBS	Air Traffic Control Radar Beacon System
ATM	Air Traffic Management
AWW	Alert Weather Watch
CAVS	CDTI Assisted Visual Separation
CDA	Continuous Descent Approach
CDTI	Cockpit Display of Traffic Information
CFAR	Code of Federal Regulations
CFIT	Controlled Flight into Terrain
ConOps	Concept of Operations
COUHES	Committee On the Use of Humans as Experimental Subjects
CPDLC	Controller Pilot Data Link Communications
CTAF	Common Traffic Advisory Frequency
D-ATIS	Digital Automated Terminal Information Service
DME	Distance Measuring Equipment
EFB	Electronic Flight Bag
EHS	Enhanced Surveillance
ELS	Elementary Surveillance
ELT	Emergency Locator Transmitter
EVS	Enhanced Vision System
FAA	Federal Aviation Administration
FIS-B	Flight Information Service - Broadcast
FLIR	Forward Looking Infrared
FMS	Flight Management System
FRUIT	False Returns Uncorrelated in Time
FSS	Flight Service Station
GA	General Aviation

GAATAA	General Aviation and Air Taxi Activity and Avionics
GBT	Ground Based Transceiver
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HAI	Helicopter Association International
HFOM	Horizontal Figure of Merit
HPL	Horizontal Protection Limit
ICAO	International Civil Aviation Organization
IFF	Identify Friend or Foe
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
JPDO	Joint Planning and Development Office
MAPS	Minimum Aviation System Performance Standards
METAR	Aviation routine weather reports
MFD	Multifunction Display
Micro-EARTS	Micro En route Automated Radar Tracking System
MIT	Massachusetts Institute of Technology
MLAT	Multilateration
MLS	Microwave Landing System
MOPS	Minimum Operational Performance Standards
MSAW	Minimum Safe Altitude Warning
MSL	Mean Sea Level
MVFR	Marginal Visual Flight Rules
NAC_P	Navigation Accuracy Category for
NAC_V	Navigational Accuracy Category for Velocity
NAS	National Airspace System
NEXCOM	Next Generation Air/Ground Communication
NEXRAD	Next Generation Weather
NextGen	Next Generation Air Transportation System
NIC	Navigational Integrity Category
NOTAM	Notice to Airmen
NTSB	National Transportation and Safety Board
NUC	Navigation Uncertainty Category
PFV	Primary Field of View
PIREP	Pilot Report
PRM	Precision Runway Monitoring
PSR	Primary Surveillance Radar
RA	Resolution Advisory
RNP	Required Navigational Performance

RTCA	Radio Technical Commission for Aeronautics
SAMM	Surface Area Movement Management
SFAR	Special Federal Aviation Regulations
SIGMET	Significant Meteorological Information
SIL	Surface Integrity Level
SSR	Secondary Surveillance Radar
SUA	Special Use Airspace
TAF	Terminal Area Forecast
TAS	Traffic Awareness System
TAWS	Terrain Awareness and Warning System
TCAS	Traffic Collision and Alerting System
TDMA	Time Division Multiple Access
TFR	Temporary Flight Restriction
TIS-B	Traffic Information Service - Broadcast
TSO	Technical Standard Order
TWIP	Terminal Weather Information for Pilots
UAT	Universal Access Transceiver
UAV	Unmanned Aerial Vehicle
UHF	Ultra-high Frequency
UPS	United Parcel Service
URET	User Request Evaluation Tools
VDL	VHF Datalink
VFR	Visual Flight Rules
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
VPL	Vertical Protection Limit
WAAS	Wide Area Augmentation System
WSI	Weather Services International

1. Motivation

Automatic Dependent Surveillance – Broadcast (ADS-B) is a category of technologies and applications that could fundamentally change the way aircraft are tracked in the national airspace system (NAS). Instead of relying on costly radar technology, aircraft will broadcast their state vector and other information to ground receivers and other aircraft. ADS-B has the potential to increase capacity, improve efficiency, reduce costs, and improve safety in the NAS.

Applications not possible with today's radar technology can be performed with ADS-B. For example, with an ADS-B Cockpit Display of Traffic Information (CDTI), pilots are able to "see" other aircraft even low visibility conditions. Pilots can then maintain separation from these aircraft without instructions from Air Traffic Control (ATC). Due to the relatively low cost of ground receivers, ATC surveillance coverage can be expanded beyond current radar coverage areas. Some forms of ADS-B also allow information to be broadcast to pilots in the cockpit, enhancing awareness of current weather and airspace restrictions.

For ADS-B to replace radar technology, however, every aircraft tracked by ATC must be equipped with ADS-B. How to reach full equipage poses a problem, since most benefits do not accrue until all aircraft are equipped. There are three major strategies for achieving full equipage. The first is mandating equipage, which was done for ATC transponders and for TCAS. This is an effective strategy, but it can lead to political opposition to equipage.

The second method for achieving full ADS-B equipage is including stand-alone applications and benefits that do not depend on full equipage. This way, operators who equip early receive benefits immediately. The inclusion of broadcast information about weather and airspace restrictions is an example of an ADS-B application that does not require full equipage.

The third method for achieving full ADS-B equipage is to provide specific benefits to operators who operate in a specific region, creating a critical mass of ADS-B equipage in one region, without requiring operators to equip across the NAS.

The FAA is using a combination of all three methods for ADS-B equipage in the NAS. This paper focuses on identifying benefits to operators for various applications.

2. Background and History of ADS-B

2.1 History of Surveillance Technologies

Initially, Air Traffic Control (ATC) was done via aircraft position reports over radio to air traffic controllers who used time to separate aircraft. However, with radar technology developed during WWII, air traffic controllers were able to obtain aircraft positions without radio reports using radar. Primary surveillance radar (PSR) works by reflecting radio waves off of airframes. No equipment is needed on the aircraft, thus primary radar is an independent surveillance technology. However, primary radar also reflects off of birds, ground objects, and atmospheric phenomena, making it hard for controllers to uniquely identify aircraft.

Primary radar has since been enhanced with the Air Traffic Control Radar Beacon System (ATCRBS), more commonly know as secondary surveillance radar (SSR). With the ATCRBS system, each aircraft is equipped with a transponder which replies to interrogations from ground radars with unique data. This way, controllers can identify the "blips" on their radar screens. Mode A transponders reply with a 4 digit code, Mode C transponders reply with the 4 digit code along with altitude, Mode S transponders reply with the 4 digit code, altitude, a unique identifier, along with data needed for collision avoidance functions. SSR is a dependent surveillance technology since a functional transponder is required on the aircraft to be observed by SSR.

The next evolutionary step in aircraft surveillance technology was the implementation of the Traffic Collision Avoidance System (TCAS). TCAS works by one aircraft interrogating other aircrafts' transponders. This way, each TCAS equipped aircraft can locate nearby transponder equipped aircraft, and potential collisions can be detected. TCAS identified traffic can be displayed on a graphical display in the cockpit which depicts the traffic's range and bearing. TCAS is a semi-independent surveillance technology in that it does not require any ground infrastructure; however it does require one aircraft to be equipped with a TCAS system and the other aircraft to have at least a Mode C transponder.

2.2 ADS-B Architecture

The next step in surveillance technology evolution is ADS-B, where each aircraft's state vector (3-D position plus 3-D velocity) is transmitted ("ADS-B

Out") by the air vehicle component in the blind to other aircraft via an air-to-air datalink and to ground stations via an air-to-ground datalink (Figure 1). Other aircraft can use this state vector ("ADS-B In") along with their own state vector to calculate relative range and bearing to other aircraft and display this information on a Cockpit Display of Traffic Information (CDTI), much like TCAS intruders are displayed in equipped cockpits currently. Likewise, the data received by ground stations is fed to air traffic control displays to indicate the equipped aircraft's location, altitude, and other data.
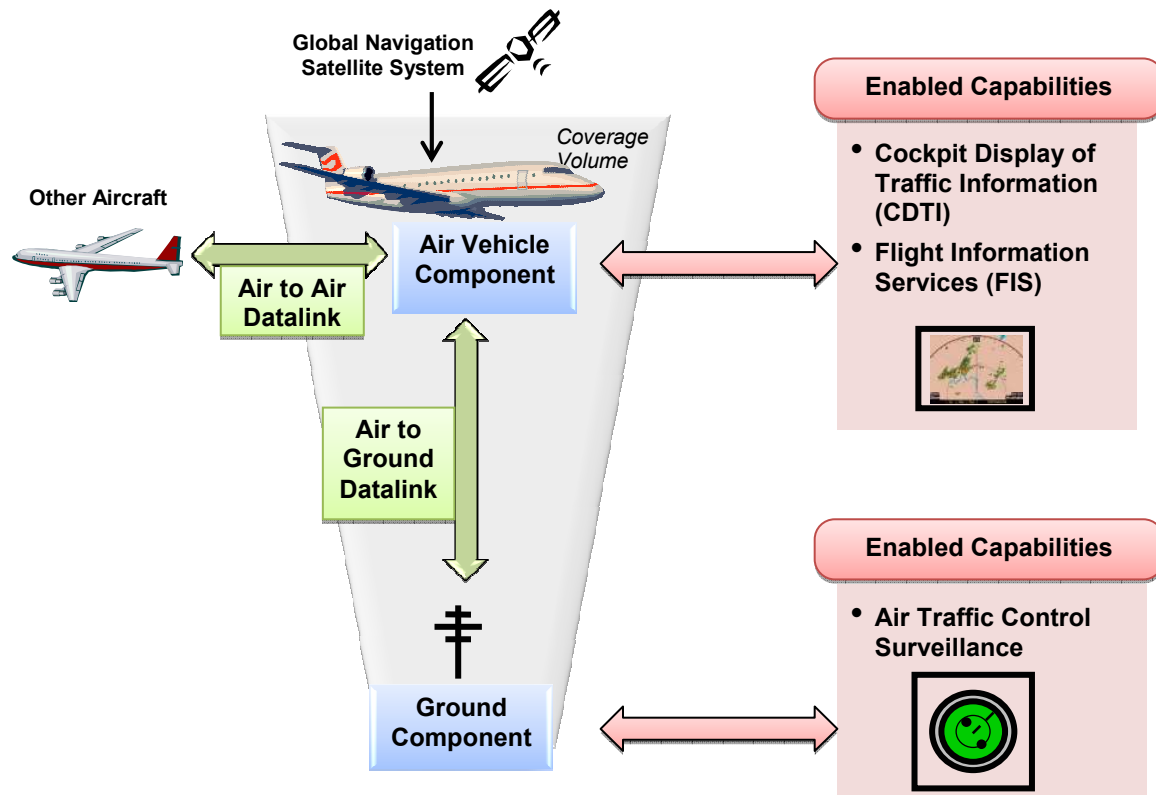
Figure 1: ADS-B components and links showing the enabled capabilities for both air to air and air to ground links [From Weibel et al, 1]

ADS-B is a broadcast technology, in that the aircraft state vector is disseminated without any knowledge of or replies needed from receiving aircraft or ground stations, what is termed "ADS-B Out." With transponders for TCAS and SSR, responses are only sent in reply to interrogations since time is used to measure distance. ADS-B is automatic because messages are sent without any pilot action. Finally it is dependent surveillance, since unlike primary radar surveillance, ADS-B is dependent on the aircraft's own position source and functional transmitter, much like secondary radar is dependent on aircraft transponders.

However, unlike transponders, the accuracy and integrity of the whole surveillance system is dependent on the aircraft's position source. This dependency means that the airborne equipment requirements must be well defined before a safety analysis of individual ADS-B applications can be made.

ADS-B is in the same class of surveillance technologies as TCAS, in that both require all aircraft to be equipped in order to receive benefits. If other aircraft are not equipped with Mode C transponders, TCAS equipped aircraft cannot avoid collisions with them. Likewise with ADS-B, if other aircraft are not broadcasting their state vector, the ADS-B aircraft with a traffic display cannot depict them. Additional, ADS-B cannot replace existing SSR installations in the NAS, until all aircraft are equipped with ADS-B equipment to broadcast state vector information.

Therefore, methods must be developed to equip all aircraft in the NAS with ADS-B in order to receive the benefits of the technology. The most effective method to equipage is a legal mandate. A legal mandate was used to require TCAS equipage for aircraft with greater than 10 seats. Legal requirements were also used to mandate Mode-C transponder equipage for aircraft that operate under instrument flight rules (IFR) or near class B and C airspace. However, a mandate is likely to be faced with political opposition since aircraft owners will have to pay out of pocket for the ADS-B equipment. Another method is to encourage voluntary aircraft equipage by providing benefits that outweigh, or at least off-set, the costs.

2.3 Stakeholder Benefit Matrices

There is likely to be an un-even distribution of costs and benefits, where the stakeholders who incur the costs may not receive proportional benefits [2]. The costs and benefits are also distributed over time. Stakeholder support for adopting ADS-B is dependent on their perceived benefits and receiving those benefits soon after their cost outlay. By implementing high benefit operational procedures or varying the order of implementation, the benefits and costs can be better distributed amongst stakeholders, leading to more widespread support of the ADS-B technological transition.

Matrices of stakeholders and benefits are used in Marais and Weigel [2] to graphically portray the benefits for each stakeholder. As seen in the notional stakeholder-benefit matrix in Figure 2, benefit categories are listed on the left and

stakeholders are listed across the top. Each cell contains an icon to indicate the amount of benefit to that stakeholder for that benefit category.
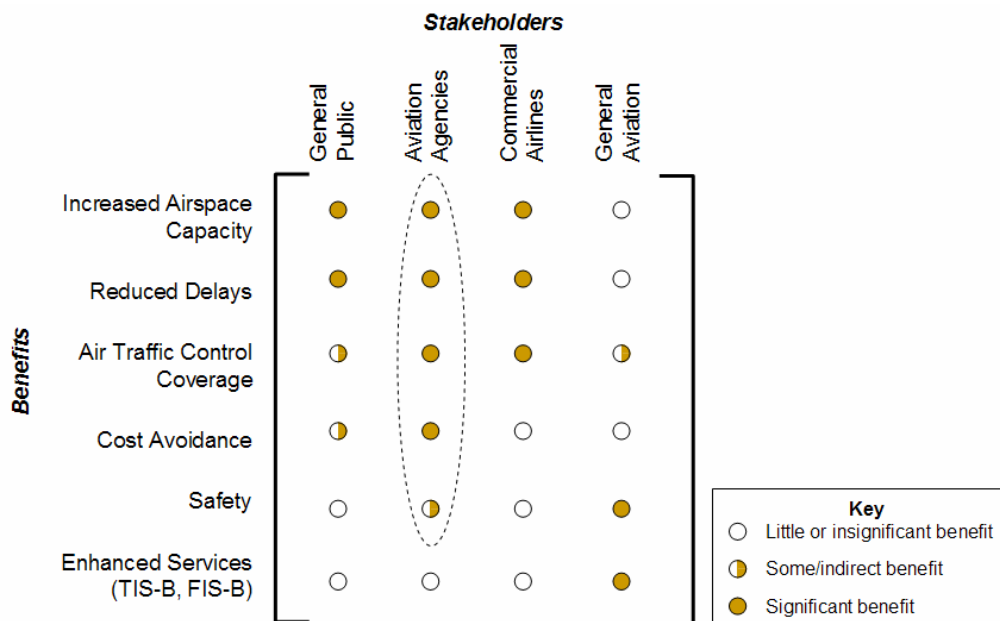
Figure 2: Notional stakeholder benefit matrix where the amount of each benefit is identified for each stakeholder
[2]

The goal of this research is to investigate actual benefit levels for operational procedures (applications) of ADS-B with stakeholders in the NAS. In order to create the notional stakeholder benefit matrices, a list of benefits was needed. However, instead of using broad benefit categories such as "Safety" and "Cost Avoidance" used by Marais and Weigel [2], the benefits were broken down by applications, listed below in section 3.1.   Tangible benefits such as reduced costs can be determined based on the application itself. The result of this research is a stakeholder-benefit matrix in Section 5.2 based on a survey of over one thousand pilots in the NAS.

By identifying the useful applications, the required capabilities of the transmitter/receivers can be identified, since a few applications will "require higher integrity and certification levels" [3]. These applications with more stringent integrity drive the equipment requirements.

Identifying applications and benefits of those applications also allows a realistic cost-benefit analysis to be made by stakeholders on whether to voluntarily equip with ADS-B.

2.3.1 Identifying Stakeholders

The stakeholders for the ADS-B benefit analysis were chosen to reflect the diversity of operators in the NAS along with other groups that influence ADS-B equipage. Large stakeholder groups such as general aviation were broken down into subgroups with similar operating patterns. Some small stakeholder groups such as glider and lighter-than-air operators have been excluded due to the size of these groups and their limited interaction with ATC in the NAS.

The stakeholder groups chosen for this research are:

1. Part 91 Recreational Airplane
   Airplanes used for recreational purposes. Typically these flights are conducted under Visual Flight Rules (VFR) in the local region.
2. Part 91 Business Airplanes
   Airplanes used for business purposes. These flights are predominately cross-country flights under Instrument Flight Rules (IFR) or VFR.
3. Part 91 Flight Training Airplanes
   Flight training operators and students. These flights are mostly within one local region and VFR.
4. Part 91 Commercial Airplanes
   This category encompasses a number of operations including agricultural, local tour flights, aerial photography. A complete list is in 14 CFAR 119.1(e).
5. Part 121
   Major air carriers
6. Part 135 Airplane
   Fixed wing air taxi and commuter carriers
7. Helicopter
   Helicopter operation not covered by the Law Enforcement or Military categories
8. Military
   Military flights within in the NAS. These include coast guard and military training flights.

2.4 Other Motivations

In addition to identifying benefits of ADS-B applications to encourage voluntary equipage, there are three other motivations for studying ADS-B: projected traffic growth, ADS-B safety benefits, and the Federal Aviation Administration's (FAA) planned ADS-B implementation.

2.4.1 Projected Traffic Growth

According to the NextGen Joint Planning and Development Office (JPDO), air traffic is expected to grow 2-3 times the current levels by 2025 [4]. This these estimations can be seen in Figure 3, which shows aircraft revenue departures and revenue passenger emplanements from 1955 to 2006, along with 1.5x, 2x, and 3x growth trend lines for revenue departures based on a 2004 baseline.
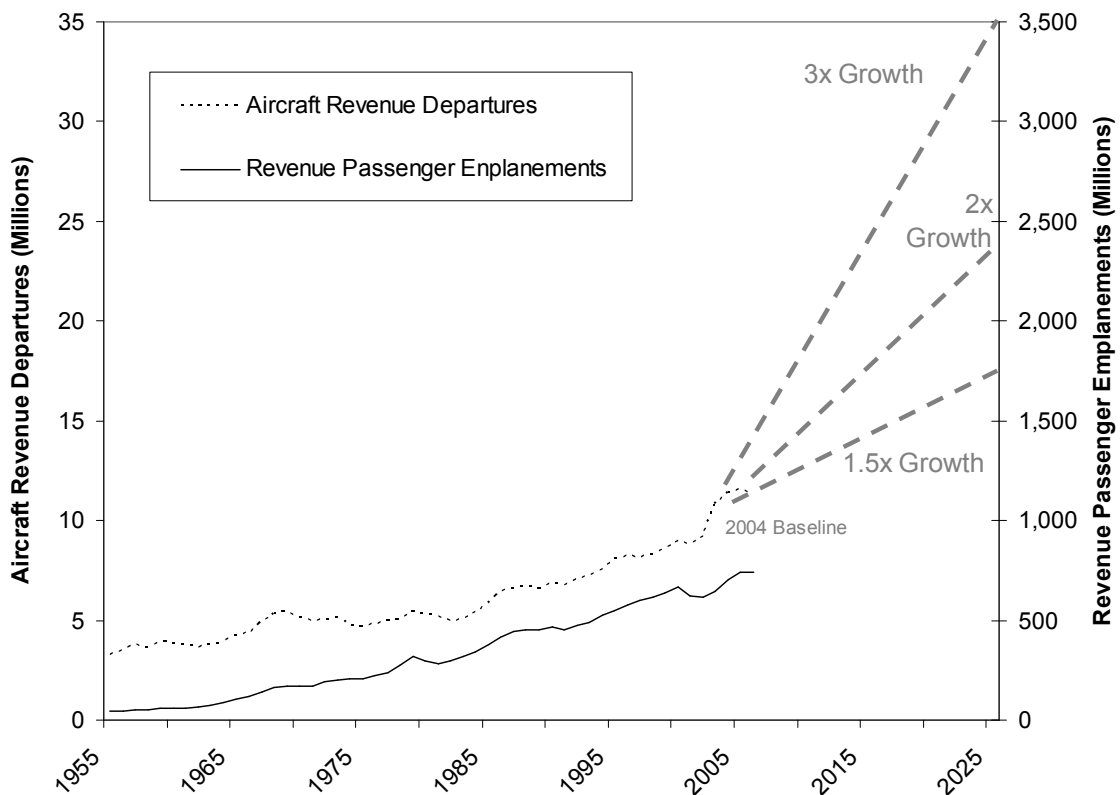
Figure 3: Air traffic 1955-2006 based on Aircraft Revenue Departures and Revenue Passenger Enplanements with 1.5x, 2x, and 3x future growth scenarios depicted [5]

The air traffic system must be capable of handling this increased traffic, else delays and flight cancellations will become ever more common. Currently, capacity constraints come primarily from airport arrival and departure rates, which can decrease dramatically during bad weather causing delays. Terminal area airspace in highly congested areas like the New York also limits traffic.

ADS-B enhanced information sharing between aircraft, other aircraft, and the ground creates the foundation for new procedures that could increase the capacity and safety of the NAS.   As discussed below, some of the applications of ADS-B have the potential to increase the arrival and departure rates at airports and reduce airspace capacity constraints.

2.4.2 Safety Benefits

There are important safety benefits associated with ADS-B. The National Transportation Safety Board (NTSB) has been pushing for timely implementation of ADS-B since it could reduce the number of runway incursions, one of the NTSB's most wanted aviation safety improvements [6]. The NTSB is also pressing for ADS-B implementation in Hawaii to reduce the number of helicopter air tour operator accidents [7].   These safety benefits come from the ability of aircraft to detect and avoid other aircraft by observing a CDTI and the ability to avoid hazardous weather conditions by utilizing datalink weather.

There are also safety benefits by increasing radar-like air traffic control services to areas without radar coverage. Controllers can better detect deviations and prevent mid-air collisions when aircraft are displayed on a radar screen than when relying solely on pilot position reports and time-based separation. Additionally, controllers can issue minimum safe altitude alerts to aircraft in communication with ATC, whether IFR or VFR.

In addition, search and rescue activities can be improved both inside current radar coverage and outside of radar coverage. The last few ADS-B position reports are invaluable in helping rescuers locate a downed aircraft.

Finally, the ADS-B datalink can also be used to upload weather information to pilots. This weather information can be used to prevent encounters with thunderstorms, icing, or instrument meteorological conditions.

2.4.3 FAA Plans

The FAA has publicly stated that it plans to introduce ADS-B nationwide by 2014 [8] with an equipage mandate expected in 2020 for certain classes of airspace [9]. The ADS-B will most likely be mandated in airspace where mode-C transponders are currently required, that is Class A, B, C airspace and airspace within 30 nm of the airports listed in 14 CFR 91.215, Appendix D [10].

Future NAS capacity is one of the major challenges facing the FAA in the next decades. The number of aircraft operating in the NAS may triple in the next 25 years [11], and the current system is not expandable to those levels of traffic. Increasing the capacity of the NAS is one of the primary focuses of the Next Generation Air Transportation System (NextGen) plan. ADS-B technologies have the potential to aid in a number of the FAA's operational improvement goals through increasing capacity, improving efficiency, reducing costs, and improving safety [12]. The FAA is hoping to reduce operating costs by eliminating 50% of the secondary surveillance radars in the US when ADS-B is fully implemented

ADS-B is just one integrated part of the NextGen plan, and thus must be considered alongside the other technologies to be implemented with NextGen including Required Navigation Performance (RNP), datalink communications, and new automation tools like surface management systems. Together these technologies along with the policies and procedures that support them will allow for increased capacity and safety in the NAS.

2.5 Radar Technologies

2.5.1 Primary and Secondary Surveillance Radar

Surveillance in the NAS currently consists of two major systems, primary and secondary surveillance radars. The primary surveillance radar (PSR) tracks aircraft by reflecting radio waves off aircraft, while secondary surveillance radar (SSR) interrogates aircraft transponders which respond with aircraft information. Thus for SSR to work, aircraft must be equipped and respond to the interrogations, thus the equipped aircraft are known as cooperative targets. PSR on the other hand, does not require the aircraft to be equipped or cooperative in order to track the aircraft.

Since PSR cannot easily obtain altitude information, Mode-C and Mode-S transponders respond to secondary radar interrogations with altitude information, along with a unique 4 digit code assigned by air traffic control, known as a transponder squawk code.

The primary and secondary radars can be further sub-divided into en-route and terminal radars. En-route radars have a slower update rate, yet cover a much larger geographic area. Terminal radars, have a faster update rate for terminal operations near airports, but cover a smaller geographic area. The standard update rate for en-route radars is 12 seconds, while the update rate for terminal radars is 4.2 seconds.

The entire continental US is covered by radar above a 24,000 ft, yet at lower altitudes, the radar coverage is more varied as shown in Figure 4. All large airports that are surrounded by class C or B airspace have surveillance coverage down to a few hundred feet above the surface. The low level radar coverage of the US is depicted in Figure 5. As seen in the figure, there are small gaps of low level radar coverage in the Southeast, the Vermont/New Hampshire region, and along the West Coast, along with large areas lacking low level radar coverage in the Great Plains and in the West. Since general aviation operators tend to fly low, they are often outside of radar coverage as detailed below in Section 5.3.1.

October 2005 Lowest IFR Altitude Track Report (ASDI)

MSL
< 3
< 6
< 9
< 12
< 15
< 18
< 24
24 +

Traffic at Altitudes for Current Surveillance Coverage
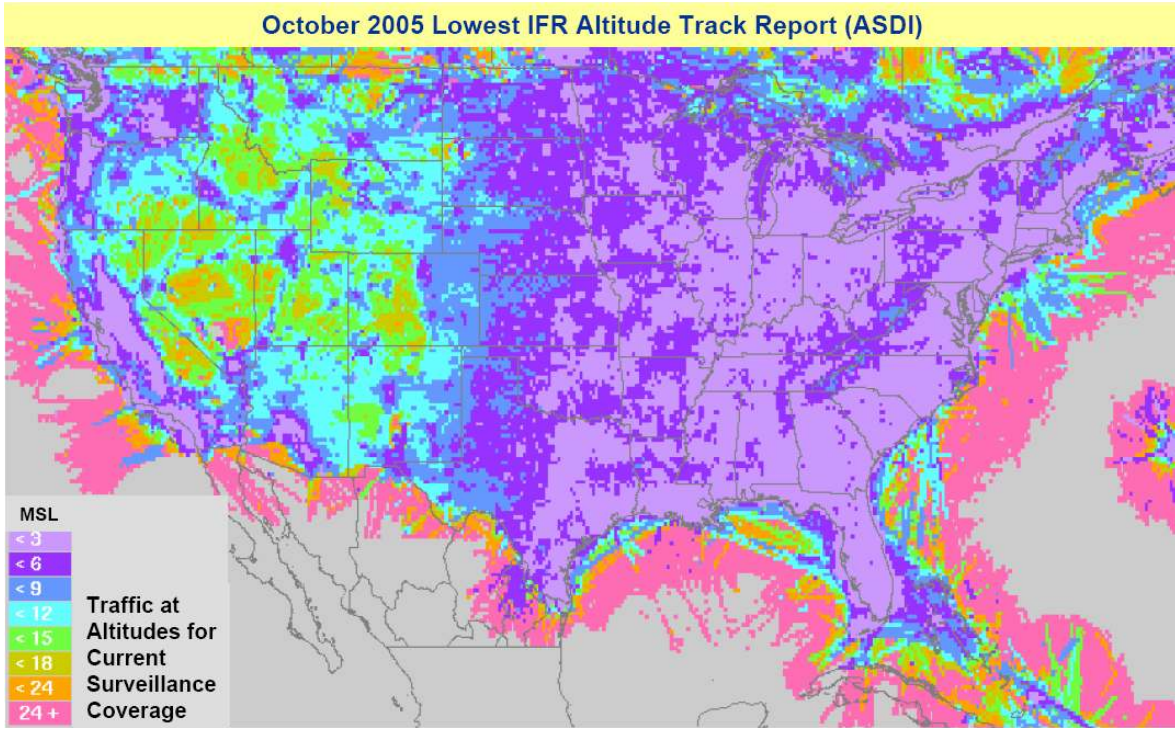
Figure 4: ATC surveillance coverage above mean sea level (MSL) in the continental US based on IFR altitude tracks [13]

AGL (ft.)
< 500
< 1.0
< 1.5
< 2.0
< 2.5
< 3.0
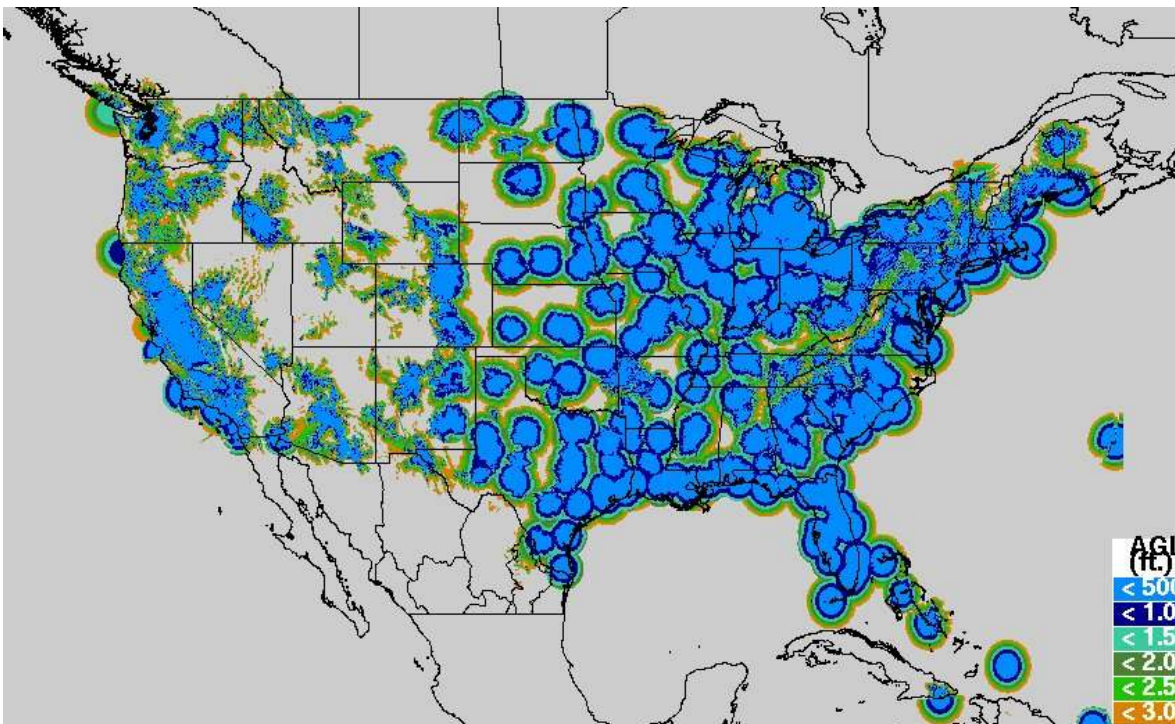
Figure 5: Low altitude terminal and enroute radar coverage above ground level (AGL) in the continental US based on radar coverage models [14]

2.5.2 Surface Surveillance

There are two surveillance technologies commonly used on the airport surface. The first is Airport Surface Detection Equipment (ASDE), a form of primary radar. The most common model is ASDE-3 which shows both aircraft and ground vehicles with an update rate of approximately 1 second [15]. Because ASDE-3 is a primary radar-based surveillance technology, vehicles do not need any onboard equipment, but no data about each ground target is available to the controller.

The second is Airport Surface Detection Equipment, Model X (ASDE-X). This system uses a combination primary radar, secondary radar, ADS-B, and multilateration (MLAT) to create a detailed surface map for tower controllers. This system can detect unequipped vehicles, but vehicles equipped with a transponder or ADS-B transmitter can be identified on the controller's display. This system was designed to reduce major runway incursions [16]. A total of 35 large airports are to have ASDE-X installed and 10 ASDE-X installations have already been commissioned.

2.6 ADS-B Technologies

There are a number of technologies necessary for ADS-B to function both in the air and on the ground. Ground stations or Ground Based Transceivers (GBTs) will be needed on the ground to send and receive ADS-B information. The surveillance data must be transmitted to ATC facilities for use by controllers and traffic flow managers. In the air, an ADS-B transceiver is necessary for sending and receiving ADS-B data, along with a pilot interface for entering any data and a cockpit display of traffic information (CDTI) for viewing the data.   Refer to Figure 1 above for a picture of the required links and equipment.

2.6.1 "ADS-B Out"

ADS-B data exchange can be broken down in to two categories: "ADS-B Out" and "ADS-B In." "ADS-B Out" is the periodic broadcast in the blind of aircraft state information. These broadcasts are not in response to interrogations, unlike existing transponder technology. The state information contains the aircraft's position, state vector, and intent information, along with other information relating to the source and accuracy of the data. The position information could come from any position source with accuracy at or above a given threshold, based on the required navigational performance (RNP) specifications. However, most ADS-B equipment will be connected to a Global Navigation Satellite System (GNSS) receiver such as a Global Positioning System (GPS). As a backup source of position information, some are considering DME-DME measurements or eLoran technology [17]. If the ADS-B implementation proceeds as planned, "ADS-B Out" will be required to operate in most congested airspace, much as Mode-C transponders are required today. "ADS-B In" is currently slated to be optional, except to participate in certain future applications.

As shown in Figure 6, "ADS-B Out" information in the aircraft comes from a primary position source, aided by an optional backup position source, an altitude source, a heading source, an optional flight management system (FMS) for intent information, and a pilot accessible control interface.   This data is collected by the ADS-B processor and broadcast to other aircraft and to GBTs. "ADS-B In" data is received by the ADS-B processor and send to the CDTI, consisting of a Multifunction Display (MFD) or Electronic Flight Bag (EFB). They data may also be used to generate aural alerts or augment the TCAS system (see Section 2.6.3.3 for more details on ADS-B and TCAS).
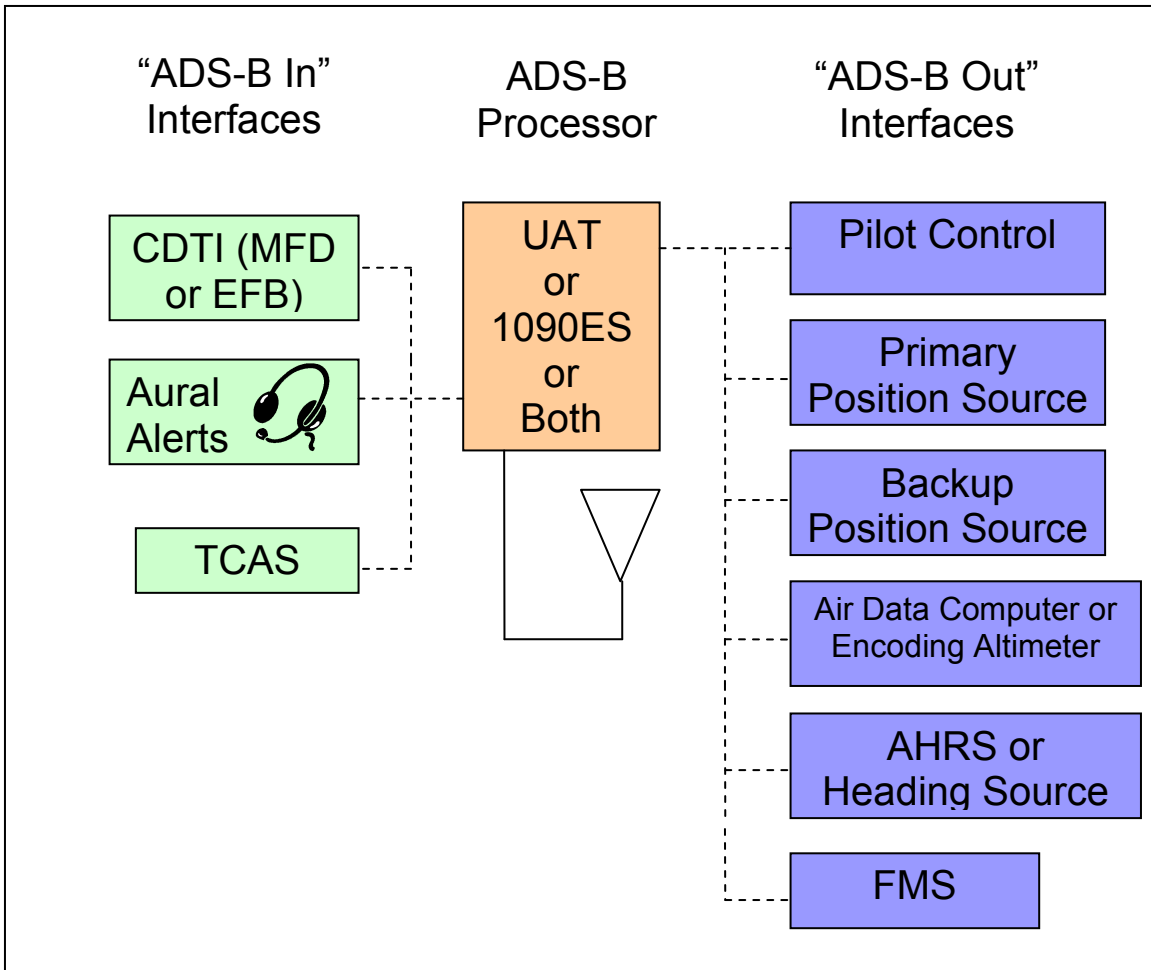
Figure 6: ADS-B Aircraft Interfaces for "ADS-B In" and "ADS-B Out"

[Created from 3, p. 13]

According to the Minimum Aviation System Performance Standards (MAPS) for ADS-B, DO-242A [3, pp. 27-48] the following information can be included in the "ADS-B Out" message, although not all applications require all data elements, so some ADS-B transceivers may not send all the data elements:

- Time of Applicability-time at which reported values were valid
- Call Sign
- Unique 24-bit ICAO address (may allow anonymous mode)
- ADS-B Emitter Category – describes the type of vehicle. See Appendix A for a full list
- Aircraft length and width – coded, for use by surface applications
- Position –geometric position
- ADS-B Position Reference Point – location of position source
- Altitude – barometric pressure altitude and geometric altitude (above WGS-84 ellipsoid)
- Horizontal velocity – both groundspeed and airspeed
- Vertical rate – either barometric or geometric
- Heading
- Capability Class – avionics capabilities for ADS-B applications
- Operational Mode – TCAS RA, Ident, receiving ATC services
- Navigational Integrity Category (NIC) – size of containment radius, Rc, and vertical protection level (VPL) height
- Surveillance Integrity Level (SIL) – probability positions is within containment radius or cylinder in NIC.
- Navigation Accuracy Category for Position (NAC_P) – Accuracy of position as determined by estimated position of uncertainty
- Navigational Accuracy Category for Velocity (NAC_V) – Horizontal velocity error
- Barometric altitude quality code – resolution of barometric altitude
- Emergency/Priority Status
- Intent Information – Two types: Target State Reports for current horizontal and vertical targets for the active flight segment and Trajectory Change Reports which define future flight segments

The two major US "ADS-B Out" protocols are 1090 MHz Extended Squitter (1090-ES, section 2.6.3.1 for details) and Universal Access Transceiver (UAT, section 2.6.3.2 for details). The requirements for 1090-ES equipment are detailed in the Radio Technical Commission for Aeronautics (RTCA) Minimum Operational Performance Standards (MOPS) DO-260 and the newer DO-260A. The requirements and details of the UAT protocol are defined in RTCA MOPS

DO-282 and DO-282A. DO-260A and DO-282A incorporated many of the findings from the Australian trials of DO-260 equipment. Also, additional detail and guidance is provided in DO-260A and DO-282A. According to the introduction to the DO-260A [18], the RTCA released DO-260 and DO-282 with some sections incomplete with the intention of updating the requirements. In the earlier versions, horizontal protection limit (HPL), a measure of GPS integrity, or horizontal figure of merit (HFOM), a measure of GPS accuracy, could be used for the Navigation Uncertainty Category (NUC) output. However, because two different pieces of information could be encoded as the NUC, the NUC became effectively useless since it was impossible to interpret the data consistently. In the DO-260A and DO-282A protocols, only HPL can be used for the NUC.

Only DO-282A equipment meets the FAA TSO, so older DO-282 equipment will have to upgrade. Likewise for 1090-ES, DO-260 equipment will eventually have to upgraded to DO-260A capabilities. Avionics manufactures and operators have been hesitant to implement the DO-260A standard in the equipment because of uncertainty in which standard the FAA will support, or if they will revise the DO-260 standard again in the future.

2.6.2 "ADS-B In"

"ADS-B In" is the ability to receive information via an ADS-B transceiver. This "in" data can be further broken down into three categories: air-air traffic, ground-air traffic, and other information. Air-air traffic is aircraft state information acquired directly from an "ADS-B Out" equipped aircraft. The two aircraft must utilize the same ADS-B protocol for air-air traffic data to be exchanged.

Ground-air traffic, or Traffic Information Service—Broadcast (TIS-B), is traffic information up-linked from a ground station. This data may be collected from a number of sources including secondary surveillance radar, MLAT, or different protocol ADS-B receivers (see Section 2.9 for a description of these MultiLink GBTs). This ground-air traffic information is what allows cross-protocol traffic information dissemination.

The final category of ADS-B data is other information, which can include weather graphics, textual weather information, NOTAMs, TFRs, SUA information, and any other digitized informational product. This category is commonly referred to as Flight Information Service—Broadcast (FIS-B).

There are a few issues related to how "ADS-B In" traffic data is displayed. For applications with a high level of criticality, like collision avoidance, the traffic display must be in the pilot's primary field of view (PFV).   However, no EFBs and only some MFDs displays are located in the PFV.

There are also three classes of EFBs which vary in price. The least expensive EFBs are class I EFBs, which must be stowed for take-off and landing, thus cannot be used during those phases of flight. Class II EFBs do not have a high level of integrity and thus cannot show the aircraft's own position or ownship on a moving map.   The most expensive EFBs are Class III EFBs. Class III EFBs can display the ownship position and are best suited for "ADS-B In" displays. However, the FAA is considering allowing the ownship to be displayed on Class II EFBs.

2.6.3 ADS-B Protocols

Since ADS-B is a digital radio data link technology, there must be a standard protocol for encoding and decoding the data. In the US there are two proposed data link protocols, 1090 MHz Extended Squitter (1090-ES) and Universal Access Transceiver (UAT). Sweden and Russia are advocating a third protocol, VHF Datalink Mode 4 (VDL-M4), be used [19].   Since the US is committed to 1090-ES and UAT, they will be discussed in detail in this paper.

2.6.3.1 1090 MHz Extended Squitter (1090-ES)

1090 MHz Extended Squitter or 1090-ES is an ADS-B protocol based on the Mode S transponder. When equipped for 1090-ES, the Mode S transponder broadcasts additional data, including position, velocity, and intention in the Mode S signal without interrogation from a SSR on the ground or a TCAS system. The 1090 MHz frequency is already allocated for SSRs and TCAS and the ADS-B information does not interfere with the existing uses of the Mode-S transponder.

The 1090-ES protocol is also capable of receiving TIS-B traffic information from ground stations, but is bandwidth limited and not capable of receiving larger FIS-B information. 1090-ES has a 40 nm air-to-air range in high density/interference environments and a 90 n m range in low density/interference environments [32]. The variation is due to the fact that Mode S transponders use reduced power transmissions in high density environments to prevent frequency congestion.

2.6.3.2 Universal Access Transceiver (UAT)

Universal Access Transceiver (UAT) is an ADS-B protocol which operates at 978 MHz. This slice of the electro-magnetic spectrum has been allocated to ADS-B domestically in the US, but not internationally as it is used by some non-US DME stations. The UAT protocol was used successfully by the FAA for the Capstone ADS-B trial project in Alaska. Like the 1090-ES protocol, UAT equipment is capable of receiving TIS-B traffic information from ground stations, but due to more bandwidth at 978 MHz versus 1090 MHz, UAT equipment can also receive high bandwidth graphical data from ground stations. The ground to air data uplink can operate at speeds up to 100 kbps [20].

2.6.3.3 Frequency Congestion and Mitigation

The Mode S transponder was developed as part of the TCAS system in the 1970s and is still an integral part of the TCAS system. 1090-ES ADS-B technology actually enhances the effectiveness of the TCAS system while still maintaining the independence of the TCAS safety backup. The protocol for ADS-B integration with TCAS was done as part of TCAS II Change 7, which was completed in 1999 [21].

As traffic density has increased, there has been increased concern over frequency congestion at 1090 MHz, which is used by SSR, transponders, and TCAS. TCAS Change 7 modified the way in which TCAS interrogates nearby and distant targets, limiting the number of interrogations in a given area. However, in order to reduce the number of interrogations in a crowded environment, the range of the interrogations is limited to that necessary to avoid a collision. This limited range reduced the effectiveness of TCAS for general traffic situational awareness.

Change 7 also allows 1090-ES ADS-B position reports to be used for TCAS, through what is called hybrid surveillance [22]. When a 1090-ES target is encountered, its ADS-B position is validated using the traditional Mode S range and bearing calculation. If the position is validated, the Mode S only re-interrogates the target once every 10 seconds to revalidate the position report, relying on passive surveillance during the interim. If at any time the position does not match the range/bearing calculation or the target gets within 3 nm or 3000 feet, the TCAS begins traditional active surveillance, thus maintaining TCAS's independence from the ADS-B position source. Based on simulations, this hybrid surveillance could reduce the number of interrogations in the Dallas, Texas area from 1059 per second to 335 per second (just implementing Change 7 reduces the number from 1059 per second to 773 per second). ADS-B also allows

for more general long range traffic situational awareness without the frequency congestion associated with long range active interrogations.

An additional concern with introducing ADS-B technology into an airspace system that already uses TCAS is the inability to reduce separation standards without changing the TCAS code.   The better ADS-B position reports and fast update rate could possibly lead to reduced ATC separation standards, below the current 3 mile terminal and 5 mile enroute lateral separation. However, if this was done, the number of false TCAS resolution advisories (RAs) would increase dramatically since the TCAS algorithms are based on a 3 mile separation standard. Already, there are a large number of RAs under visual conditions since aircraft are allowed to reduce their separation below 3 miles if the other aircraft is in sight and visual separation can be maintained. Figure 7 depicts RAs observed in the Boston area by Lincoln Lab's SSR, which average 9 RAs per day [23]. There is a strong correlation between visibility and RAs, since when the visibility is good, visual separation is more likely to occur, especially on the approach paths to Logan airport (KBOS).   RAs are also found frequently around the Hanscom airport (KBED), where TCAS equipped business jets interact with small piston planes under visual conditions.
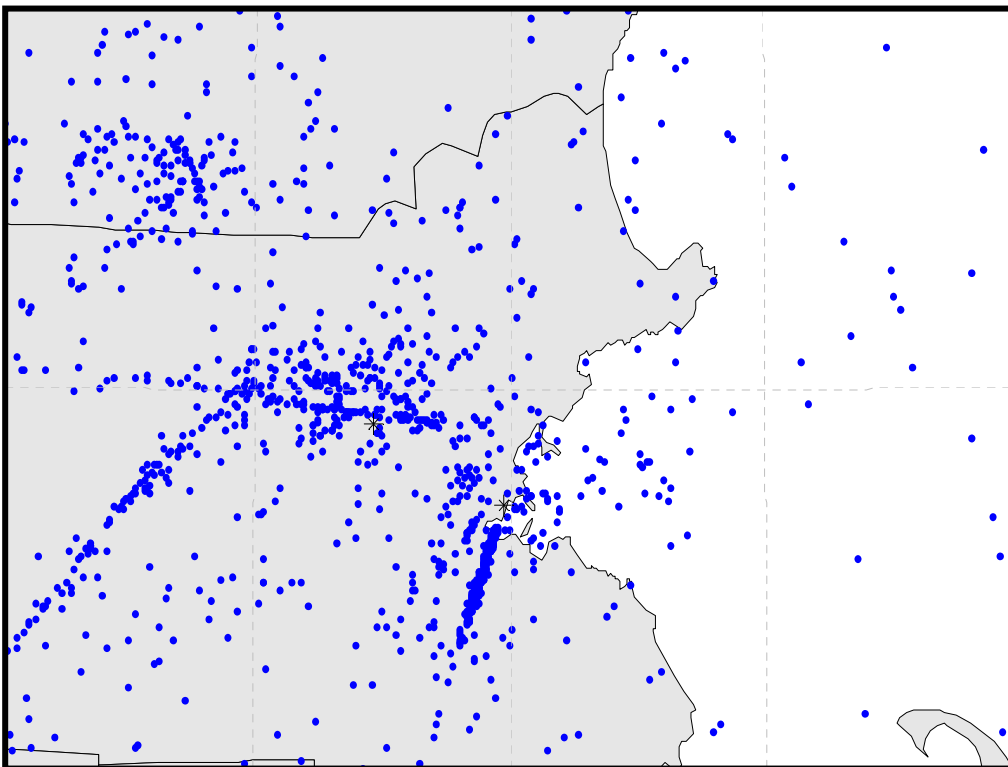
Figure 7: November 2004- May 2005 TCAS RAs in the Boston area.
The dense areas are the approaches to Logan airport and the area around the KBED airport [23].

2.6.4 Cockpit Display of Traffic Information (CDTI)

Cockpit Display of Traffic Information or CDTI is a technology that enables many ADS-B applications described below in Section 3.4. The simplest CDTI displays, like the one in Figure 8, show nearby traffic in a TCAS-like format that depicts bearing and range graphically with the relative altitude and trend information attached to the traffic symbol. More advanced CDTI displays can overlay this graphical traffic information on a digital map product, enhancing situational awareness more. Finally, for the more complex ADS-B operations such as station keeping or merging, additional automation-generated information such as closure rate or target airspeed can be displayed as part of the CDTI. CDTI may be presented on a Multifunction Display (MFD) or Electronic Flight Bag (EFB).

Figure 8: Notional Cockpit Display of Traffic Information (CDTI)
depicting traffic identifiers, relative altitudes, and tracks [24]

2.6.5 NEXCOM

A discussion of ADS-B would not be complete without a discussion of NEXCOM, the FAA's next generation communication infrastructure, since both utilize data link technology and will require changes to the aircraft avionics. The FAA has chosen VDL Mode 3 as the data link and digital voice protocol for NEXCOM. Using TDMA technology, VDL Mode 3 allows four channels of voice or data on a single VHF frequency. Nominally, there would be two voice and two data channels on each VHF frequency, although this breakdown can be changed based on future demand. Unlike ADS-B data links, the VDL Mode 3

data link is bidirectional, allowing for digital controller-pilot communications, starting with next-frequency uploads and clearance requests, assignments, amendments, and "read backs." However, the data channels could also be used for FIS-B data uplinks or any other single or two-way data communication.

The FAA's VDL Mode 3 plan must be considered when researching possible ADS-B applications since some applications, such as controller-pilot data links, are being covered by the NEXCOM project. Additionally, VDL Mode 3 equipage timeframes must be harmonized with ADS-B timeframes in order to minimize the impacts of installing either equipment.

2.6.6 Multilateration

Multilateration (MLAT) is a complementary technology to ADS-B that can work independently or with ADS-B. MLAT technology uses multiple receivers that listen for Mode A/C/S transponder responses and triangulate the aircraft position. Active MLAT can also "ping" transponders, so that MLAT can be used in areas without SSR to replace SSR.   Sine MLAT receivers can also receive ADS-B broadcasts, the technology is seen as an intermediary step prior to full ADS-B implementation, since it is backwards compatible with existing transponder technology, yet can also form the receiver backbone of an ADS-B only surveillance system.

MLAT is being deployed in Mongolia, Taiwan, and Tasmania in lieu of SSR [25]. It is also being installed for use for terminal surveillance at the Ostrava airport in the Czech Republic, the Beijing Airport in China, and the inner harbor of Vancouver, Canada. MLAT is also being implemented in Colorado to provide low level surveillance coverage of mountainous airports [11].

2.7 ADS-B History

2.7.1 FAA Technology Implementation History

The plan to implement ADS-B should be prefaced with three past FAA technology implementation projects: Mode-S, the Microwave Landing System (MLS) and the Controller Pilot Data Link Communications (CPDLC) project. All three of these programs, Mode-S, MLS, and CPDLC, have undermined the FAA's credibility with the industry. Lessons from these projects can be used to help make the ADS-B implementation successful.

The FAA tried to mandate Mode-S for all new transponders before the Mode-S ground stations were built, which lead to a backlash from the general aviation community [26]. The FAA eventually backed down and the final rule mandated Mode-S and TCAS for aircraft with 10 or more seats. Those aircraft with less than 10 seats can operate to this day with just a Mode-C transponder in all classes of airspace.

The FAA initially deployed MLS systems in outlying airports in order to prove the technology to regional and corporate aircraft [27]. However, with this implementation plan, the advanced capabilities were never demonstrated to the airlines. Thus the airlines resisted equipping with airborne MLS receivers. Additionally, the MLS system was surpassed technologically by GPS, which also allow curved approaches to existing ILS installations.

Like the MLS, CPDLC was a revolutionary technology pursued by the FAA with high expectation for radical change in the air transport system. American Airlines was one of the early adopters of the CPDLC technology and used it as a technology demonstrator project jointly with the FAA. However the FAA did not continue with the deployment of the CPDLC ground infrastructure beyond the Miami Center trial site, essentially making American Airline's investment worthless [28].

Industry stakeholders are worried that ADS-B could be another example where some industry members equip, and then the FAA does not follow through with the requisite ground infrastructure or mandate.

2.7.2 US ADS-B Trials

One of the first trials of ADS-B technology in the US was in the Safe Flight 21 program whose goal was to investigate free flight regimes. The Safe Flight 21 program focused on the Ohio River Valley area and Alaska. In the Ohio River Valley, the FAA partnered with the Cargo Airlines Association to develop ADS-B procedures and tested different ADS-B datalink technologies with UPS, Fedex, and Airborne Express.

Further research of ADS-B applications for busy terminal areas was conducted at UPS's hub in Louisville, KY. UPS has been a leader of ADS-B technology in the US incorporating 1090-ES "ADS-B In" with Cockpit Displays of Traffic Information (CDTI) in their fleet of Boeing 757s and 767s [29]. Eventually UPS will equip its entire fleet with Class III EFB CDTI. UPS has been conducting enroute merging and spacing trials of ADS-B coupled with continuous descent approaches (CDAs). The software used for the UPS trials will be used for surface operations as well as enroute merging and spacing [30]. The surface area movement management (SAMM) software will display the ownship symbol on a moving map of the airport surface, along with "ADS-B Out" equipped aircraft. The SAMM software will also provide audio and visual alerts for collision avoidance.

Another part of the Safe Flight 21 program was the Capstone program in Alaska. The Capstone project's goal was to improve safety for aviation in the state of Alaska, where many residents and remote communities depend on aviation for transportation and supplies. Along with other safety and procedural improvements, over 140 aircraft were equipped by the FAA with UAT ADS-B transceivers along with Multifunction Displays (MFDs) for displaying traffic, weather, and terrain. Ground stations were installed which provided traffic through TIS-B and weather through FIS-B to pilots participating in the program.

The Capstone project also integrated the ADS-B feed from ground stations into the Anchorage Air Route Traffic Control Centers (ARTCC) Micro En route Automated Radar Tracking System (Micro-EARTS) allowing controllers to see ADS-B equipped traffic on radar screens in areas without primary or secondary radar coverage [31]. This resulted in the first demonstration of positive radar-like separation between two ADS-B equipped aircraft in the world.

2.7.3 ADS-B International Trials

The original ADS-B trials were done in Sweden using VHF Digital Link Mode 4 (VDL-M4) technology in the 1980s [32]. These trials were continued throughout Europe and Russia. Recently the Swedish and Russian aviation authorities signed an agreement to begin implementing VDL-M4 ADS-B in the region [19].

ADS-B trails have been conducted in Europe, Australia, Iceland, and Canada. In addition, Indonesia is conducting ADS-B trials with three ground stations installed by SITA and Airservices Australia [33]. In all of these areas, 1090-ES is the datalink chosen for ADS-B. There are concrete plans to implement 1090-ES ADS-B around the Hudson Bay in Canada and in central parts of Australia. Both of these regions are using ADS-B to fill areas lacking radar coverage.

Europe is mandating Mode S transponders with additional capacities in all aircraft by March 31, 2008 [34]. Depending on the type of operation, these Mode-S transponders must be capable of Elementary Surveillance (ELS) or Enhanced Surveillance (EHS). These transponders squitter (transmit) on the 1090 MHz frequency, so the transponders must be capable of 1090 Extended Squitter, the foundations of 1090-ES ADS-B. The only difference is that the ELS and EHS Mode-S transponders are not required to send out position information which is required to be sent by 1090-ES ADS-B transponders.

2.7.4 US Implementation Schedule

Since many of the applications of ADS-B require a significant percentage of aircraft equipping with "ADS-B Out" and "ADS-B In" and almost all of the applications require ground station coverage, implementing ADS-B in the NAS is a major challenge. There may be political opposition to a mandate of ADS-B equipage due to the high costs, thus other methods must be developed to create incentives for ADS-B equipage. Due to the costs and site-selection challenges, ADS-B ground stations cannot be installed everywhere at once, thus initial site selection is critical to making ADS-B a success.

2.7.4.1 FAA Implementation Schedule

The FAA has broken down the ADS-B implementation schedule into four segments [11]. The first segment (2006-2010) includes building ground stations in a number of key areas as depicted in Figure 9. These areas were chosen as ADS-B test sites due to their high traffic volumes or their proximity to existing ADS-B infrastructure (Kansas, Nebraska, and Louisville). However not all of the

areas show in Figure 9 will have "ADS-B In" ground stations. Many are just TIS-B/FIS-B locations. Only Louisville, Philadelphia, the Gulf of Mexico, Ontario, and parts of Alaska will have ADS-B ground based transceivers (GBTs). Instead of purchasing the ground stations, the FAA will instead contract for the ADS-B service, with the contractor owning and operating the GBTs.

The FAA's implementation plan is different than international ADS-B implementations in that the US is focusing on areas that already have SSR coverage (except in Alaska) while international implementations are focusing on expanding surveillance coverage to areas without SSR.

(a)

(b)
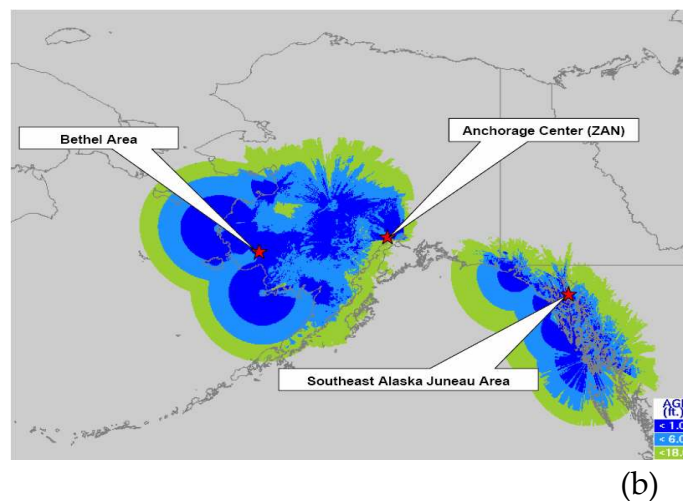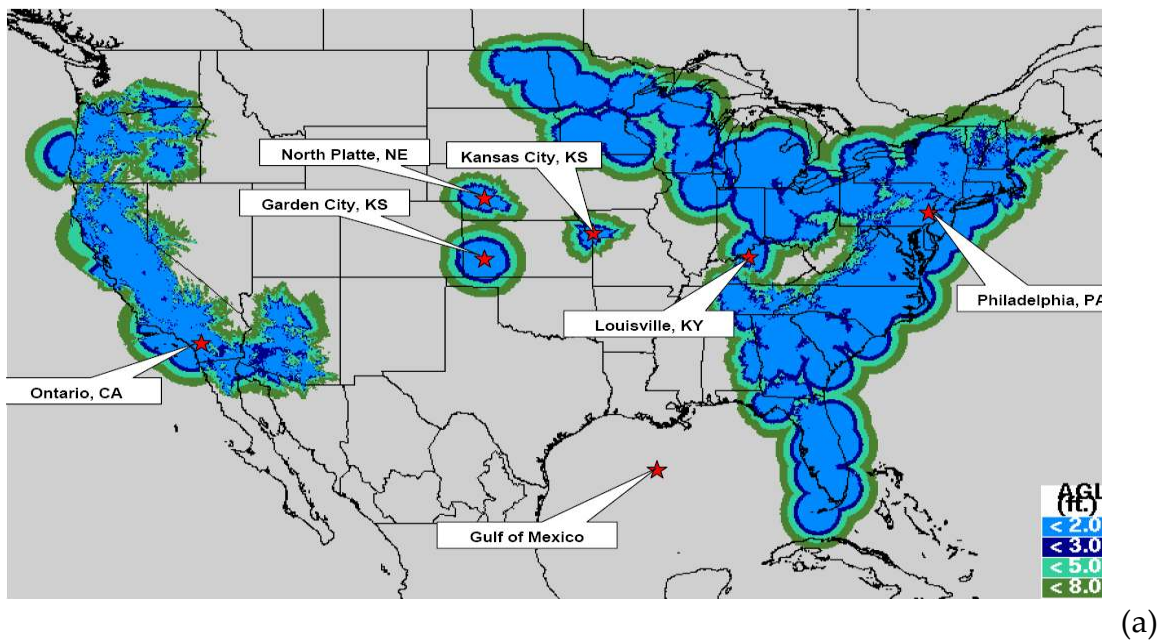
Figure 9: FAA proposed segment 1 coverage (including TIS-B/FIS-B only coverage) in the continental US (a) and Alaska (b) [11]

The second segment (2009-2014) of the US implementation involves completing ground station coverage of the US in existing SSR airspace and ramping up aircraft equipage up to 40%. The expansion is likely to be done by completing infrastructure at airports and airspace within an ARTCC in order to maximize benefits in a region. Segment 2 also includes finalizing the "ADS-B Out" definition.

By Segment 3 (2015-2020) 100% of aircraft are to be equipped with at least "ADS-B Out" with the final definition for "ADS-B In" being created. More applications of ADS-B will be certified.

Finally in Segment 4 (2020-2025), legacy surveillance equipment, especially SSR, is to be decommissioned. Applications that require full equipage will be fully implemented.

2.7.4.2 Regional Implementation

The FAA's plan for implementing ADS-B is by geographical regions, so benefits of ADS-B must be identified for each region. The object of implementation is to achieve a "critical mass" of ADS-B equipage in a given area in order to reap the benefits. It is not necessary to equip all planes in all places at once. A regional approach also allows for targeted regional incentives if needed, and spreads out costs to large operators over time since they may only need to equip their fleet one region at a time.

There are different types of regional ADS-B airspace users. First, there are users that operate completely in the ADS-B service volume. These users include local commercial flights such as regional jets or air taxi services, ground vehicles, and local general aviation operations (fixed wing and rotor). The second group of users operates one-ended in the ADS-B service volume. These are usually network carriers with a hub in the region or network carriers with destinations in the region. The model for this type of operation is the pioneering work done by UPS in their Louisville, KY hub. The third and final type of regional user is transient operations who fly over or through the ADS-B service volume. Each type of operation expects different levels of services and receives varying benefits from ADS-B.

2.7.5 Gulf of Mexico

The FAA is planning on a regional introduction of ADS-B ground stations and services, allowing operators in those regions to begin to reap the benefits of the technology introduction without waiting on implementation across the entire NAS. One of the phase one regions for ADS-B introduction is the Gulf of Mexico, chosen for the immediate benefits available to operators since there is a lack of radar coverage [11]. The costs for the service provider and operators in the Gulf of Mexico are similar to the costs in other regions.

There are more than 650 helicopters operating in the Gulf of Mexico that support more than 5,000 offshore oil and gas platforms [35] as seen in Figure 10. There are also numerous enroute flights over the Gulf which currently must use 30-mile oceanic separation standards due to the lack of surveillance.

The benefits are more operator and service provider dependent and harder to quantify and estimate than costs. In the Gulf of Mexico, off-shore helicopter operators would initially benefit from fleet tracking and radar-like IFR separation applications. Operators who fly across the Gulf would also initially benefit from the same applications, however until a critical mass of operators equipped, many of the benefits such as increased capacity due to radar-like and not procedural separation would not be realized. All operators could initially benefit from enhanced visual acquisition of traffic, leading to increased safety and possibly increased capacity in VFR and Marginal VFR (MVFR) conditions. The FAA in the Gulf realizes very few benefits until the critical mass is reached and current procedural separation standards can be replaced by more efficient radar-like separation. Likewise, across the NAS, the FAA does not receive financial benefits until the critical mass is reached and radar sites can be phased out and more ATC automation can be implemented. The time-frame for achieving this critical mass is an unknown variable in all cost-benefit analysis's. However, as the FAA closes on a mandate date, the uncertainty in this variable decreases.

The FAA partnered with Helicopter Association International (HAI) in the ADS-B roll-out in the Gulf. The FAA agreed to provide ADS-B ground equipment (through a contract) and surveillance services and the helicopter operators providing access to 20-30 off shore oil rigs for the "ground" stations and equipping their helicopters [35]. This joint venture is the model the FAA would like to see across the US, where operators voluntarily equip in return for the FAA providing benefits to the operators through ADS-B implementation.
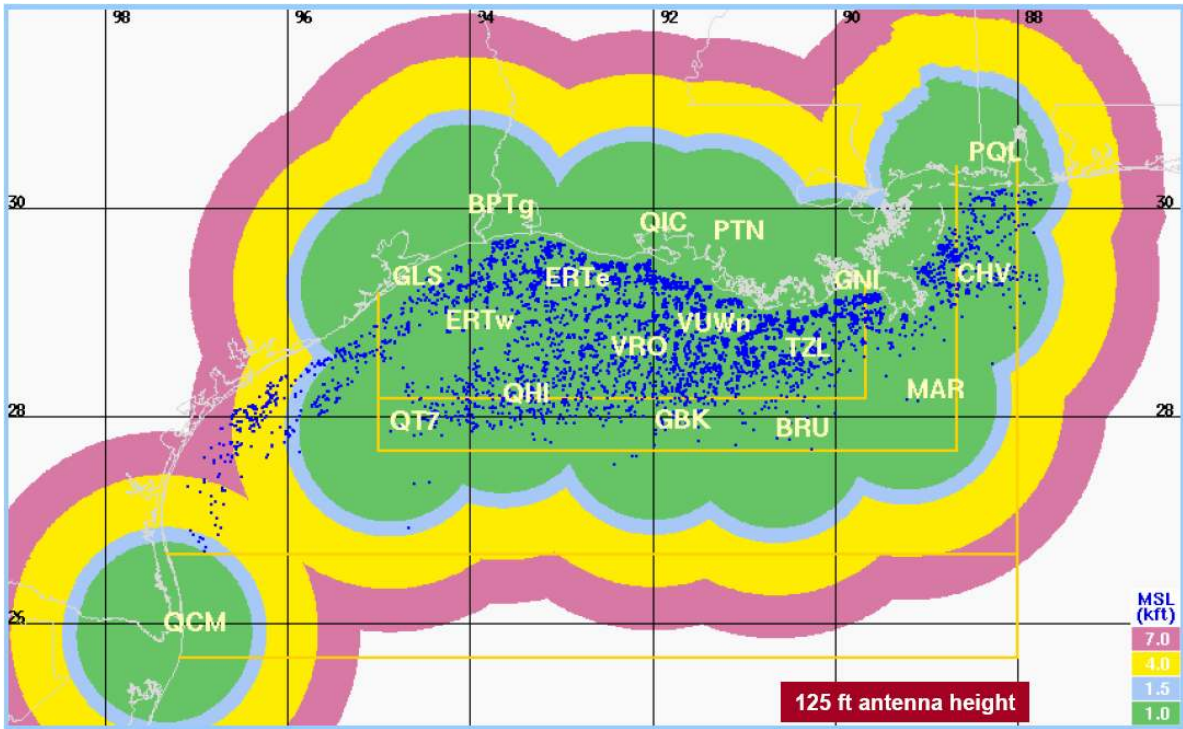
(a)
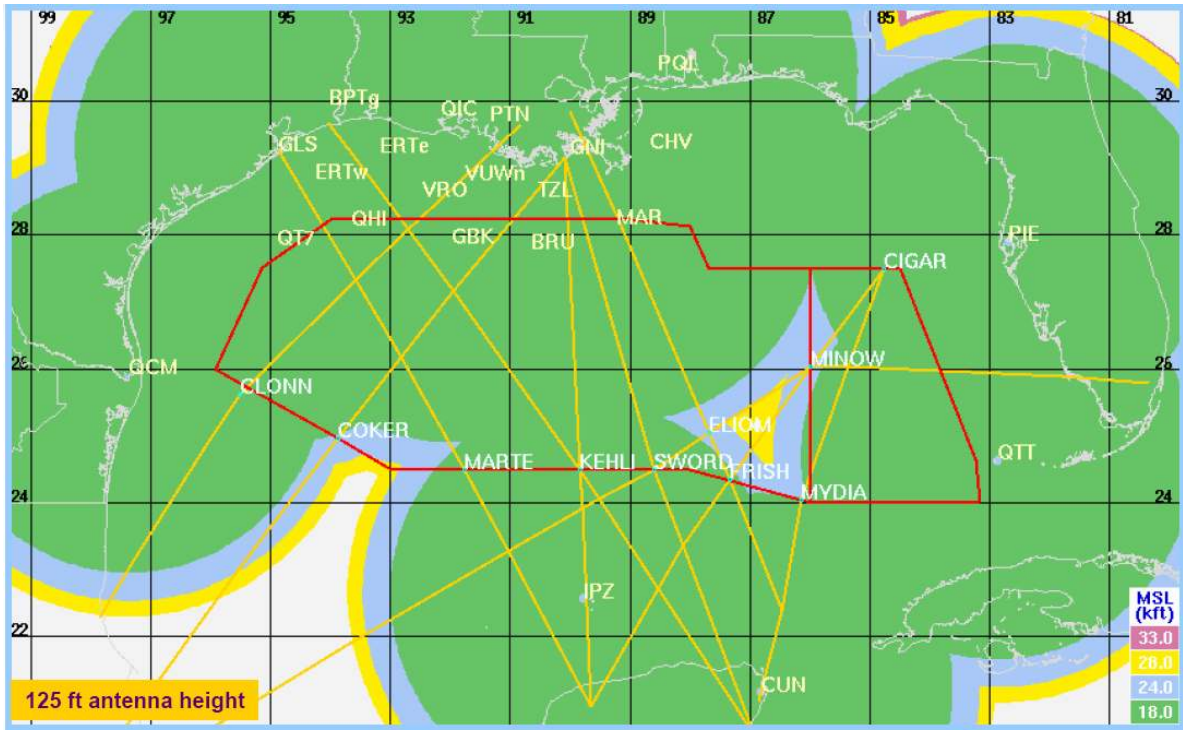
(b)

Figure 10: Proposed ADS-B coverage at (a) low altitudes and (b) high altitudes in the Gulf of Mexico [13]. Note the oil platforms represented as blue dots in (a).

2.7.6 Hawaii

Hawaii presents its own unique problems in which ADS-B technology has been called on to solve. There are 4 terminal radars that cover the 6 major islands with roughly 20 airports. In addition there are numerous heliports on all of the islands. Much of Hawaii, especially low areas, is not covered by radar as seen in Figure 11. However, it is these low areas that have the highest density of air tour operators, both fixed wing and rotorcraft.

Coverage (ft msl)
500
1,000
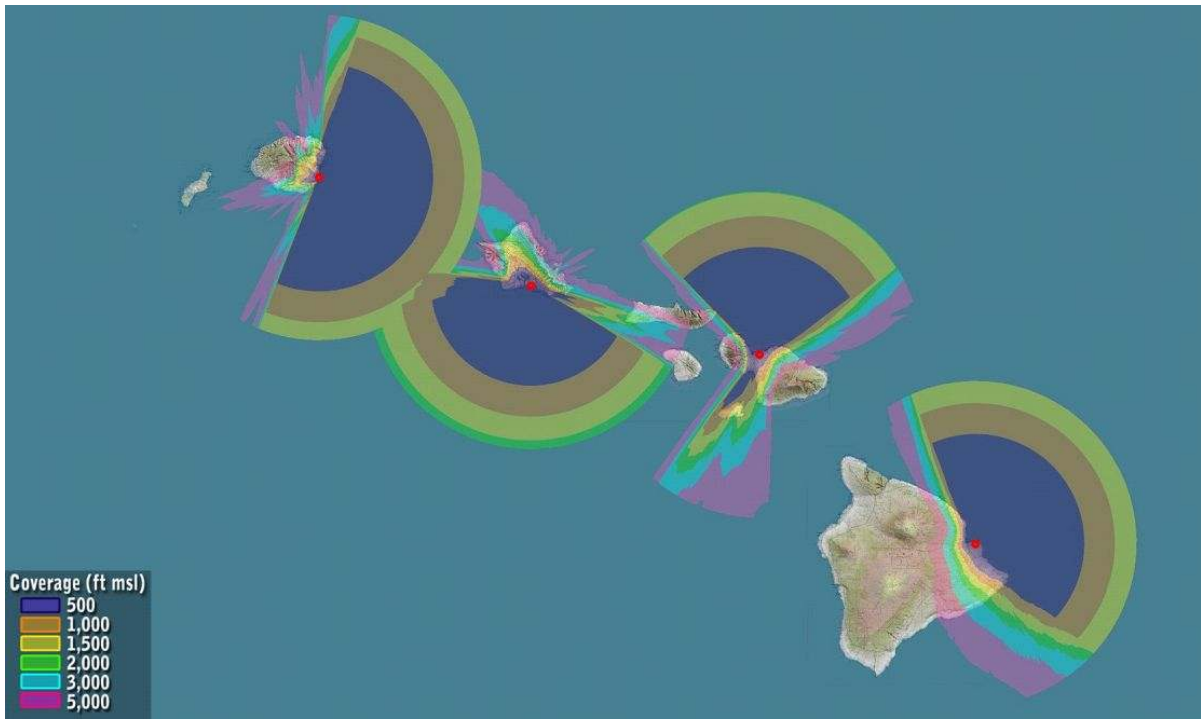1,500
2,000
3,000
5,000

Figure 11: Existing terminal radar coverage in Hawaii showing the significant gaps in coverage for low level operators such as air tour operators [36]

Hawaii presents an operational environment with special consideration needed. A detailed study of the applications of ADS-B for air tour operators in Hawaii is presented in Appendix F.

2.8 Costs

In order to investigate how to implement ADS-B in the NAS, the costs must be analyzed, since cost is one of the biggest disincentives to technological progress. The costs can be broken down into two major categories, initial and reoccurring costs, and then broken down further by who pays the costs.

With ADS-B, costs for both the FAA and operators are much easier to predict than benefits since benefits are much more dependent on how the technology is utilized within the entire NAS. However, there are still uncertainties with the costs leading to a range of estimates. For large operators, the equipment costs are straight forward since ADS-B Mode-S transponders are already in production and being installed in airliners. The uncertainties come from the installation and integration costs which are dependent on the finalized standard (DO-260, DO-260A, or other). Differing standards for ADS-B position sources may or may not require a new GPS receiver or an FMS computer upgrade, both of which would add significant costs to the installation. For general aviation operators equipping with UAT, the cost of the equipment is more uncertain since there is a notion of a reduction of equipment costs with multiple avionics manufacturers competing and producing receivers in large volumes [37].

Initial Operator Costs:
- **Avionics Hardware**
  - "ADS-B Out" (UAT/1090ES)
  - Position source (RNP)
  - "ADS-B In" (UAT/1090 ES) (optional)
  - CDTI (Class III EFB or moving map) (optional)
- **Avionics Install**
  - Labor
  - Aircraft downtime
- **Initial Personnel Training**
  - Flight Crew
  - Maintenance personnel
  - Dispatchers

Reoccurring Operator Costs:
- **Avionics Maintenance**
  - Calibration
  - Repairs
  - Aircraft downtime
- **Recurrent Personnel Training**
  - Flight Crew
  - Maintenance personnel
  - Dispatchers
- **Equipment Usage**
  - ANSP Fees

Initial ANSP Costs:
- **Ground Station Hardware**
  - Development
  - Certification
  - Installation
- **ATC Hardware**
  - Development
  - Certification
  - Installation
- **ATC Procedures**
  - Development
  - Certification
  - Dissemination
- **Initial Personnel Training**
  - Controllers
  - Maintenance personnel
  - Management

Other Costs:
- **Avionics and S/W**
  - Development
  - Certification

Reoccurring ANSP Costs:
- **Ground Stations**
  - Calibration/Flight Check
  - Repairs
  - Data bandwidth costs
- **ATC Hardware**
  - Repairs
- **ATC Procedures**
  - Development
  - Dissemination
- **Recurrent Personnel Training**
  - Controllers
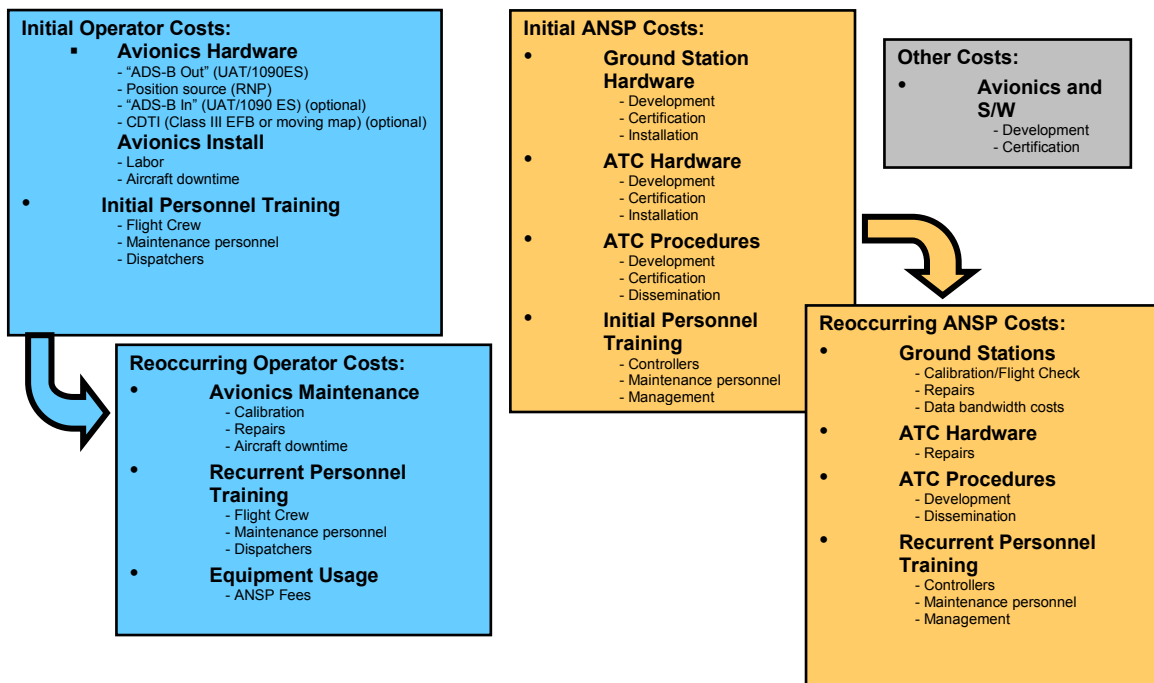 - Maintenance personnel
  - Management

Figure 12: List of initial and reoccurring ADS-B Costs

2.8.1 Initial Costs

The initial costs to the service provider (the FAA in the US) include purchasing or contracting for the hardware, creating procedures, and personnel training. The hardware for both the ground stations and the ATC facility must be developed, certified, and installed. The procedures must be developed, certified, and disseminated to the users. Controllers, maintenance personnel, and management must all be trained in operation of the new technology.

The operators also have significant initial costs. They must acquire and install the avionics along with training personnel. The avionics include at a minimum the "ADS-B Out" processor, a position source, an antenna, and interfaces with existing aircraft systems. For increased functionality, an "ADS-B In" processor must be acquired along with a MFD or EFB capable of displaying the data. There are also costs associated with the labor and aircraft downtime for the installation.

In addition, the flight crews, maintenance personnel, and dispatcher must be trained for using the new equipment along with utilizing new procedures. There are also initial costs associated with the development and certification of the avionics themselves, although they are normally passed along to the operator in the price of the avionics.

2.8.2 Reoccurring Costs

For the service provider there are reoccurring costs associated with the ground stations, the control facility hardware, procedures, and recurrent personnel training. The ground stations must be calibrated and flight checked periodically along with being repaired. There may also be costs with data transmission from the ground station to the control facility. The facility hardware associated with ADS-B will need repairs periodically. The ADS-B procedures will need constant re-evaluation and development work.

For the operator, the avionics will need calibration and repairs, which could result in aircraft downtime costs. The personnel who needed initially training will also need recurrent training.

2.8.3 Initial Avionics Cost Estimates

During the initial explorations of ADS-B with the Safe Flight 21 program in the United States, an estimate was created for various ADS-B technologies. This study, completed in 2001, looked at the costs to retrofit and forward fit various

categories of aircraft with ADS-B technologies [37]. The study looked at various scenarios consisting of 1090 ES, UAT, and VDL-M4 single protocols and various mixed protocols.

The study found that UAT would be slightly cheaper than 1090-ES for all types of aircraft, but VDL-M4 was significantly more expensive than UAT or 1090-ES. The authors also found that there would be a significant quantity discount of up to 40% for low/mid GA. These costs are solely for the avionics and not for the certification. The certification costs per aircraft are equal for 1090 ES and UAT, slightly more for VDL-M4, and approximately 20% more for mixed protocols.

2.9 US Dual Link Decision

While ADS-B holds the potential to improve system capacity, stakeholders can not agree on an appropriate communications implementation or protocol standard. There is competition between for communication technologies, VDL Mode-4 (VDL-M4), 1090 Extended Squitter (1090-ES), and Universal Access Transceiver (UAT).   As described above, a study conducted in 2001 commissioned by the FAA Safe Flight 21 program [37], compared the relative costs of the 3 implementations and hybrid combinations of 2 of the technologies. For low end GA operations, UAT was found to be the cheapest single link, 17% less than 1090-ES, while VDL-M 4 was 31% more expensive than 1090-ES. For air carriers, UAT and 1090-ES costs were roughly equivalent, while VDL-M4 was between 12% and 59% more expensive. This study also found the benefits to UAT and 1090-ES links to be roughly equivalent, while VDL-M4 benefits to be less. This study effectively killed VDL-M4 in the US.

Based in part on the 2001 Safe Flight 21 cost benefit analysis, a more technical review of the various UAT and 1090-ES single and hybrid schemes was undertaken. The result of this review was the 2002 ADS-B link decision of supporting both UAT and 1090-ES in the NAS. This decision is outlined in "Overview of the FAA ADS-B Link Decision" [32] and detailed in "The Approach and Basis for the FAA ADS-B Link Decision" [38]. VDL-M4 was rejected due to high cost and lack of ICAO assigned frequencies.   1090-ES was chosen for high altitude operations since many air carriers are already equipped with 1090 MHz Mode S transponders and due to international 1090-ES standard agreement. However, 1090-ES may not be able to support long range (>40 nm) deconfliction in areas of high density traffics such as the Los Angeles basin in 2020. However, as the models for estimating frequency congestion improved, this long range reception problem became less of a threat.

UAT was chosen for GA aircraft that operate at lower altitudes in order to reduce the 1090 MHz frequency congestion (UAT operates at 978 MHz) and because of the 17% lower costs found in the 2001 Safe Flight 21 analysis. UAT also has the bandwidth for broadcast flight information service (FIS-B) data. UAT can also support long range reception (>120 nm) in the dense traffic environment. 1090-ES was chosen as the link for high end general aviation, corporate, and air taxi users, with the "encouragement" for those operators to equip with both 1090-ES and UAT in order to operate in areas with UAT traffic.

However, the dual link decision requires the addition of a "MultiLink Gateway" to all ground stations so that UAT traffic information is uplinked to 1090-ES equipped aircraft and 1090 ES traffic information is uplinked to UAT equipped aircraft (Figure 13). This gateway will provide Automatic Dependent Surveillance Rebroadcast (ADS-R) reports of UAT traffic to 1090-ES equipped aircraft and 1090-ES reports to UAT traffic. This means that aircraft with different ADS-B links will only be able to see each other on a CDTI in regions of ground station coverage. This eliminates the ability to perform air to air separation applications without working ground stations.
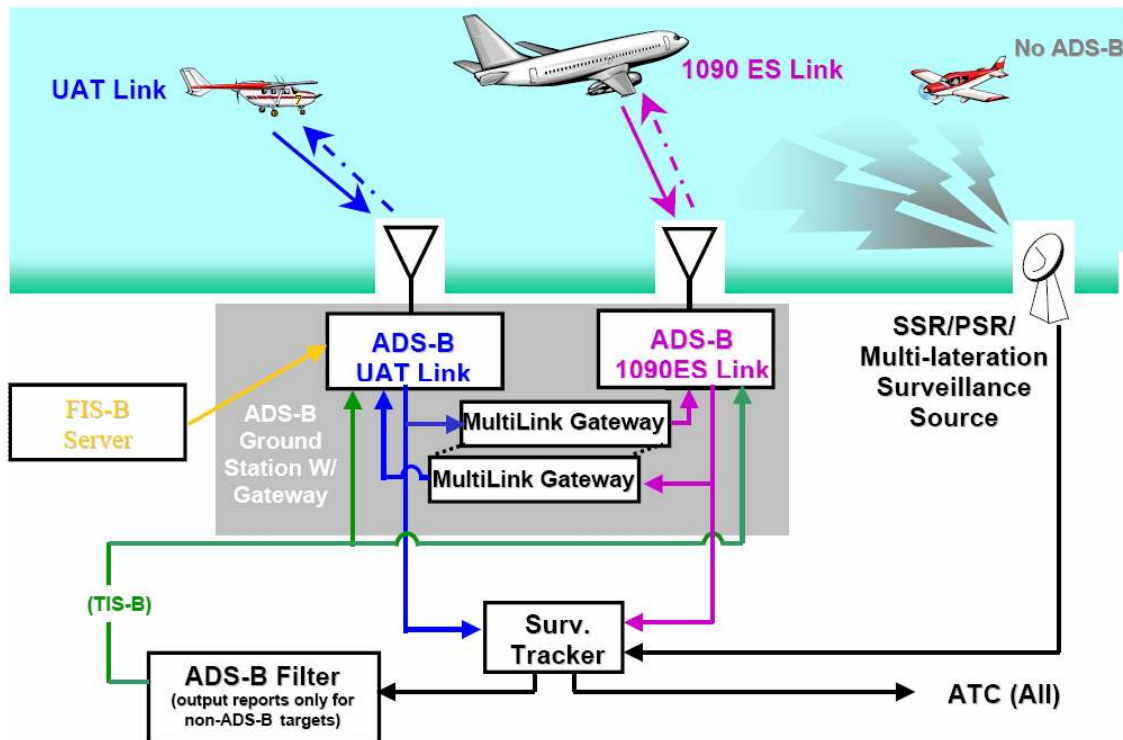
Figure 13: MultiLink Gateway design needed for dual link airspace

[32]

2.9.1 System Latency

The dual link also increases latencies to the system, possibly preventing dual link ADS-B to be used for conflict avoidance or even CDTI situational awareness since the data would be stale. With a MultiLink Gateway architecture, there are 3 sources of latency. First, there is the time to process and broadcast the GPS position. This latency is required to be less than 1 second for initial aircraft surveillance applications [39]. The second source of latency is the GBT processing of the position report then rebroadcast the position on the other link.

The third source of latency is the receiving aircraft's processing and display. With a single link the second source of latency is removed.

According to the Minimum Aviation System Requirements for ADS-B [3, p. 100], for critical application ($NAC_P \geq 10$ or $NIC \geq 9$), the ADS-B transmitter latency should be less than 0.4 seconds and for less critical applications ($NAC_P < 10$ or $NIC < 9$) less than 1.2 seconds latency. In general, the amount of latency reduces the warning time for a collision by about the same amount [3, p. J-13]. To mitigate the latency problem, each ADS-B message contains a Time of Applicability, with the UTC time in which the GPS measurement occurred. Consumers of the ADS-B data can use this time to throw out late reports or account for the latency.

The latency for TIS-B from a radar source is 3.25 seconds and 1 second for an ADS-R message from one ADS-B link to another via the MultiLink gateway [40]. So for an ADS-B dual link system the latency is going to be at least 2.2 seconds.

2.9.2 Single Link Option

An interesting recent development related to the dual link decision is one contractor's bid for the Segment 1 ground infrastructure, which only includes one link, 1090-ES [41]. The ADS-B ground infrastructure contract is a performance-based service contract, where the contractor will own and operate the infrastructure and provide the ADS-B data to the FAA. Since the FAA does not specify the details of the equipment or the means for implementing the solution, the contractor was free to eliminate the UAT link, and instead provide the FIS-B service to pilots via the XM satellite service. By utilizing a single link, the contractor's bid eliminates the need for the MultiLink gateway at the ground based transceivers (GBTs) and the associated costs, latency, and technical challenges.

3. ADS-B Applications

In order to better understand the benefits of ADS-B and to properly create incentives for users, the application of ADS-B must be understood. To this end, a consolidated application list for this research was created based on industry and government ADS-B application lists. Each of these consolidated applications is described in Section 3.1.

There are four application lists consulted to create the consolidated application list. They are from the FAA's National Airspace System Surveillance and Broadcast Services Concept of Operations [42, p. 32], RTCA's DO-289 [39], Boeing [43], and a joint FAA/Industry focus group [44]. Each of these lists can be found in Appendix B.

Benefits of ADS-B can be grouped into three categories: pair-wise benefits, user benefits based on ground infrastructure improvements, and full population benefits [3, pp. 11-12]. Pair-wise benefits come about when two aircraft in the same area are equipped, allowing them to maneuver or take some responsibility for separation from ATC. Not all aircraft need be equipped in order to gain pair-wise benefits. Pair-wise benefits can also be obtained with limited equipage through TIS-B in radar coverage areas, since data about transponder equipped aircraft is transmitted to aircraft equipped with "ADS-B In". Ground infrastructure benefits come from increased or improved ATC surveillance. These benefits increase with increased equipage, but some benefits can be obtained in a mixed equipage environment. Finally, full population benefits occur when all aircraft in a given airspace are equipped with ADS-B. These benefits are derived from the ability to rely on other aircraft equipage allowing aircraft deconflictions and potential reduced infrastructure costs.

3.1 Consolidated Application List

The existing application lists were consolidated into a list of applications that could be evaluated by pilots with a limited knowledge of ADS-B technology. Some of the initial FAA applications were expanded into applications applicable to different classes of users. This consolidated list is used in the preliminary interviews, the online survey, and the resultant benefit matrix.

Table 1 contains the consolidated application list along with a mapping to the category of the application (Pair-Wise, User/Ground, Full Population). The applications are divided into 4 groupings used throughout this thesis. The groupings are based on equipage ("ADS-B In" vs. "ADS-B Out"), radar coverage, and datalink services. The 4 groups are: Non-Radar "ADS-B Out" Applications, Radar Airspace "ADS-B Out" Applications, "ADS-B In" Traffic Display Applications, and "ADS-B In" Datalink Applications. All of these applications are described in detail below.

Table 1: Consolidated Application List with application category

Application	Application Category
Non-Radar "ADS-B Out" Applications	
Non-Radar Operation Center/Company/Online Flight Tracking	User/Ground
Non-Radar Radar-like IFR Enroute Separation	Full Population
Non-Radar Increased IFR Airport Acceptance Rate	Full Population
Non-Radar Increased VFR Flight Following Coverage	User/Ground
Non-Radar ATC Tower Airport Surface Surveillance	Full Population
Non-Radar ATC Tower Final Approach and Runway Occupancy Awareness	Full Population
Radar Airspace "ADS-B Out" Applications	
Radar Airspace Improved ATC Traffic Flow Management	Full Population
Radar Airspace Increased Enroute Capacity	Full Population
Radar Airspace Improved Operation Center/Company/Online Flight Tracking	User/Ground
Radar Airspace Monitoring of Parallel Approaches	Full Population
Radar Airspace Reduced Separation Standards	Full Population
Radar Airspace More Accurate Search and Rescue Response	User/Ground
"ADS-B In" Traffic Display Applications	
CDTI Enhanced Visual Acquisition	Pair-Wise
CDTI Cockpit Airport Surface Surveillance	Pair-Wise
CDTI Cockpit Final Approach and Runway Occupancy Awareness	Pair-Wise
CDTI Assisted Visual Separation (CAVS)	Pair-Wise
CDTI Merging and Spacing to a Final Approach Fix	Pair-Wise
CDTI Continuous Descent Approach	Pair-Wise
CDTI VFR-like Separation in All Weather Conditions	Pair-Wise
CDTI Self-separation or Station Keeping	Pair-Wise
CDTI In-trail Climbs and Descents	Pair-Wise
"ADS-B In" Datalink Applications	
Datalink Cockpit Weather Information	User/Ground
Datalink Cockpit Airspace Information	User/Ground

3.2 Non-Radar "ADS-B Out" Applications

Non-radar "ADS-B Out" applications arise from the increased radar-like surveillance coverage made possible by "ADS-B Out" equipped aircraft and ground based transceivers (GBTs). The information collected by the GBTs would be displayed on a radar-like display in an air traffic control facility. Because of the reduced cost of ADS-B GBTs compared with PSR or SSR facilities, more GBTs could be installed to cover the NAS. The main radar coverage holes which could be filled with ADS-B GBTs include mountainous areas, low altitude areas, and the Gulf of Mexico because those areas are hard to cover with PSR/SSR.

Figure 14 shows regions of terminal and enroute radar coverage in the NAS at low altitudes. There are large areas without radar coverage at low altitudes in the Great Plains states and the Rocky Mountain States. There are also smaller gaps in low level radar coverage in the Southeast, the New Hampshire/Vermont region, Texas, and along the Pacific coast.
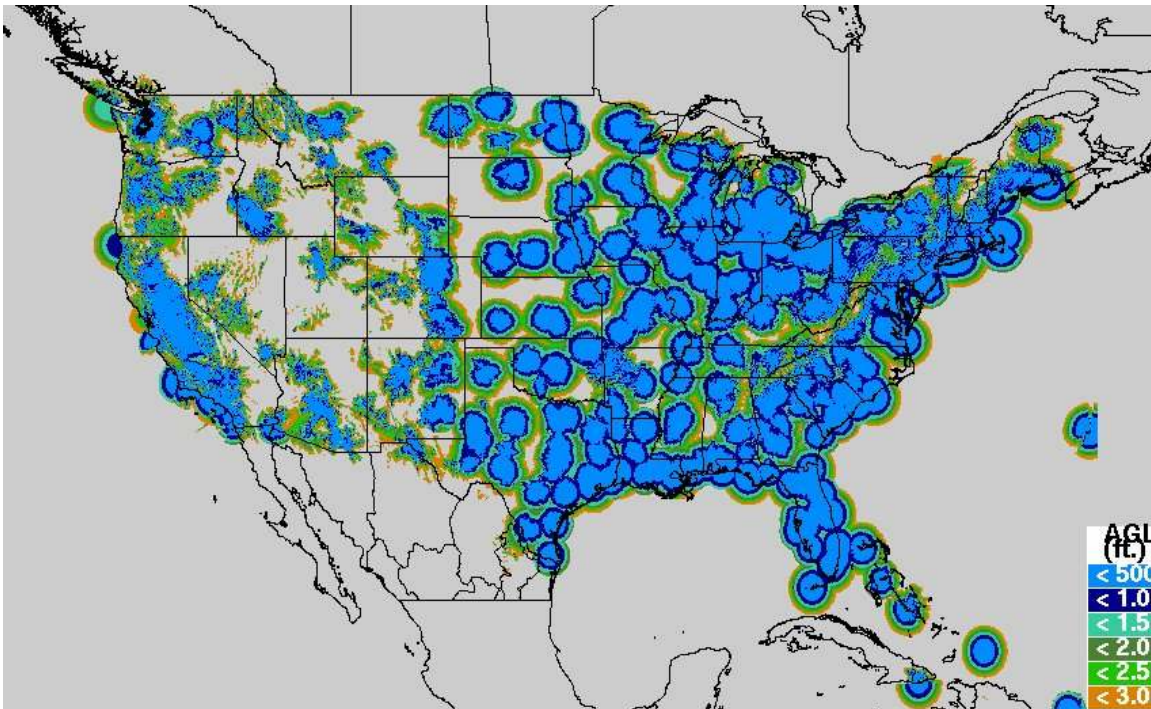

Figure 14: Low altitude terminal and enroute radar coverage

in the continental US in AGL [14]

3.2.1 Non-Radar Operation Center/Company/Online Flight Tracking

Flight tracking in a non-radar environment would allow operation centers or other interested parties to monitor the progress of flights when they leave SSR coverage. Currently this flight tracking ability is limited to areas of SSR.

The benefits of these flight tracking services would be to the operators who can more effectively utilize their fleets. It would also allow flight schools and instructors to track students at low altitude training areas. Only operators who operate in non-radar environments would receive benefits since the information is already available in areas of SSR.

3.2.2 Non-Radar Radar-like IFR Enroute Separation

Currently in non-radar environments, controllers must resort to procedural separation to maintain aircraft separation. These procedures greatly reduce the number of aircraft in a given volume of airspace.

Radar-like separation would increase the sector capacity for non-radar sectors, reducing delays. Only operators who operate in non-radar environments under IFR would receive benefits.

3.2.3 Non-Radar Increased IFR Airport Acceptance Rate

During instrument conditions, airports without radar coverage switch to one-in, one-out procedures, limiting the arrival rate significantly. With ADS-B, controllers could maintain radar separation standards in areas with ADS-B GBTs and no radar.

Benefits would include increased arrival rates at non-radar airports resulting in less holding prior to approach. Only operators who operate in non-radar environments under IFR would receive benefits.

The Gulf of Mexico, Alaska, and the Rockies are usually given as examples of region locations for increase IFR acceptance rates, but there are also a significant number of GA airports, both towered and un-towered not in radar coverage across the NAS. As larger airports reach capacity in the future, more operators will be utilizing these smaller airports. Even if not all aircraft are equipped, the arrival rates for equipped aircraft could be increased through preferential treatment.

3.2.4 Non-Radar Increased VFR Flight Following Coverage

Many General Aviation (GA) pilots, who fly VFR, use the ATC flight following service. This service allows controllers to advise pilots of nearby traffic along with minimum safe altitude warnings (MSAW). However, at low altitudes where GA planes fly, this service is often unavailable due to the limited radar coverage at low altitudes.

Increased VFR flight following coverage would benefit low-level GA operations equipped with "ADS-B Out." By expanding this service to areas of ADS-B coverage, the risk of mid-air collisions and controlled flight into terrain (CFIT) would be diminished.   MSAW could also be issued for flights on IFR flight plans in non-radar airspace.

3.2.5 Non-Radar ATC Tower Airport Surface Surveillance

ADS-B can also be used on the ground to reduce the risk of ground collisions or runway incursions. By equipping ground vehicles and aircraft with "ADS-B Out" and installing an ADS-B GBT, the ground traffic could be displayed in the tower to assist ground controllers in moving vehicles around the airport. However, one interviewee cautioned about the performance of ADS-B is not up to the current ASDE-X performance standard.

3.2.6 Non-Radar ATC Tower Final Approach and Runway Occupancy Awareness

This application is tied to the Airport surface surveillance, allowing controllers in the tower or automation to monitor runway occupancy and the final approach segment to warn of possible runway incursions.

It will reduce the risk of dangerous runway incursions for equipped aircraft at equipped airports.

3.3 Radar Airspace "ADS-B Out" Applications

ADS-B surveillance data is superior to existing radar data for a number of reasons. First the update rate is approximately once per second, which is much quicker than the 4.2 second update rate of terminal radars and the 12 second update rate of en-route radars. A faster update rate means a controller can identify problems much sooner. Also, the ADS-B position information is much more accurate then radar position information and the accuracy does not

decrease with the distance from the ground station. In addition, "ADS-B Out" data contains more information than can currently be obtained from a radar track. It contains information relating to the heading, airspeed, altitude, target heading and altitude, ground speed, ground track, vertical velocity, and equipage [44, p. 78]. The altitude data is also sent in 25 ft increments like ELS and EHS in Europe, instead of the current 100 ft resolution for Mode-C/S transponders.

3.3.1 Radar Airspace Improved ATC Traffic Flow Management

The extra information provided by the ADS-B information can be fed into air traffic control automation tools, such as URET, to improve their predictive capabilities of the air traffic management (ATM) system. This information can also be used by traffic flow management specialists to better analyze traffic capacity issues. ADS-B acts as an enabler for increased capacity automation. However, current ADS-B standards do not provide intent information, greatly limiting the usefulness of this application without a revised standard.

This benefits all operators due to reduced congestion, shorter routes, and more efficient altitudes.

3.3.2 Radar Airspace Increased Enroute Capacity

Due to better automation tools and more accurate ADS-B information, controllers will be more efficient at vectoring and spacing aircraft in the enroute system. Anecdotal information from the ADS-B trials in Australia showed reduced controller personal buffer zones for separating traffic. By reducing these personal buffer zones, which are added to the required separation, improvements in capacity can occur without changing the minimum required separation. Further capacity improvements could occur due to actually reducing the separation standards (Section 3.3.5) or through self-separation or station keeping (Section 3.4.8).

3.3.3 Radar Airspace Improved Operation Center/Company/Online Flight Tracking

The improved ADS-B data could be fed to airline or corporate operation centers to improve their flight tracking procedures. The data from ADS-B would have a faster update rate and extra information like heading and airspeed in addition to the data currently provided by the SSR feed. Also, unlike current flight tracking, fleet tracking would be available for all aircraft, independent if they have an

assigned squawk code from ATC. This would allow flight schools to track training aircraft better.

3.3.4 Radar Airspace Monitoring of Parallel Approaches

Currently, for parallel runways less than 4300 ft apart, precision runway monitoring (PRM) radar is required for simultaneous approaches in IFR conditions [45]. This PRM radar, which monitors a non-transgression zone, has an update rate of 1 Hertz, the same as ADS-B. With an ADS-B GBT and "ADS-B Out" equipped aircraft, the PRM radar could be decommissioned or parallel approaches could be performed at airports without PRM radar.

PRM benefits equipped operators at equipped airports by increasing the arrival rates in instrument conditions. It would also encourage additional closely spaced runways to be built at the busiest airports.

This application can be deployed on an airport by airport basis, so the benefits can be targeted to airports with existing PRM radars that need decommissioning or newly build closely spaced parallel runways.

3.3.5 Radar Airspace Reduced Separation Standards

With improved surveillance data, the current separation standards could be reduced. The existing separation standards are based on first generation radar technology and wake-vortex dissipation. With ADS-B, the position uncertainty decreases eliminating the need for spacing based on radar uncertainty. In addition, with a faster update rate deviations and compliance can be determined faster by a controller, further reducing the need for spacing due to uncertainty in aircraft track. Reducing separation standards, may increases sector capacity, if the controllers can handle more ADS-B aircraft or if sectors can be further sub-divided.

If procedures are developed to separate ADS-B aircraft with different standards then Mode A/C/S aircraft, then separation standards could be reduced for equipped aircraft before all operators equipped.

However, there is a risk to this application in that TCAS logic may need to be revised as it was designed for existing IFR separation standards (See Section 2.6.3.3).

3.3.6 Radar Airspace More Accurate Search and Rescue Response

The last few ADS-B position reports are more accurate than the position provided by an Emergency Locator Transmitter (ELT), including the new 406 MHz transmitters (except those equipped with a GPS). This means that aircraft that make emergency or precautionary landings within ADS-B ground station coverage will receive faster search and rescue response.

3.4 "ADS-B In" Traffic Display Applications

CDTI enabled applications come from the ability to see other traffic on a display in the cockpit. This technology is dependent on "ADS-B In" and other aircraft being equipped with "ADS-B Out" or receiving TIS-B traffic information from another source (MLAT, SSR).

3.4.1 CDTI Enhanced Visual Acquisition

Enhanced visual acquisition is the ability to find traffic visually in marginal visibility conditions in order to maintain visual separation. Being able to maintain visual separation in marginal weather increases the capacity of the airspace. The marginal visibility conditions could arise from fog, smoke, haze, or even direct sunlight into the cockpit.

Since equipped operators could follow traffic "visually", they receive benefits even if other traffic is not equipped with "ADS-B In" or not equipped with ADS-B at all in a TIS-B environment.

3.4.2 CDTI Cockpit Airport Surface Surveillance

With "ADS-B In" and a CDTI, ground traffic could also be displayed in the cockpit to further mitigate the risk of a ground collision. In addition to other aircraft, ground vehicle positions can be displayed.

When bundled with an ASDE-X installation at an airport, aircraft and vehicles not equipped with "ADS-B Out" can be displayed in the cockpit through TIS-B.

3.4.3 CDTI Cockpit Final Approach and Runway Occupancy Awareness

With "ADS-B In" and a CDTI pilots can monitor the runway prior to landing to ensure no vehicles pose a collision hazard. Likewise, pilots can check the final approach course for traffic prior to positioning on an active runway. The target

vehicles must be equipped with "ADS-B Out" or operate in an airport with an ASDE-X system and TIS-B. When incorporated with cockpit automation, pilots could be alerted to potentially dangerous situations. Automation can also be used to avoid wake turbulence given ADS-B information and a CDTI.

3.4.4 CDTI Assisted Visual Separation (CAVS)

CDTI Assisted Visual Separation or CAVS is one step beyond Enhanced Visual Acquisition. With CAVS, the equivalent of visual separation is maintained in IFR-like weather when the visibility could be zero.   Instead of maintaining separation by visually acquiring and tracking another aircraft, the other aircraft's position is tracked on the CDTI. This further increases the capacity of a terminal area during IFR conditions, when usually the capacity is greatly diminished. In addition, with CDTI and "ADS-B In", pilots could take responsibility for non-transgression zone monitoring, potentially decreasing the response time to a deviation.

3.4.5 CDTI Merging and Spacing to a Final Approach Fix

Merging and Spacing procedures and automation are used to separate traffic and coordinate arrivals without the use of air traffic control. Using CDTI and automation, aircraft establish the necessary speed to maintain a given interval with the lead aircraft. In addition, space is created so that enough space is left in two merging streams of traffic to allow coordinated merging. Merging and spacing reduces low-level vectoring and speed changes which save fuel, reduced emissions, and reduced noise pollution.

3.4.6 CDTI Continuous Descent Approach

While not directly an ADS-B application, ADS-B, along with RNP, is an enabling technology for efficient Continuous Descent Approaches or CDAs. CDAs allow aircraft to descent from cruise to the initial approach fix with engines near idle, reducing fuel burn and airframe noise. ADS-B and automation are used to space the aircraft so that they arrive at the approach fix at the correct spacing. ADS-B CDTI is used by the pilots to ensure separation from other planes during the descents.

Based on the UPS trials at Louisville CDAs reduce noise, low level emissions, and fuel consumption. The trials showed that noise was reduced by 30%, emissions below 3,000 ft by 34%, and fuel consumption by 500 lb [30].

3.4.7 CDTI VFR-like Separation in All Weather Conditions

ADS-B, along with a CDTI, provides the ability to maintain visual-like separation in instrument meteorological conditions (IMC). During visual meteorological conditions (VMC), controllers can transfer separation responsibility to pilots through the "maintain visual separation" command. This allows aircraft to safely operate in closer proximity than standard IFR separation rules would allow increasing airspace capacity.

If pilots could perform similar separation during IMC, there would not be a reduction in airspace capacity and associated delays during periods of bad weather.

This concept has been termed "Electronic Flight Rule" flying by some since separate regulations and procedures would need to be developed outside of the existing VFR and IFR regulations.

3.4.8 CDTI Self-separation or Station Keeping

Using CDTI, aircraft fly user-preferred routings and provide self-separation from other traffic. Self-separation may be conducted in controlled airspace, in which separation responsibility is delegated from controller to cockpit, or in free flight airspace. Station keeping involves maintaining a given time or distance separation from another aircraft, without continual commands being given from the controller to the pilot. Both of these applications reduce controller workload and can increase the capacity of the airspace.

3.4.9 CDTI In-trail Climbs and Descents

In-trail procedures include climbing or descending through a lead aircraft flight level while maintaining separation. These procedures, based on existing TCAS climbs and descents, are initially planned for non-radar oceanic airspace.

3.5 "ADS-B In" Datalink Applications

Data uplink features of ADS-B, also know as FIS-B products, are only available on the UAT protocol due to bandwidth limitations of the 1090-ES link. This information is uploaded to the cockpit from a ground station for display on a multi-function display (MFD) or an electronic flight bag (EFB). However, much of the proposed uplink information is already available to pilots via commercial

satellite providers, XM and WSI, for a nominal monthly fee ($30-$50 / month). A detailed discussion of datalink options is in Section 6.

3.5.1 Datalink Cockpit Weather Information

Cockpit weather information includes graphical weather radar depictions, AIRMETs, and SIGMETs along with textual products such as METARs, TAFs, and PIREPs. This information increases a pilot's mental weather depiction while airborne without using FSS or ATC frequencies for basic weather requests.

3.5.2 Datalink Cockpit Airspace Information

Dynamic airspace information can also be up-linked to the cockpit via FIS-B. This includes constantly changing temporary flight restrictions (TFRs). In addition, important time critical NOTAMs can be up-linked to the cockpit. This information could reduce the number of airspace incursions due to general aviation pilots.

4. Online Survey

In order to identify applications and benefits of ADS-B technology, an online survey was conducted with stakeholders, namely pilots, throughout the US. This survey was posted on the internet and responses were solicited from pilots in all segments of aviation.

4.1 Preliminary Work

Prior to the online survey, preliminary structured interviews were conducted with stakeholders familiar with ADS-B technology. A focused interview form was used to guide these stakeholder interviews. The focused interview forum went through a number of revisions, and the final version can be found in Appendix C. A complete list of interview subjects is in Appendix J. Modified versions of this focused interview form were used to conduct interviews with general aviation stakeholders and Hawaii helicopter operators. The results of the focused interview were used to identify any missing applications and to better structure the online survey.

Many pilots in the US are unfamiliar with ADS-B technology. A recent informal poll by *Flying* magazine found that 42% of respondents had no idea what ADS-B was and 18% were "foggy on the details" [46]. While many of the interview subjects were familiar with ADS-B, the survey participants were not. Thus the interview and survey were written so that a subject unfamiliar with ADS-B technology could rate the benefits.

Both the preliminary interviews and the online survey were conducted with the approval of the MIT Committee on the Use of Humans as Experimental Subjects (COUHES).

4.2 Conducting the Online Survey

The online survey has many of the same questions as the preliminary focused interview, but with a reduced number of open ended questions. The survey had to take less than 15 minutes for participants to complete in order to get a significant number of responses. Feedback from the FAA Surveillance and Broadcast Services program office and AOPA was incorporated into the online survey prior to its release. The full survey can be found in Appendix D.

The survey was advertised on a number of online pilot bulletin boards including AirlineCrew.net, PPRuNe.org, Piperowner.org, AOPA.org, and AviationForum.org. Articles about the online survey also appeared in the AvWeb and Experimental Aircraft Association (EAA) email newsletters.

The online survey was open between June 14 and July 31, 2007. Responses from the survey were collected using the CGIemail program developed at MIT by Bruce Lewis [47]. These responses were reduced to a comma separated file for analysis using the process-comments.pl Pearl script [48].

4.3 Survey Structure

The survey is divided into three major sections: Background, ADS-B Applications, and Aircraft Equipage. In the Background section, participants are asked about their piloting experience, the type of flying performed, and operating regions. The background section also includes two questions about operating outside of radar coverage.

At the beginning of the ADS-B Application section, the participants are given a brief introduction to ADS-B. The applications are then broken down into the 4 application categories as laid out in Section 3.1 (Non-radar Airspace "ADS-B Out" Applications, Radar Airspace "ADS-B Out" Applications, "ADS-B In" Traffic Display Applications, and "ADS-B In" Data Link Applications), with a brief introduction to each category. In this section, participants are asked to rank the benefits to each application using the following four choices:

- **N/A**: not applicable to your type of operation
- **No benefits**: application would not lower expenses, increase efficiency, or increase safety
- **Some benefits**: application would marginally lower expenses, increase efficiency, or increase safety
- **Significant benefits**: application would considerably lower expenses, increase efficiency, or increase safety

A free-form text box is included at the end of the application list for participants to list any applications that are not included in the survey. Participants are also asked in this section how much they would be willing to pay to equip with ADS-B In avionics.

In the final Aircraft Equipage section, participants are asked about their current GPS, EFB/MFD, Datalink Weather, and ADS-B equipage.

4.4 Online Survey Demographics

A total of 1159 responses to the online survey were received. Of those, 20 were blank and 3 were duplicates leaving 1136 valid responses to the survey.

All but 1% of the responses were certified pilots, with the largest group being Private pilots (44%) followed by Commercial pilots (34%). These numbers are similar to the overall pilot population in the 2006 Airman Statistics [49], as seen in Figure 15. It should be noted that since the responses come from pilots and not company management, the results presented here are from a pilot's perspective, which man not always align with the interests of other decision makers within a company.
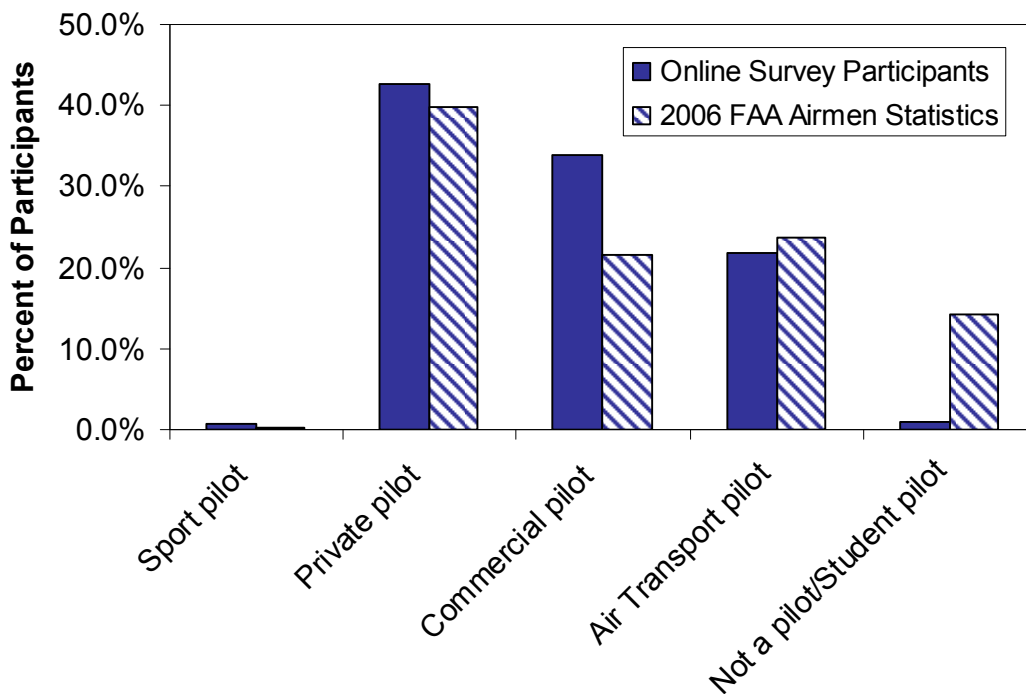

Figure 15: Pilot ratings held by the online survey participants
along with the 2006 FAA Airmen Statistics for comparison

Participants in the survey had a wide variety of total flying hours. Almost a quarter of the participants were low time pilots with less than 500 hours of flying time. However, over 20% of participants were experienced pilots with over 5,000 hours of flying time (Figure 16).
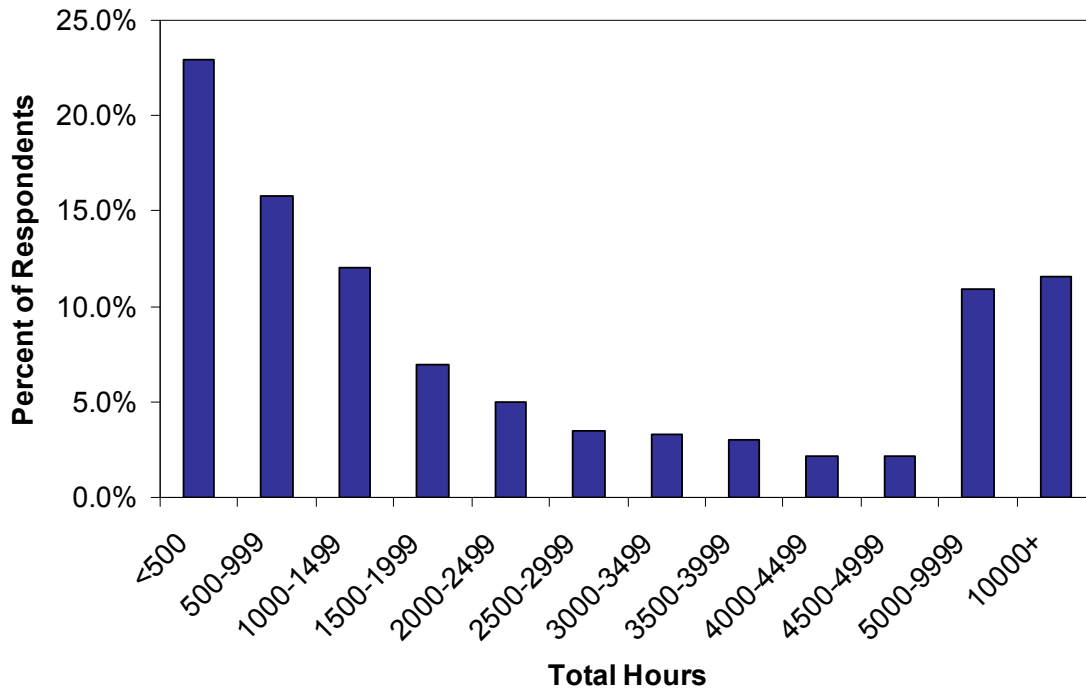

Figure 16: Survey participants' total flight time.

Note that the last two columns are not 500 hour blocks like the other columns.

78% of participants to the survey held an instrument rating compared with 60% of the total pilot population from the FAA 2006 Airmen statistics.

The pilots completing the survey came from a wide geographic distribution in the US. Participants were asked to list their primary operation region, along with 2 other regions. The results of these questions can be found in Figure 17, which show the number of participants who list the region as their primary operating region along with those who list the region as one of their top 3 operating regions.
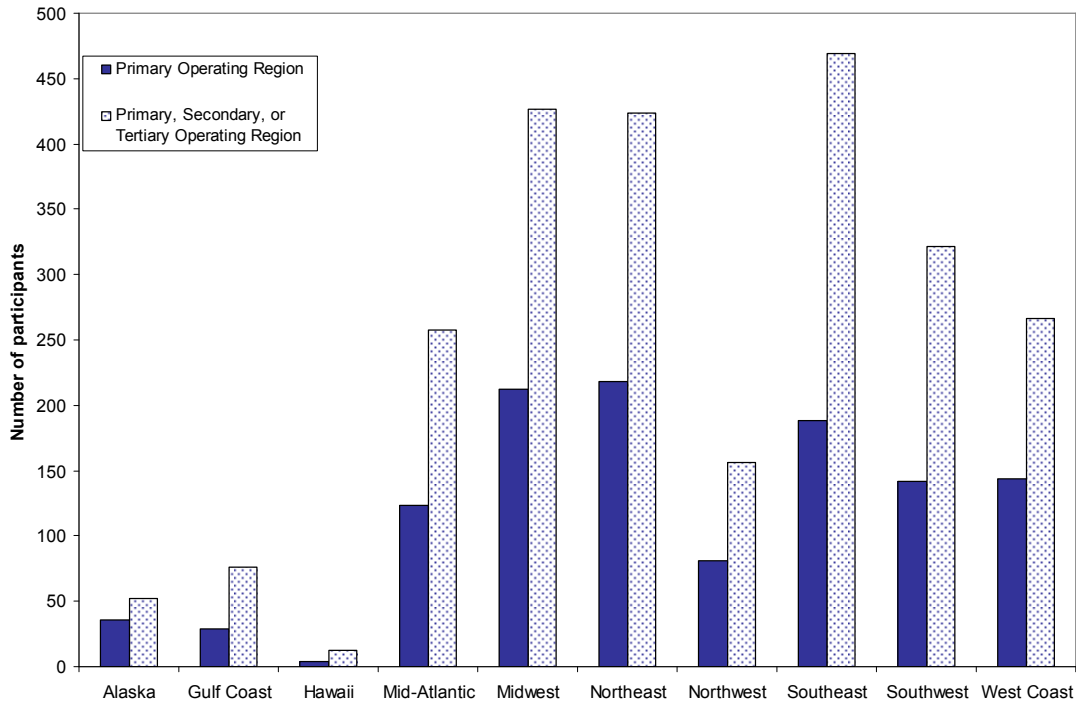
Figure 17: Survey participants' operating regions

The vast majority of the survey participants were primarily airplane pilots (1097), followed by rotorcraft (19), and glider (14). Primary lighter-than-air and powered-lift pilots only consisted of 4 of the participants. Due to the low number of glider, lighter-than-air, and powered-lift responses, conclusions about these groups could not be made based on the survey alone.

The survey participants listed a variety of primary types of operation. The majority, 55%, were part 91 recreational flyers, followed by those who fly part 91 for business travel. The complete break down of types of flying is in Figure 18.
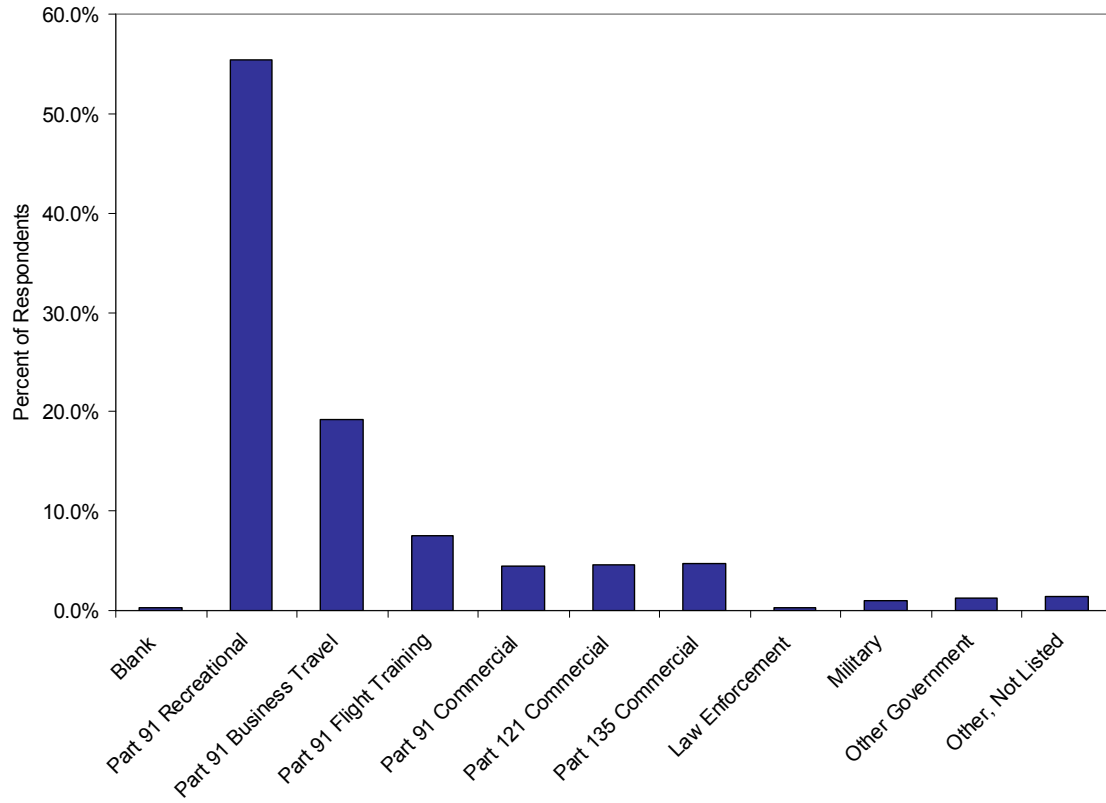
Figure 18: Survey participants' primary type of operation

5. Results

5.1 Online Survey Benefit Results

The results for each application were tallied up by the stakeholder groups defined in Section 2.3.1: aircraft owners, Part 91 recreational pilots, Part 91 Business traveling airplane pilots, Part 91 Flight Training airplane pilots, Part 91 Commercial airplane pilots, Part 135 airplane pilots, part 121 airplane pilots, and helicopter pilots. There were not enough responses in other user categories to draw conclusions. The aggregate survey results were not used since the responses from Part 91 recreational pilots, which make up 55% of the participants, wash out the responses from other stakeholder groups.

For each application and stakeholder group the percentage of participants who marked "Significant Benefits" and the percentage of participants who marked "Some Benefits" were calculated.   Almost all applications, except those not applicable to the type of operation, showed benefits.   The number of responses indicating "Significant Benefits" allowed the applications to be ranked in order of preference as presented in Figure 19. The number of responses indicating "Some Benefits" did not prove useful for analysis since for all applications, roughly the same number of responses indicated "Some Benefits."

Next, using ordered significant benefit graphs, cutoffs were established at 66% of participants marking significant benefits and 50% of participants marking significant benefits. These were natural breaks in the data where the number of significant benefits dropped as shown in Figure 19. These beaks allow applications with strong benefits to be identified for each user group. Appendix E includes the ADS-B benefits graphs for each stakeholder group.
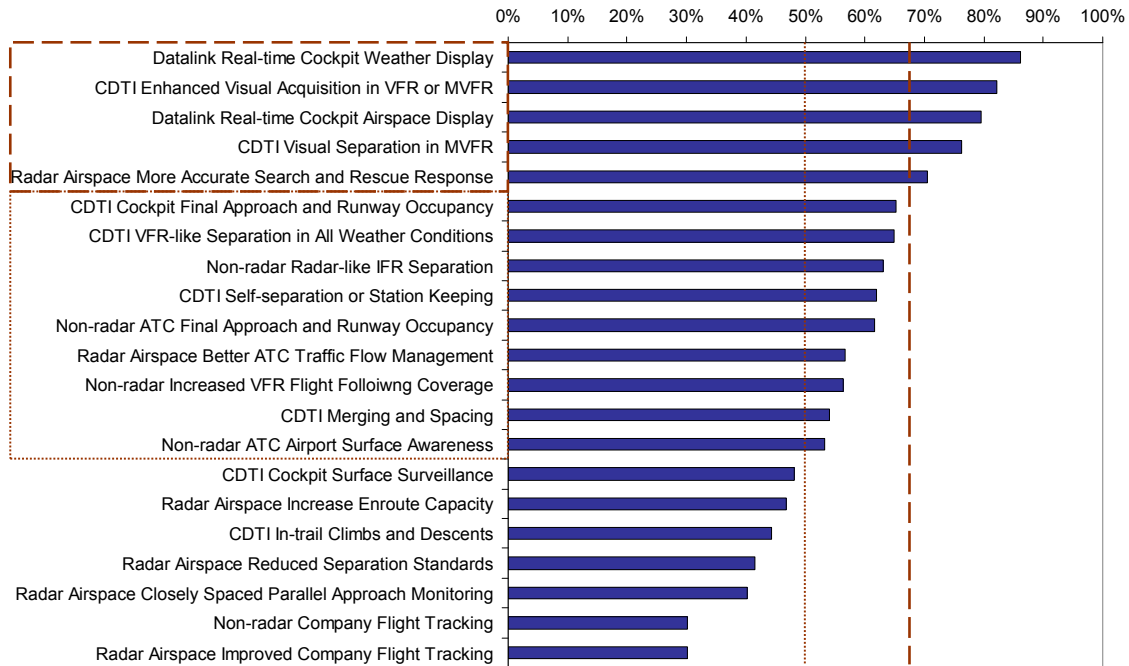
Figure 19: Percent of all participants who indicate significant benefits for each application.

Natural breaks at 66% and 50% are indicated by dashed lines.

5.2 Application Benefit Matrix

For the user groups with enough responses in the survey and using the criteria for significant and some benefits as described in Section 5.1, an initial benefit matrix could be created shown in Figure 20.

A couple of interesting trends become apparent when looking at Figure 20. First, strong benefits are identified by all groups for "ADS-B In" Enhanced Visual Acquisition and VFR Separation in MVFR conditions. These two applications both require CDTI, but only at a situational awareness level of criticality. These applications also lead to benefits in dense traffic areas such as busy terminal areas that already have ATC radar coverage.

Column groups:
- "ADS-B In" Data Link Apps
- "ADS-B In" Traffic Display Apps
- Radar Airspace "ADS-B Out" Apps
- Non-Radar Airspace "ADS-B Out" Apps

Column headers:
- Real-time cockpit airspace display
- Real-time cockpit weather display
- In-trail climbs and descents
- Self-separation or station keeping
- VFR-like separation in all weather conditions
- Merging and spacing
- Visual separation in VFR and MVFR conditions
- Cockpit final approach and runway occupancy
- Cockpit surface surveillance
- Enhanced visual acquisition in VFR or MVFR
- More accurate search and rescue response
- Reduced separation standards
- Closely spaced parallel approach monitoring
- Improved company flight tracking in radar airspace
- Increase enroute capacity
- Better ATC traffic flow management
- ATC final approach and runway occupancy
- ATC airport surface awareness
- Increased VFR flight following coverage
- Radar-like IFR separation in non-radar airspace
- Company flight tracking in non-radar airspace

Operator Category (rows):
- Aircraft Owners
- Part 91 Rec Airplane
- Part 91 Biz Airplane
- Part 91 Flight Training Airplane
- Part 91 Commercial Airplane
- Part 121 Airplane
- Part 135 Airplane
- Helicopter

Key:
- > 66% Marked Significant Benefits
- 50%-66% Marked Significant Benefits
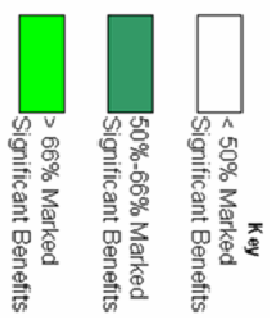- < 50% Marked Significant Benefits

Figure 20: Application benefit matrix from online survey pilot responses

Second, the two "ADS-B Out" applications with the largest perceived benefits are Radar-like IFR separation and Improved Search and Rescue accuracy. These benefits only occur by installing ADS-B GBTs in regions with no current ATC radar coverage. As described below in Section 5.3.1, for general aviation participants the most used region outside radar coverage is within 100 nm of a Class B or C airport, but remote and mountainous areas are also important. For Part 121 operators, the most use region of non-radar airspace is over water, followed by mountainous terrain.

Third, cockpit weather and airspace provide significant benefits to all pilots regardless of type, including part 121 and part 135 operator pilots.

Pilots do not gain strong benefits from surface surveillance applications, either from the tower or in the cockpit with a CDTI. However, general aviation and part 135 operators who operate primarily under IFR (part 91 commercial, part 91 business), do see significant benefits from final approach and runway occupancy awareness from the tower or from within the cockpit. All other operators see some benefits from final approach and runway occupancy applications.

5.2.1 Stakeholder similarities and differences

The results show there are some similarities between all stakeholders. All stakeholders receive significant benefits from real-time displays of weather and airspace information in the cockpit. Also all stakeholders identified significant benefits from applications used to aid in maintaining visual separation from other aircraft. Improved search and rescue response also provided benefits across the board. In general operators found little use for surface situational awareness from either the cockpit or the ATC tower, yet stronger benefits were identified from final approach and runway occupancy awareness from both the cockpit and the ATC tower.

The major differences between the stakeholders can be explained by the fact that some operators utilize visual flight rules (VFR) while others utilize instrument flight rules (IFR). VFR pilots do not interact with air traffic control except around busy airports or while utilizing VFR flight following. IFR pilots utilize air traffic control services throughout the entire flight.

Based on the identified benefits, Part 91 recreational and Part 91 flight training stakeholders operate under VFR, which is to be expected. The only significant

addition to the common benefits is the benefit from VFR flight following coverage outside of radar airspace.

Part 121 and Part 135 operators receive more benefits since they operate in the IFR environment. These operators identified significant benefits from improved traffic flow management and closely space parallel approach monitoring, two applications that could possibly increase the arrival rates at busy airports, thus reducing delays.

Part 91 business and commercial operators receive the strongest benefits of all groups since they operate under both VFR and IFR. These operators utilize VFR when the weather is nice, but then also operate under IFR when the weather deteriorates.

Figure 21 depicts the percent of both Part 91 recreational airplane and Part 121 airplane participants who identified significant benefits for each application. This graph clearly depicts the different benefits for IFR and VFR operations, along with the common benefits.
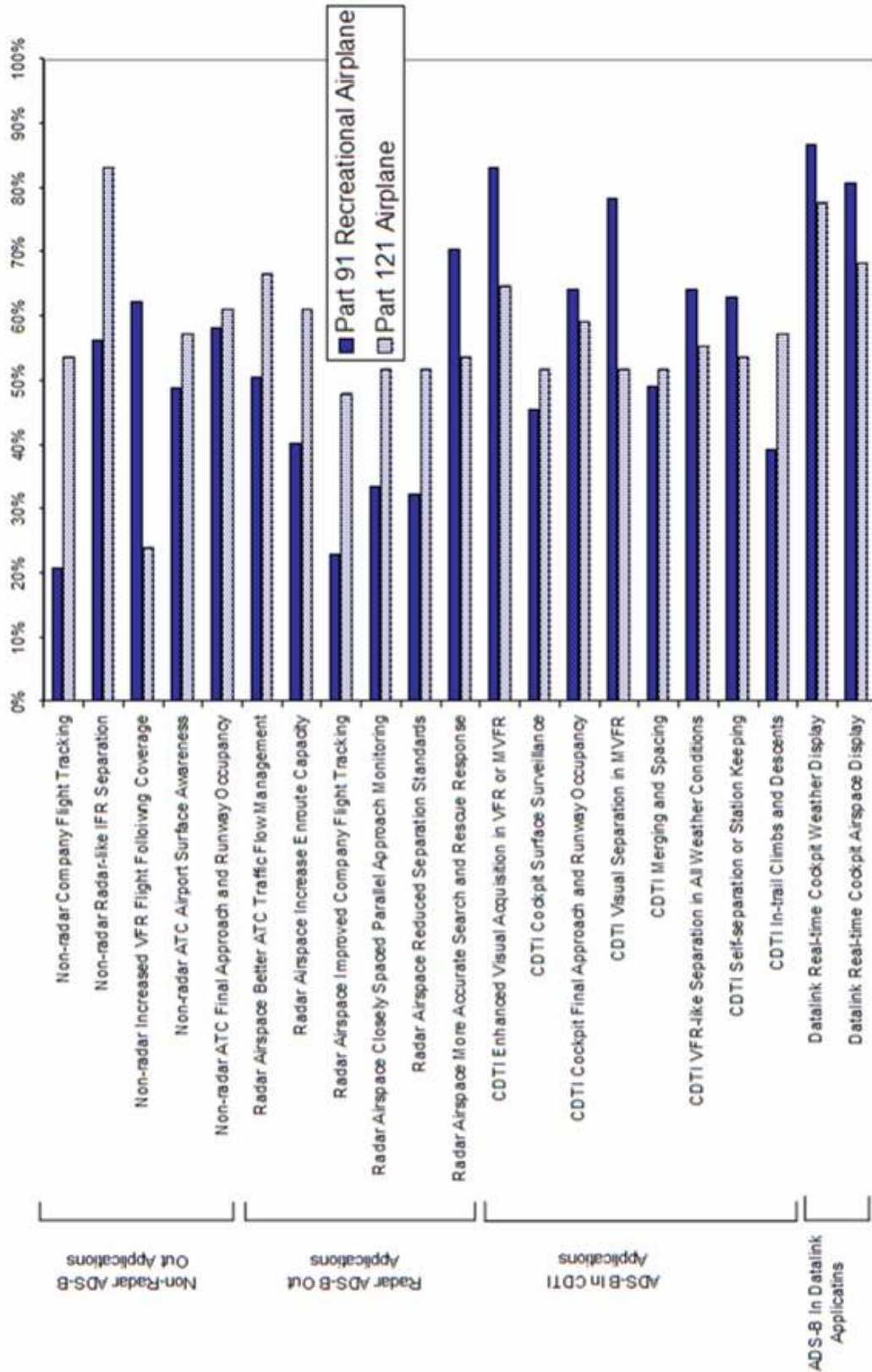
Figure 21: Comparison of Part 91 Recreational Airplane and Part 121 Airplane pilots' "significant benefits"
applications from the online survey

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5.3 Other Benefit Findings

5.3.1 Non-Radar Operating Environments

Given the benefits found for non-radar applications, non-radar operating environments were investigated in the online survey. Over half of the participants in the online survey spend at least 10% of their flight time outside of radar coverage. This highlights the importance of ADS-B in expanding the regions of ATC radar-like coverage. The full cumulative plot of participants' time outside radar coverage is in Figure 22.
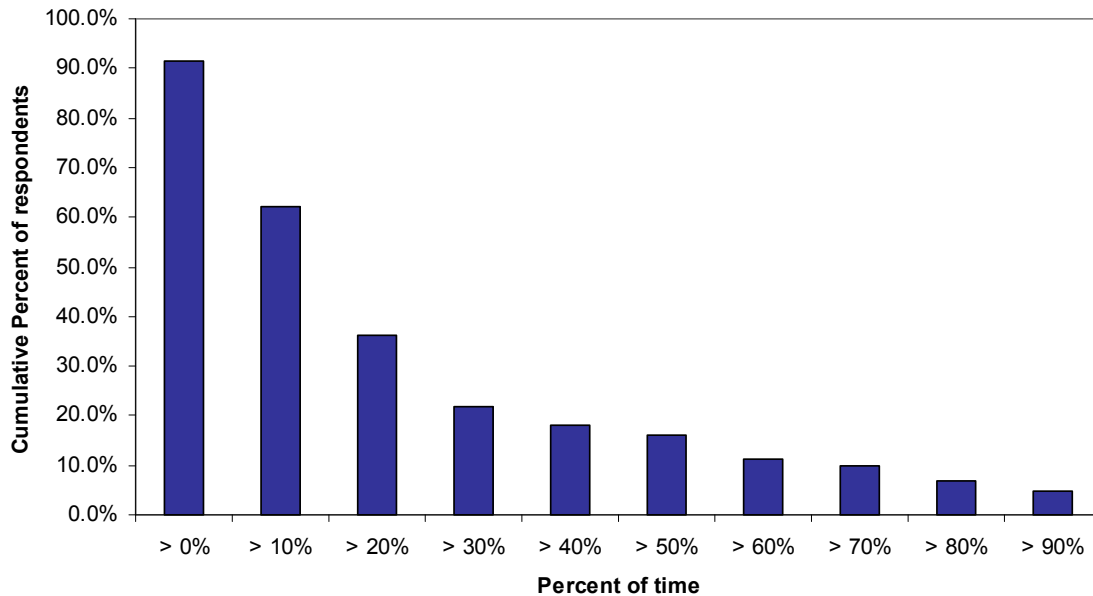
Figure 22: Time spent outside of ATC radar coverage from online survey

Survey participants were also asked the primary type of location where they encountered a lack of ATC radar coverage. The results differed for the various user groups. Part 91 Recreation users spend the most time below radar coverage in congested regions (defined as within 100 nm of a Class B or C airport), which reflects the operating patterns of these users who utilize satellite airports and fly at low altitudes. Figure 14 depicts these areas lacking low altitude radar coverage.

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Figure 23: Regions where non-radar airspace is encountered by user group from the online survey

Business Part 91, Part 121, and Part 135 pilots encountered a lack of radar coverage more in mountainous terrain or over water, reflecting their expanded operating areas compared with Part 91 Recreational pilots.

5.3.2 General Aviation Existing Equipage

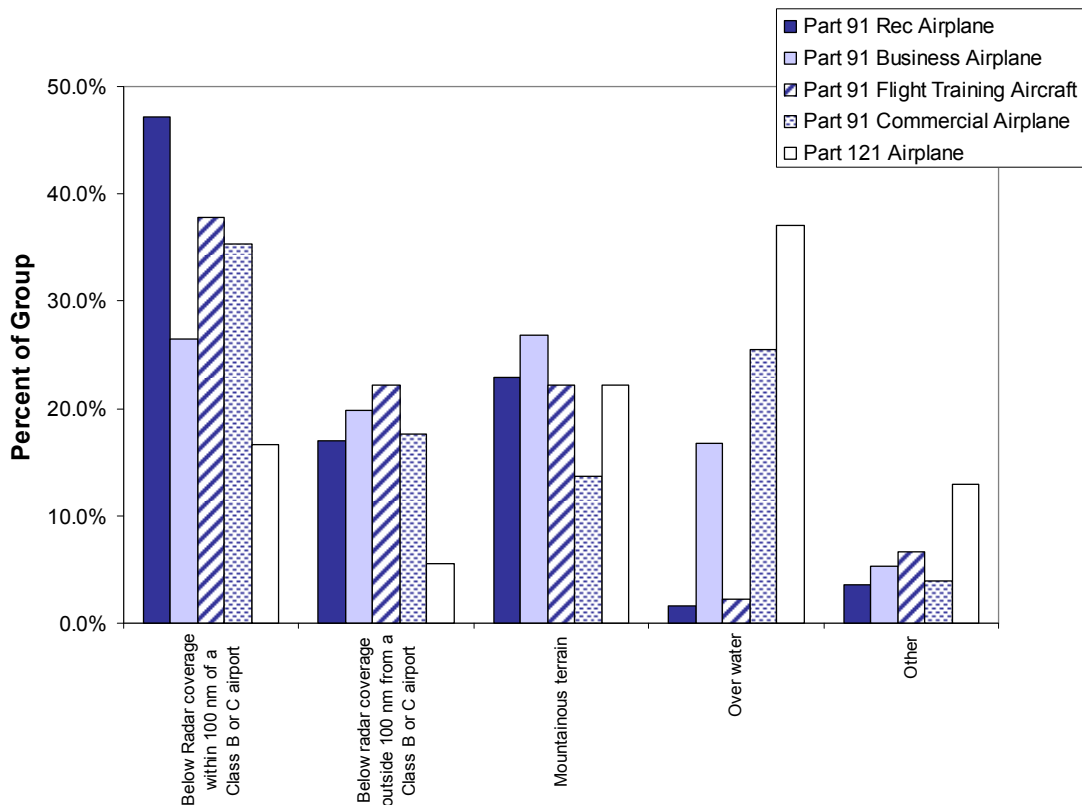According to the survey, there is already a large amount of GPS equipage in GA aircraft. 22.5% of aircraft owners reported owning an IFR Certified GPS, including 8.3% with a WAAS capable IFR GPS. This is similar to the 2005 GAATAA survey which found 35% GA aircraft were equipped with an IFR certified GPS and 4.9% with WAAS [50]. IFR certified GPS's were considered since they have the required integrity needed for ADS-B. Additionally, 18.8% of aircraft owners use portable GPS devices.

26.5% of aircraft owners had a multifunction display (MFD) in their aircraft along with 3.7% with an electronic flight bag (EFB). The MFD equipage is much higher than the 13.4% value reported in the 2005 GAATAA survey. However 44% of the GAATAA participants reported having a moving map [50], so this

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inconsistency could be explained by a lack of definitions for a MFD versus a moving map display. A small handheld GPS may be considered a moving map display.

37.2% of aircraft owners reported having a datalink weather receiver in their aircraft. Roughly half of these receivers are portable XM receivers, approximately one fifth are panel mounted XM receivers, and less than 5% are WSI receivers or ADS-B UAT receivers (Figure 26).

In terms of ADS-B 3.7% of participants reported having UAT ADS-B and 0.8% reported 1090-ES receivers. These numbers are slightly higher than the GAATAA survey numbers of 1.5% for UAT and 0.3% for 1090-ES [50], but this could be explained by the self-selected nature of an online survey. Operators already familiar with ADS-B are more likely to respond and complete a survey on ADS-B applications. Interestingly, 14% of survey participants and 10% of aircraft owners didn't know whether their aircraft was equipped with ADS-B.

5.3.3 ADS-B Price Point

Survey participants were asked, "If this real-time weather and airspace information was provided for free and given that there was a future mandate, how much would you pay to voluntarily equip prior to the mandate with **ADS-B In** avionics that would give access to the weather and airspace information, along with a display of nearby traffic?"

As seen in Figure 24, over half of the participants would be willing to spend $5,000 or less to equip with "ADS-B In" voluntarily. While few participants (<10%) are willing to equip with "ADS-B In" at the expected price of $15,000, these results do show that aircraft owners are willing to voluntarily equip with ADS-B if the price is right.
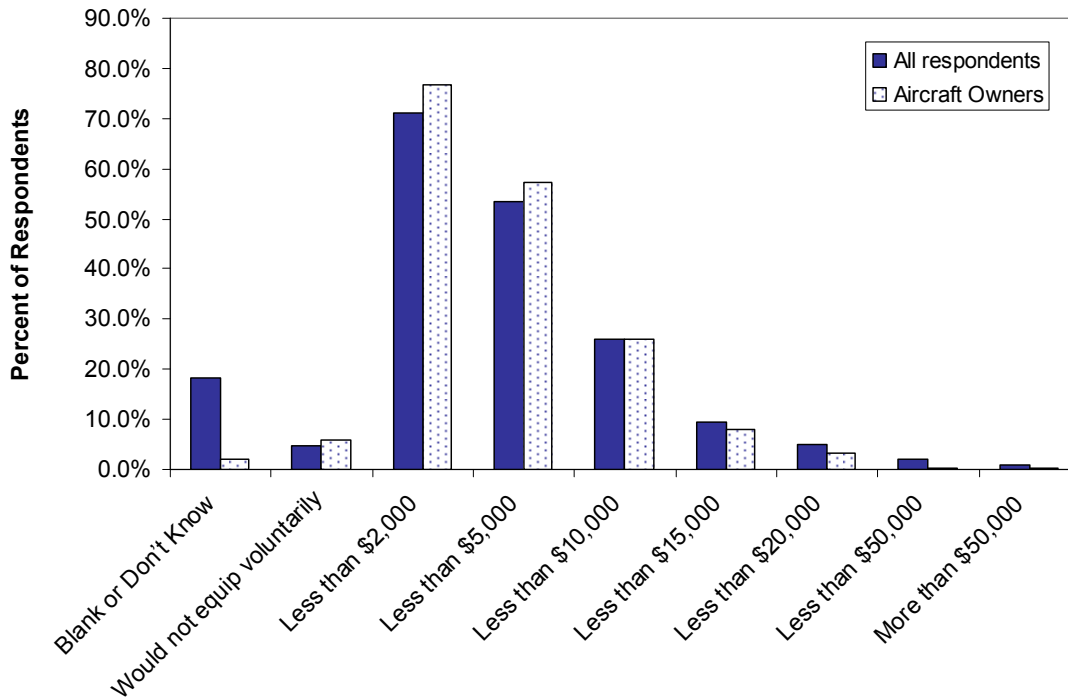
Figure 24: Amount survey participants would be willing to spend for "ADS-B In" equipment

These results were further broken down by those operators who have datalink weather and those who don't. The hypothesis is that operators who are willing to spend more to equip with ADS-B are the ones that are early adopters who are already equipped with datalink weather. This hypothesis seems to hold true given Figure 25, which indicates that those who have datalink weather make up a larger percentage of those willing to pay $5,000 or more to voluntarily equip.

This indicates that datalink weather via UAT may not be a strong benefit to encourage voluntarily equipage since those who would potentially equip already have datalink weather.
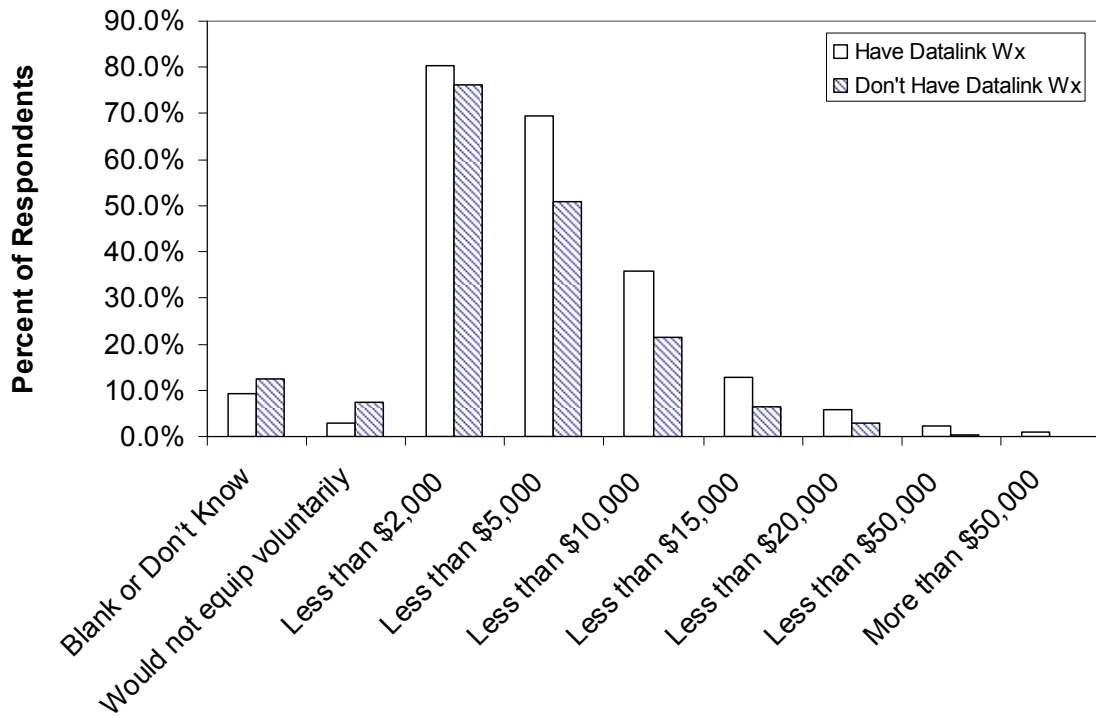
Figure 25: Amount survey participants would be willing to spend for "ADS-B In" equipment broken down by those already equipped with datalink weather

5.3.4 Other Applications Proposed by Participants

Participants were asked to describe any additional applications not included in the survey application list. Some of the applications were restatements of applications included in the survey. About half of the proposed applications were generic datalink applications that could be added to any datalink architecture (ADS-B, NEXCOM, Satellite, etc.). These are applications like CPDLC, Digital ATIS, IFR clearances, and next frequencies for handoffs.

The following is a list of applications proposed by participants that have merit and could be used to encourage ADS-B equipage:

- Law enforcement ground units could track positions of airborne assets, via "ADS-B In" receivers in patrol cars
- Flight schools could dispatch planes to practice areas that aren't crowded by online tracking of the density of operations in a given area
- "Lo-Jack" like tracking to prevent aircraft theft and recover stolen aircraft
- Downlink/Uplink of automatic Pireps to other pilots and to NOAA to improve atmospheric forecasting models

- Real-time information regarding the status of parachute, aerobatic, or UAV areas
- Real time reporting of NAVAID operational status
- Billing of airspace or airport user fees

5.3.5 Military Insights

Only 1% of the survey participants indicated that they were associated with the Military. However, four of the preliminary focused interviews were conducted with experts knowledgeable about ADS-B and other military avionics programs. The following is a summary of the military ADS-B concerns and potential benefits.

The largest concern for US military decision makers is global interoperability for their fleet of over 14,000 aircraft. Other than the training fleet, almost all military aircraft are deployed overseas at some point. When operating overseas, the US aircraft must meet the local equipage standards or apply for a waiver. For ADS-B, the military does not want a separate or unique equipage requirement for the US, but instead, a global standard. Since Mode-S transponders are already being deployed, the US military prefers 1090-ES over UAT.

The US Air Force decided to equip its fleet with Mode-S Enhanced Surveillance (EHS) in order to meet the European mandate. This upgrade has been a great challenge due to the wide variety of aircraft in the fleet ranging from 1950s era B-52s to modern UAVs. Many of the older aircraft did not have the EHS needed information on the databus and thus needed extensive wiring changes.

The military's cycle for upgrades is a major modernization program for each type of aircraft approximately every 20 years, with a different program office assigned to each type. This causes problems with fleet-wide equipage mandates. Currently plans are being made and equipment designed to upgrade to IFF Mode 5, if ADS-B upgrades could be part of the same package, installation and equipment costs could be greatly reduced. However, the ADS-B standards are still up in the air, so the Air Force has not made a commitment to ADS-B.

In terms of benefits, there would be significant benefits to the training fleet of T-38s, T-37s, and T6-2s that operate in busy areas like Pensacola and Key West, Florida. Most of the training areas are covered by radar, but many of the low level training routes out west are not in radar coverage.

In the past the T-38s agreed to equip with TCAS, but did not since a study by Lincoln Labs show that the algorithms would not be effective for jet trainers since designed for airliner flight characteristics.

UAV programs would also benefit from ADS-B technology, especially if it was mandate in certain airspace since it could be used as part of a UAV "see and avoid" system.

Additionally, the military has unique requirements for ADS-B systems. First, the squittering must be suppressible during combat operations.   Also, the system must be compatible with the existing Identify Friend or Foe (IFF) system on the aircraft.

Pilots from the US Customs and Border Protection in the Department of Homeland Security saw benefits of ADS-B CDTI during interception procedures. However, since many intercepted aircraft may be uncooperative (transponder turned off), the pilots did not want to see the elimination of any primary radar coverage. They were also concerned with the potential lack of GA equipage especially with small Light Sport Aircraft or LSAs.

In 2001 a cost estimate was done to equip all 14,000 aircraft in the US military with 1090-ES ADS-B out, which resulted in a cost of approximately $1 Billion. Currently this estimate is being updated, but preliminary results show roughly the same costs.

6. Analysis of In-Cockpit Datalink Offerings

Based on the survey results that indicate significant benefits from cockpit weather and airspace information and the recent introduction of competing datalink technologies, a more detailed investigation of the available in-cockpit datalink offerings was conducted.

Of those who completed the online survey, one third were equipped with datalink weather. Participants were also asked to include the type of datalink weather receiver. The types of datalink weather receivers for the survey participants who have datalink are in Figure 26. XM equipment has a strong command of the datalink weather market, with the predominant type of receivers being uncertified handheld, laptop, or PDA receivers.
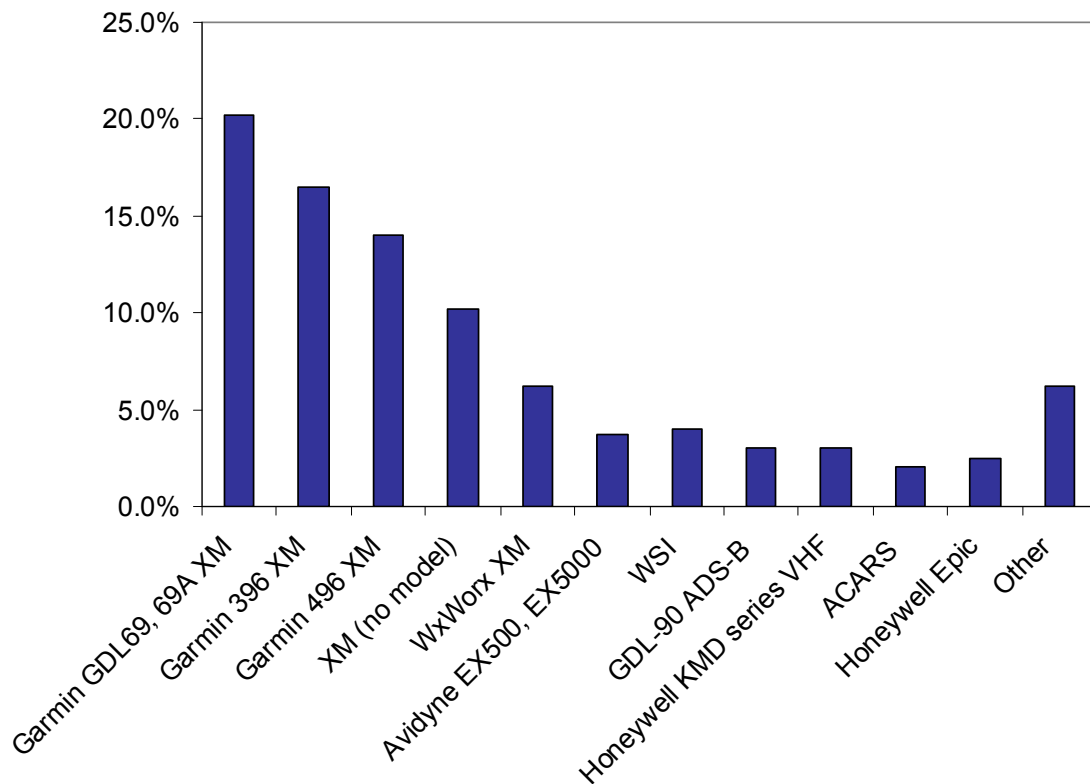

Figure 26: Type of datalink receiver for datalink equipped online survey participants

The dual link decision (see section 2.9) was made prior to the recent growth of satellite-based in-cockpit weather. The largest provider of weather is XM radio, whose weather products are produced by Baron Services' WxWorx. In addition

WSI Corporation offers in-cockpit weather via its network of private satellites and via Sirius Satellite radio.

The authors of the dual link decision in 2002 did not anticipate the rapid growth of satellite based weather and airspace information. The XM satellite service was not launched until 2001 and WSI's InFlight service was not launched until 2002. According to the online survey, roughly 1/3 of pilots already utilize datalink weather. This undercuts the assumption of the dual link decision that UAT is the only feasible data link for providing FIS services to low and mid-level general aviation users.

The official term for in-cockpit weather provided by the FAA is the Flight Information Service (FIS). Since this FIS data is usually provided via a broadcast method (instead of a request-reply method), it is commonly referred to as Flight Information Service – Broadcast (FIS-B). According to DO-267A, the *Minimum Aviation System Performance Standards (MAPS) for Flight Information Services-Broadcast (FIS-B) Data Link*,

> "The goal of FIS-B data link systems is to provide weather and other non-control flight advisory information to pilots in a manner that will enhance their awareness of the flight conditions and enable better strategic route planning consistent with guidance provided by the Federal Aviation Regulations and corporate policy. The information provided by FIS-B will be advisory in nature, and considered non-binding advice provided to assist in the safe and legal conduct of flight operations" [51].

While commercial weather products are not considered FIS-B by the FAA, they provide the same services with the same advisory nature. Since both government and commercial weather services are "advisory" in nature, the level of system assurance is low.

6.1 VHF FIS

Prior to the advent of satellite-based in-cockpit weather, the only source of weather for general aviation was the Flight Information Service (FIS) provided by Honeywell's Bendix/King division. The FIS data is broadcast from over 150 privately owned ground stations across the US, via the VHF VDL Mode 2 protocol [52]. This protocol provides a 31.5 kbps transmission rate.

Because the FIS system is based on line of sight transmission from a limited number of ground stations, the low altitude coverage of the service is limited. Coverage increases with altitude. The published minimum coverage altitude is 5,000 ft above ground level (AGL) [52]. As seen in Figure 27, even at 5,000 ft AGL there are coverage holes and not until 15,000 ft AGL is the continental US covered. No service is guaranteed below 5,000 ft AGL, so unless one of the ground stations is located near the airport, the data will not be available until the aircraft is airborne.

Honeywell provides textual weather products (METARs, TAFs, AIRMETs, SIGMETs, Convective SIGMETs, Alert Weather Watches, and PIREPs) for free, while graphical weather products such as graphical METARs, graphical NEXRAD, Graphical AIRMETs, graphical SIGMETs, graphical convective SIGMETs and graphical alert weather watches (AWWs) cost beween $50 and $70 per month. The Honeywell FIS service can be displayed on a range of panel mounted Bendix/King avionics.
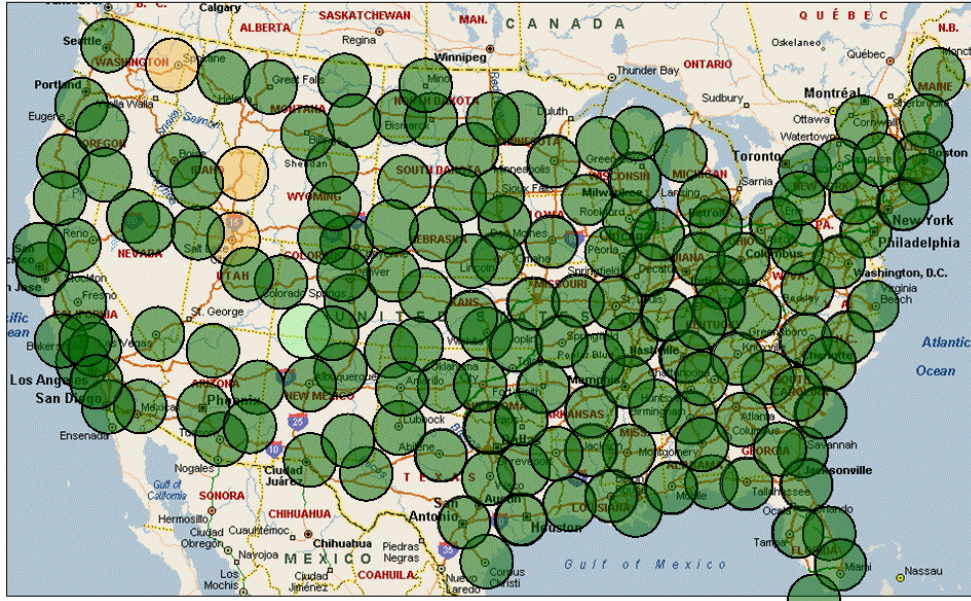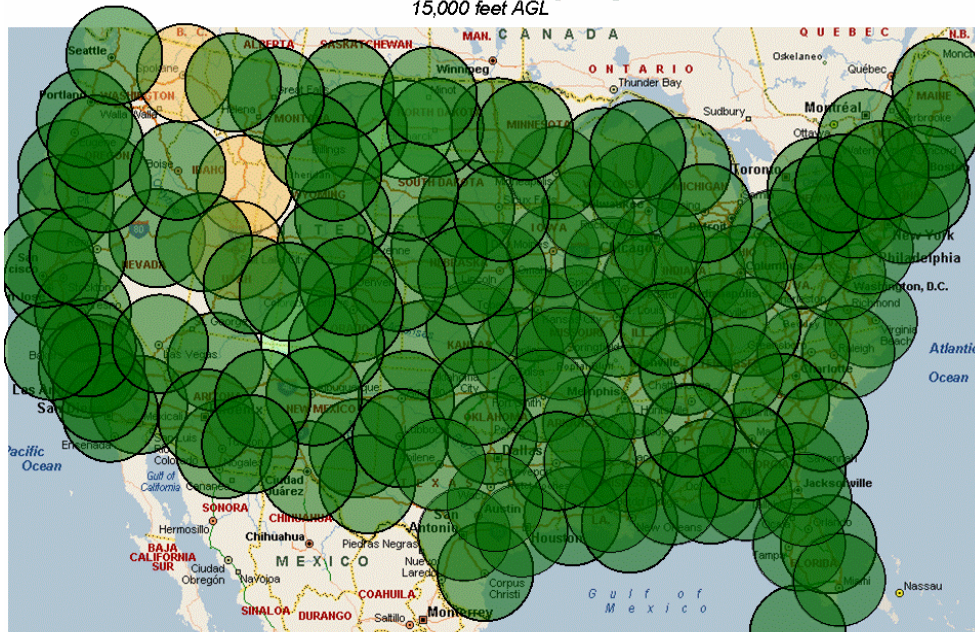
Figure 27: Honeywell FIS Network coverage at (a) 5,000 ft AGL and (b) 15,000 ft AGL
[52]

6.2 XM and WSI Weather

XM and WSI both provide in-cockpit weather via satellite broadcasts. XM WX satellite weather uses XM's existing set of geosynchronous satellites (Rock, Roll, and Rhythm), which are primarily used for satellite radio broadcasts. WSI is currently transitioning to the Sirius Radio's set of satellites which orbit in an elliptical orbit. Legacy WSI satellite service is to be discontinued in September 2007 [53].

XM provides two packages, consisting of different weather products, priced at $30 and $50 per month [54]. The $30 package contains graphical NEXRAD, TFRs, city forecasts, county warnings, precipitation type, METARs, and TAFs. The $50 package contains the same information as the lower priced alternative with the addition on AIRMETs, SIGMETs, Echo Tops, sever weather storm tracks, surface analysis weather maps, lightning, winds aloft and satellite mosaic. WSI weather packages are priced between $40 and $100 per month [55]. The cheapest package contains graphical NEXRAD and graphical and textual METARs, while the most expensive package contains graphical NEXRAD, METARs (both US and Canadian), TAFs (both US and Canadian), AIRMETs, SIGMETSs, Lightning, TFRs, PIREPs, winds and temperatures aloft, and Canadian radar.

6.3 Proposed ADS-B FIS-B

The FAA is proposing to provide weather and airspace over the UAT datalink protocol to aircraft equipped with UAT ADS-B receivers. There will be no charge for these services, however, the ground station contractor will be allowed to charge for additional "value added products" [56]. However, these additional products must be approved and certified by the FAA.

The FIS-B products will include at a minimum: "graphical and textual weather reports and forecasts, NEXARD [sic] precipitation information, Special Use Airspace (SUA) information, NOTAMs, electronic pilot reports (E-PIREPS), and other similar meteorological and aeronautical information" [42]. The Final Program Requirements for Surveillance and Broadcast Systems [56] states that the minimum required meterological products are AIRMETs, METARs, Severe Weather Forcast Alerts (AWW) and Severe Weather Watch Bulletins (WW), Ceilings, SIGMETs, Echo tops, lightning strikes, NEXRAD, PIREPs, Winds/Temps Aloft, TAFs, Terminal Weather Information for Pilots (TWIP). The

minimum required aeronautical information products are Digital Automated Terminal Information Service (D-ATIS), Local, Distant, and Flight Data Center NOTAMs, and Status of Military Operations SUA.

Since this is a ground-based line of sight datalink, the service will only be available above a certain altitude. DO-282A states that FIS-B service will not be available below 3,000 ft AGL, unless a ground station is present at the airport. Ground stations are to be built on all airports with control towers for surface surveillance applications. XM and WSI service is available on the surface at any airport in the continental US.

Another major differentiation between the proposed UAT FIS-B and the service offered by XM and WSI is the product coverage. XM's data covers the entire US and WSI's data covered the US along with parts of Canada and Mexico. Contrast that with the UAT FIS-B product coverage which will only give information at most 500 nm away from your present location. Each ground station will only broadcast the data for the surrounding geographical area. This means the data cannot be used for extended flight planning on long trips.

The products and their coverage will be determined by the ADS-B ground station provider, as part of the contract bidding process. However, the FAA has presented some example numbers for the various types of service volumes. Surface and low level service volumes, 0 to 1000 feet AGL and 500 feet AGL to 5,000 feet MSL respectively, will broadcast METARs, TAFs, NOTAMs, and AIRMETs and SIGMETs for the surrounding 100 nm only and NEXRAD radar to 250 nm [57]. Terminal and high level service volumes, 500 feet AGL to FL180 and 5,000 feet MSL to FL600, will have data from 500 nm away for METARs, TAFs, PIREPs, SUA, AIRMETs and SIGMETs, 250 nm for NEXRAD, and 100 nm for NOTAMs. What this means is that even if the airport has a UAT ground station, you will not be able to get the METAR or the terminal forecast for your destination on the ground if the destination is greater than 100 nm away. Then in flight, the coverage is more extensive, yet is still limited, especially for some of the fast general aviation aircraft and can only be used for tactical avoidance of weather, not long range flight planning.

6.4 Datalink Service Comparison

A comparison between the offerings of XM, WSI, Honeywell and the proposed UAT datalink weather is in Table 2. As can be seen, all of the services provide

the basic weather products most useful to pilots including NEXRAD radar, METARs, and TAFs. The XM service provides the most weather products of all 4 services. WSI provides similar products, but has more Canadian product offerings than XM.

Table 2: Product comparison between datalink providers

Product	XM WX [54]	WSI InFlight [55]	Honeywell FIS [52]	Proposed UAT FIS-B [56]
Weather				
NEXRAD	X	X	X	X
Echo Tops	X	X		X
METARs	X	X	X	X
TAFs	X	X	X	X
AIRMETs	X	X	X	X
SIGMETs (inc. convective)	X	X	X	X
Lightning	X	X		X
Winds/Temps Aloft	X	X		X
PIREPs	X	X	X	X
Alert Weather Watches (AWW)			X	X
Weather Watch Bulletins (WW)				X
Terminal Weather (TWIP)				X
City Forecasts	X			
County Warnings	X			
Precipitation Type	X			
Storm Tracks	X			
Surface Analysis Maps	X			
Satellite Mosaic	X			
Ceilings				X
Non Weather				
TFRs	X	X		X
D-ATIS				X
NOTAMs				X
Military SUA status				X

In addition to weather products, various airspace related products are offered. The Honeywell FIS service offers lacks Temporary Flight Restrictions (TFRs), which are becoming increasingly more of a problem for General Aviation pilots in a post-9/11 world. In addition to the TFRs offered by XM and WSI, the proposed FIS-B service offers digital ATIS (D-ATIS), NOTAMs, and Military SUA status. If this information was available in a useful format and there was user demand, XM or WSI could add these products to their offering. Because XM and WSI compete for customers, the product selection is based on market demand [58].

In addition to the products offered, the update rate of the products is important. Since the products are sent via a serial stream, the service provider can decide how arrange the products in the stream. However, since the bandwidth is limited, faster update rates for one product come at the expense of update rates for other products.

The update rates for XM and the proposed UAT FIS-B service are listed in Table 3. The proposed UAT FIS-B update rates are quicker than the XM rates; however since the UAT FIS-B data covers a limited geographic region, there is not as much data as the nation-wide data provided by XM. Since the update rate is inversely proportional to the total amount of periodic data, by sending less total data than XM, the UAT FIS-B can achieve a faster update rate.

Table 3: Comparison of FIS-B and XM Update Rates

Product	Proposed FIS-B Update Rate [56] minutes	XM Update Rate [54] minutes
NEXRAD	2.5	5
METARs	1 or 5	12
TAFs	5	12
TFRs	5	12
County Warnings	n/a	5
City Forcasts	n/a	5
Freezing Level	5	5
Winds Aloft	5	12
Echo Tops	5	7.5
Storm Tracks	n/a	1.25
Satellite Mosaic	n/a	15
AIRMETs	5	12
SIGMETs	5	12
Surface Analysis	n/a	12
Lightning	5	5
AWW/WW	5	n/a
Ceilings	5	n/a
D-ATIS	1	n/a
Pireps	5	n/a
SUA Status	5	n/a
TWIP	1	n/a

The update rate for NEXRAD imagery is misleading. The actual NEXRAD radar information is updated every 10 minutes in clear air mode, used during clear days and light snow, and every 5 minutes in precipitation mode, for heavy precipitation [59]. The reason for these rates is due to the fact that the radar must collect data at various elevation angles, and then combine the data to present the composite radar picture, more angles are collected in precipitation mode, but at a courser resolution [60]. The NEXRAD update rates listed in Table 3 are more frequent than the actual update rate of the raw data in order to prevent latency. Thus if the NEXRAD is updating at 5 minutes, the XM with a data update rate of 5 minutes could be out of phase and thus have up to a 5 minute latency, the UAT FIS-B on the other hand could have at worst a 2.5 minute latency. However, while the UAT FIS-B latency may be less, the graphical refresh rate of the NEXRAD will still be every 5 minutes.

7. Conclusions

ADS-B technology has great promise to modernize the US NAS. The technology can reduce the reliance on high-cost older secondary surveillance radars. ADS-B also acts as an enabler for advanced operational procedures like self-spacing. With these types of procedures and reduced separation standards airspace capacity can be increased, while safety can be improved.

However, there are number of potential stumbling blocks, as seen from the MLS and CPDLC experience: industry opposition, lack of FAA infrastructure implementation, and surpassing technologies. There is also risk from the continually changing ADS-B standards. Operators are reluctant to equip prior to a mandate when they feel the equipment standard may change. The solution is to identify applications with benefits for stakeholders in the NAS. Implementing ADS-B in such a way that maximizes these benefits will encourage voluntary equipage.

7.1 Key Applications

The matrix in
Figure 20 should be used to identify benefits to a specific stakeholder group in order to develop partnerships in ADS-B implementation, like the agreement between the FAA and HAI for Gulf of Mexico helicopter operators.

For more general focus areas, below is a list of the key applications in each of the four categories based on the online survey. These applications are the ones identified by a majority of stakeholder groups as having significant benefits, and should be developed and implemented early in the ADS-B roll-out. They are listed in order of significance within each category.

Non-Radar "ADS-B Out" Applications
1. Non-Radar radar-like IFR separation
2. Non-Radar ATC final approach and runway occupancy awareness

Radar "ADS-B Out" Applications
1. Radar Airspace more accurate search and rescue response
2. Radar Airspace better ATC traffic flow management

"ADS-B In" CDTI Applications
1. CDTI enhanced visual acquisition in VFR or MVFR
2. CDTI visual separation in VFR and MVFR conditions

"ADS-B In" Datalink Applications
1. Datalink cockpit weather display
2. Datalink cockpit airspace display

It should be noted that these applications do not require a high level of criticality. Part of this study's aim was to identify the most beneficial applications in order to determine the criticality level of the ADS-B equipment. Other than the radar-like IFR separation application, the rest of these applications would fall under the "situational awareness" level of criticality. This is important because it means the initial ADS-B deployment should have a higher level of criticality for "ADS-B Out" than "ADS-B In", yet there are still beneficial applications for a situational awareness-only CDTI. The more advanced applications like merging and spacing and self-separation do not provide as many significant benefits, and thus can be delayed until the ADS-B system has been proven.

This leads to the ILS metaphor, described by Rich Heinrich of Rockwell Collins during a preliminary interview. The ILS system and airborne equipment were not designed for Category III approaches from the beginning. Instead, the ILS Category I system was implemented and proven through operational use, then the Category II minimum and equipment, and finally Category III minimums and equipment were approved. During each change, operators were willing to upgrade their airborne equipment in order to receive the benefits of lower minimums. Likewise, a building block approach should be taken towards ADS-B, where an initial operational capacity should be achieved, and then additional requirements for higher criticality applications can be added later. For the ILS system the end goal, which has been achieved, was 0-0 landings. For the ADS-B system, the end goal is self-separation, but it cannot happen immediately.

7.2 Other Findings

Based on the current datalink equipage (Section 5.3.2), the superiority of satellite-based FIS (Section 6.4), military support (Section 5.3.5), and the dual link technical challenges (Section 2.9), the single 1090-ES ADS-B link implementation

with satellite-based FIS augmentation is the desired architecture. The UAT link should be eliminated in favor of a single 1090-ES ADS-B link.

The results in Section 5.3.3 also indicate that datalink weather via UAT may not be a strong benefit for voluntary equipage since the operators willing to spend more to voluntarily equip with ADS-B already have datalink weather in the cockpit.

Also, there are quantifiable benefits to operators in current non-radar airspace. The FAA's plan to use existing radar coverage as a baseline for rolling out ADS-B service volume coverage should be revisited. There is a fundamental difference between using ADS-B to expand surveillance service coverage like in Alaska, the Hudson Bay, and central Australia, and using ADS-B to augment existing radar coverage, like the plans by the FAA in the US. When expanding surveillance service coverage, the benefits to the users are readily apparent, while when replacing or augmenting existing radar coverage, the benefits are much harder to identify and quantify.

Instead the FAA should focus on expanding ADS-B to coverage to areas currently lacking radar coverage along with busy terminal areas with dense operations. Operators in dense traffic environments receive the most safety and efficiency improvements from "ADS-B In" and "out".

7.3 Further Research

Research could be done with the data set collected from the online survey to look for regional differences in benefits. Operating location and home base was not taken into account when analyzing the application benefits, but these attributes could be used to investigate regional differences. The data can be broken down so that each type of operator in each region can be analyzed separately.

Additionally, further research could be done to investigate the price at which owners are willing to equip with a more realistic set of "ADS-B Out" and "in" applications, versus a price for all ADS-B applications as done in the online survey for this research.

Appendix A: ADS-B Emitter Categories

From [3, p. 29]:

- Light (ICAO) – 7,000 kg (15,500 lbs) or less
- Small aircraft – 7,0000 kg to 34,000 kg (15,500 lbs to 75,000 lbs)
- Large aircraft – 34,000 kg to 136,000 kg (75,000 lbs to 300,000 lbs)
- High vortex large (aircraft such as B-757)
- Highly maneuverable (> 5g acceleration capability) and high speed (>400 kts cruise)
- Rotorcraft
- Glider/Sailplane
- Lighter-than-air
- Unmanned Arial vehicle
- Space/Trans-atmospheric vehicle
- Ultralight/Hang glider/Paraglider
- Parachutist/Skydiver
- Surface Vehicle – emergency vehicle
- Surface Vehicle – service vehicle
- Point obstacle (includes tethered balloons)
- Cluster obstacle
- Line obstacle

Appendix B: ADS-B Application Lists

B.1 FAA Planned Applications

The FAA's National Airspace System Surveillance and Broadcast Services Concept of Operations [42, p. 32], lists seven initial ADS-B applications for the near-term NAS implementation. These are applications that "the FAA and industry have agreed to deploy." They are:

1. ATC Surveillance
2. Airport Surface Situational Awareness
3. Final Approach Runway Occupancy Awareness
4. Enhanced Visual Acquisition
5. Enhanced Visual Approach
6. Conflict Detection
7. Weather and NAS Status Situational Awareness

These are a subset of the DO-289 applications.

Additionally, the Concept of Operations lists various "Application Scenarios" which expand upon the seven initial applications. These scenarios include increased arrival rates at mountainous airports, Gulf of Mexico surveillance, reduced separation standards, more accurate ATC automation for Conflict Alerts and Minimum Safe altitude Warnings, enhanced traffic flow management prediction models, fleet management, collaborative decision-making (CDM), Department of Defense and Homeland Security applications, and temporary obstruction and mobile obstacle awareness.

The Concept of Operations also lists future ADS-B enabled applications that are not part of the initial deployment. These also are a subset of the DO-289 applications. They are:

1. CDTI/MFD Assisted Visual Separation
2. Merging and Spacing
3. In-Trail Procedure in Oceanic Airspace
4. Approach Spacing for Instrument Approaches
5. Enhanced Sequencing and Merging
6. Independent Closely Spaced Parallel Approaches

7. Airborne Conflict Management
8. Paired Approach

B.2 RTCA Applications

The FAA's applications are a subset of those applications listed in the RTCA DO-289 document, *Minimum Aviation System Performance Standards for Aircraft Surveillance Applications (ASA) [40].* The DO-289 applications are broken down into two groups: background applications and coupled applications. Background applications occur without flight crew or ATC input or selection of target aircraft. Coupled applications are those that operate only on traffic specifically chosen by the flight crew or ATC.

Background Applications
1. Enhanced Visual Acquisition
2. Conflict Detection
3. Airborne Conflict Management
4. Airport Surface Situational Awareness
5. Final Approach and Runway Occupancy Awareness

Coupled Applications
6. Enhanced Visual Approach
7. Approach Spacing for Instrument Approaches
8. Independent Closely Spaced Parallel Approaches

Additionally in RTCA DO-303, *Safety, Performance and Interoperability Requirements Document for the ADS-B Non-Radar-Airspace (NRA) Application*, further applications of ADS-B are identified [61]. These applications enhance existing air traffic services in non-radar airspace. They are:

1. Air traffic control separation services
2. Transfer of responsibility for control
3. Air traffic control clearances
4. Flight information services
5. Notification of rescue co-ordination centers
6. Plotting of aircraft in a state of emergency
7. Air Traffic Advisory Services (a.k.a. Flight Following)

The Minimum Aviation System Performance Standards (MAPS) for ADS-B as laid out in DO-242A, break down ADS-B applications differently [3]. The operational applications of ADS-B are given as:

1. Cockpit Display of Traffic Information
2. Airborne Collision Avoidance
3. Conflict Management and Airspace Deconfliction (both air and ground based, including non-radar airspace surveillance)
4. ATS Conformance Monitoring (including simultaneous approaches, incursion processing)
5. Other potential applications: improved search and rescue, enhanced flight following, lighting control and operation, airport ground vehicle operational needs, altitude/height keeping performance measurements, GA operations control.

B.3 Boeing Applications

The Boeing Air Traffic Management group created a comprehensive list of ADS-B applications broken down by phase of flight [43]. Some of the applications span multiple phases of flight. Each application was given a code by the Boeing group. The applications identified by Boeing are:

Surface
1. Airport Surface Surveillance: includes runway incursion alerting, low visibility surface operations (ADS-B-APT)
2. Enhanced Traffic Situational Awareness: supplements out-the-window observations, includes runway occupancy alerting (ATSA-SURF)

Departure
3. Enhanced Traffic Situational Awareness: nearby traffic display with flight ID and position, general awareness, see and avoid (ATSA-AIRB)
4. Enhanced Air-Ground Surveillance: provide aircraft derived data to enhance ground ATC automation (ADS-B-ADD)
5. Enhanced Crossing and Passing: controller identifies problem and delegates solution to aircraft (ASPA-C&P)

Enroute
6. Radar Airspace: reduce cost of radar infrastructure by using ADS-B air-ground (ADS-B-RAD)
7. Enhanced Traffic Situational Awareness (ATSA-AIRB)
8. Enhanced Air Ground Surveillance (ADS-B-ADD)

9. Enhanced TCAS: increase scope of TCAS
10. Sequencing & Merging (ASPA-S&M)
11. Enhanced Crossing and Passing: spacing application using lateral maneuvers (ASPA-C&P)
12. Vertical Crossing and Passing: spacing application using vertical maneuvers (ASPA-VC&P)
13. Lateral Crossing and Passing: separation responsibility transferred to crew for the specific identified problem (ASPA-LC&P)
14. Self-separation in segregated free flight airspace: aircraft fly user-preferred routings and provide self separation (SSEP-FFAS)
15. Self-separation in managed airspace
16. Airborne Short Term Conflict Alert: safety backup for fully automated ATC
17. Airborne Autonomous Conflict Management: aircraft detects and resolves conflicts by modifying its 4D trajectory

Arrival Management

18. Enhanced Traffic Situational Awareness (ATSA-AIRB)
19. Enhanced Air-Ground Surveillance (ADS-B-ADD)
20. Merging and Spacing: centralized metering by early speed control towards single merge point, aircraft self spacing during CDA decent (UPS M&S)
21. Sequencing and Merging: maintain in-trail spacing, merge behind, can include path stretch by controller heading and CDA profiles (ASPA-M&S)
22. Enhanced TCAS
23. Airport Short Term Conflict Alert

Approach/Landing

24. Precision Runway Monitoring: Closely spaced parallel operations to 2500 ft (PRM)
25. Enhanced Visual Separation on the Approach: to aid in acquiring and maintaining visual separation with lead aircraft on approach (ATSA-VSA)
26. CAVS or CEFR: attain and maintain visual separation even when out-the-window visibility is lost
27. Enhanced Traffic Situational Awareness (ATSA-SURF)
28. Approach Spacing in Instrument Approaches: In-trail spacing to visual minima in IMC and Independent parallel runway operations to 750 ft (ASIA)

Oceanic/Remote

29. Non-Radar Airspace: provide air-ground surveillance instead of radar: providing separation services where there are currently are only procedural (ADS-B-NRA

30. Enhanced Traffic Situational Awareness: Traffic information broadcast-remote crossing route safety (ATSA-AIRB)
31. Oceanic In-Trail Procedures: aircraft climbs through lead aircraft flight level, behind lead and closer than oceanic in-trail minimum, to reach more efficient flight level (ATSA-ITP)
32. Oceanic In-Trail Follow: aircraft to maintain time or distance behind lead aircraft (replaces Mach rule) (ATSA-ITF)
33. Self-Separation in Organized Track System: crew can choose altitude and speed freely. (SSEP-FFT)

B.4 Prioritized applications

A joint FAA / industry group prioritized potential near-term operational applications of ADS-B [44]. These applications were listed in DO-259, but do not align with the other RTCA application lists in Section B.2. The prioritized applications are:

High
- Facilitate closely-spaced parallel approaches in IMC
- Enhanced visual acquisition of other traffic in VFR traffic pattern at uncontrolled airports
- Enhanced visual acquisition of other traffic for "see-and-avoid"
- Traffic situational awareness in all airspace (GNSS-enhanced collision avoidance system)
- Surveillance enhancements for TCAS/ACAS in all airspace
- Conformance monitor during simultaneous parallel and converging approaches

Medium
- In-trail climb and in-trail descent in oceanic, remote, or domestic non-radar airspace
- Station keeping in oceanic, remote, or domestic non-radar airspace
- Enhanced visual approaches
- Conflict situational awareness (with TA's) in all airspace

Medium/Low
- Lateral passing maneuvers in oceanic, remote, or domestic non-radar airspace
- Application of "pseudo-radar" separation standards at airports without radar coverage

Low
- Airport surface situational awareness (VFR day, night)
- Collision situational awareness (with TAs and RAs) in all airspace. ADS-B collision avoidance.

Appendix C: Final Interview Forms

ADS-B Stakeholder Focused Interview Form (version 7-Short)
John Hansman, Ted Lester, MIT International Center for Air Transportation

Interviewee: _____   Date: _____

Organization: _____

Inform subject that participation is voluntary, they may refuse to answer any and all questions, and they may decline further participation, at any time, without adverse consequences. All answers will be anonymous, unless further permission is requested.

The FAA has recently begun the process of implementing of ADS-B in the NAS. While some ADS-B applications and benefits have been identified (e.g. enhanced surveillance, visual acquisition, surface situational awareness, merging and spacing) there appear to be many other potential ADS-B applications which could provide benefit to users and other stakeholders. The goal of this investigation is to identify potential ADS-B applications and implementation strategies which would have sufficient benefits to encourage rapid user equipage of ADS-B. Because the potential benefits, costs, barriers and operational concerns will vary for different stakeholders we are interviewing a number of key stakeholders to get their views on the ADS-B.

Because there are a variety of systems termed ADS-B for the purpose of this interview "ADS-B out" is transmission of aircraft states at 1090 or UAT (DO-260A, DO-282A) and "ADS-B in" is the reception and display of other aircraft ADS-B data as well as other potential flight info.

Part I: Background

   1. What is your role in your organization?

   2. What is your experience with ADS-B?

Part II: Applications and Benefits

   3. What do you see as the near, mid, and far term potential applications of "ADS-B **out**"? What benefits do you see from each of these to your organization?

Page 1 of 5

Please comment on the applicability and possible benefits for each of the following ADS-B out applications:

Increased ATC Surveillance Coverage Enabled Applications
- AOC/Company/Online flight tracking in non-radar environment

- IFR separation in non-radar enroute environment

- Increased IFR acceptance rate at non-radar airports

- Increased VFR flight following coverage

- Airport surface surveillance (tower)

- Final approach and runway occupancy awareness (tower)

Enhance ATC Surveillance Enabled Applications
- ATC Traffic Flow Management

- Increased sector capacity

- Improved AOC/Company/Online flight tracking in existing radar environment

- Precision Runway Monitoring (PRM)

- Reduced separation standards (terminal separation in enroute, etc.)

4. What do you see as the near, mid, and far term potential applications of "ADS-B **in**" (both from other aircraft and from ground stations) and Cockpit Display of Traffic Information (CDTI)? What benefits do you see from each of these to your organization?

Please comment on the applicability and possible benefits for each of the following ADS-B out applications:

Cockpit Display of Traffic Information (CDTI) Enabled Applications
- Enhance visual acquisition

- Airport surface surveillance (cockpit)

- Final approach and runway occupancy awareness (cockpit)

- CDTI Assisted Visual Separation (CAVS)

- Merging and Spacing to Final Approach Fix

- Continuous Descent Approaches

- Self-separation / Station keeping

- In-trail climbs / descents

Data Uplink Enabled Applications
- Cockpit weather information

- Cockpit airspace information

- Airport diagrams

5. What do you see as the most important potential applications of ADS-B to you or your organization?

6. What do you see as the major barriers or concerns regarding ADS-B implementation and operational use? *(e.g. procedures, ground infrastructure, certification, funding)*

7. The FAA has listed 5 regions for phase 1 ADS-B implementation:
   a. Gulf of Mexico
   b. Louisville (KY), Kansas City (MO), Garden City (KS), and North Platte (NE)
   c. Philadelphia (PA) and Ontario (CA)
   d. Juneau (AK)
   e. East Coast, Great Lakes, California (TIS-B and FIS-B only, no ADS-B)
   To what extent do you operate in these regions, and how much would you benefit from ADS-B services in these regions?

8. What regions of ADS-B equipage would benefit your organization?

Part III: Current Equipage.

9. Do you currently have ADS-B out equipment on any of your aircraft (both TSO'd or latent capacity to upgrade):
    a. Transponders?

    b. ADS-B processing?

    c. Position sources?

Specifically, which aircraft models are equipped?

10. Do you currently have the ability to display ADS-B information (traffic and/or weather) on any aircraft? If so, what systems?

11. What are your current sources of in-cockpit weather information (text, graphics, forecasts, communication with dispatch, communication with FSS, etc.)? Do you pay for these services?

12. What is your current ability to communicate with controllers via data-link? Do you pay for these services?

Part IV: Future Fleet Equipage

13. What are the factors which would drive your decision to equip with ADS-B or other avionics equipment?

14. Do you currently have plans for future ADS-B equipment retrofit? New aircraft equipage? EFBs (or MFD) equipage?

15. Do you have subfleets which are more likely to equip?

16. What are the obstacles you see in equipping your fleet with ADS-B equipment?

17. If you decided to equip your entire fleet with "ADS-B out" how long would it take if the installations were part of the normal maintenance cycle to minimize out of service costs? For "ADS-B in" with cockpit displays?

18. Do you see any major ongoing maintenance issues associated with ADS-B?

19. What incentives or mandates (financial, regulatory, etc) would be most effective in encouraging your fleet to equip?

20. *(International carriers only)* Is your current ADS-B upgrade plan influenced by the European Mode-S mandates?

21. Is your current ADS-B upgrade plan influenced by future digital voice/data-link (both 1-way and 2-way) requirements?

ADS-B General Aviation Stakeholder Interview Form (version 8-Sun 'n Fun)
John Hansman, Ted Lester, MIT International Center for Air Transportation

Interviewee: _____   Date: _____

1. What is your background in aviation?

2. What do you know about ADS-B?

Describe ADS-B "out" and "in" for those unfamiliar.

3. Given the following applications of ADS-B "out", which would you find beneficial?
   Increased ATC Surveillance Coverage Enabled Applications
   - AOC/Company/Online flight tracking in non-radar environment
   - IFR separation in non-radar enroute environment
   - Increased IFR acceptance rate at non-radar airports
   - Increased VFR flight following coverage
   - Airport surface surveillance (tower)
   - Final approach and runway occupancy awareness (tower)

   Enhance ATC Surveillance Enabled Applications
   - ATC Traffic Flow Management
   - Increased sector capacity
   - Improved AOC/Company/Online flight tracking in existing radar environment
   - Precision Runway Monitoring (PRM)
   - Reduced separation standards (terminal separation in enroute, etc.)

4. Given the following applications of ADS-B "in", which would you find beneficial?
   Cockpit Display of Traffic Information (CDTI) Enabled Applications
   - Enhance visual acquisition
   - Airport surface surveillance (cockpit)
   - Final approach and runway occupancy awareness (cockpit)
   - CDTI Assisted Visual Separation (CAVS)
   - Merging and Spacing to Final Approach Fix
   - Continuous Descent Approaches
   - Self-separation / Station keeping
   - In-trail climbs / descents

   Data Uplink Enabled Applications
   - Cockpit weather information
   - Cockpit airspace information
   - Airport diagrams

5. What do you see as the major barriers or concerns regarding ADS-B implementation and operational use?

6. Does the plane(s) that you fly have an IFR-certified GPS receiver? What kind?

7. Does the plane(s) that you fly have a MFD or EFB? What kind?

8. Does the plane(s) that you fly have datalink weather? What kind? What are the problems or limitations of the datalink weather?

9. What factors affect your decision to upgrade your avionics?

Appendix D: Online Survey Forum

Page 1:

MIT ICAT ADS-B Survey

Recently the FAA began the process of implementing of Automatic Dependent Surveillance-Broadcast (ADS-B) in the US. The ground infrastructure is expected to be complete by 2014 [1], and the FAA is considering requiring ADS-B in certain classes of airspace in the 2020 time frame [2].

The MIT International Center for Air Transportation, in the Department of Aeronautics and Astronautics, is working with the FAA to investigate applications and benefits of ADS-B technology and user equipage. We are conducting surveys with stakeholders (pilots, operators, owners, manufacturers, etc.) to get their views on the uses of this technology because the potential benefits, costs, barriers, and operational concerns will vary for different stakeholders.

No knowledge of ADS-B technology is required to complete this survey.

The survey will take about 10-15 minutes to complete. This survey is voluntary. It is not necessary to answer every question, and you may stop the survey at any time. You will not be compensated for this survey.

Data from this survey will be used by the MIT International Center for Air Transportation for ongoing research on technology in the National Airspace System. This survey will be useful in informing the FAA on ADS-B implementation, however it is only advisory and other factors may influence the final ADS-B implementation plans.

If you have any questions about this survey, please contact Ted Lester (elester@mit.edu) or Professor John Hansman (rjhans@mit.edu).

Click here to begin the survey

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[1] Hughes, David. "FAA Administrator Says ADS-B Going Nationwide by 2014". Aviationweek.com. 3 May 2006.
[2] "ADS-B by 2020?". AOPA ePilot. 9 (3), 19 Jan 2007.

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MIT ICAT ADS-B Survey

Background

Pilot rating:

Total hours (*estimate*):

Do you hold an instrument rating? ☐ Yes ☐ No

Do you own your own aircraft? ☐ Yes ☐ No

What type of aircraft do you primarily fly?

[▼]

What is your primary type of operation?

[▼]

If you participate in more than one type of operation, please choose your primary type, and answer the rest of the survey with regards to that type.

Home base (ICAO identifier, if known): [ ]

Region(s) where your aircraft(s) operate: *(select up to 3)*

[▼][▼][▼]

What percent of your flight time is in areas outside of ATC radar coverage?

[ ] **%**

In what location, outside of ATC radar coverage, do you operate in the most?

[▼]

ADS-B Applications

[1]

ADS-B (Automatic Dependent Surveillance - Broadcast) is a surveillance technology where each aircraft broadcasts its altitude, heading, GPS-driven position, and other information to ground stations and to other aircraft. This broadcast data, represented by the green lines above, is known as **ADS-B Out** information. Ground stations will receive the ADS-B Out aircraft information for display on air traffic controllers' screens. Because the ground stations are less expensive than existing radar installations, they can be installed in more locations giving controllers radar-like coverage and control in non-radar environments.

Other equipped aircraft will receive the aircraft information for in cockpit traffic displays. Receiving and displaying ADS-B information in the cockpit is known as **ADS-B In**. Additionally, ground stations are able to uplink data such as weather and airspace information to aircraft using the ADS-B link.

Assuming that all the necessary infrastructure were in place and your aircraft is equipped, please consider the following applications of ADS-B technology and rank the potential benefits of the application **to your operations**. For each application, please select from the following scale considering financial, efficiency, safety, and other operational benefits **to you or your organization**:

- **N/A:** not applicable to your type of operation

- **No benefits:** application would not lower expenses, increase efficiency, or increase safety

- **Some benefits:** application would marginally lower expenses, increase efficiency, or increase safety

- **Significant benefits:** application would considerably lower expenses, increase efficiency, or increase safety

Non-Radar Airspace "ADS-B Out" Applications

The first set of applications relate to **ADS-B Out** technology where each aircraft broadcasts its position, altitude, airspeed, trend information, and aircraft ID to ground stations in areas where there is **no existing ATC radar coverage** (at low altitudes and in mountainous, remote, and over water areas). This data is fed to ATC to produce radar-like displays of traffic information for controllers and other interested parties.

Application	N/A	No benefits	Some benefits	Significant benefits
Operation Center/Company/Online flight tracking of aircraft in the non-radar environment based on ATC data feed	☐	☐	☐	☐
Radar-like IFR separation in the non-radar enroute environment	☐	☐	☐	☐
Increased VFR flight following coverage outside of radar coverage	☐	☐	☐	☐
Increased airport surface awareness from the air traffic control tower	☐	☐	☐	☐
Increased final approach and runway occupancy awareness from the air traffic control tower	☐	☐	☐	☐

Radar Airspace "ADS-B Out" Applications

The second set of applications derive from the fact that the **ADS-B Out** information from each aircraft sent to air traffic controllers is better than existing radar-based information **in existing radar airspace**. ADS-B has a faster update rate, more accurate position reporting, heading, and velocity as well as aircraft ID.

Application	N/A	No benefits	Some benefits	Significant benefits
Better air traffic control traffic flow management of enroute sectors and busy terminal areas	☐	☐	☐	☐
Increased enroute capacity	☐	☐	☐	☐
Improved Operation Center/Company/Online flight tracking in the existing radar environment due to better data	☐	☐	☐	☐
Monitoring of closely space parallel approaches allowing more utilization of parallel runways	☐	☐	☐	☐
Reduced separation standards	☐	☐	☐	☐
More accurate search and rescue response	☐	☐	☐	☐

"ADS-B In" Traffic Display Applications

The third group of ADS-B applications is enabled by **ADS-B In** technology where the ADS-B Out information described above is received by individual aircraft in addition to ground stations, so that **traffic is displayed in the cockpit** on a dedicated display, a multifunction display (MFD), or an electronic flight bag (EFB), similar to the notional display below.

[2]

Application	N/A	No benefits	Some benefits	Significant benefits
Enhanced visual acquisition allowing pilots to identify other aircraft visually in VFR or Marginal VFR conditions	☐	☐	☐	☐
Airport surface surveillance, allowing pilots to view other vehicles operating on the airport surface	☐	☐	☐	☐
Final approach and runway occupancy awareness	☐	☐	☐	☐
Increased ability to maintain visual separation in VFR or Marginal VFR conditions	☐	☐	☐	☐
Merging and spacing to a final approach fix	☐	☐	☐	☐
VFR-like separation standards in all weather conditions	☐	☐	☐	☐
Self-separation or station keeping	☐	☐	☐	☐
In-trail climbs and descents while maintaining separation from a lead aircraft on the same route	☐	☐	☐	☐

"ADS-B In" Data Link Applications

The final set of **ADS-B In** applications relate to **data uplink** enabled applications, where data from the ground can be uplinked to the cockpit to a display similar to the notional display below.

[3]

Application	N/A	No benefits	Some benefits	Significant benefits
Display of real-time weather information in the cockpit	○	○	○	○
Display of real-time airspace information in the cockpit	○	○	○	○

Are there any other applications of ADS-B not listed above that could provide benefits?

[text box]

For General Aviation (GA) owners and operators: If this real-time weather and airspace information was provided for free and given that there was a future mandate, how much would you pay to voluntarily equip prior to the mandate with **ADS-B In** avionics that would give access to the weather and airspace information, along with a display of nearby traffic?

[dropdown]

Aircraft Equipage

Is the aircraft you normally operate currently equipped with a . . . *(check all that apply)*

☐ IFR Certified GPS? ☐ IFR Certified GPS with WAAS?

☐ Panel Mounted VFR GPS? ☐ Portable GPS?

What GPS model(s)?

```
[                                    ]
```

Is the aircraft you normally operate currently equipped with a . . . *(check all that apply)*

☐ Multifunction Display (MFD)? ☐ Electronic Flight Bag (EFB)

What MFD/EFB model(s)?

```
[                                    ]
```

Is the aircraft you normally operate currently equipped with datalink weather receiver?

◯ Yes ◯ No

If yes, what datalink receiver model?

```
[                                    ]
```

Is the aircraft you normally operate currently equipped with ADS-B Out transponder?

◯ Yes, UAT ◯ Yes, 1090-ES ◯ No ◯ Don't Know

If yes, what model transponder?

```
[                                    ]
```

Is there anything you would like to add?

If you would be willing to be contacted to answer follow up questions, please enter your email address (optional):

Click Here to Submit

[1] http://www.ads-b.com/home.htm
[2] Bobby Nichols. "Surveillance and Broadcast Services Program Overview."

Presentation to NWAAAE. 3 Oct 2006. Available at
http://www.adsb.gov/briefing_nwchapter.htm
[3] ibid

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MIT ICAT ADS-B Survey

Thank you for taking the time to complete this survey. If you have any further questions, please contact Ted Lester (elester@mit.edu) or Professor John Hansman (rjhans@mit.edu).

Appendix E: Application Benefits by Stakeholder

Below are graphs showing the number of online survey participants in each stakeholder group who indicated "Significant Benefits" for each application.
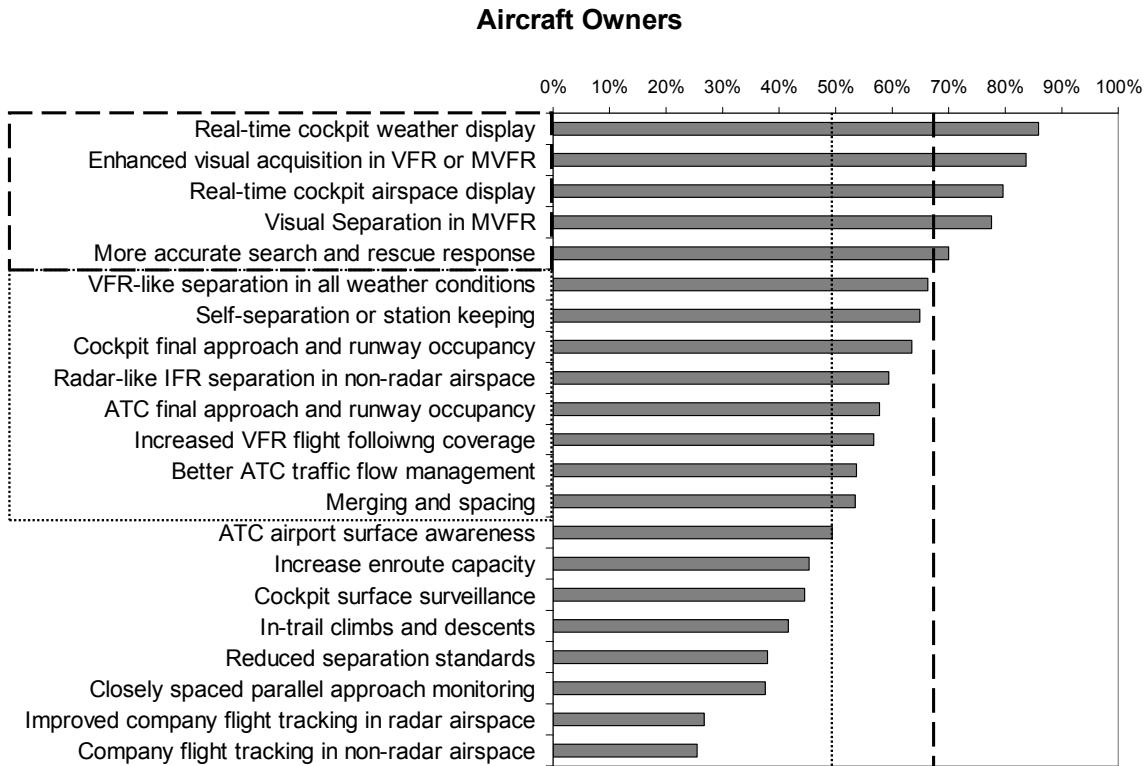
Aircraft Owners

Figure 28: Percent of aircraft owners indicating significant benefits on the online survey

Part 91 Recreational Airplane
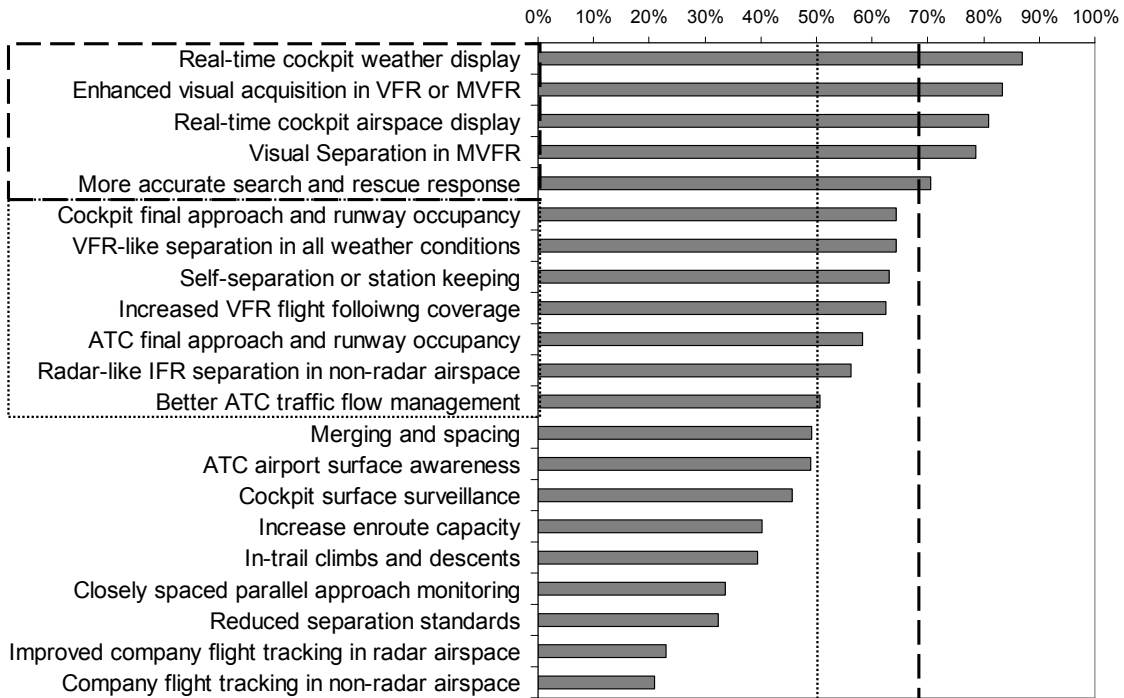
Figure 29: Percent of Part 91 recreational airplane pilots who indicated significant benefits on the online survey

Part 91 Business Airplane

Figure 30: Percent of Part 91 business airplane pilots who indicated significant benefits on the online survey

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Part 91 Flight Training Airplane

Figure 31: Percent of Part 91 flight training airplane pilots indicating significant benefits on the online survey

Part 91 Commercial Airplane

Figure 32: Percent of Part 91 commercial airplane pilots indicating significant benefits on the online survey

117

Part 121 Airplane
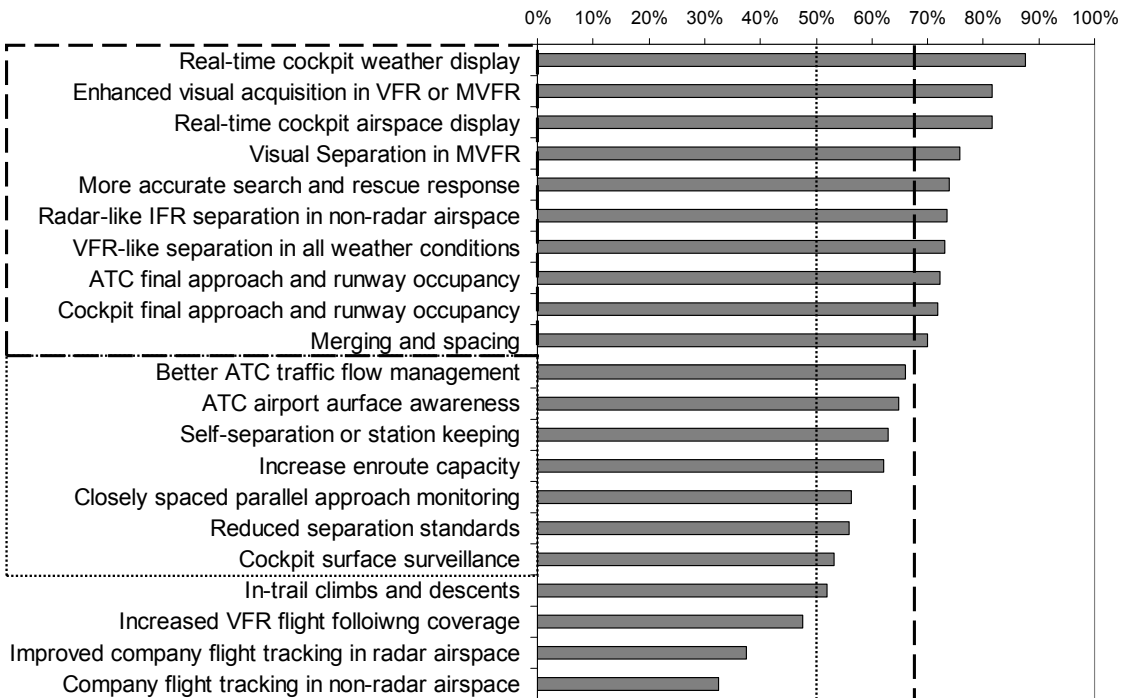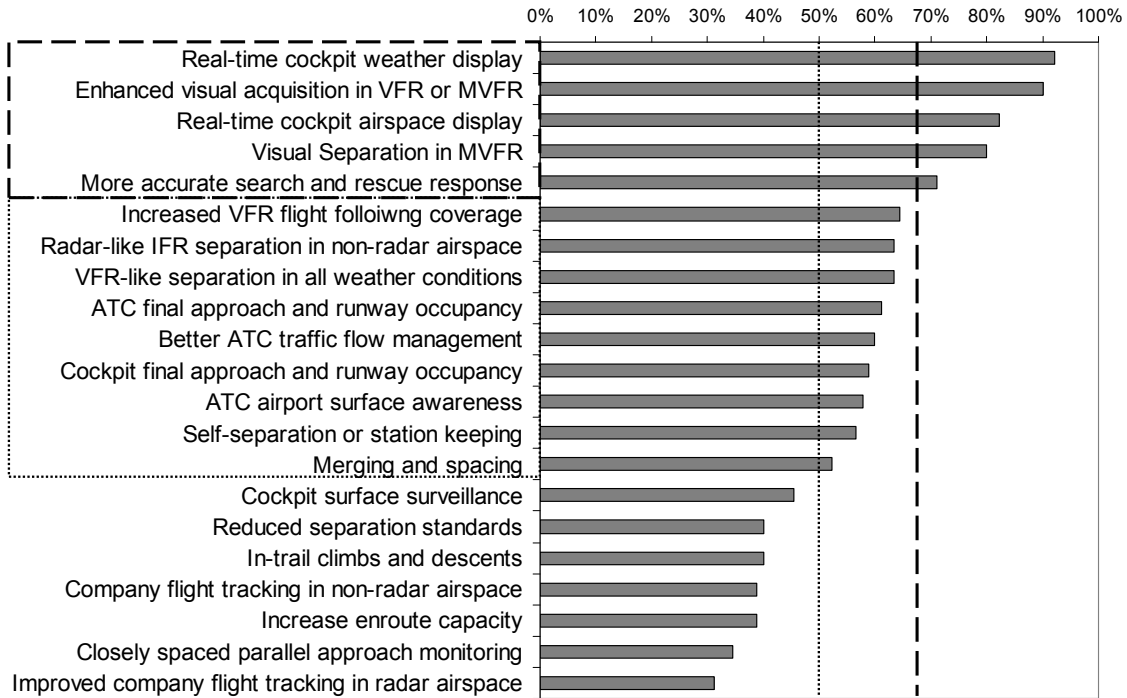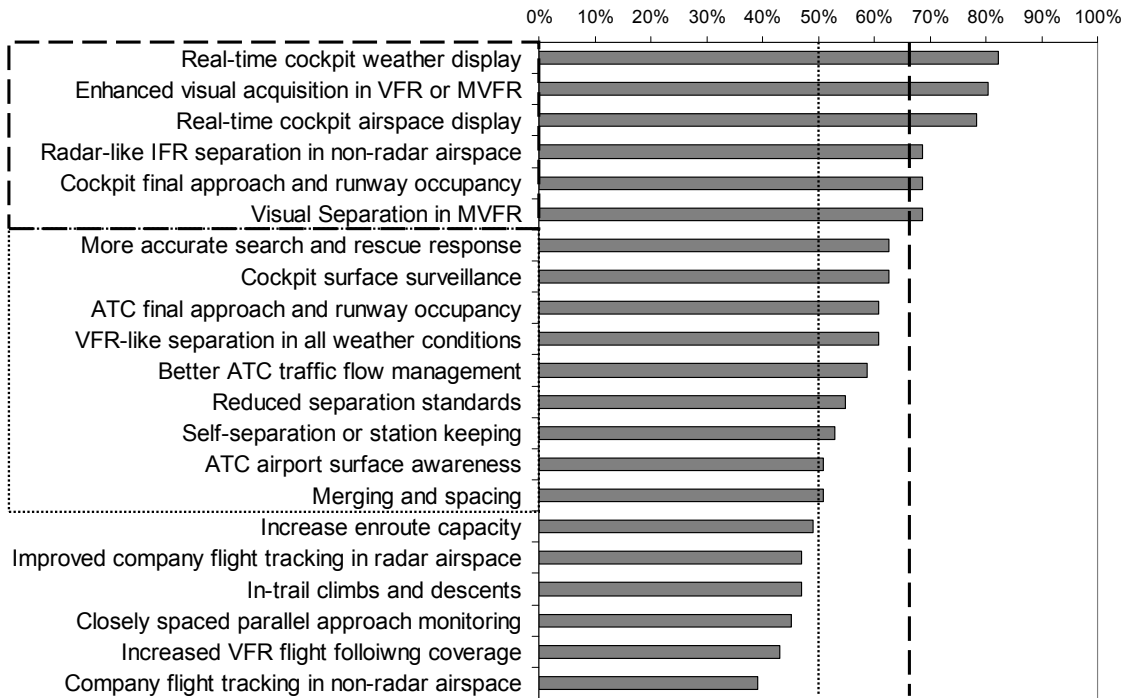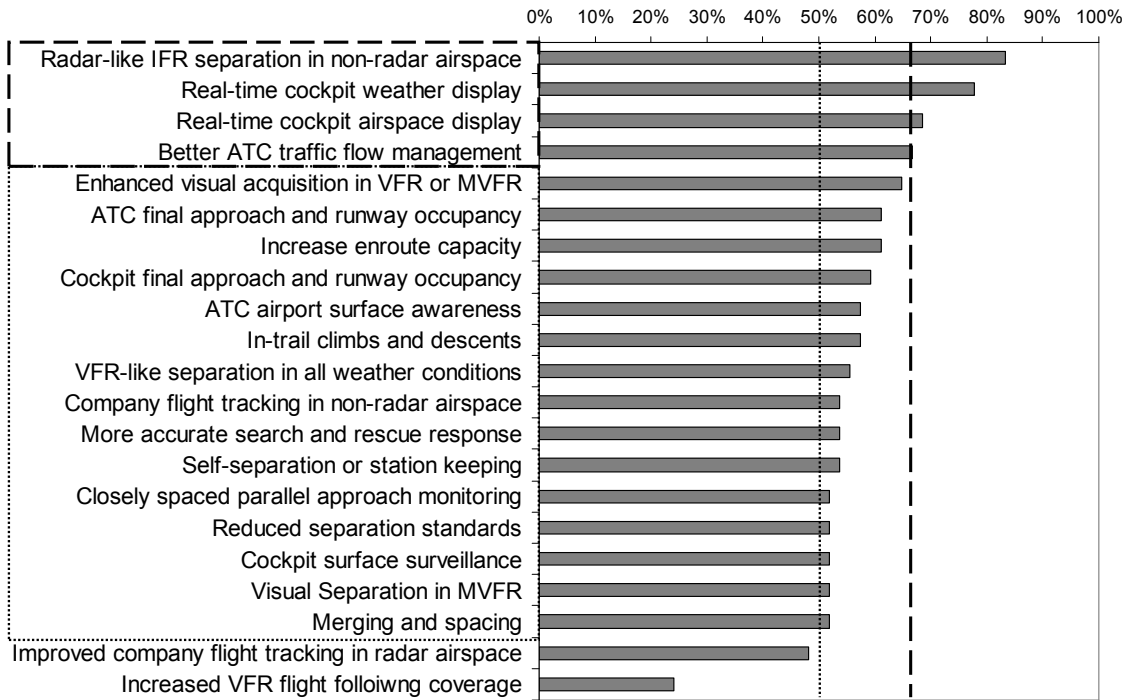

Figure 33: Percent of Part 121 airplane pilots indicating significant benefits on the online survey
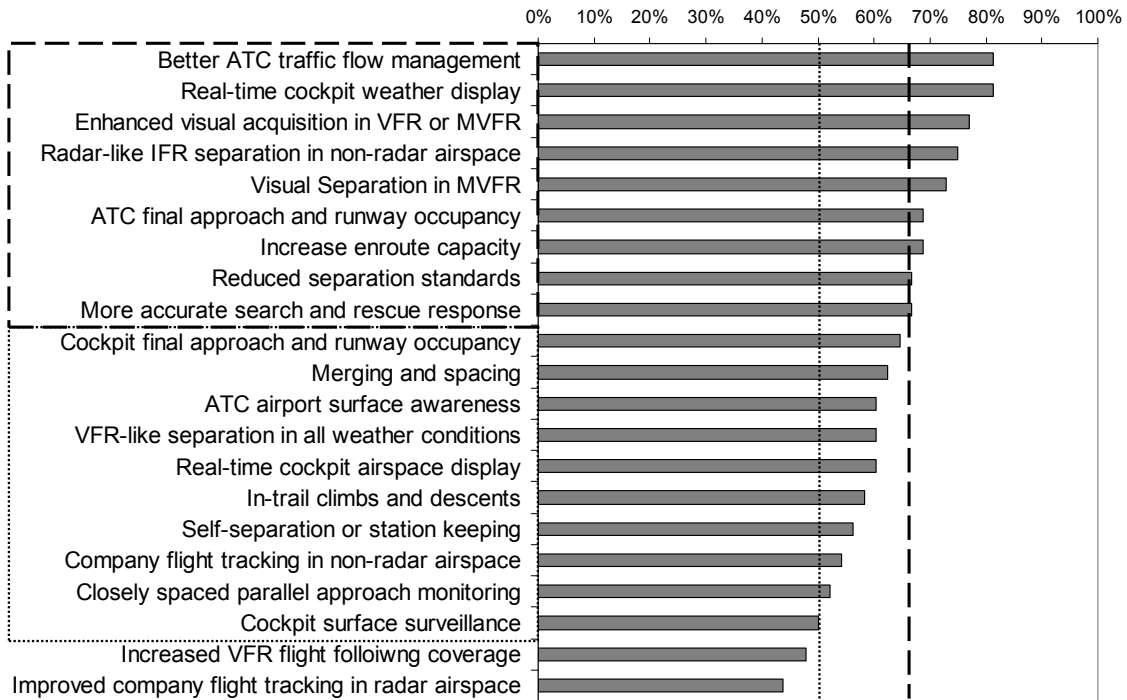
Part 135 Airplane

Figure 34: Percent of Part 135 airplane pilots indicating significant benefits on the online survey

Appendix F: Hawaiian Helicopter Local Benefits Analysis[1]

F.1 Motivation

In response to the September 24, 2004 crash of a Bell 206B helicopter being operated under 14 CFAR Part 91 by Bali Hai Helicopter Tours, Inc on the island of Kauai in Hawaii the National Transportation and Safety Board (NTSB) issued nine recommendations to the Federal Aviation Administration (FAA) [7]. Several of those recommendations relate to Automatic Dependent Surveillance-Broadcast (ADS-B) technology including:

> Accelerate the implementation of automatic dependent surveillance-broadcast (ADS-B) infrastructure in the State of Hawaii to include high-quality ADS-B services to low-flying aircraft along heavily traveled commercial air tour routes. (A-07-25)

ADS-B ground infrastructure is currently planned to be installed in Hawaii between 2010 and 2013 as part of the National Airspace System (NAS) wide implementation of ADS-B. Current plans call for ADS-B coverage to be focused on areas of existing radar coverage. However, a large majority of the commercial air tour routes are conducted in regions outside of existing radar coverage due to mountainous terrain and limited radar facilities. The NTSB recommendation would therefore require a change to the ADS-B implementation plans.

In addition the NTSB recommended mandating ADS-B equipment for air tour operators:

> Require that Hawaii air tour operators equip tour aircraft with compatible automatic dependent surveillance-broadcast (ADS-B) technology within 1 year of the installation of a functional National ADS-B Program infrastructure in Hawaii. (A-07-26)

This would also require a change in ADS-B implementation. Currently, the FAA does not plan on mandating ADS-B out equipage until around 2020, and then only in class A, B, and C airspace. In Hawaii, only Oahu and Maui have class B

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[1] This section is adapted from a previously release report. E. Lester, R. Hansman. (2007, June). "Preliminary Analysis of Potential ADS-B User Benefits for Hawaiian Helicopter Air Tour Operators." ICAT-2007-1. [Online]. Available: http://dspace.mit.edu/handle/1721.1/37596

or class C airspaces, thus many air tour operators would not be required to equip with ADS-B out under the existing plan.

An alternative approach to address the NTSB recommendations outside an early mandate would be to establish a Memorandum of Agreement similar to that currently established for the Gulf of Mexico with Helicopter Association International (HAI). The agreement established a collaborative agreement, where the FAA will provide ADS-B ground infrastructure and separation services for offshore helicopters, while the HAI operators agreed to equip their helicopters and grant use of off-shore oil platform space for ADS-B equipment. If a similar agreement could be reached between the FAA and Hawaiian air tour operators, the ground infrastructure could be in place and operators equipped sooner than 2020, and the ADS-B implementation could attempt to provide focused benefits for Helicopter air tour operators.

The objective of this study is to identify helicopter air tour operator requirements and potential ADS-B applications which would provide user benefits sufficient to justify early equipage with ADS-B technology. In order to identify user requirements a series of focused interviews, surveys and a flight observation were conducted during a joint FAA / HAI Helicopter Air Tour safety summit in Honolulu on May 22-23, 2007.

F.2 Method

User input was obtained through a survey instrument and focused interviews with participants in the Joint FAA / HAI Helicopter Air Tour safety summit.

The conference was attended by over 50 representatives from 19 Hawaiian air tour operators, representing a significant majority of the helicopter air tour operators in Hawaii (80% of the operators listed on the Hawaii Visitors and Convention Bureau website [62] attended, plus an additional 9 operators). The participants consisted of Chief Pilots, Directors of Operations, Maintenance Directors, Presidents, and CEOs.

ADS-B was briefed to the participants by the FAA Surveillance Broadcast Systems program office. In conjunction with the briefing, written surveys were distributed to the air tour operators. A copy of the survey instrument is presented in Appendix G.   Surveys were completed by 44% of the Hawaiian helicopter air tour operators in attendance as well as two surveys completed by

fixed-wing air tour operators in Hawaii, and one completed by a Hawaiian FSDO inspector who is also a commercially rated helicopter and fixed-wing pilot.

Focused interviews were conducted with sixteen representatives of air tour operators using the interview question protocol in Appendix 2 as a guide. Due to intensive nature of the summit and the limited time to interview many of these interviews were conducted in groups. As part of the interviews, operators were asked to trace their flight routes on FAA sectional charts. A compilation of these sketched routes can be found in Appendix I.

In total, feedback was collected from 84% of the Hawaiian air tour operators present at the safety summit. The survey and interview participants are listed in Appendix J.

In order to assess operational considerations, a site visit and flight observations were conduced during a typical air tour flight around the island of Oahu. The flight was conducted on an Aerospatiale AS350BA "A-Star" helicopter, operated by Makani Kai Helicopters departing from Honolulu International Airport (Figure 35). During this site visit additional input was solicited from the president and operations manager. The flight route was typical of a normal tour and is shown in Figure 36.

Figure 35: AS350 Helicopter Operated by Makani Kai Helicopters

Figure 36: Standard Oahu tour route flown during the observational flight

F.3 Operational Environment

Air tour operators in Hawaii conduct their business in a unique operating environment, based on details obtained during the interviews and field observations. The air tours usually consist of flights of fifteen minutes to an hour, departing and arriving from the same airport or heliport with upwards of 6 passengers. The tours are conducted primarily in Aerospatiale ES350 A-Star and Bell 206 single turbine helicopters, however at least one operator uses piston powered R44s and another uses Augusta A109 twin turbine engine helicopters.

The tours are conducted over the coast, over mountainous terrain, and in small canyons. A sample route map for the island of Kauai can be seen in Figure 37. A complete set of maps for routes flown by the interviewees is in Appendix I. The operators must also deal with the low clouds and rain which are common with the Pacific trade-wind driven weather patterns on the Hawaiian Islands, where

moist air from the ocean is driven up the windward slopes creating a cloud layer below a larger scale temperature inversion.63 This causes larges amounts of rain in some areas of the islands, with the rainiest part being Mt. Waialeale on Kauai with an annual average rainfall of approximately 450 inches. This contrasts greatly with the leeward coasts and high slopes which can see an annual rainfall of less than 10 inches.
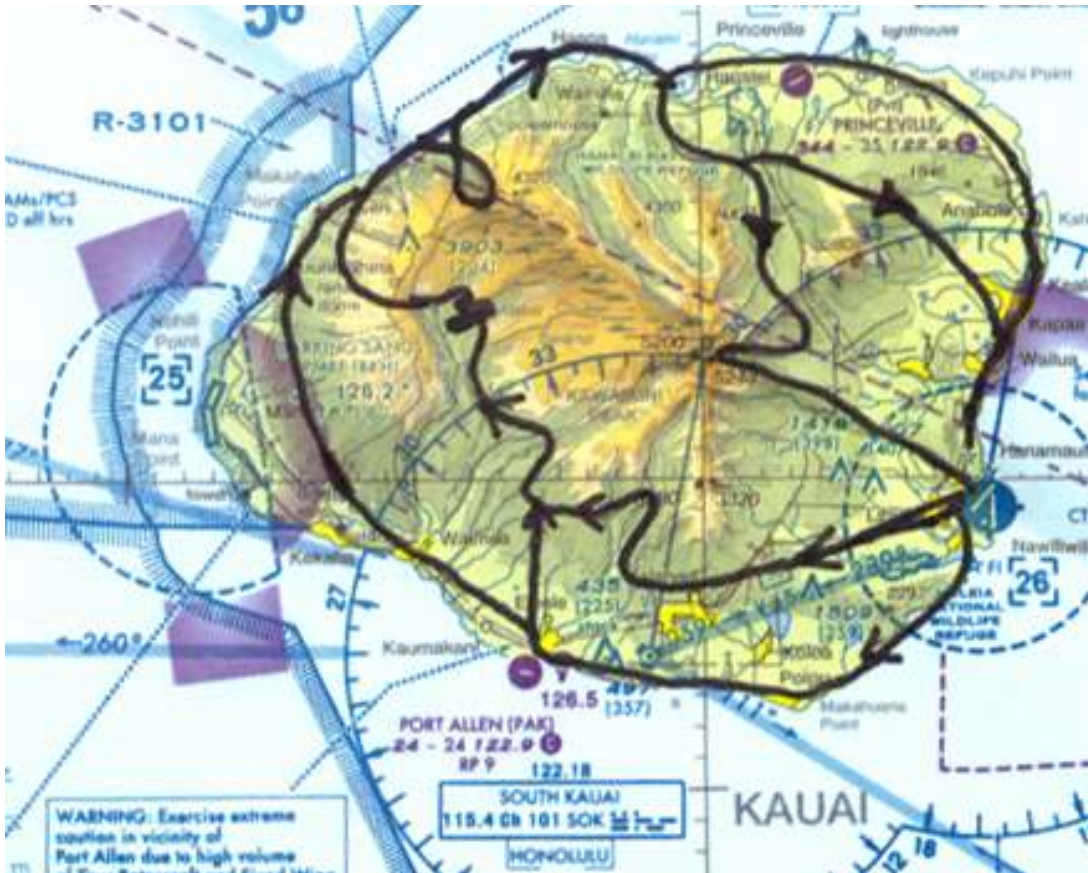
Figure 37: Variety of air tour routes on Kauai.

The coastal routes are used during periods of low ceilings, while the inland routes are preferred.

Compounding the weather impacts on Hawaiian helicopter operators is the minimum altitude restriction placed on Hawaiian air tour operators under 14 CFAR Part 136 Appendix A (formally SFAR 71). This restriction, in effect since 1996, restricts air tour operators to a minimum altitude of 1500 feet, as opposed to the standard minimum altitude of 300 feet for Part 135 helicopter operators (14 CFAR 135.203 b). While the full grounds for this rule creation were not investigated, anecdotal accounts indicate that it was driven by both safety and noise abatement concerns. This restriction limits the ability of tour operators to launch with low clouds. Unfortunately the 1500' rule may actually increase noise

impact since when the weather deteriorates, operators fly over the low, populated coastal areas.

Based on the interviews and comments during the safety summit question and answer period, most operators have FSDO-granted deviations from the 1500' rule in certain places, allowing 1000' or 500' ground clearance. However, the standard is still 1500' for non-scenic segments of the route.

The NTSB has concerns that the "SFAR 71 altitude restrictions may increase the potential for inadvertent encounters with could layers", yet the NTSB determined that there is not enough data to asses the significance of this relationship. One operator noted that there have been 19 fatalities on the island of Kauai alone since the enactment of SFAR 71, and directly attributes them to the altitude restriction and the increased chance of VFR into IMC encounters. While this obviously stretches the diverse causes of the accidents, it illustrates the operators' strong safety concerns with the 1500' rule.

F.4 Survey Results

F.4.1 Benefits

In general helicopters air tour operators in Hawaii were receptive to the implementation of ADS-B technology in Hawaii, especially after they learned more about the technology. 100% of the survey participants saw value in ADS-B services (question 7, Appendix G), but 22% wrote that the benefits would be "limited" or "little."

Survey participants were presented with a list of potential applications to indicate if they would have "significant benefits", "limited benefits", "no benefits" from the given application for their operation considering financial, efficiency, safety, and other operational benefits. As can be seen in Figure 38, the applications with strongest benefits from surveys, with 44% or more of the participants indicating significant benefits, are company flight tracking, increased VFR flight following, enhanced visual acquisition, cockpit assisted visual separation (CAVS), and cockpit datalink weather.
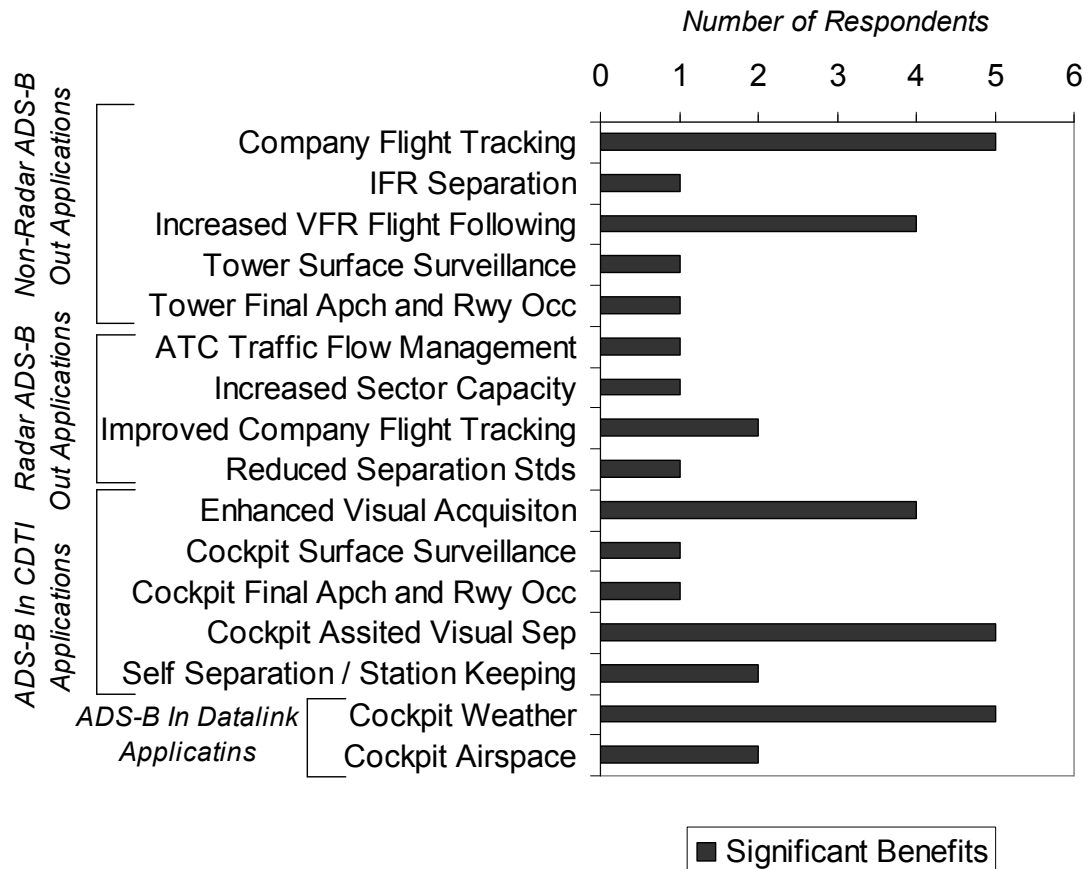
Figure 38: Survey results listing the number of participants who marked significant benefits for each application

As expected, categories with IFR-only benefits, such as ATC traffic flow management and increased sector capacity, had little appeal to the helicopter air tour operators who operate in a VFR-only environment. Additionally, airport applications for surface surveillance or final approach awareness are of little use to helicopter operators.

In additions, when asked what other applications would provide benefits to the air tour operations, participants listed NOTAMs via datalink, two way communications with the office (brought up by two survey participants), make and model of aircraft ahead for wake turbulence (from a fixed wing operator), and tracking of aircraft for search and rescue and precautionary landings (brought up by both an interviewee and another operator during the open question and answer period). The communication and flight tracking applications are analyzed in detail below in the Primary Focused Interview Findings section.

F.4.2 Equipage

Approximately two thirds of operators have GPS equipped aircraft, but a majority of those are VFR panel mounted units. The helicopter used for the observational flight had VFR GPS, but it was not used at all by the pilot during the air tour. No operators currently have MFDs, EFBs, or datalink weather capabilities. Half of the operators have Mode-S transponders. Therefore, there is almost no latent capacity to equip with ADS-B technology, besides the possible upgrades to the Mode-S transponders for 1090-ES ADS-B out. Operators will need to equip with GPS receivers certified to IFR standards in order to meet the accuracy and integrity ADS-B performance requirements. Additionally, operators will need to install certified displays for ADS-B in applications.

When asked "What are the factors which would affect your decision to voluntarily equip with ADS-B or other avionics equipment?", 75% of the participants for the question listed price or cost of avionics. In addition, 50% listed weight as a concern. Similar responses were given to the question, "What are the obstacles you see in equipping your fleet with ADS-B equipment?". 5 operators listed weight as a concern, with one participant writing, "How much the pilot weighs is already an issue". 6 operators listed financial concerns and 5 listed size or panel space concerns.

These concerns highlight the fact that operators will consider cost, size, and weight of avionics in addition to benefits when deciding whether or not to equip.

F.4.3 Other

A majority of the survey participants projected that the number of air tour operations would continue to increase in Hawaii, agreeing with the NTSB statement that, "As Hawaii's air tour industry continues to grow, increasing numbers of aircraft will be flying over rugged, scenic terrain in a finite airspace." However, one operator noted that the number of passengers will always be finite and the air tour industry will reach a limit. Another commented that he wasn't sure the number of aircraft will continue to climb. This also conflicts with a statement by the president of a Maui-based tour operator, who wrote that the "numbers indicate air tour in Hawaii are on the decrease not growing." Finally, the owner of a seaplane business in Honolulu for many years indicated that there are a decreasing number of air tours in Oahu and fewer operators than 10 to 20

years ago. Further investigation is needed on the trends of the air tour industry in Hawaii.

F.5 Primary Focused Interview Findings

Based on the focused interviews, the following four findings were consistent across the all interviews and identified by at least 50% of the Hawaiian helicopter operators interviewed.

1. *Hawaii specific weather products must be provided.*

Weather information is the greatest benefit of ADS-B technology cited by operators. One Director of Operations claimed that weather and lack of weather information are the leading causes of flight cancellations. This is consistent with the survey results, where all of the participants found significant or limited benefits to cockpit weather information, with a majority selecting significant benefits.

However, during the interviews it became apparent that the weather information needed by the helicopter air tour operators is not the same information needed for enroute fixed wing operations and reflected in the current ADS-B UAT datalink weather products. The METAR, TAF, and area forecast do not reflect the diverse and rapidly changing weather patterns in Hawaii. Radar and satellite images are useful for seeing approaching or building storms, but alone they do not provide enough data for a go/no go decision or in-flight decision making.

Operators need to be able to identify weather around the corner and on the opposite side of an island, especially ceiling and visibility. Currently operators rely on sources outside of official National Weather Service products for obtaining weather information, obtaining a briefing from the flight service station, which usually consists of "VFR Not Recommended", as a formality. From the ground, the operators call civilians living or working in key sites to ask about cloud heights and visibilities in relation to known mountains and passes or call both military and civilian air traffic control towers to speak with the controllers about the current local weather.

Once airborne, pilots relay informal pilot reports (PIREPs) over the common traffic advisory frequency (CTAF), to other operators. However, these CTAF

communications are limited to line of sight communication, so reports of weather on the other side of an island cannot be heard by the helicopters' base of operations or even from a helicopter on one side of a ridge to the other. This voiced based weather reporting system was observed during the observational flight, along with details of an operator ahead waiting for a pass to clear due to low clouds.   The complex weather of the Hawaiian Islands was also observed on the flight, with some areas of Oahu covered with low clouds and rain (Figure 39) while others just a 15 minute flight away (approximately 15 nm) had only scattered clouds (Figure 40).

Numerous operators expressed interest in the possibility of weather cameras located in key sites for observing the weather. This came after a presentation at the air safety summit by Nancy Schommer on the FAA's Weathercam project in Alaska, where low cost weather cameras have been placed at key sites such as passes across the state and the feeds are available free on the internet. Operators in Hawaii claimed that a similar system would be invaluable in Hawaii due to the quickly changing weather patterns and lack of weather reporting stations along the air tour routes. Operators also suggested that if feeds from these weather cameras could be made available to pilots in the cockpit through an ADS-B datalink, the pilots could make better decisions about when to continue a flight during marginal weather conditions. However, further research needs to be done to see if there is bandwidth available on an ADS-B datalink for transmission of images with sufficient resolution to identify ceilings and visibilities at the weather camera locations.

Figure 39: Low clouds and rain during the observational flight

Figure 40: Scattered clouds 15 minutes later and 15 nm away on the observational flight

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2. *Voice communication enhancements must be installed with the ADS-B ground infrastructure.*

After weather information, the second most cited benefit of ADS-B technology by operators is the enhanced communication coverage provided by ADS-B ground station installations. If ground stations were installed to cover the low level tour routes, communication equipment would also need to be installed to allow air traffic control (ATC) services.

Operators were less interested in talking with ATC as they were interested in extending CTAF VHF coverage beyond line of sight to allow communications with other helicopters for informal weather reports and communication with the operator's base of operations. VHF radio repeaters could be installed at ADS-B ground stations allowing communication beyond line of sight.

One operator was considering a satellite phone system for their helicopters and thought that a service charge of $120 per month was reasonable for this service. However, technical issues prevented the equipage. This shows the willingness of operators to find ways to communicate continuously with their helicopters.

3. *Flight tracking provides targeted benefits to air tour operators.*

There is interest in the ability to track company helicopters through ADS-B technology at the base of operations. This data could be used for flight scheduling and observing deviations due to weather. One operator pointed out during the question and answer period and another noted on the survey the importance of locating helicopters quickly during precautionary or forced off-airport landings. This search and rescue capability of ADS-B is especially useful for helicopter operators who are not required to have Emergency Locator Transmitters (ELTs) on board.

As the NTSB points out, ADS-B data could also be used for internal or FAA investigations of potential altitude violations. The use of ADS-B reports by the FAA for enforcement actions troubled at least two operators since they claimed that pilots may just turn off the equipment to avoid enforcement.

4. *Cockpit traffic displays only useful if regions of mixed flight activity with equipped fixed wing operators.*

42% of Hawaiian operators in the interviews had less interest in cockpit traffic displays than cockpit weather information and enhanced voice communications. Currently separation is conducted visually through the aid of pilot position reports broadcast on the CTAF. This voluntary voice based coordination of positions was observed during the observational flight. No operators utilize a Traffic Collision Avoidance System (TCAS) or a Traffic Awareness System (TAS) on their helicopters. The air tour operators maintain order by flying similar routes in the same direction, maintaining a single file line.

The primary interest in traffic displays is in areas of mixed flight activity. As one large operator put it, the concern is not with other helicopter air tour traffic but with fixed wing and military flights. Occasionally, the helicopters will be orderly orbiting over a scenic location like a crater, when a small single engine fixed wing aircraft will fly right over the scenic location causing the helicopters to "scatter". Operators usually attribute this fixed wing behavior to student pilots and pilots unfamiliar with the area, who don't use the CTAF position reporting. Operators also commented that military flights occasionally transition the air tour routes without announcing since military aircraft are usually only equipped with UHF communications equipment. Military and fixed wing ADS-B equipage must be considered integral for an ADS-B system in Hawaii to work for traffic awareness and separation.

Further study should be conducted to see if regions of mixed flight activity, such as training areas and military routes, are under existing secondary radar coverage so that TIS-B could be utilized to provide benefits to early adopters of ADS-B in technology.

F.6 Other Interview Observations

1. *Applications must be tailored to VFR not IFR operations.*

Helicopter operators in Hawaii operate exclusively under visual flight rules (VFR). Thus many of the applications and benefits, such as merging and spacing, that are proposed for fixed-wing operators in the IFR-based ATC system, are not applicable to the VFR operations in Hawaii. This

consideration of VFR operations must be taken into account when developing and ADS-B system in Hawaii that is of use to helicopter air tour operators.

Both in the surveys and in the interviews, participants, especially chief pilots, expressed concern that the ADS-B technology would reduce the amount of time pilots spend with their heads "out of the cockpit" maintaining attitude, terrain separation, traffic separation, and weather separation visually, since they would be looking at displays on the helicopter panel. Another concern, cited by the director of the TOPS safety program for helicopters, is that advanced cockpit technologies send the wrong message to pilots by allowing them to get closer to IFR conditions with a false sense of comfort.

2. *Select technologies should be bundled with ADS-B to encourage operator equipage.*

While there doesn't appear to be enough support for voluntary ADS-B equipage alone, when combined with other cockpit avionics, operators are more receptive to ADS-B equipage. Based on question 15 of the survey (Appendix G), in addition to ADS-B In cockpit display of traffic information (CDTI) and data link weather information in the cockpit, 44% of participants would like to see a system combined with GPS navigation and a moving map. This is consistent with the existing general aviation ADS-B installations done for the Capstone project in Hawaii.

A Terrain Awareness and Warning System (TAWS) was requested as a bundled technology in the surveys, but to a lesser extent than CDTI and datalink weather products, only 33% of participants. This result is backed up by our interview results that found only one operator currently has TAWS equipage in their helicopters. The rest of the operators found TAWS not useful in visual conditions where the air tours operate.

One important finding from the site visit to a helicopter operator was that many operators provide live video footage to passengers on an instrument panel display as seen in Figure 41. This footage comes from multiple cameras placed around the helicopter, and is recorded for sale as a DVD to passengers after their flight. Since panel space is so restricted in the cockpit, ADS-B moving map or weather displays must be able to share a display with these video monitors. The Hawaiian operator that has already equipped their

helicopters with TAWS, uses a display that can switch between video and the TAWS alerting screen.

No operators would bundle ADS-B technology with an enhanced vision system (EVS) like forward-looking infrared (FLIR) or with a 3D synthetic vision system. This reflects the VFR-only operating environment of the air tours.

Figure 41: Air tour helicopter panel with video monitor

3. Operator concerns must be addressed prior to expecting any equipage.

Interview participants had a number of concerns. Like in the survey, size, weight, and cost concerns were brought up. As pointed out earlier, some are worried that additional avionics will keep pilots' heads in the cockpit. One chief pilot suggest that the avionics should be voice activated and that PIREPs could be recorded and transmitted to other helicopters via the datalink so that no time is spent heads down typing or reading written PIREPs. While this may not be feasible with existing ADS-B technology, the concept deserves researching for possible integration with future communication technologies.

There are also concerns that ADS-B out would be used as a surveillance tool to monitor and violate operators for 14 CFAR Part 136 Appendix A minimum altitude limit violations. It is difficult for operators to know altitude above

ground level or horizontal distance from terrain, thus the potential for strict enforcement may cause an unwillingness of operators to equip.

F.7 Hawaiian ADS-B Conclusions

There are ADS-B benefits to Hawaiian air tour operators, which center on useful weather information and enhanced communication. Flight tracking and cockpit traffic displays provide additional benefits for air tour operators. The major concerns for operators are equipment price and the potential for FAA enforcement actions based on surveillance data. When weighed with the concerns, the benefits of ADS-B out or in are not enough by themselves for widespread air tour operator voluntary equipage in Hawaii. However, operators would be interested in voluntarily equipping with ADS-B technology if it enabled relief from the 14 CFAR 136 Appendix A restrictions or if it allowed the general limit to be moved from 1500' to 300'-500'.

Appendix G: Helicopter Operator Survey

ADS-B Helicopter Operator Survey

Name: _____ Email: _____

Organization or business: _____

MIT ICAT is investigating applications and benefits of ADS-B technology in order to provide input to the FAA regarding the implementation roll-out plan of ADS-B in the National Airspace System. We are seeking input from a variety of operators and pilots throughout the country.

This survey is voluntary. You have the right not to answer any question, and to stop the survey at any time. You will not be compensated for this survey. Data from this survey will be used by the MIT ICAT for ongoing research on technology in the National Airspace System.

1. What is your role in your organization?

2. Pilot qualifications *(circle all that apply):*

   None   Private   Commercial   ATP   Fixed Wing   Rotorcraft   Instrument Rated

3. What airports/heliports do you normally operate from (use ICAO identifier if known)?

Assuming that all necessary infrastructure were in place and your aircraft were equipped, please consider the following applications of ADS-B technology and identify the potential benefits of the application **to your operations** considering financial, efficiency, safety, and other operational benefits.

Non-Radar Airspace ADS-B Out Applications

The first set of applications relates to **ADS-B Out** technology where each aircraft broadcasts its position, altitude, airspeed, trend information, and aircraft ID to ground stations in areas where there is **no existing ATC radar coverage** (at low altitudes and in mountainous, remote, and over water areas). This data is fed to ATC to produce radar-like displays of traffic information for controllers and interested parties.

Check one for each application

Application	N/A	No benefits	Limited benefits	Significant benefits
Operation Center/Company/Online flight tracking of aircraft in the non-radar environment				
IFR separation in the non-radar enroute environment				
Increased VFR flight following coverage outside of radar coverage				
Increased airport surface awareness from the air traffic control tower				
Increased final approach and runway occupancy awareness from the air traffic control tower				

(continued on back)

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Radar Airspace ADS-B Out Applications

The second set of applications derives from the fact that the **ADS-B Out** information from each aircraft sent to air traffic controllers is better than existing radar-based information in **existing radar airspace**. ADS-B has a faster update rate (1 sec), more accurate position reporting, heading, and velocity as well as aircraft ID.

Application	N/A	No benefits	Limited benefits	Significant benefits
Better air traffic control traffic flow management of enroute sectors and busy terminal areas				
Increased enroute sector capacity				
Improved Operation Center/Company/Online flight tracking in the existing radar environment				
Reduced separation standards				

Check one for each application

4. Are there any other applications of **ADS-B Out** (both in and out of existing radar airspace) not listed above that could benefit your organization?

ADS-B In Traffic Display Applications

The third set of ADS-B applications is enabled by **ADS-B In** technology where the **ADS-B Out** information described above is received by individual aircraft in addition to ground stations, so that **traffic information is displayed in the cockpit** on a dedicated display, a multifunction display (MFD), or an electronic flight bag (EFB).

Application	N/A	No benefits	Limited benefits	Significant benefits
Enhanced visual acquisition allowing pilots to identify other aircraft visually in VFR or marginal VFR conditions				
Airport surface surveillance, allowing pilots to view all other vehicles operating on the airport surface				
Final approach and runway occupancy awareness				
Increased ability to maintain visual separation in VFR or Marginal VFR conditions				
Self-separation or station keeping				

5. Are there any other applications of **ADS-B In** Traffic Displays not listed above that could benefit your organization?

ADS-B In Datalink Applications

The final set of **ADS-B In** applications relate to **data uplink** enabled applications, where data from the ground can be uplinked to the cockpit for display.

| | | *Check one for each application* | | |
Application	N/A	No benefits	Limited benefits	Significant benefits
Display of real-time weather information				
Display of real-time airspace information				

6. Are there any other applications of **ADS-B In** Datalink not listed above that could benefit your organization?

7. Do you see value in these ADS-B services as a whole? Why or why not?

Current Equipage

8. Are any of the aircraft you operate currently equipped with a … *(check all that apply)*
    IFR Certified GPS? ☐   Panel Mounted VFR GPS? ☐   Portable GPS? ☐
    What model(s)?

9. Are any of the aircraft you operate currently equipped with a… *(check all that apply)*
    Multifunction Display (MFD)? ☐   Electronic Flight Bag (EFB)? ☐
    What model(s)?

10. Are any of the aircraft you operate currently equipped with datalink weather receivers? If yes, what models(s)?

(continued on back)

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11. Are any of the aircraft you operate currently equipped with Mode-S transponders? If yes, what models(s)?

Operating Patterns and Avionics

12. What are the constraints on your business? (helicopters, tourists, pilots, competition, weather, regulations, etc.)

13. Do you agree with the following statement from the NTSB on Hawaiian helicopter operations, "As Hawaii's air tour industry continues to grow, increasing numbers of aircraft will be flying over rugged, scenic terrain in a finite airspace"?
    Yes ☐   No ☐   Why or why not?

14. Rank the following potential avionics upgrades from 1 to 8 based on operational benefits (safety, efficiency, cost savings, etc) with 1 being the most beneficial and 8 being the least beneficial:

    ___ ADS-B Out transponder
    ___ ADS-B In cockpit traffic display
    ___ ADS-B Datalink in-cockpit weather
    ___ Enhanced Vision System (EVS), like Forward Looking Infrared (FLIR)
    ___ GPS navigation
    ___ Moving map display
    ___ 3D Synthetic Vision System
    ___ Terrain Avoidance and Warning System (TAWS)

15. ADS-B Out capabilities may be combined with other avionics to create a single system for helicopter installations. What capabilities would you combine with ADS-B Out to create an affordable system which benefits your operations? *(check all that apply)*

☐ ADS-B In cockpit traffic display   ☐ Enhanced Vision System
☐ ADS-B In datalink weather   ☐ GPS navigation
☐ Moving map display   ☐ 3D Synthetic Vision System
☐ Terrain Display and Alerting   ☐ Other: _____

16. For the combined system you created above, how much would you be willing to pay?
    $

17. For the combined system you created above, how much would you expect to pay, given the current prices of avionics?
    $

18. What are the factors which would affect your decision to voluntarily equip with ADS-B or other avionics equipment?

19. What are the obstacles you see in equipping your fleet with ADS-B equipment?

20. If you decided to equip your entire fleet with a simple ADS-B Out system how long would it take if the installations were part of the normal maintenance cycle to minimize out of service costs?

    For an ADS-B In system with cockpit displays?

21. Any other comments regarding ADS-B?

Thank you for taking the time to complete this survey. We are interested in getting more detailed insight about operations in Hawaii. Please stop by the MIT booth (at the FAA booth) where several students and faculty will be taking detailed comments.

Appendix H: Helicopter Focused Interview Questions

Massachusetts Institute of Technology

International Center for Air Transportation

MIT ICAT

ADS-B Hawaii Focused Interview Questions
John Hansman, Ted Lester, MIT International Center for Air Transportation

Interviewee: _____   Date: _____

Organization: _____

☐ Part 91 Helicopter Air Tour   ☐ Part 135 Helicopter Air Tour

☐ Other: _____

Inform subject that participation is voluntary, they may refuse to answer any and all questions, and they may decline further participation, at any time, without adverse consequences. All answers will be anonymous, unless further permission is requested.

Part I: Background

1. What is your role in your organization?

2. What is your experience with ADS-B?

3. Are you a pilot? ☐ Helicopter   ☐ Fixed Wing
   If so, what is the highest certificate you hold?
   ☐ Private   ☐ Commercial   ☐ ATP

   Number of total hours?

Part II: Operational Patterns

4. What percent of your organization's pilots are instrumented rated?

5. What airports/heliports do you utilize (ICAO identifiers if known)?

6. What routes do you travel? (trace on color maps)

7. What are your low visibility or low ceiling procedures? Do the routes change?

8. How has the Hawaiian helicopter air tour 1500' rule affected your flight patterns and business?

9. What are the areas lacking radar coverage? (indicate on color maps)

10. Do you have operational problems entering or leaving radar controlled airspace? What are they?

11. What are the leading causes of your flight cancellations?

12. What are other constraints on your business? (helicopters, tourists, pilots, competition, weather, FARs...)

13. Do you agree with the following statement from the NTSB on Hawaiian helicopter operations, "As Hawaii's air tour industry continues to grow, increasing numbers of aircraft will be flying over rugged, scenic terrain in a finite airspace"? Why or why not?

Part II: Applications and Benefits

14. What do you see as the most beneficial applications of **ADS-B Out** to your business?

15. What do you see as the most beneficial applications of **ADS-B In** and Cockpit Traffic displays to your business?

16. What do you see as the major barriers or concerns regarding ADS-B implementation and operational use?

17. If you had in-cockpit datalink weather and airspace data, what weather and airspace information would you want?

Part III: Current Equipage.

18. Do you currently have ADS-B out equipment on any of your aircraft (both TSO'd or latent capacity to upgrade)? *(What models?)*
    a. Mode-S Transponders?

    b. ADS-B processing?

    c. Position sources (GPS)?

Specifically, which aircraft models are equipped?

19. Do you currently have the ability to display ADS-B information (traffic and/or weather) on any aircraft through MFDs or EFBs? If so, what systems?

20. What are your current sources of in-cockpit weather information (text, graphics, forecasts, communication with dispatch, communication with FSS, etc.)? Do you pay for these services?

Part IV: Future Fleet Equipage

21. What are the factors which would affect your decision to voluntarily equip with ADS-B or other avionics equipment?

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22. Do you currently have plans for future ADS-B equipment retrofit? New aircraft equipage? EFB (or MFD) equipage?

23. What are the obstacles you see in equipping your fleet with ADS-B equipment?

24. If you decided to equip your entire fleet with "ADS-B out" how long would it take if the installations were part of the normal maintenance cycle to minimize out of service costs?

For "ADS-B in" with cockpit displays?

25. Do you see any major ongoing maintenance issues associated with ADS-B?

Part V: Costs

26. How much per aircraft would you be willing to pay for the following capabilities installed, and how much would you expect to pay for them installed?

	Willing to pay	Expect to pay
ADS-B Out transponder		
ADS-B In cockpit traffic display		
ADS-B Datalink in-cockpit weather		
Enhanced Vision System (EVS)		
GPS navigation		
Moving map display		
3D Synthetic Vision System		
Terrain Avoidance and Warning System (TAWS)		

27. ADS-B Out capabilities may be combined with other avionics to create a single system for helicopter installations. What capabilities would you combine with ADS-B Out to create an affordable system which benefits your operations?

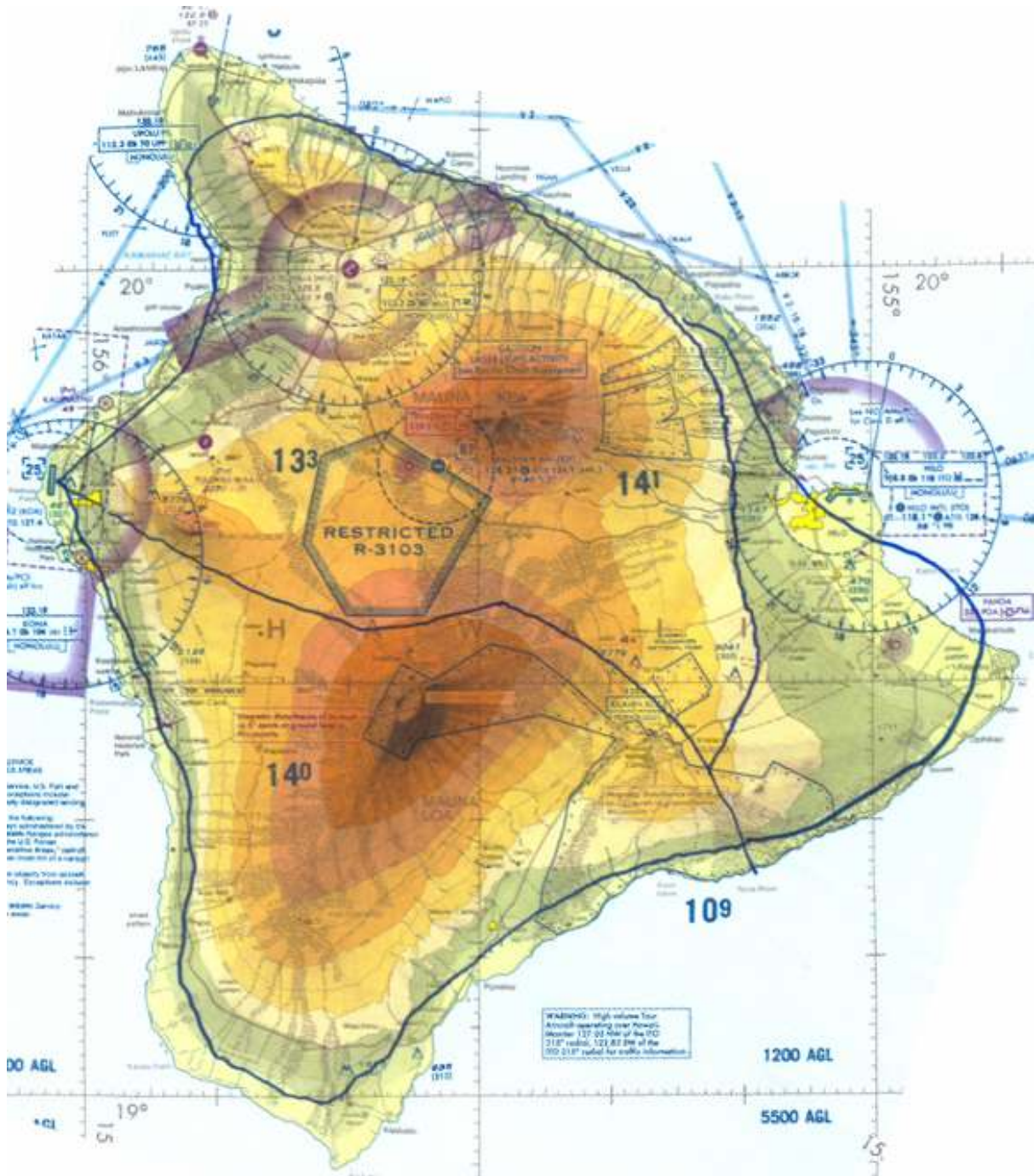How much would you expect to pay for such a system? How much would you be willing to pay?

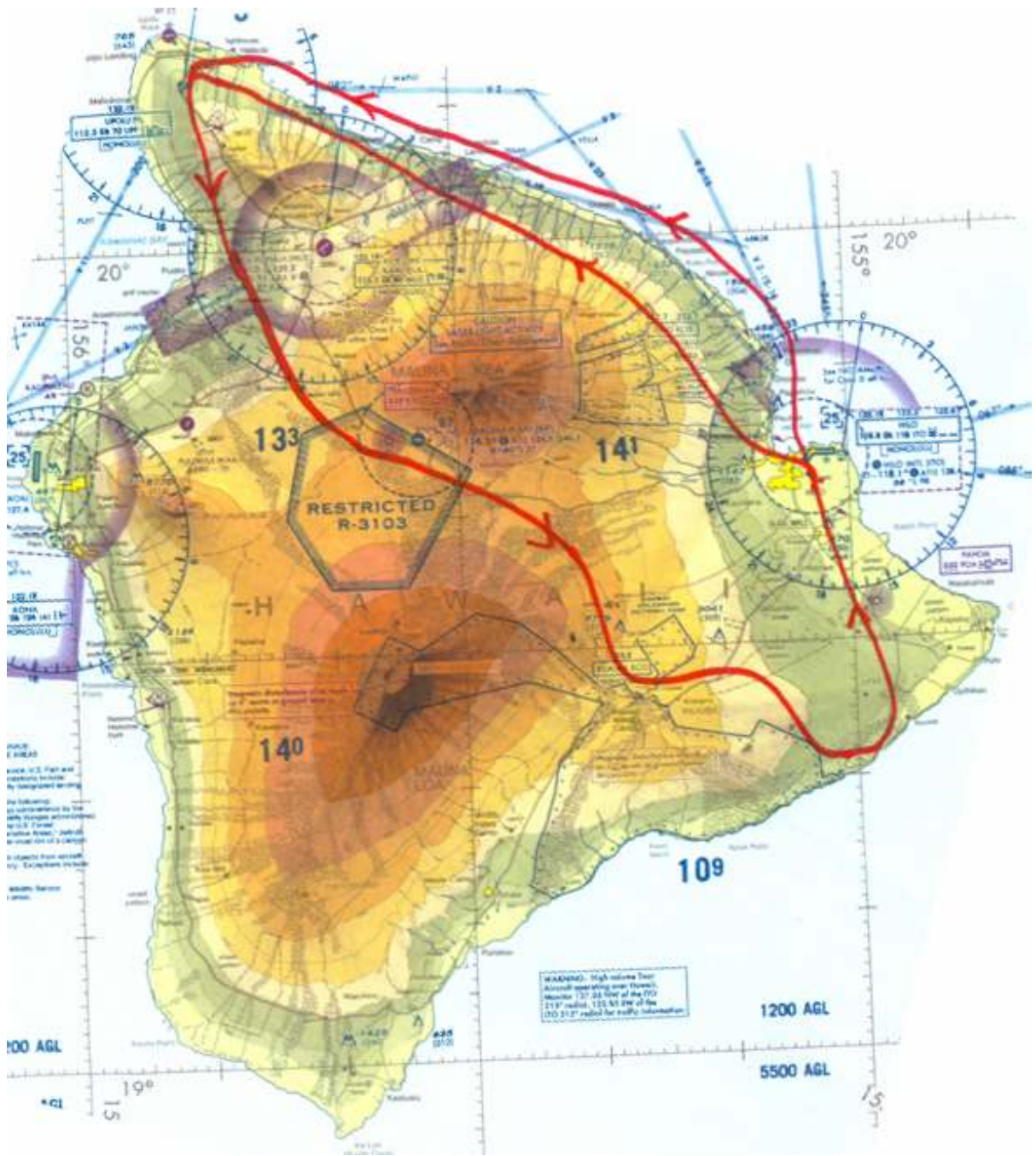28. Any other comments regarding ADS-B?
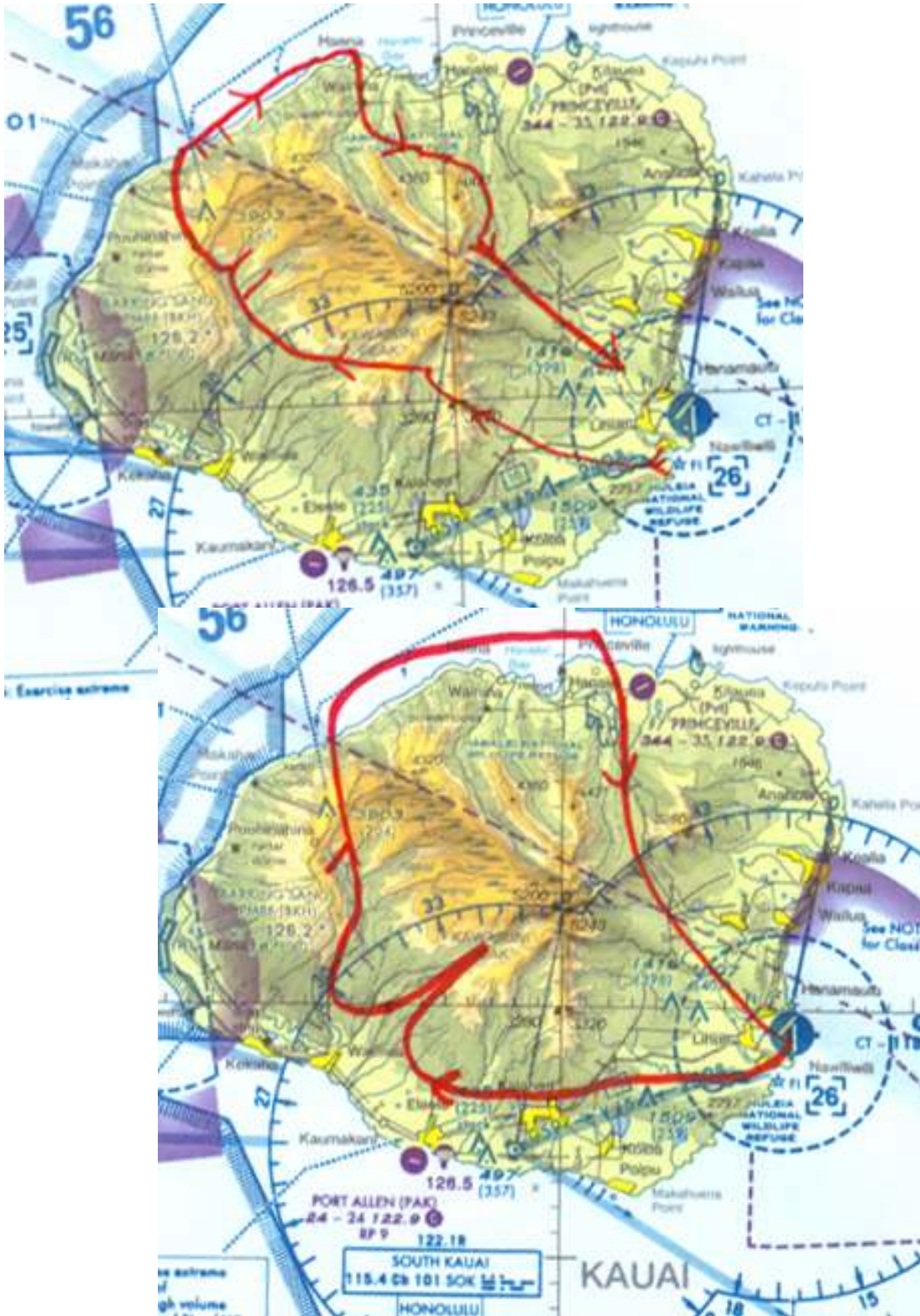
Appendix I: Route Maps

Oahu

Hawaii (Big Island)
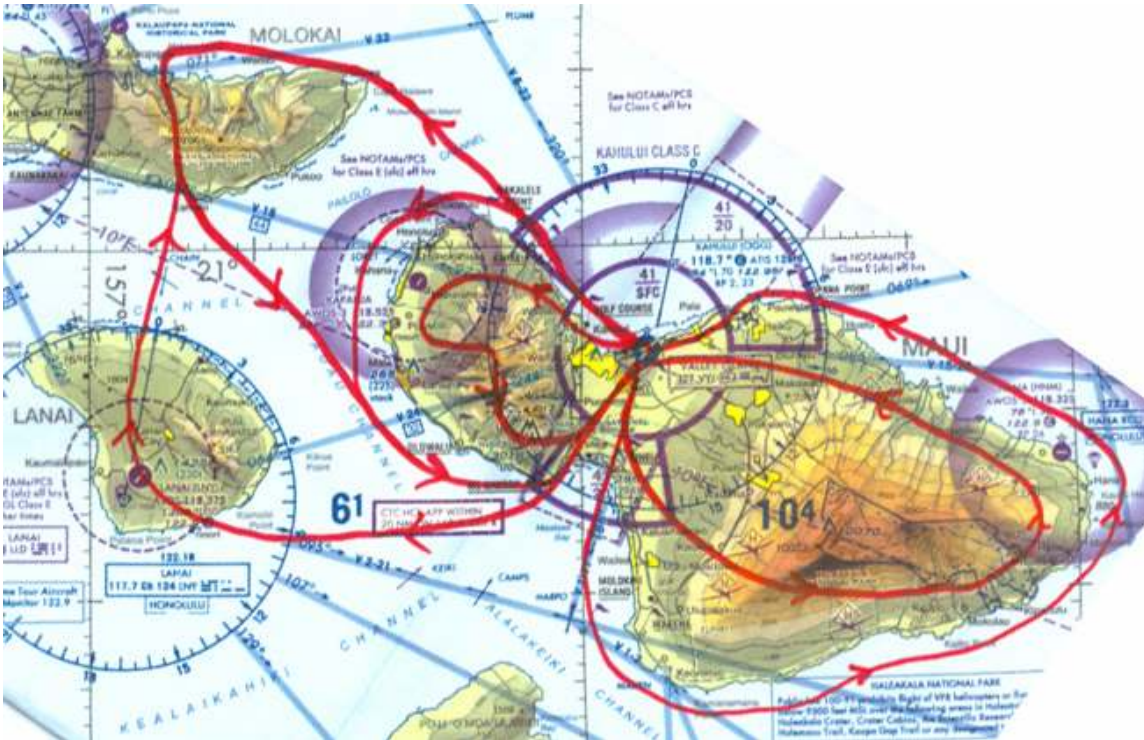
Kauai

Maui

Appendix J: Study Participants

Domestic Preliminary Focused Interview Participants

Name	Title	Organization
Bill Hall	Chief Information Officer	Citation Shares
Bill Thedford	Consultant	USAF/DoD
Bradford Chambers + 2 other pilots	UH-60 and Citation C5 Pilot	Department of Homeland Security
Charles Kubik	GA pilot	
Dan Craig	GA pilot	
Jake Hookman	Avionics Manager	Avionics Systems, LLC
Kelvin Domingue	Avionics Manager	Era Helicopters
Ken Speir	Former Chief Technical Pilot, Chair ATMAC ADS-B working group	Delta Airlines
Lance Chase	Flight Instructor	Embry Riddle (FL)
Matt Nuffort		USAF Global ATM Office
Mike Goulian	Director of Operations	Executive Flyers, Linear Air
Perry Clausen	Manager, Air Traffic Systems	Southwest Airlines
Rich Heinrich	Director of Strategic Initiatives	Rockwell Collins
Rocky Stone	Chief Technical Pilot	United Airlines
Sarah Dalton	Director of Airspace and Technology	Alaska Airlines
Steve Bucklin	Bell OH58 Pilot	Lakeland, FL Police Department
Steve Vail	Senior Manager of Air Traffic Operations	Fedex

Hawaii Helicopter Survey Participants

Name	Title	Organization
Benjamin Fouts	President	Mauna Loa Helicopters
Cary Mendes	Former Chief Pilot	AlexAir
David Ryon	FAA Inspector	Hawaii FSDO
Gardner Brown	Director of Operations	Will Squyers Helicopter Service
Katsuhiro Takahashi	Pilot, CFI	Above It All, Inc
Paul Morris		Sunshine Helicopters
Rick Johnson	General Manager	Heli USA
Steve Egger	President/Owner	Air Maui helicopter tours
Steve Gould	President/Director of Operations	Mauiscape Helicopters

Hawaii Helicopter Interview Participants

Name	Title	Organization
Anthony Fink	Pilot, Safety Director	Above It All, Inc
Casey Pauer		
Chuck DiPiazza	President/ Director of Operations	Air Kauai Helicopters
Chuck Lanza	Operations Manager	Makani Kai Helicopters
Curt Lofstedt	President	Island Helicopters Kauai
Dan Betencourt	Lawyer	
Dana Rosendal	Chief Pilot	Niihau Hilicopters
Darl Evans	Chief Pilot	Blue Hawaiian Helicopters
David Chevalier	President	Blue Hawaiian Helicopters
David Ryon	FAA Inspector	Hawaii FSDO
Eric Lincoln	Director of Operations	Blue Hawaiian Helicopters
Nigel Turner	President/CEO	Heli USA Airways
Preston Myers		Safari Helicopters
Rich Johnson	General Manager, Hawaii	Heli USA Airways
Richard Schuman	President	Makani Kai Helicopters
Robert Butler	Directors	TOPS Program
Tom Yessman	President	Liberty Helicopters

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