Surveillance and Broadcast Services (SBS) Program Office

Automatic Dependent Surveillance - Broadcast In-Trail Procedures (ADS-B ITP) Operational Flight Evaluation

Economic Benefits Analysis Report

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1. Introduction

In 2008, the Federal Aviation Administration (FAA) Surveillance and Broadcast Services (SBS) program established a project for the purpose of performing an operational flight evaluation of Automatic Dependent Surveillance-Broadcast In-Trail Procedures (ADS-B ITP) in revenue service. The objective of the project was to validate the operational performance and economic benefits of ITP and accelerate the use of ADS-B in operational service.

The FAA established agreements with United Airlines and Honeywell to accomplish the work necessary for the development, certification and installation of onboard systems for 12 United Airlines Boeing 747-400s. Goodrich Aerospace was selected by the partners to be the project's auxiliary display supplier. These onboard systems calculate the ADS-B ITP criteria and display that information to the pilot. Honeywell was primarily responsible for the development of the traffic computer and traffic computer software, as well as the ITP display software. Goodrich Aerospace was responsible for the auxiliary display hardware and operating system software. United Airlines was responsible for overall coordination and installation of ITP equipment, obtaining operational approval and conducting the flight evaluation.

Each B747-400 equipped with ADS-B ITP required an average of 1,000 man-hours of maintenance labor to install the equipment. This is due to the B747-400's layout with the avionics bay below the First Class cabin, and the cockpit being located above the First Class cabin. Many of the man-hours involved cabin dis-assembly and reassembly after the installation of wiring from the electronics bay up to the cockpit. United estimated that installation of this equipment on almost any other aircraft would require about half the number of man-hours. The equipment installation included a Traffic Computer located in the electronics bay, and two Aircraft Interface Devices with associated Smart Display Units (SDUs) in the cockpit. The Traffic Computer included an ADS-B In processor in addition to housing the Traffic alert and Collision Avoidance System (TCAS).

United completed the installation and flight test of the prototype aircraft on Nov. 10, 2010. The last of 12 aircraft equipped was completed on Oct. 23, 2011. United received approval to perform ITP demonstrations from their FAA Principal Operating Inspector (POI) on two flights conducted on Aug. 15, 2011. The initial approval for ITP was only for the South Pacific Region. The POI later modified the operational approval to include the North Pacific (only areas controlled by Oakland Center).

United commenced pilot training initially through "hands on" training with Line Check Airmen (LCA). In September 2012, United signed a Memorandum of Understanding (MOU) with the Air Line Pilots Association (ALPA) covering the ITP procedure and pilot training for ITP. United developed a Computer Based Training (CBT) program which was voluntary for pilots to complete, and released it for use on Dec. 11, 2012. By the end of 2012 United only had a few pilots trained beyond their B747-400 LCAs. In April 2013 United included ITP training in one of their Integration Training modules, which effectively made ITP training mandatory. United completed ITP training of 100% of their B747-400 flight crews on April 16, 2013.

In September 2013 United participated in pilot discussions concerning ITP. The discussions were guided by human factors experts from the Department of Transportation (DOT) Volpe Center. Pilots generally rated the value of the ITP equipment as high, not for the ITP procedure itself, but rather for the situational awareness enabled by the ITP display. Many discussed that they were able to make more efficient and effective normal altitude change requests based on the traffic on their ITP display, and many stated that they thought there should be an economic benefit for using the display in this manner.

This paper is a summary of the operational economic benefits United Airlines experienced as a result of ADS-B ITP equipage.

2. Initial Fuel Burn Analyses

2.1 Individual ITP events

United and the FAA initially attempted to look at individual savings enabled by climbs accomplished through ITP requests. United did an analysis of several individual ITP events. It should be noted that for these individual ITP events, the savings are postulated over the period immediately after the ITP climb, with the assumption that the climb could not have been made without the ITP request. It is assumed that after two hours of flight time, there is no longer an ITP benefit, as it is likely that a standard climb could be accomplished within this amount of time.

It is impossible to determine the exact amount of time the aircraft would have been stuck at an inefficient altitude, therefore exact benefits for individual ITP cases are difficult to calculate. A careful examination of a few ITP events, where detailed data did exist, demonstrated that each ITP event saved approximately 330 pounds of fuel per event. Unfortunately, there was not enough granularity in the data to support a statistically defendable analysis of these individual ITP events.

2.2 Additional fuel

ITP procedures were initially envisioned to reduce the amount of additional discretionary fuel loaded on ITP-equipped aircraft flying on South Pacific routes to and from Australia. It was assumed that flight crews would reduce the amount of discretionary fuel loaded as they became more confident that the ITP equipment could be used to reduce the probability of being stuck at a suboptimal altitude.

United's experience with ITP did not lead to lower discretionary fuel uplifts. United crews stated that they do not have sufficient confidence in receiving approved altitude change clearances, resulting from ITP requests, to reduce additional fuel. A review of the data shows during the period from the beginning of the flight evaluation until United discontinued 747-400 service on these routes (August 2011 – April 2014), the percentage of climb clearances received from an ITP request along these routes was 82%. United has stated that flight crews would need to experience approval rates closer to 90% of the time before they would reduce this additional fuel. The overall flight evaluation percentage for

approved climb clearances from an ITP request rose to 90% from May 2014 to June 2015 but by then by then United had discontinued 747-400 service to Australia.

United has transitioned to a system of performance based unplanned contingency fuel that is based on statistics regarding the trip burn deviation history for a particular fleet on a particular city pair. The statistical program uses the historical trip fuel burn deviation (defined as the burn deviation between planned and actual trip burn) for the specific city pair and fleet type. If the burn deviation trend narrows, subsequent flights may be planned with reduced unplanned contingency fuel. A reduction in actual trip burn deviations enabled by ITP-equipment could influence these statistics over time, resulting in more precise unplanned contingency fuels being loaded for subsequent flights.

3. Aggregate benefits of ITP equipage due to enhanced situational awareness

3.1 Overview of situation awareness (SA) analysis

A limitation of looking at ITP benefits in the above manner is that it does not account for the ability of the crew to continuously optimize their altitude with the knowledge of proximate traffic around them. In other words, these individual ITP benefits are only calculated over a 2-hour time period within a flight, while the crew can continuously use the display to optimize their altitude over the entire flight time, typically 10-14 hours.

As stated earlier, during pilot interviews conducted in September 2013, pilots stated that they felt there were economic benefits from the use of the situational awareness aspect of the ITP display. It was postulated that the situational awareness benefits are primarily knowledge of where other "same direction" aircraft are proximate to the ITP-equipped aircraft, allowing flight crews to make standard climb requests with a higher probability of success. These standard climb requests can be made at any time over the duration of a flight. Also, knowing the traffic competing for optimum altitudes at oceanic entry points, particularly on the North Atlantic, allows for an earlier request for the optimum altitude.

United Airlines and FAA personnel developed a process that was used to assess the SA benefits of ITP equipage. Comparisons were made between planned and actual fuel airborne burn for Non-ITP-equipped Aircraft (Non-ITP A/C) and ITP-equipped Aircraft (ITP A/C). Planned fuel burn takes into account a fuel burn bias which is calculated for each individual aircraft as its performance decrements compared to "book" performance. Taxi fuel burn was removed from the planned and actual fuel burn data to allow a comparison between planned and actual airborne fuel burn

This assessment assumes that the major difference in airborne fuel burn is because of ITP equipage, rather than other factors influencing airborne fuel burn such as not having a constant Cost Fuel Index or major differences in aircraft weight. This comparison uses planned versus actual airborne fuel burns, averaged over a very large sample size, for Non-ITP A/C and ITP A/C. Those average airborne fuel burns for both pre-ITP operations and post-ITP operations time periods are calculated for Non-ITP A/C and ITP A/C, with the aggregate benefit being the improvement in ITP A/C over Non-ITP A/C when comparing the two operations' periods.

Note that this method is not a direct comparison of Non-ITP A/C and ITP A/C. This method is necessary because 10 of the 12 UAL ITP A/C are United's oldest and worst performing 747-400 aircraft. Although the fuel burn bias calculation in the planning software attempts to remove the impact of the fuel burn of these older aircraft, it is not perfect. As a result, instead of directly comparing the performance of the two "sub-fleets" (with ITP and without ITP), the comparisons are done in a manner that attempts to remove as much performance bias as possible.

When the initial aggregate calculations were complete, the standard deviations were much higher and the skews were quite large. It turned out that there were select data records in which there were either transcription or transmission errors. Barring a manual check of all valid records and to not "cherry-pick" good data, the way to remove these outliers algorithmically was to perform a sensitivity analysis around the effect of using only those fuel savings values within a percentage range of the total planned fuel burn. The outcome of this sensitivity analysis was to use those fuel savings' absolute values within 5% of planned fuel, for otherwise valid records. This resulted in a better set of standard deviations and low skew values in accordance with the expected distribution of the savings, i.e. no bias towards savings or loss in planned vs. actual. The skew of the data was used to ensure that invalid outliers were not present in the data. Skew is a measure of the asymmetry of the probability distribution of a real-valued random variable about its mean. A low skew value, i.e. less than the absolute value of 1 and as close to zero as possible, indicates the distribution is symmetric about the mean and there are no significant outliers impacting the data.

The analyses also took into account benefits for various oceanic regions. While ADS-B ITP operations were only authorized in Oakland Oceanic controlled airspace (in the Pacific), crews were allowed to use the SA aspect of the system in any oceanic airspace region they were operating in. For these analyses, data was obtained and analyzed for 15 trans-Pacific and 3 trans-Atlantic city pairs.

As a result of a start date sensitivity analysis (discussed in section 3.3), 10/15/2013 is used as the start date for ITP operations, marking the line between pre- and post-ITP (or start of ITP) operations for the purposes of analyzing the SA fuel benefit of ITP equipage. The "pre-ITP operations" and "post-ITP operations" date ranges were:

Pre-ITP operations: 11/1/2012 – 10/15/2013

Post-ITP operations: 10/16/2013 – 4/28/2015

Note also that due to a change in the UAL data warehouse, pre-ITP fuel burn data are not available any earlier than 11/1/2012. It was also considered desirable to use at least one years' worth of data to remove any possible effects from seasonality.

3.2 Aggregate Fuel Benefit Results

Table 1 shows the results obtained for the 18 city pairs contained in the analyses. For each "subfleet" (ITP/non-ITP) and for each time frame (pre- and post-ITP start dates), the Table 1 columns list the average fuel savings, the standard deviation of the fuel savings, the number of flights and the skew of the fuel savings results. The average difference

between the planned and actual airborne fuel burns, in both time periods and for both subfleets, is calculated and shown in Table 1. (A positive difference has actual airborne performance better than planned, and a negative difference shows that that flight burned more fuel in the airborne segment than planned.) The improvements within a subfleet are then obtained by subtracting the pre-ITP airborne fuel burn difference from the post-ITP airborne fuel burn difference. Finally, the two subfleets are compared to obtain the fuel savings for the ADS-B ITP-equipped aircraft ("ADS-B In equipped") versus the non-ADS-B ITP-equipped aircraft ("Non-ADS-B In equipped").

All valid Scheduled flights, Trans-Pacific and Trans-Atlantic both directions, with valid City Pairs		Average Fuel Savings (Avg of Planned-Actual Airborne Fuel Burn)	Std. Dev. Fuel Savings	Number of flights	Skew of the Fuel Savings
Pre-ITP: 11/1/2012 – 10/15/2013					
	ADS-B In equipped	671.09	3667.12	3458	-0.15
	Non-ADS-B In equipped	1377.38	3887.48	2954	-0.16
Post-ITP: 10/16/2013 – 4/28/2015					
	ADS-B In equipped	1787.12	3689.20	5175	-0.02
	Non-ADS-B In equipped	1920.05	3597.79	5186	-0.06
	Improvement				
	ADS-B In equipped	1116.02			
	Non-ADS-B In equipped	542.67			
	Fuel Benefit	**573.36**			

Table 1 – Aggregate Fuel Benefit for ITP Equipage.

In Table 1 it can be seen that the average planned vs actual fuel difference for the ADS-B ITP-equipped airplanes prior to ITP operations is 671 lbs. per flight. The average fuel difference for these same aircraft after ITP operations are in effect is 1787 lbs. per flight. Comparing these numbers show that there is an overall improvement for the ADS-B ITP-equipped airplanes of 1116 lbs. per flight after ITP operations are in effect. A similar analysis of the non-ADS-B ITP-equipped aircraft shows there is an overall improvement of 542 lbs. per flight. Subtracting these two results demonstrates that the aggregate SA fuel burn savings is calculated to be 573 lbs. per flight. This means that for every flight of an ITP-equipped airplane, that airplane saved an average of 573 pounds of fuel over an aircraft that did not have ITP equipment. This is an indication that flight crews are using the ITP equipment to improve their operations.

It should be noted that even though statistically, there are enough flights to perform this analysis, the standard deviation of the fuel burn deltas between planned and actual is significantly larger than the average of the fuel burn deltas. There is high variability in the data, which leads one to the conclusion that this SA Fuel Benefit trends toward supporting the qualitative survey conclusion from the human factors work with the UAL flights crews but that there are undoubtedly other variables driving the fuel burn delta.

The aggregate fuel benefit values were also identified for the Trans-Atlantic and Trans-Pacific flights, as shown in Tables 2 and 3.

All valid Scheduled flights, Trans-Atlantic both directions	Average Fuel Savings (Planned-Actual Airborne Fuel Burn)	Std. Dev. Fuel Savings	Number of flights	Skew of the Fuel Savings
Pre-ITP: 11/1/2012 – 10/15/2013				
ADS-B In equipped	866.61	3592.19	837	-0.11
Non-ADS-B In equipped	1783.56	3622.51	752	0.00
Post-ITP: 10/16/2013 – 4/28/2015				
ADS-B In equipped	2033.73	3534.44	919	-0.23
Non-ADS-B In equipped	2280.39	3377.69	915	-0.26
Improvement				
ADS-B In equipped	1167.12			
Non-ADS-B In equipped	496.82			
Fuel Benefit	**670.30**			

Table 2 – Aggregate Fuel Benefit of ITP Equipage for Trans-Atlantic Flights Only

All valid Scheduled flights, Trans-Pacific both directions, with valid City Pairs	Average Fuel Savings (Planned-Actual Airborne Fuel Burn)	Std. Dev. Fuel Savings	Number of flights	Skew of the Fuel Savings
Pre-ITP: 11/1/2012 – 10/15/2013				
ADS-B In equipped	608.66	3688.55	2621	-0.16
Non-ADS-B In equipped	1238.67	3964.40	2202	-0.18
Post-ITP: 10/16/2013 – 4/28/2015				
ADS-B In equipped	1733.86	3719.63	4256	0.02
Non-ADS-B In equipped	1842.85	3638.57	4271	-0.01
Improvement				
ADS-B In equipped	1125.21			
Non-ADS-B In equipped	604.18			
Fuel Benefit	**521.03**			

Table 3 – Aggregate Fuel Benefit of ITP Equipage for Trans-Pacific Flights Only

On average, trans-Atlantic ADS-B ITP-equipped flights save 670 lbs. per flight and trans-Pacific ADS-B ITP-equipped flights save 521 lbs. per flight. This is somewhat expected since, in general, there is more traffic in the Northern Atlantic region and the traffic is more tightly grouped. As a result, it can be more difficult to receive climbs in the North Atlantic region. With ADS-B ITP equipment, crews have a much better understanding of the traffic picture and can make more informed requests and are more likely to receive a beneficial climb from a climb request.

3.3 Sensitivity Analysis for Determining Start Date for ITP Operations

The analyses performed also took into account when pilots were fully trained and familiar with the ADS-B ITP systems. It is acknowledged that a learning curve would occur between initial training and before full ITP operations were considered "started" within the ITP-equipped subfleet. United assumed this learning curve would take place approximately over a 6-month period. This allowed for time for pilots to become more familiar with the display and discover new ways to gain efficiency from using the traffic display.

As mentioned previously, 10/15/2013 was chosen as the start date for ITP operations, marking the line between pre- and post-ITP operations for the purposes of analyzing the SA fuel benefit of ITP equipage. A sensitivity analysis to this start date was performed to ensure its validity. A start date for the data used in this analysis was chosen as 7/1/2013, with the assumption that if the data did not show a learning curve, an earlier date would need to be chosen. An end date of 1/27/2014 was chosen to ensure that the learning curve had fully plateaued. Given that many of the flights in the data set are frequency flights (i.e. do not run seven days a week), there was no need to run the analysis at any finer granularity than one date per week. Chart 1 shows the results of the sensitivity analysis.

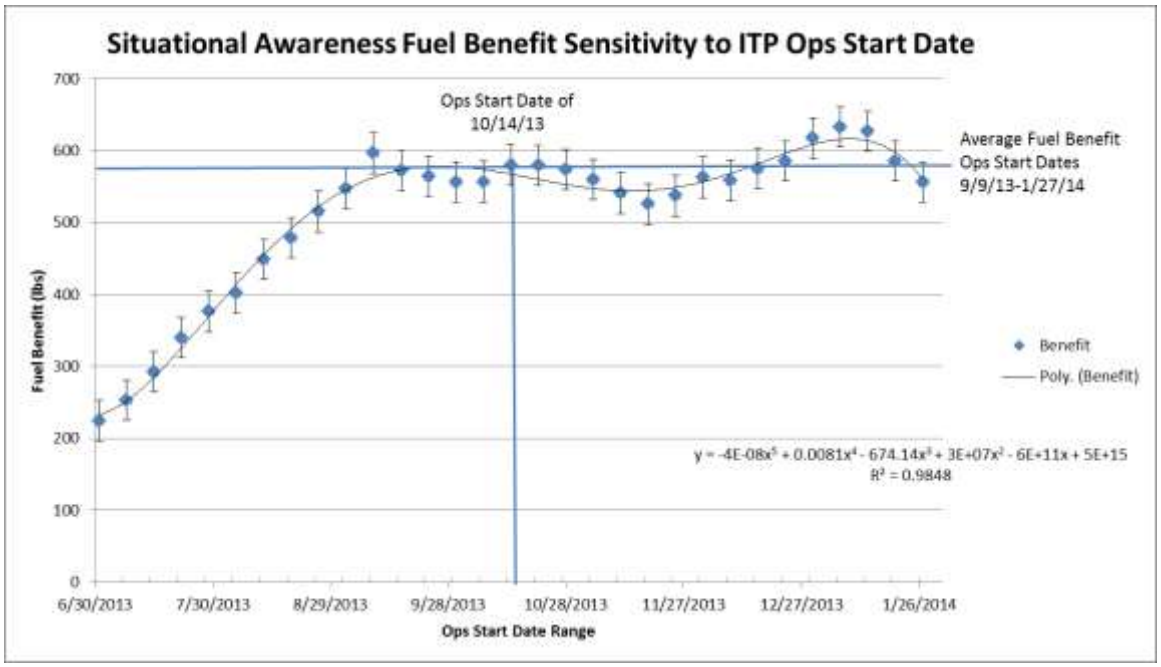

Chart 1 – Sensitivity Analysis of ITP Ops Start Date

A learning curve is clearly shown until early September 2013 and effectively plateaus then. There is no appreciable statistical difference between September and October start dates. The horizontal blue line at 573.75 lbs. is the average of the fuel benefits calculated for each of the start dates in the analysis range of 9/9/2013-1/27/2014. That average has a standard deviation of 27.72 lbs., so the sensitivity to changing the start date in that

range is low, and does not drive a need to alter the 10/15/2013 date. Also, with the 10/15/2013 start date, one can be certain to be past the learning curve, so this date remained the ITP operations start date for the SA benefit analysis.

4. Summary

ADS-B ITP equipage has demonstrated situational awareness (SA) benefit anecdotally based on flight crew surveys and is supported with SA fuel benefit values when the data are analyzed at the aggregate level for all valid flights inbound and outbound in both the Trans-Atlantic and Trans-Pacific regions. The SA fuel savings benefit is 573 lbs. for all valid flights inbound and outbound in both the Trans-Atlantic and Trans-Pacific regions; this is the improvement of ITP-equipped aircraft over Non-ITP-equipped aircraft measured between the pre-ITP operations period and the ITP operations period. The SA fuel benefit for all flights both directions for the Trans-Atlantic sector is 670 lbs. and for the Trans-Pacific sector is 521 lbs. Note that all of these benefit values have significant standard deviations reflecting some variability of the results which should be taken into account when applying these conclusions to other fleets.