Measured Impact of ADS-B In Applications on General Aviation and Air Taxi Accident Rates

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While General Aviation (GA) and Air Taxi accident rates have been declining over time, the remaining accidents still result in a substantial loss of life and property. One way the FAA is addressing GA and Air Taxi safety is through the Surveillance and Broadcast Services (SBS) program. SBS uses satellite-enabled technology known as Automatic Dependent Surveillance-Broadcast (ADS-B) to provide applications that use traffic and weather information received in the cockpit on the ADS-B frequency (ADS-B In). This document describes current SBS-enabled cockpit applications and explores their impact on accident rates in two separate analyses: the first examines the impact of ADS-B In on GA (Federal Aviation Regulations [FAR] Part 91) and Air Taxi (FAR Part 135) users in the Contiguous United Sates (CONUS); the second considers Air Taxi operators in Alaska. The results indicate a reduction in relevant accident rates from 40 to 60 percent for ADS-B In equipped aircraft.

I. Introduction

For 27 years, the Aircraft Owners and Pilots Association (AOPA) Air Safety Institute has produced the Joseph T. Nall Report [1] – a review of General Aviation (GA) accident rates and trends. While GA (FAR Part 91) accident rates have been declining over time, the remaining accidents still result in a substantial loss of life and property. The most recent Nall report detailed 1,173 GA accidents in 2015 with 221 of those being fatal. GA accident rates are much larger than airline accident rates. The Nall report documents a number of reasons why this is the case, including a wider variety of missions, variability of pilot certificate and experience levels, a greater variety of facilities, more takeoffs and landings, less weather-tolerant aircraft, and limited cockpit resources and flight support [1].

The mission of the Federal Aviation Administration (FAA) is to provide the safest, most efficient aerospace system in the world [2]. One way the FAA is addressing GA safety is through the Surveillance and Broadcast Services (SBS) program that uses currently available satellite-enabled technology known as Automatic Dependent Surveillance-Broadcast (ADS-B). One major facet of the SBS program has been deploying ground infrastructure and automation to support air traffic control surveillance using signals transmitted from the aircraft (ADS-B Out). In areas with limited radar surveillance, ADS-B Out surveillance can lead to increased Air Traffic Control (ATC) services for all users, including more efficient search and rescue following accidents [3]. The other major facet of SBS is providing operational improvements that use information received into the cockpit on the ADS-B frequency (ADS-B In). The available information includes weather and airport/airspace information through Flight Information Surveillance-Broadcast (FIS-B) and information on surrounding traffic either directly using ADS-B Out signals from other aircraft or through ADS-B Rebroadcast (ADS-R) or Traffic Information Surveillance-Broadcast (TIS-B). The most widespread use of ADS-B In to date has been by the GA community who primarily use safety and traffic situational awareness applications.

The FAA business case for SBS, developed in 2007, quantified a number of safety benefits for the GA and Air Taxi community based on the proposed ADS-B applications [4]. Because of relatively low equipage rate and the necessary lag in finalizing accident report data, there have been few previous studies measuring the safety impacts of ADS-B.

This document describes current SBS-enabled cockpit applications and explores their impact on accident rates in two separate analyses: the first examines the impact of ADS-B In on GA and small Air Taxi users in the Contiguous United Sates (CONUS), the second analysis considers Air Taxi (FAR Part 135) operators in Alaska. Both sections include

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descriptions of the original benefit estimate claims and new data and analyses examining accident rates through October 2017.

II. SBS applications and their use in the GA community

The SBS program has developed a number of ADS-B In application for both commercial and GA users. Commercial efficiency applications include Cockpit Display of Traffic Information (CDTI) Assisted Visual Separation (CAVS) and the oceanic In-Trail Procedure (ITP). This paper focuses on GA safety applications that address hazards from other traffic, weather, and terrain. The following paragraphs describe the available applications and current use.

The principle of "see-and-avoid" (whereby the pilot visually searches out the window for other aircraft, and alters flight path to avoid them if necessary) is well established in regulation, procedure, and practice. However, there are practical limitations associated with the see-and-avoid principle due to the difficulty for the pilot to visually acquire other traffic in a consistent and reliable manner.

Unlike GA and small Air Taxi aircraft, the majority of aircraft used in passenger revenue operations are currently equipped with the Traffic Alert and Collision Avoidance System (TCAS). TCAS-II is required on all aircraft with more than 30 seats and includes both traffic advisory and conflict resolution capabilities. In addition, TCAS-I is required on small 10 to 30 seat commuter aircraft and provides conflict detection. While the applications described below will primarily benefit non-TCAS aircraft, it is expected that the improved accuracy and update frequency of ADS-B will improve conflict detection for TCAS aircraft as well.

The Enhanced Visual Acquisition (EVAcq) application improves the pilot's ability to visually acquire traffic so that the see-and-avoid principle can be more effectively applied. Based on information gained from a CDTI, the pilot can better focus his/her visual search for other ADS-B aircraft, as well as better monitor their movements once acquired. The result is greater pilot situational awareness, greater scan effectiveness, and the ability to plan for avoidance earlier in an encounter scenario..

The Traffic Situation Awareness with Alerts (TSAA) capability builds on the EVAcq application by providing the pilot or flight crew with alerts for conflicting traffic that may or may not have been pointed out by ATC. The alert acts as an attention-getting mechanism, so the pilot or flight crew is not required to continually scan the traffic display to determine if and which aircraft are a conflict. After receiving the alert, the pilot or flight crew takes the necessary action in accordance with the operational rules in effect at the time. This application is an ADS-B enabled application for properly equipped aircraft; it is not intended as a TCAS replacement. The left side of Figure 1 shows an example of an ADS-B airborne traffic display with alerts available to GA aircraft [5]; display details vary by vendor.

The SBS program provides the data necessary to enhance see-and-avoid by two methods. CDTI-equipped aircraft will always see other ADS-B equipped aircraft within the line of sight of the ADS-B receiver as long as the receiver operates on the same frequency. There are 2 approved ADS-B frequencies: 978 Megahertz (MHz) and 1090 MHz. While most aircraft transmit one of the frequencies, many ADS-B In receivers accept both frequencies. Additionally, CDTI-equipped aircraft will also be able to see local transponder-equipped aircraft positions broadcast where TIS-B service is available. TIS-B service is available above 6,000 feet NAS-wide and even lower in the vicinity of the service broadcast points. As ADS-B equipage levels increase, the proportion of additional aircraft broadcast using the TIS-B service will decrease. It is expected that TIS-B service will discontinue after full equipage.

Another major hazard to pilots is inclement weather. The primary objective of the Weather and NAS Situation Awareness (WNSA) application is to provide the flight crew with improved access to textual and graphical weather and other aeronautical information (i.e., Aviation Routine Weather Report (METAR), Terminal Area Forecast (TAF), Significant Meteorological Advisory (SIGMET), Pilot Report (PIREP), Notice to Airmen (NOTAM), Next Generation Weather Radar (NEXRAD), Special Use Airspace status, etc.). Many types of information, such as graphical weather products, are not easily conveyed by voice, as considerable detail is lost and the time and attention devoted to conveying the information is lengthy and diverts the pilot from primary flight duties. This application provides for the transfer of this information on the 978 MHz data link using the FIS-B system. The right side of Figure 1 shows an example of a WSNA application available to GA aircraft [6]; display details vary by vendor.

A third relevant hazard for GA pilots is Controlled-Flight-Into-Terrain (CFIT). CFIT accidents are defined as those in which the pilot inadvertently allows the aircraft to strike terrain, a water surface or an obstacle, even though the aircraft is in full control. These accidents are usually attributable, to some extent, to the pilot's lack of awareness of aircraft altitude relative to proximate terrain and obstacles. CFIT accidents usually occur during flight conditions in which the pilot cannot visually ascertain terrain/obstacle clearance (e.g., visual obscuration from fog, clouds, or precipitation; nighttime with unlighted terrain features; and poor contrast in the landscape due to snow, glassy water surfaces, etc.).

Since the mid-1970s, most U.S.-registered transport-category aircraft have been required to have Ground Proximity Warning Systems (GPWS). These systems are intended to warn pilots that the aircraft may be coming dangerously close to terrain while in the cruise configuration or that it may not be in the proper configuration for a normal landing. The Terrain Awareness and Warning System (TAWS) mandate states that any aircraft with six or more passenger seats must be equipped with TAWS. Over 90% of aircraft in CONUS have fewer than six passenger seats.

While SBS does not offer additional navigation and terrain information, the associated GPS-enabled displays that provide the EVAcq, TSAA, and WSNA information often also provide pilots who are operating aircraft not included under the TAWS mandate with a safe and cost-effective means to be aware of the aircraft's altitude with respect to the surrounding terrain. The equipment often provides an alerting function that monitors terrain clearance and issues an appropriate warning to the pilot if inadequate terrain clearance is anticipated. Although many aircraft and pilots may have had GPS-enabled terrain clearance applications before SBS, some fraction have gained these capabilities when upgrading to ADS-B/TIS-B/FIS-B equipment.

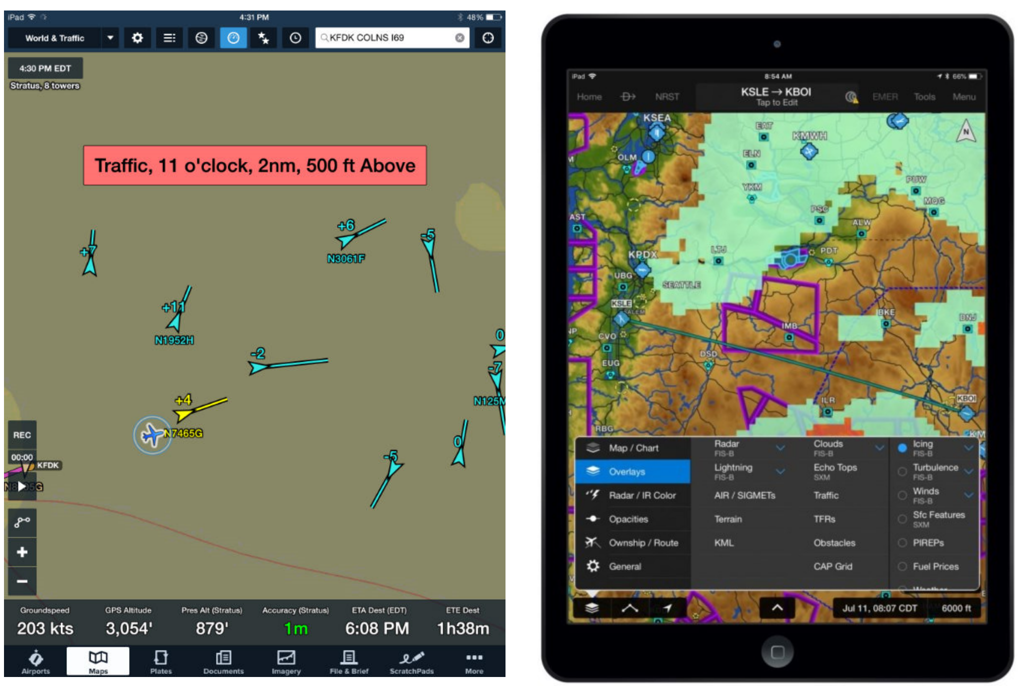

Fig. 1 Examples of ADS-B In cockpit applications from [4] and [5]

ADS-B and FIS-B were first made available in parts of Alaska in early 2000s. By 2013 ADS-B, FIS-B, and TIS-B were available across the CONUS. The Massachusetts Institute of Technology (MIT) performed a survey study on pilot perceptions and use of ADS-B Traffic and Weather services in 2014 [7]. The study used responses from 1,407 pilots, a majority of whom had used ADS-B In services. Some of the results included [7]:

> "A majority of respondents had used ADS-B In, with 56% of respondents reported having experience with either an installed or portable system. Of the group who had experience with ADS-B In, 85% used portable systems and 30% used installed systems."

"Among pilots who use ADS-B traffic on a regular basis, 42% of respondents indicated that it had helped them avoid a mid-air collision."

"Respondents commonly used ADS-B In flight information (weather, airspace, and other system information) as a resource when changing altitude or rerouting."

"Some respondents also reported occasions where the knowledge that they would receive this information in the air influenced their decision to take off (in situations where they otherwise might not have)."

"This study showed that ADS-B In traffic, weather, and other flight information services are changing the way that pilots fly. ADS-B In traffic has provided increased situation awareness for operation in VFR environments, such as congested traffic patterns, as well as in IFR environments as a backup for ATC separation services and traffic advisories. ADS-B In flight information services have clearly impacted pilot decision making in the air, with occasional benefits prior to takeoff by impacting go/no-go decisions."

III. CONUS GA and Air Taxi Accident Rate Analysis

This section first describes the predicted estimates of the effectiveness of ADS-B In services for reducing GA and Air Taxi accidents in the CONUS. It then continues with an analysis of the impact of ADS-B In services on accident rates using historical operations and accident data.

A. Background

The FAA approved the move to ADS-B services based on a business case for the SBS program presented in 2007. The supporting ground infrastructure was deployed starting in 2008, and by 2013, ADS-B, FIS-B, and TIS-B were available across the CONUS.

The original SBS business case [4] estimated the impact of ADS-B In services on four types of GA and Air Taxi accidents:

- Mid-air collisions
- Weather-related accidents
- CFIT accidents
- CFIT + weather accidents.

The overall effectiveness of ADS-B In services in reducing future accidents for each type was estimated using inputs obtained during a two-day workshop held July 13-14, 2005. Five to six subject matter experts rated the effectiveness of an ADS-B display on a sample of accidents using a score of zero to five, with five being the highest value. The responses were used to create distributions of effectiveness for the business case. The resulting risk-adjusted effectiveness values for preventing each accident type were as follows:

- 72.3% for mid-air collisions
- 26.4% for weather-related accidents
- 17.6% for CFIT accidents
- 53.6% for CFIT +weather accidents.

In the final benefit estimate, the effectiveness percentages for mid-air collisions and weather-related accidents were applied to all projected ADS-B In equipped GA and Air Taxi operations. The CFIT and CFIT + weather effectiveness percentages were applied to a subset of operations that represented an incremental increase in operations that used GPS-enabled terrain warning information compared to a baseline without ADS-B In services.

B. Accident analysis

The accident rate analysis uses accident reports for all GA and Air Taxi accidents between October 2012 and September 2017 from the National Transportation Safety Board (NTSB) website [8]. Final accident findings can lag behind the accident date by up to a year. A variety of filters were used to isolate particular types of accidents. Table 1 presents the filters used for each accident type listing the relevant table, field, and values used.

Table 2 Filters used to identify accident types in NTSB database

Accident type	Table	Field	Value
Midair	Events	mid_air	"Y"
Weather-related	Events	mid_air	"N"
	Findings	findings_code	like "0303*"
	Findings	cause_factor	"C" or "F"
CFIT	Events	mid_air	"N"
	Event Sequence	occurrence_code	like "*120 "
CFIT & Weather	Events	mid_air	"N"
	Event Sequence	occurrence_code	like "*120 "
	Findings	findings_code	like "0303*"
	Findings	cause_factor	"C" or "F"

Some notes on the filtering:

- Mid-air collisions are directly indicated in the "Events" table.
- The "Findings" table contains a findings_code field that documents events, phenomena, or equipment that may have contributed to the accident; when the field findings_code starts with 0303 the code refers to environmental issues such as low visibility and ceiling, precipitation, wind, extreme temperatures, etc.
- The weather-related accidents were further filtered in the Findings table using the cause_factor field; a cause_factor of "C" or "F" indicates that weather was the cause of the accident or a factor in causing the accident.
- The analysis also used the "Event Sequence" table. The occurrence_code field identifies discrete events in the accident event sequence timeline; an occurrence_code value that ends with 120 indicates a CFIT.
- Accidents in the CFIT & Weather category were removed from the list of CFIT accidents and the list of Weather-related accidents to avoid double-counting.

After gathering accident data, the next step was to determine which aircraft were ADS-B In equipped at the time of the accident. The ADS-B Performance Monitor receives ADS-B data from the SBS nationwide network of ADS-B receivers and assesses the performance against the requirements of the ADS-B Out Final Rule [9]. The Performance Monitor records ADS-B Out and the presence of ADS-B In functionality. The ADS-B Performance Monitor helps the FAA Aviation Safety Office, the SBS Program Office, and other stakeholders to:

- Identify ADS-B equipped aircraft performing below the requirements defined in the ADS-B Final Rule
- Monitor ADS-B equipage growth
- Identify trends in avionics performance
- Manage the ADS-B Rebate Program and assess the performance of the validation flight
- Support Public ADS-B Performance Report (PAPR) requests.[10]

Aircraft identification data from the ADS-B Performance Monitor was matched to NTSB data to determine which accidents included aircraft with ADS-B In equipment. Reliable identification data from the Performance Monitor started in October 2012; this is one of the reasons the CONUS analysis was limited to fiscal years (FYs) 2013 to 2017. Table 2 lists the annual Part 91 and 135 CONUS accidents by equipage and type per year.

C. Equipped fleet and operations estimates

To claim a difference in effectiveness between ADS-B In and unequipped aircraft one needs to consider the accident rates. Determining an accident rate requires the estimation of some relevant count related to the frequency or duration of equipped flights. This analysis uses flight operations, where an operation is defined as either an airport arrival or a departure. The FAA APO Terminal Area Forecast (TAF) [11] estimates the total yearly operations per each airport by user type. The TAF also includes historical operations counts. There are 4 user types in the TAF: Air Carrier, Commuter and Air Taxi, General Aviation, and Military. For our purposes we are interested in all the General Aviation operations (which align well with Part 91), but only the portion of the Commuter and Air Taxi operations that are small Air Taxi (Part 135). An analysis of one year of more specific flight information by aircraft type from the Traffic Flow Management System Counts (TFMSC) database [12] was used to estimate that approximately 20% of the Commuter & Air Taxi operations were Air Taxi.

Two methods were used to estimate the percent of the historical operations that were ADS-B In equipped in a particular year.

1. Fleet Method: Identified the number of ADS-B In equipped non-Air Carrier aircraft using the ADS-B Performance Monitor [10] relative to the total GA and Air Taxi fleet per year from the APO FAA Fleet Forecast [13]
2. Flight Hour count method: Determined hourly counts of ADS-B In equipped and non-equipped aircraft per hour across NAS using vendor data provided to the SBS program, filtered for non-Air Carrier aircraft.

The share of ADS-B In equipped aircraft was then applied to total GA and Air Taxi operations per the TAF to estimate equipped and non-equipped operations per year.

For both the Fleet method and the Flight hour method, the data was only available in snapshots (i.e. end of the FY). Consequently, the average share of equipped aircraft calculated from the beginning to the end of the FY was used to estimate the equipped share during the year. Figure 2 presents the CONUS estimates of GA and Air Taxi equipped operations using both the Fleet method and the Flight Hour method for years 2012 through 2018. The two methods find similar results.

Table 2 Accident counts by type and year

	ADS-B In					Unequipped				
Year	Midair	Weather	CFIT	CFIT+ Weather	Total (fatal)	Midair	Weather	CFIT	CFIT+ Weather	Total (fatal)
2013	0	0	0	0	0	18	223	34	18	293 (91)
2014	0	1	0	0	1	8	240	21	31	300 (90)
2015	0	0	0	0	0	14	213	13	28	268 (72)
2016	0	9	0	0	9 (2)	9	245	15	9	278 (57)
2017	0	23	0	1	24	0	168	9	9	186 (17)
Total	0	33	0	1	34 (2)	49	1089	92	95	1325 (326)

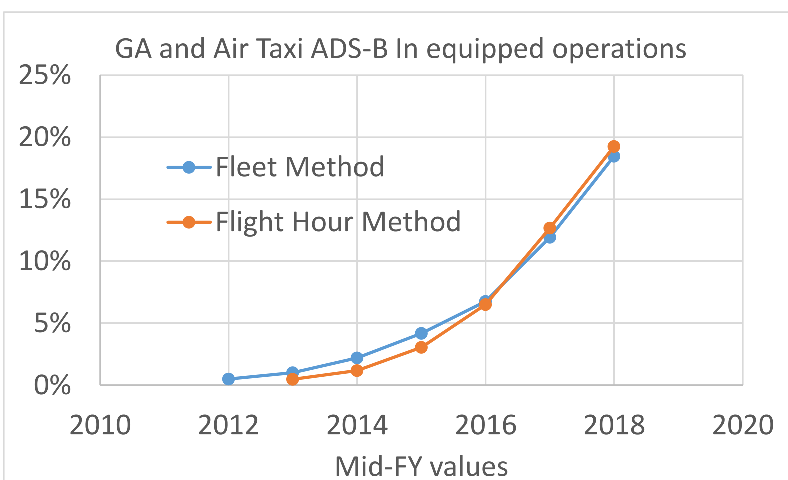

Fig. 2 Share of ADS-B In Equipped GA and Air Taxi Aircraft

D. Results

Because of the rarity of accidents and the relatively low levels of ADS-B In equipage in the early years, the analysis focused on a 5-year accident rate (from 2013 through 2017). ADS-B In accident rates were calculated by dividing the number of ADS-B In equipped accidents (by type) by the number of equipped operations. The same calculation was then performed for the unequipped accident rates. Rates were also calculated for the subset of accidents that were fatal. The analysis was performed using equipped and unequipped operations using both the Fleet method and the Flight hour method.

For each accident type, the difference between the ADS-B In equipped and unequipped rates was calculated. A binomial test was performed to gauge if the difference in the rates was statistically significant. If the difference was found to be statistically significant, a percent reduction in the accident rate for ADS-B In equipped aircraft was calculated, as well as an estimate of the number of avoided accidents over the 5-year period. Table 3 presents the 5-year accident rate results, the percent reductions, and the estimates of avoided accidents.

Table 3 Accident Rate analysis GA and Air Taxi CONUS

	5-year accident rates (2013-2017) (Accidents per million operations)		Reduction in rate for ADS-B In	Estimate of avoided accidents in 5-year period
Using Fleet Method	**ADS-B In**	**Unequipped**		
Mid-air	0	0.30	NSS	
Weather-related	3.69	6.64	44%	26
CFIT	0	0.56	100%	5
CFIT & Weather	0.12	0.58	81%	4
Combined (fatal only)	**3.80 (0.22)**	**8.08 (1.98)**	**53% (89%)**	**38 (18)**
Using Flight Hour Method	**ADS-B In**	**Unequipped**		
Mid-air	0	0.30	NSS	
Weather-related	4.04	6.61	39%	21
CFIT	0	0.56	100%	5
CFIT & Weather	0.12	0.58	NSS	
Combined (fatal only)	**4.16 (0.25)**	**8.04 (1.98)**	**48% (88%)**	**32 (14)**

NSS = Not Statistically Significant

There are a few interesting notes and conclusions that can be drawn from the results presented in Table 3.

1. The results using the combined data (i.e. all four accident types) indicate a significant reduction in the total accident rate (48% to 53%) and in the fatal accident rate (88 to 89%).
2. While there was a measured reduction in the mid-air accident rate, the scarcity of those accidents precluded claiming that the reduction was statistically significant.
3. An argument could be made that the CFIT and CFIT + Weather accidents are not necessarily related to ADS-B In equipage. Repeating the analysis with only mid-air and weather-related accidents still results in a significant reduction in the total accident rate (41% to 47%) and in the fatal accident rate (88% to 89%)

IV. Alaska Part 135 Accident Rate Analysis

This section covers the analysis of the impact on Part 135 accidents in Alaska. Similar to the previous section, it first describes the predicted estimates on the effectiveness of ADS-B In, and then presents an analysis of accident rates using historical accidents and operations.

A. Background

The first large-scale implementation of ADS-B and FIS-B became operational in southwest Alaska starting in 2000. Alaska was a good test bed for these technologies because of limited radar surveillance, a relatively small population of aircraft that needed to be equipped, and an accident rate that was high compared to the CONUS. This early implementation (called the Alaska Capstone Program) provided a valuable proving ground for ADS-B and FIS-B data, which was used to support the NAS-wide SBS program business case. In 2007, the FAA decided incorporate the Alaska Capstone program into the NAS-wide SBS program.

The Alaska Capstone Program consisted of three phases:

- Phase I provided avionics and surveillance and broadcast services to Part 135 users in the Yukon-Kuskokwim Delta region of Alaska
- Phase II provided avionics and surveillance and broadcast services to Part 135 users in the Southeast region of Alaska
- Phase III expanded surveillance and broadcast services to other parts of the state.

The Capstone program also included a number of airport infrastructure upgrades (such as automated weather stations, communications, and route and approach procedure development) that supported providing better information to pilots and/or expanded use of IFR services available.

The primary operational impact in Alaska claimed by the SBS program was a reduction in aviation accidents. A set of 2,045 aviation accidents in Alaska was analyzed for the initial investment decision. Each one was assigned a combination of 23 risks. A focus group consisting of 20 Alaskan pilots was held in the spring of 2006. The results from the focus group were used to estimate the overall SBS/Capstone mitigation for each risk by phase of flight, FIS-B coverage, and user type (Part 91 or 135). Mitigation mechanisms included availability of weather in the cockpit, ATC monitoring, company monitoring, additional IFR procedures, and additional weather stations. More details concerning the original estimates can be found in the SBS Benefits Basis of Estimate (BBOE) [4]. The actual reduction in accidents was previously examined in two reports for Alaska Capstone Program Phase 1 [14] and Phase 2 [15].

E. Accident analysis

Much like the CONUS analysis, the original Alaska analysis used accidents from the NTSB database. Unlike the CONUS analysis, however, the Alaska analysis focused on Part 135 operators only and included all accident types. This decision aligns with the business case analysis, which considered a broad range of accident types and risk mitigations. The analysis also covered a longer time period (2005 to 2017), since ADS-B services have been used in Alaska longer than in the CONUS.

For years after 2012, aircraft identification data from the ADS-B Performance Monitor was matched to NTSB data to determine which accidents included aircraft with ADS-B In equipment (similar to the CONUS analysis). For years prior to 2012, the analysis used lists of equipped aircraft (including those equipped inside and outside the Capstone program) that were available internally to the SBS Program Office. Table 4 lists the total number (and the number of fatal) ADS-B In equipped and unequipped Part 135 aviation accidents in Alaska per year.

F. Equipped fleet and operations estimates

Like the CONUS analysis, the Alaska analysis develops rates based on flight operations where an operation is defined as either an airport arrival or a departure. TAF data for Part 135 operations in Alaska were found to be incomplete, and were therefore supplemented with data from the Bureau of Transportation Statistics (BTS). The BTS database [16] allows examination of the number of operations performed at each airport per company for a large set of the commercial operators (both Part 121 and 135). To separate Part 135 carriers from Part 121 carriers in the BTS data, the SBS program obtained a list of every Part 135 aircraft operating in Alaska from FAA Flight Standards (AFS 260) [17]. The list contained both the tail numbers and the operator.

The methodology to estimate the share of Part 135 operations that are ADS-B In equipped was somewhat different than used in the CONUS analysis. The share of operations equipped by company was developed using a list of Part 135 aircraft per company, a detailed list of which aircraft were ADS-B In equipped, and BTS data on the number of operations by company. This allows the analysis to somewhat correct for the differing number of flights per operator, as opposed to just assuming each aircraft flies a similar number of flights (as in the Fleet methodology used in the CONUS analysis).

While the data was more specific in Alaska, there were also a few complications. Many of the Part 135 operators changed names during the period of analysis, at least two of the major operators moved from Part 135 to Part 121 operations, aircraft were bought and sold out of the state, and the BTS data was incomplete because some Part 135 operators did not submit data. Even with these complications, the estimates of Part 135 operations and the share of equipped aircraft that were developed for this study are more accurate than previously available data. Table 4 lists the annual Part 135 operations and the share of equipped aircraft per year.

Table 4 Part 135 operations and accidents in Alaska

Part 135 in Alaska			Accidents (fatal)	
Year	Annual Operations (millions)	ADS-B In equipped %	ADS-B In	Non-ADS-B In
2005	1.23	50.7%	2 (0)	19 (0)
2006	1.21	48.2%	8 (0)	11 (0)
2007	1.23	48.4%	9 (2)	8 (2)
2008	1.18	47.6%	7 (1)	12 (2)
2009	1.10	51.9%	7 (0)	14 (0)
2010	1.14	53.8%	3 (1)	11 (2)
2011	1.18	54.4%	6 (2)	12 (1)
2012	1.15	52.4%	9 (1)	17 (2)
2013	1.15	51.2%	5 (0)	16 (3)
2014	1.15	50.4%	4 (1)	9 (0)
2015	1.15	48.2%	3 (2)	9 (0)
2016	1.11	46.7%	4 (1)	7 (1)
2017	1.05	53.0%	6 (2)	15 (1)
2005-2017			73 (13)	160 (14)

G. Results

The ADS-B In accident rates were calculated by dividing the number of ADS-B In equipped accidents with the number of equipped operations. The same calculation was performed for the unequipped accident rates. Rates were also calculated for the subset of accidents that were fatal.

For each time period, the difference between the ADS-B In equipped and unequipped rates was calculated. A binomial test was performed to gauge if the difference in the rates was statistically significant. If the difference was found to be statistically significant, a percent reduction in the accident rate for ADS-B In equipped aircraft was calculated as well as an estimate of the number of avoided accidents over the 5-year periods. Table 5 presents the 5-year accident rate results, the percent reductions, and the estimates of avoided accidents.

Table 5 Accident Rate analysis Part 135 Alaska

5-Year periods	5-year accident rates (Accidents per million operations)		Reduction in rate for ADS-B In	Estimate of reduced accidents in the period
	ADS-B In	Unequipped		
2005-2009	11.2	21.2	47.0%	29
2006-2010	11.6	19.1	39.0%	21
2007-2011	10.8	20.1	46.4%	27
2008-2012	10.7	24.0	55.2%	39
2009-2013	10.0	25.9	61.6%	48
2010-2014	8.9	23.7	62.3%	44
2011-2015	9.1	22.4	59.4%	39
2012-2016	8.8	20.2	56.6%	32
2013-2017	7.8	19.9	60.5%	33
2005-2017	9.6	21.5	55.3%	90

There are a few interesting notes and conclusions that can be drawn from the results presented in Table 5.

1. The Part 135 accident rate results using all aviation accidents shows a statistically significant reduction for ADS-B In equipped flights over every 5-year period studied, as well as over the entire 18-year period. The overall reduction ranged between 39% and 62%.
2. There was no statistically significant reduction measured for the Part 135 fatal accident rate.

V. Conclusions and Next Steps

The results from Tables 3 and 5 clearly indicate that aircraft installed with ADS-B In capable equipment are experiencing a reduced accident rate compared to those without this equipment. The analysis does not prove that ADS-B In applications would have prevented the accidents for the unequipped flights. However, the trend is positive and supports the effectiveness assumptions made in the FAA business case for the SBS program. A more specific analysis could be developed to examine accidents in more detail using subject matter experts to assess whether ADS-B In would have reduced risk. In some cases, the difference between the equipped and unequipped accident rates was not determined to be statistically significant because of the relative scarcity of data (e.g. mid-air collisions). Periodic updates to the analysis will be performed to add data over time and retest the effectiveness and significance.

Acknowledgments

This work was supported by the SBS program through contract 693KA9-18-D-00010. The authors would like to thank Andy Leone of FAA, Joe Post of FAA Systems Engineering and Integration, John Hansman of MIT, Matias Palavecino, Joakim Karlsson, and Gary Paull of Regulus Group for providing documentation and valuable discussions.

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