1. Introduction

Automatic Dependent Surveillance – Broadcast (ADS-B) is a key enabling technology for the Next Generation Air Transportation System (NextGen) in the United States. The current air traffic control system depends on ground based radar, voice communications over VHF radio, and limited data feedback from the aircraft in the system (primarily altitude data via mode-C transponders and, for equipped aircraft, TCAS conflict resolution). The NextGen system replaces the ground based command-and-control system with a GPS-based autonomous system where fully equipped aircraft will be able to 'see' all nearby aircraft and their important state data in real time.

ADS-B has the potential to simultaneously improve safety and efficiency. ADS-B provides potential safety benefits by giving pilots improved situational awareness with nearby traffic. Efficiency improvements are possible due to reduced delays and improved routing from reduced traffic conflicts.

This report examines the potential improvements in helicopter operations in the GoMex due to the implementation of ADS-B. While there may be other benefits to ADS-B operations, such as reduced noise exposure, this report looks exclusively at potential fuel consumption reductions due to improved routing.

2. Background

The Federal Aviation Administration (FAA) introduced ADS-B in the GoMex in early 2010 to improve operations during Instrument Meteorological Conditions (IMC). The pre-ADS-B system was a grid-based system that relied on operator position reports to avoid conflicts.

The GoMex Grid System is discussed in the FAA’s Aeronautical Information Manual (AIM) (Federal Aviation Administration 2013), section 10-1-4. The following two paragraphs are taken from the AIM.

> *On October 8, 1998, the Southwest Regional Office of the FAA, with assistance from the Helicopter Safety Advisory Conference (HSAC), implemented the world's first Instrument Flight Rules (IFR) Grid System in the Gulf of Mexico. This navigational route structure is completely independent of ground-based navigation aids (NAVAIDs) and was designed to facilitate helicopter IFR operations to offshore destinations. The Grid System is defined by over 300 offshore waypoints located 20 minutes apart (latitude and longitude). Flight plan routes are routinely defined by just 4 segments: departure point (lat/long), first en route grid waypoint, last en route grid waypoint prior to approach procedure, and destination point (lat/long). There are over 4,000 possible offshore landing sites. Upon reaching the waypoint prior to the destination, the pilot may execute an Offshore Standard Approach Procedure (OSAP), a Helicopter En Route Descent Areas (HEDA) approach, or an Airborne Radar Approach (ARA). For more information on these helicopter instrument procedures, refer to FAA AC 90-80B, Approval of Offshore Standard Approach Procedures, Airborne Radar Approaches, and Helicopter En Route Descent Areas, on the FAA web site http://www.faa.gov under Advisory Circulars. The return flight plan is just the reverse with the requested stand-alone GPS approach contained in the remarks section.*
>
> *In December 2009, significant improvements to the Gulf of Mexico grid system were realized with the introduction of Air Traffic Control (ATC) separation services using ADS-B. In cooperation with the oil and gas services industry, HSAC and Helicopter Association International (HAI), the FAA installed an infrastructure of ADS-B ground stations, weather stations (AWOS) and VHF remote communication outlets (RCO) throughout a large area of the Gulf of Mexico. This infrastructure allows the FAA's Houston Air Route Traffic Control Center (ARTCC) to provide “domestic-like” air traffic control service in the offshore area beyond 12nm from the coastline to hundreds of miles offshore to aircraft equipped with ADS-B. Properly equipped aircraft can now be authorized to receive more direct routing, domestic en route separation minima and real time flight following. Operators who do not have authorization to receive ATC separation services using ADS-B will continue to use the low altitude grid system and receive procedural separation from Houston ARTCC. Non-ADS-B equipped aircraft also benefit from improved VHF communication and expanded weather information coverage.*

For this analysis, we compare the efficiencies of the flight plans for the non-ADS-B flights to the actual flights under ADS-B. The data are discussed in the Methods section below. To increase the database’s percentage of ADS-B operations, which are more prevalent in IMC, we restricted our analysis to flights between November 2011 and March 2012, when IMC is more prevalent in the GoMex.

3. Methods

This section discusses how the ADS-B and ETMS data were collected and how the helicopter fuel consumption model was developed.

3.1 ADS-B trajectory data

The ADS-B data contain the following data of interest to this project:

- Mode S code
- Latitude
- Longitude
- Horizontal speed and direction
- Vertical speed
- UTC time stamp

The ADS-B Mode S is a unique code assigned to one particular airframe. This code is also reported in the FAA aircraft registration database; these data sources were cross-linked to enable identification of the unique aircraft broadcasting the data.

The ADS-B data were provided by Volpe's Center for Air Traffic Systems and Operations. ADS-B data for the time period of interest were extracted from their native binary format and imported into a SQL database.

3.1.1 Issues with ADS-B data

While the ADS-B data themselves are of high fidelity, a number of issues arose when processing the data.

The data are reported sequentially for whatever aircraft are in the service volume. The first step in the data processing was to order the data by date and unique user. For this analysis, we removed all non-helicopter operations. We also further culled the data by only retaining the S-76 and S-92 helicopter operations, since these are the primary types used by Petroleum Helicopter, Inc. (PHI), the first operator to deploy an ADS-B fleet.

The ADS-B data contain details of the flight which the ETMS flight plan data do not. In particular, the ADS-B data contain trajectory information during the departures and arrivals; the non-ADS-B flight will require essentially the same types of maneuvering in the terminal area. When comparing total distance flown, if we included these terminal operations in the ADS-B operations, we would include data (including distance flown and fuel consumption) for the terminal operations which exist in all flights, but are only recorded in the ADS-B operations. We therefore removed all ADS-B data near the terminal location as discussed below in section 4.1.1. This enables a less biased comparison between ADS-B and non-ADS-B operations.

The ADS-B flights included a number of operations which appear to be either training flights or flights which don't support off-shore operations. Samples of these types of operations are shown below in Figures 1 and 2. Figure 1 presents the ground track of an operation at Ahart Field (KOPL); the race-track structure of the flight track suggests that this was a training operation. Figure 2 represents similar data for a completely on-shore operation. This flight begins and ends at the Lafayette airport (KLFT), and operates over the city of Lafayette and some of the neighboring towns. The two figures give an indication of the fidelity of the ADS-B data. Data of this type were removed from the analysis.

Figure 1 Possible training operation recorded in ADS-B data

Figure 2   Flight not supporting off-shore operations captured in ADS-B data

3.2 ETMS Trajectory Data

We have access to the filed flight plan data through the Enhanced Traffic Management System (ETMS). In addition to the position data mentioned above, these flight plans also include the aircraft type, the estimated time of departure, and the estimated cruising speed and altitude. Figure 3 below presents an example of an ADS-B and an ETMS flight plan track for the same origin-destination pair. The red line represents the trajectory from the ADS-B data, while the green line represents the ETMS flight plan data. An example flight plan message and how this message is de-coded is presented in Appendix A.

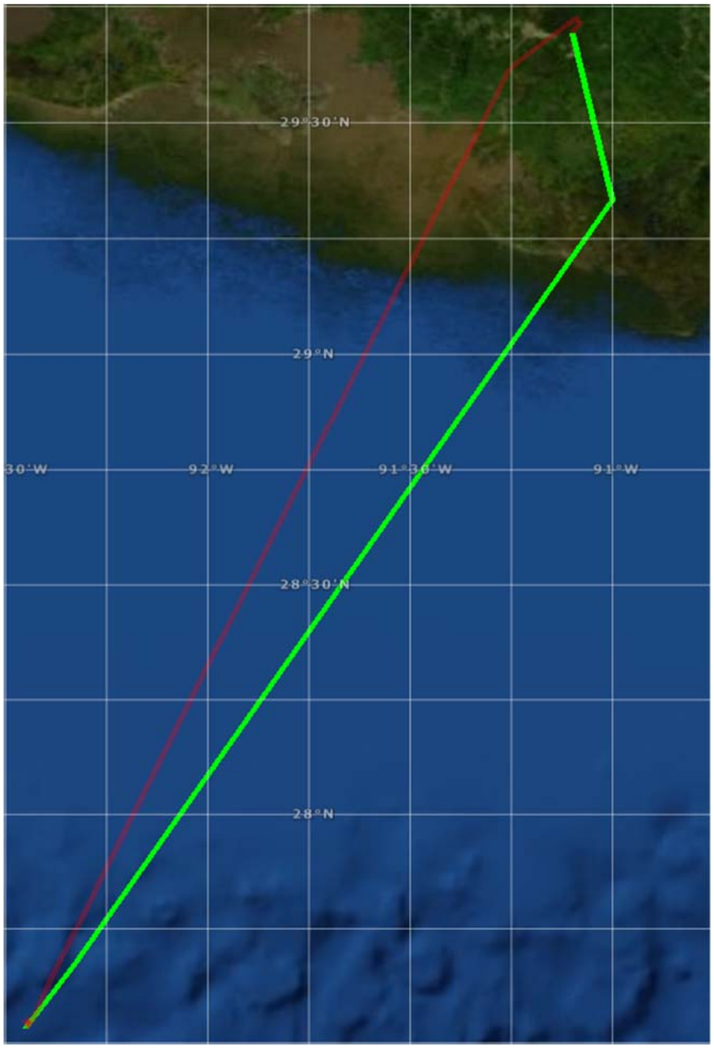

Figure 3 ADS-B and non-ADS-B flights for the same origin-destination pair

Flight plan data from ETMS for the time period were extracted from their native text file format and imported into a SQL database.

3.3 Helicopter fuel consumption

This section discusses the development of the helicopter fuel consumption methods used in this report.

3.3.1 Existing helicopter fuel consumption methods

The FAA invests resources in improving and maintaining the database of fuel consumption information for fixed-wing aircraft in the Aviation Environmental Design Tool (AEDT) (Senzig, Fleming and Iovinelli 2009). The current methods of determining fuel consumption for helicopter has lagged behind the fixed-wing model: while the fixed-wing fuel consumption model uses a physics-based method which relies on the actual characteristics of the aircraft and detailed knowledge about the state of the aircraft in flight, the helicopter fuel consumption model in AEDT relies on a mode-based method. This mode-based method does not account for physical characteristics of the helicopter operations, such as the aircraft weight, its speed and altitude, etc.

3.3.2 Proposed helicopter fuel consumption methods

A prior study looked into the physical aspects of helicopter fuel consumption modeling (Haagsma and van Veggel 2011). This study used higher-order coefficients for some terms which could lead to instabilities in the modeled data, particularly in the current case, where only standard condition data (no temperature variation and limited altitude variation) were available.

For this study we used a fuel consumption model developed by the U.S. Army (Cleek and Wolfe 1978). This method also contains a number of higher-order terms, but we found that these terms could be dropped from the analysis – the remaining lower order terms appear sufficient to capture the physical aspects of the fuel consumption.

3.3.3 Development of the fuel consumption method

Staff from Sikorsky provided fuel consumption data for the S-76 and S-92 helicopters – these are the same helicopters which PHI used for their initial ADS-B equipment installation. The fuel consumption data were digitized and used as input into a statistical package which generated the coefficients used in the equation.

The fuel consumption methods were incorporated into the SQL ADS-B and ETMS databases so that fuel consumption could be calculated for each flight in the particular database. Note that neither data source contains weight information – for consistency we assumed the helicopters would operate at their maximum weight.

Figure 4 and Figure 5 below show the modeled fuel consumption for the S-76 and S-92 helicopters operated by PHI during the period of interest. The horizontal axis is the flight time from the ADS-B data, while the vertical axis represents the fuel consumed during that particular flight. Each dot on the graphic represents one actual flight during the period of interest. There are on the order of 8,000 S-76 and 6,000 S-92 operations in the ADS-B data. The figures also contain a diagonal line which represents the average fuel consumption. The S-76 helicopters modeled fuel consumption averaged 748 pounds of fuel per hour; the S-92 helicopters averaged 1412 pounds of fuel per hour.

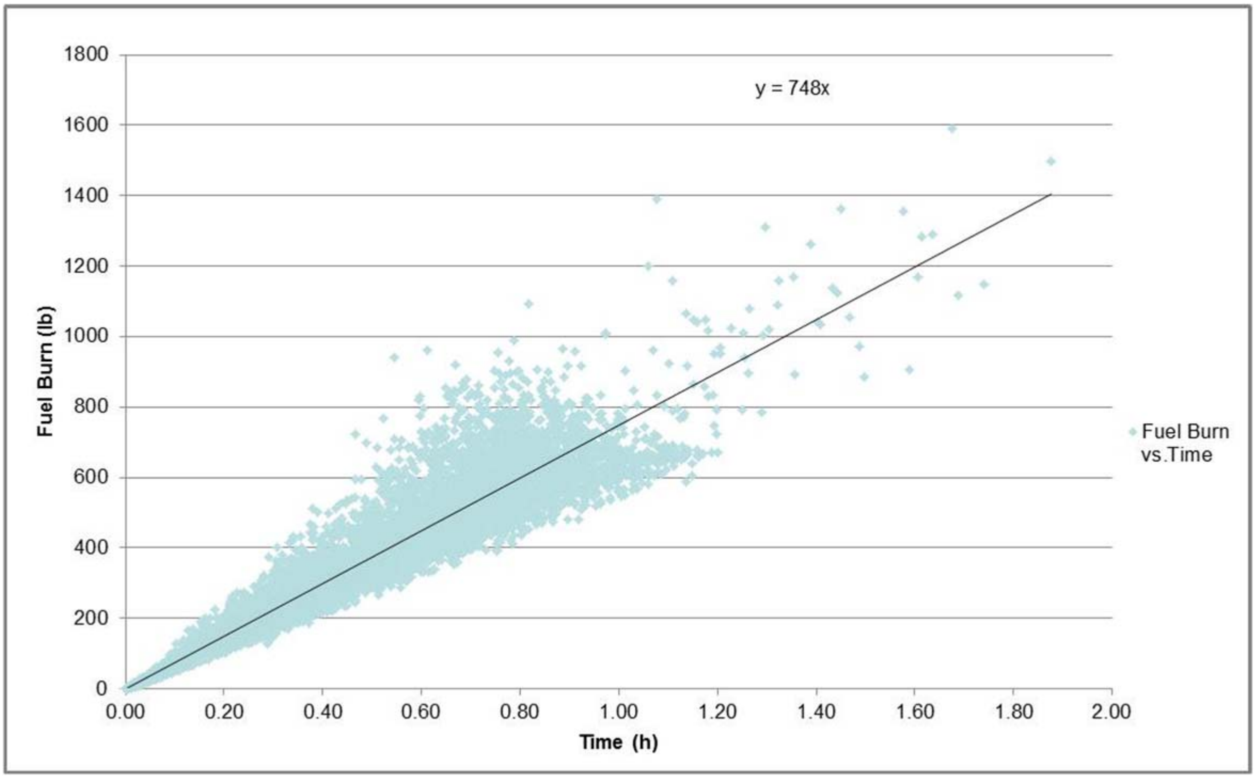

Figure 4 Sikorsky S-76 modeled fuel consumption – PHI flights

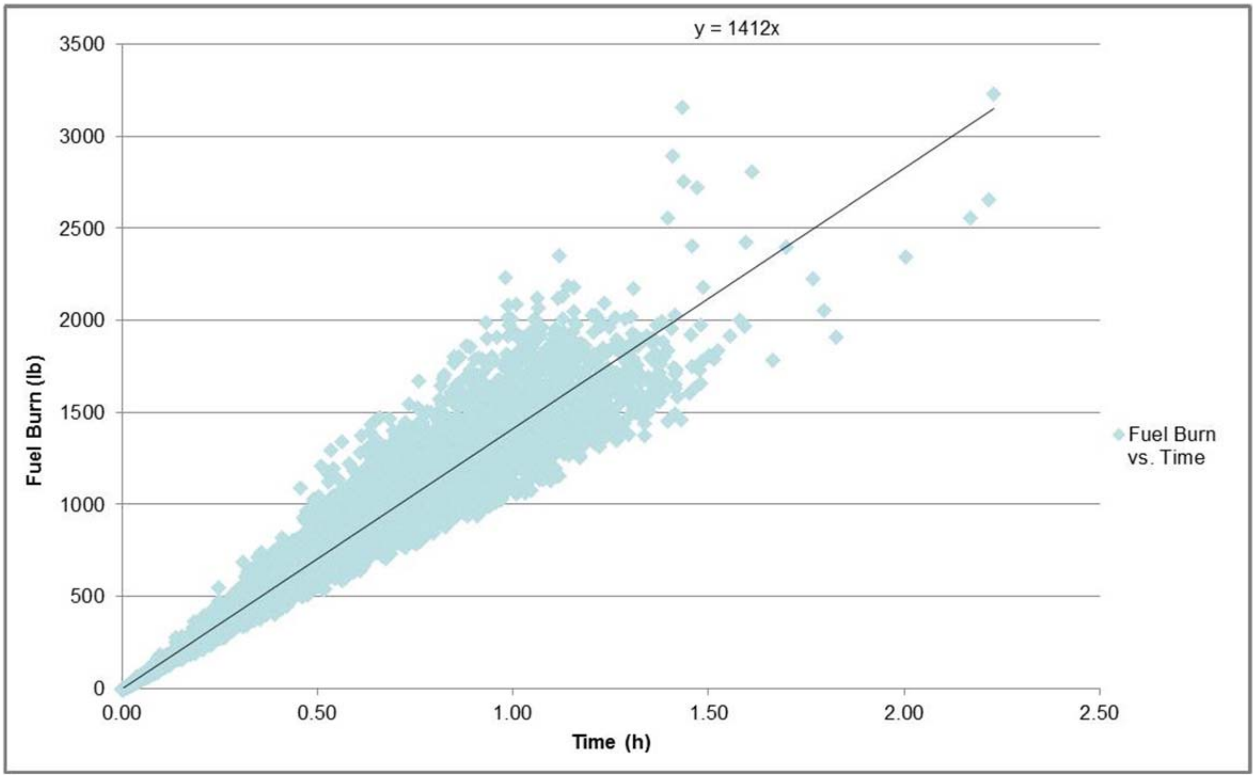

Figure 5 Sikorsky S-92 modeled fuel consumption – PHI flights

Table 1 below provides a summary of the helicopter performance data. The table gives the average airspeed, altitude, flight times and fuel consumption for the helicopters.

Table 1 Summary of Helicopter performance

Model	Avg. Airspeed (kt)	Avg. Alt. (ft)	Avg. Flight Time (h)	Avg. Fuel Burn (lb)
S-76	142	3500	0.45	336
S-92	139	4353	0.61	869

3.3.4 In-service data

PHI reported in-service fuel consumption for the two helicopters as averaging 1,350 lb/hour for the S-92 and 700 lb/hour for the S-76. The modeled averages shown in section 3.3.3 above appear within reasonable agreement of these in-service reports.

4. Analysis

In this section we discuss our methods for analyzing the data. A major factor in our analysis concerns the different fidelity levels in the ADS-B and ETMS flight plan data.

4.1 Modifications to the ADS-B data

Because the ADS-B data are significantly higher fidelity than the ETMS flight plan data, we modified the ADS-B flight data so that the ADS-B operations were not penalized for this higher fidelity. These modification issues are discussed below.

4.1.1 Terminal area issues

ADS-B data contains details which ETMS flight plan data do not. In particular, the ADS-B data contains the same level of detail in the terminal area as in cruise. So the ADS-B contain the trajectory data for the helicopters maneuvering in the terminal area which the ETMS data do not, even though the terminal area maneuvers exist regardless of the position reporting system.

To minimize any errors introduced by this discrepancy, we removed all terminal area points between the actual terminal point (e.g. the helipad) and the first point where the helicopter was lower than 75% of its cruising altitude. E.g. if an ADS-B flight had a cruising altitude of 5000 feet, the ADS-B processing method removed all trajectory points (except the actual terminal point) lower than 3750 feet.

4.1.2 Flight termination issues

The ADS-B data contains details of the aircraft state but do not contain distinct information on when a flight begins or ends. For fixed-wing aircraft, this would not necessarily present a significant problem, since flights with these types of aircraft will always begin and end on a runway – and runways have known latitudes and longitudes, so associating a flight with a known beginning and ending point is theoretically simple (though not necessarily simple in practice).

The helicopters operating in the GoMex, on the other hand, have undefined off-shore termination points. That is, the oil platforms to and from which the helicopters operate are not included in any database known to the authors. Since helicopters can hover, and the oil platforms landing pads can be hundreds of feet in the air, airspeed and altitude also cannot be reliably used to determine a terminal point.

Finally, fixed-wing aircraft will almost always shut down the engine at the terminal point and therefore have a gap in the recorded data which can be used to segregate individual flights. Helicopters, on the other hands, appear to often maintain power while at the oil rig.

For the reasons listed above we decided to use the criteria of non-movement for a period of five minutes as the determination of the end of one unique flight and the beginning of the next one.

4.2 Data processing

Maintaining a current runway, airports, and navigation waypoint data is a key part of the AEDT effort. That effort was leveraged to provide a database of waypoint and on-shore airports and heliports for this project. ETMS flight plan waypoints in the SQL database were converted to their latitude and longitude positions. The distances between the waypoints was calculated using the map projection method discussed in Appendix L of the FAA's INM User's Guide (Federal Aviation Administration 2007).

We converted both the ADS-B and the ETMS data from waypoints and latitude-longitude position data to distances along a track.

This processing gave us the distance traveled for each flight in the time period. We also had the average altitude and speed for the ETMS flights, and the per-segment altitudes and speeds for the ADS-B flights. This information was used to generate the modeled fuel consumption data for each segment of each flight; the total modeled fuel consumed for each flight was the total along all the segments. This method was used for both the ADS-B and ETMS flights.

5. Results

A simple fuel consumption comparison between the ADS-B flight and the ETMS flights would not provide insight into the relative efficiencies of the two methods, because the fuel consumed is a function of flight parameters used in the fuel consumption model and the distance flown by the helicopters. We are not confident that the ETMS flight plan speed and altitude information is accurate enough upon which to base the results of this study. Instead, we believe that the helicopters will be flown approximately the same way under ADS-B or non-ADS-B operations, so that the navigation method used would not influence the fuel consumption per distance flown.

The same is not true of the actual distance flown, however. By definition, the navigation method used for a particular flight influences the distance the aircraft fly. For that reason, we decided to focus on the distances the aircraft fly under the different navigation methods. A direct comparison of distances flown would not necessarily fairly compare the methods, since the total trip length might not have any correlation with the navigation method.

The metric of interest we used to compare the ADS-B and non-ADS-B flights was the ratio of the distance actually flown to the distance flown if the flight was conducted perfectly. A perfectly conducted flight would follow the Great Circle route between the departure and arrival terminal points – the Great Circle route is the shortest possible route between two points. The ratio makes more intuitive sense if it is expressed as the ratio of the Great Circle distance divided by the actual distance flown. We will refer to this metric as the distance ratio. With the distance ratio defined this way, a perfect flight would have a distance ratio of 1.0, and flights of less and less efficiency would come closer and closer to a distance ratio of zero.

An example of the usage of the distance ratio is given in Table 2 below.

Table 2 – Notional Distance Ratio Comparison

Flight	Great Circle Distance (nm)	Actual Distance flown (nm)	Distance ratio
1	50	60	0.83
2	200	210	0.95
3	500	530	0.94

In the example in Table 2 above, Flight 2 is the most efficient flight since this is the flight with the highest distance ratio. Flight 1 and Flight 2 both have an extra 10 nautical miles of flight distance compared to the Great Circle route, but Flight 2 has this extra distance spread over a longer total flight distance, so the flight is considered more efficient.

Because we expect shorter flights to have lower efficiency – even though eliminating the terminal maneuvers should reduce this effect – we split the flights into bins with different Great Circle route distances. This binning of flights is shown below in the fuel consumption comparisons in Table 3 through

Table 10. In addition to dividing the data by the distance flown, we have also split the data into 25% bins for flight efficiency. The most efficient flights, those in the most efficient two quartiles, are not presented since there is little to be gained by increasing the efficiency of flights which are already relatively efficient. In the tables below, we present the data for the bottom two quartiles of efficiency; the least efficient, lowest quartile flights (the bottom 0% to 25% of the flights), and the third quartile (the lowest 25% to 50%) of the flights. Each table presents the average distance ratio for that quartile, the fuel consumed if that Great Circle distance were flown by the helicopter, and the fuel consumed if the helicopter flew the extra distance associated with the distance ratio.

Table 3 - Fuel consumption for lowest quartile efficiency S-76 flights of 150 nm

Navigation Mode	Average Dist. Ratio	G.C. Fuel Consumption	Modeled Fuel Consumption
ADS-B	0.94	571 lb	609 lb
Non-ADS-B	0.92	571 lb	620 lb
Fuel saved with ADS-B			17 lb

Table 4 - Fuel consumption for third quartile efficiency S-76 flights of 150 nm

Navigation Mode	Average Dist. Ratio	G.C. Fuel Consumption	Modeled Fuel Consumption
ADS-B	0.98	571 lb	582 lb
Non-ADS-B	0.96	571 lb	597 lb
Fuel saved with ADS-B			10 lb

Table 5 - Fuel consumption for lowest quartile efficiency S-92 flights of 150 nm

Navigation Mode	Average Dist. Ratio	G.C. Fuel Consumption	Modeled Fuel Consumption
ADS-B	0.94	1094 lb	1161 lb
Non-ADS-B	0.93	1094 lb	1179 lb
Fuel saved with ADS-B			18 lb

Table 6 - Fuel consumption for third quartile efficiency S-92 flights of 150 nm

Navigation Mode	Average Dist. Ratio	G.C. Fuel Consumption	Modeled Fuel Consumption
ADS-B	0.98	1094 lb	1117 lb
Non-ADS-B	0.96	1094 lb	1143 lb
Fuel saved with ADS-B			26 lb

Table 7 - Fuel consumption for lowest quartile efficiency S-76 flights of 200 nm

Navigation Mode	Average Dist. Ratio	G.C. Fuel Consumption	Modeled Fuel Consumption
ADS-B	0.93	840 lb	905 lb
Non-ADS-B	0.90	840 lb	933 lb
Fuel saved with ADS-B			28 lb

Table 8 - Fuel consumption for third quartile efficiency S-76 flights of 200 nm

Navigation Mode	Average Dist. Ratio	G.C. Fuel Consumption	Modeled Fuel Consumption
ADS-B	0.97	840 lb	868 lb
Non-ADS-B	0.93	840 lb	901 lb
Fuel saved with ADS-B			33 lb

Table 9 - Fuel consumption for lowest quartile efficiency S-92 flights of 200 nm

Navigation Mode	Average Dist. Ratio	G.C. Fuel Consumption	Modeled Fuel Consumption
ADS-B	0.96	1566 lb	1635 lb
Non-ADS-B	0.96	1566 lb	1628 lb
Fuel *cost* with ADS-B			7 lb

Table 10 - Fuel consumption for third quartile efficiency S-92 flights of 200 nm

Navigation Mode	Average Dist. Ratio	G.C. Fuel Consumption	Modeled Fuel Consumption
ADS-B	0.98	1566 lb	1592 lb
Non-ADS-B	0.98	1566 lb	1606 lb
Fuel saved with ADS-B			14 lb

5.1 Distance ratio issues

One confounding factor is that the filed ETMS flight plan is not necessarily what the aircraft actually flew. We model the flights as proceeding directly from one waypoint to the next – so between waypoints the ETMS flights are considered to be perfectly direct – the ETMS flights follow the great circle route between waypoints.

Another issue is that the flight plans can, and often are, changed en-route, either at controller or pilot request. The impact of these amended flight plans are not considered in this analysis.

5.2 Disclaimer on results

The results presented in Table 3 through Table 10 only show the impacts of ADS-B on *flight operations*. One of the major benefits of ADS-B is the reduction in ground delays, which cannot be quantified from this type of in-flight analysis. PHI staff indicated that this reduction in ground delays is one of the primary benefits of ADS-B operations.

6. Conclusion

Examination of the ADS-B operations and ETMS flight plans shows a small but noticeable improvement in the efficiency of the helicopter flights under ADS-B due to more direct routing. For the S-76 helicopters, the improvement was on the order of 10 to 30 pounds of fuel saved for half (i.e. the least efficient half) of the flights traveling 150 to 200 nautical miles. For the S-92, the fuel saved was on the order of 20 pounds for half of the flights traveling 150 nm, with no saving noted for flights on the order of 200 nautical miles.

Though the average fuel saved on a per-flight basis might be small, given the numbers of helicopter operations in the GoMex, the fuel saving for the S-76 fleet was on the order of 28,000 lb of fuel and for the S-92 was on the order of 36,000 lb of fuel for the five month period under consideration.

7. Future work

This analysis raised a number of issues that may be of interest to pursue further.

7.1 Further validation of the helicopter fuel consumption method

The helicopter operators have supported this analysis through providing information and advice on the operation of their aircraft. At the time of this writing, we have requested additional fuel consumption data in the form of Flight Data Recorder (FDR) information from PHI, Chevron, and Bristol. If these operators provide detailed flight performance, we can potentially validate the fuel consumption methods used in this analysis and include those methods in AEDT for use in future analyses.

7.2 Potential impact of ADS-B operations on Noise

Operators have stated that ADS-B operations produce fewer noise complaints than non-ADS-B operations. ADS-B operations can potentially gain altitude more quickly into the Air Traffic System during IMC and hence increase the distance (and lower the noise) between the helicopters and the residents near the helipads. AEDT, which provides a method of modeling helicopter noise from different operational techniques, could be used to determine potential noise benefits from ADS-B operations.

8. References

Cleek, Nathan A, and Alan J Wolfe. "Flight Profile Performance Handbook." Technical Report, U.S. Army, TRADOC Systems Analysis Activity , White Sands, NM, 1978.

Federal Aviation Administration. *Aeronautical Information Manual - FAA.* March 2013. http://www.faa.gov/air_traffic/publications/atpubs/aim/index.htm.

Federal Aviation Administration. "Integrated Noise Model (INM) Version 7.0 User's Guide." Washington, DC, 2007.

Haagsma, Alexander, and Elgar van Veggel. "Helicopter Fuel Burn Modeling in AEDT." U.S. Department of Transporation, Volpe National Transportation Systems Center, Cambridge, MA, 2011.

Senzig, David A, Gregg G Fleming, and Ralph J Iovinelli. "Modeling of Terminal-Area Airplane Fuel Consumption." *Journal of Aircraft* 46, no. 4 (July-August 2009): 1089-1093.

Appendix A: Example of ETMS flight plan data format

Figure 3 in the main body of this report presents a flight track based on an ETMS flight track. The actual ETMS flight plan message for this flight is:

0306153204HFZ,0306153204,PHM031A,332,S76/G,130,2750/9159,P1630,50,2750/9159..2800N/09140W..LLARG..TBDCC..7LS3/0115

The fields have the following meaning:

0306153204HFZ	Time stamp (MMDDHHMMSS), facility code (H – Houston), and message type (FZ – Flight plan) – the time stamp is repeated
PHM031A	Flight ID
332	Computer ID
S76/G	Aircraft type (Sikorsky S-76) and equipment code (G- GPS)
130	Airspeed in knots
2750/9159	Departure coordinates (27° 50' North Latitude, 91° 59' West Longitude)
P1630	Proposed departure time, Zulu (HHMM)
50	cruising altitude (50 – 5000 feet)
2750/9159..2800N/09140W..LLARG..TBDCC..7LS3/0115	Flight route and estimated time en-route (HHMM)

The LLARG grid point has coordinates of 28° 00' North Latitude, 91° 40' West Longitude.
The TBDCC grid point has coordinates of 29° 20' North Latitude, 91° 00' West Longitude.

Appendix B: Helicopter fuel consumption methods

This appendix provides details on the helicopter fuel consumption methods used in this analysis.

U.S. Army method

The original method of calculating fuel consumption for helicopter comes from a series of reports written in the late 1970s (Cleek and Wolfe 1978). The fuel consumption method documented in these report is:

$$\begin{aligned} FF = {} & A(AS) + B(AS^2) + C(AS^3) + D(TEMP) + E(GW) + F(ALT) + G(AS^3)(TEMP) + H(AS^2) \\ & + I(AS)(TEMP) + J(AS^3)(GW) + K(AS^2)(GW) + L(AS)(GW) + M(AS^3)(ALT) \\ & + N(AS^2)(ALT) + O(AS)(ALT) + P(TEMP)(GW) + Q(TEMP)(ALT) \\ & + R(GW)(ALT) + S(TEMP)(GW)(ALT) + T \end{aligned}$$

Where

- FF = fuel flow (lb/hour)
- A..T = coefficients for the particular terms
- ALT = Altitude (feet)
- AS = airspeed (knots, true)
- GW = Gross weight (pounds)
- TEMP = Temperature (Celsius)

There are twenty terms, of which some (those involving airspeed) are fourth order. Given the limited fuel consumption data available for the helicopters, we used a smaller number of terms, which depended on the data available for the particular helicopter.

S-76 methods

Of the two helicopter types, the S-76 had the more detailed fuel consumption information. The S-76 had data available as a function of all of the parameters listed above. We removed all terms higher than third order to simplify the equation.

$$\begin{aligned} FF = {} & A(AS) + B(AS^2) + C(AS^3) + D(TEMP) + E(GW) + F(ALT) + I(AS)(TEMP) + L(AS)(GW) \\ & + O(AS)(ALT) + P(TEMP)(GW) + Q(TEMP)(ALT) + R(GW)(ALT) \\ & + S(TEMP)(GW)(ALT) + T \end{aligned}$$

S-92 methods

The S-92 documentation has fuel consumption as a function of weight and true airspeed, but only limited data on the effects of altitude and none on non-standard temperatures. In addition to the removal of the higher order terms as was done for the S-76, we also removed any terms containing temperature, since no data were available for this parameter.

$$FF = A(AS) + B(AS^2) + C(AS^3) + E(GW) + F(ALT) + L(AS)(GW) + O(AS)(ALT) + T$$

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