OPERATIONAL IMPROVEMENTS FROM THE AUTOMATIC DEPENDANT SURVEILLANCE BROADCAST IN-TRAIL PROCEDURE IN THE PACIFIC ORGANIZED TRACK SYSTEM

Ryan C. Chartrand[1], Kenneth M. Jones,[2] and B. Danette Allen[2]
NASA Langley Research Center, Hampton, VA 23681

The Federal Aviation Administration's (FAA) Surveillance and Broadcast Services (SBS) Program has supported implementation of the Automatic Dependant Surveillance Broadcast (ADS-B) In-Trail Procedure (ITP) on commercial revenue flights. ADS-B ITP is intended to be used in non-radar airspace that is employing procedural separation. Through the use of onboard tools, pilots are able to make a new type of altitude change request to an Air Traffic Service Provider (ATSP). The FAA, in partnership with United Airlines, is conducting flight trials of the ITP in revenue service in the Pacific. To support the expansion of flight trials to the rest of the United States managed Pacific Airspace Region, a computerized batch study was conducted to investigate the operational impacts and potential benefits that can be gained through the use of the ITP in the Pacific Organized Track System (PACOTS). This study, which simulated the Oakland managed portion of the PACOTS, suggests that potential benefits in the PACOTS are significant with a considerable increase in time spent at optimum altitude and associated fuel savings.

Nomenclature

ADS-B	=	Automatic Dependant Surveillance Broadcast
ATC	=	Air Traffic Control
ATSP	=	Air Traffic Service Provider
BADA	=	Base of Aircraft Data
CPDLC	=	Controller Pilot Data-Link Communication
FAA	=	Federal Aviation Administration
ITP	=	In-Trail Procedure
ITP/STD	=	standard clearance issued after an ITP request is made
kts	=	knots
LaRC	=	Langley Research Center
NASA	=	National Aeronautics and Space Administration
NATOTS	=	North Atlantic Organized Track System
NOAA	=	National Oceanic and Atmospheric Administration
NLR	=	National Aerospace Laboratory, Netherlands
nmi	=	nautical mile
PACOTS	=	Pacific Organized Track System
SA	=	Situation Awareness
SBS	=	Surveillance and Broadcast Services
SPR	=	Safety, Performance, and Interoperability Requirements
TMX	=	Traffic Manager

[1] Research Engineer, Crew Systems and Aviation Operations Branch, NASA LaRC, MS 152, AIAA member
[2] Senior Research Engineer, Crew Systems and Aviation Operations Branch, NASA LaRC, MS 152, AIAA member

I. Introduction

An experiment was performed to investigate the benefits of introducing the Automatic Dependant Surveillance Broadcast (ADS-B) In-Trail Procedure (ITP) into the Pacific Organized Track System (PACOTS). This experiment was conducted by the National Aeronautics and Space Administration's (NASA) Langley Research Center (LaRC) for the Surveillance and Broadcast Services (SBS) office of the Federal Aviation Administration (FAA). It was designed, developed, and executed as a computerized batch experiment using the TMX (Traffic Manager) flight simulation tool. This paper presents an overview of the ADS-B ITP, the PACOTS, this experiment, and summarizes some of the results.

A. ADS-B ITP

The ADS-B ITP is designed for use in airspace where the Air Traffic Service Provider (ATSP) is providing separation services through procedural separation. An ADS-B ITP aircraft will reference up to two proximate aircraft in order to perform the maneuver. The information provided by the flight crew to the air traffic controller for each referenced aircraft includes the reference aircraft identification, relative location to the ITP aircraft, and the ITP distance between the ITP aircraft and the reference aircraft. Each reference aircraft must be located vertically within 2,000 feet of the ADS-B ITP aircraft and meet one of the following criteria:

- ITP distance must be greater than or equal to 15 nautical miles (nmi) and have a closing ground speed difference less than or equal to 20 knots (kts); or
- ITP distance must be greater than or equal to 20 nmi and have a closing ground speed difference less than or equal to 30 kts.

Once an ADS-B ITP request is received by an air traffic controller, they also have a list of criteria to verify prior to issuing an ADS-B ITP clearance. The controller must confirm that:

- the current standard separation will exist at the requested altitude,
- the ADS-B ITP aircraft is not currently being referenced in any other ADS-B ITP clearance,
- the ADS-B ITP and reference aircraft are: not closing by more than 0.06 Mach, classified as same track, no more than 2,000 feet vertically separated, and not currently or expected to maneuver prior to the completion of the ADS-B ITP.

Once an ADS-B ITP clearance is received, the flight crew must re-verify that their ADS-B ITP criteria are still met with each referenced aircraft in the clearance. At that point the maneuver is similar to any other altitude change. The ADS-B ITP aircraft must maintain its current Mach number and a minimum rate of change of altitude of 300 feet per minute during the climb or descent.

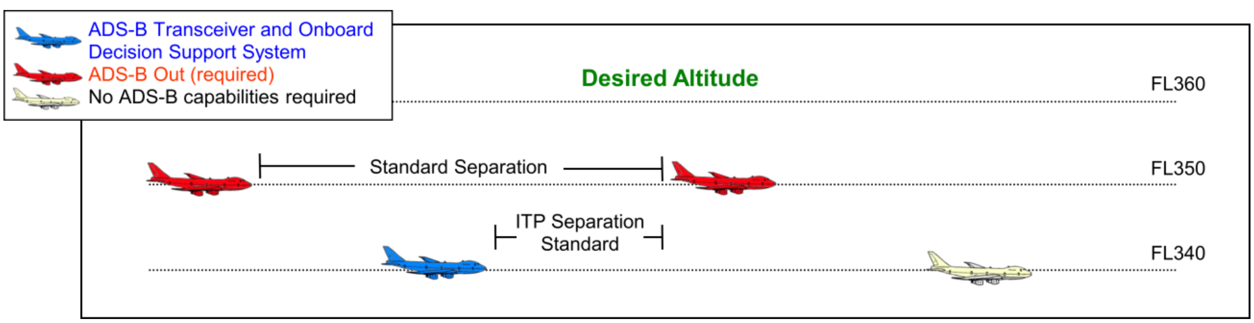

Figure 1: ITP Configuration

Figure 1 shows a typical situation encountered on an organized track system. To match its optimal fuel burn altitude or for other operational reasons, the ADS-B ITP aircraft at FL340 (blue) should be flying at FL360. While FL360 is free of any conflicting traffic, the required separation distance to either of the two red aircraft does not exist at the intermediate altitude of FL350. Without ADS-B ITP, this forces the blue aircraft to remain at the less efficient altitude of FL340. With ADS-B ITP and associated on-board tools, the blue aircraft makes use of ADS-B reports from nearby aircraft and determines which of the aircraft have qualified ADS-B data and meet the ADS-B ITP criteria. If the required conditions are met, the flight crew can make an ADS-B ITP request to Air Traffic Control (ATC). The ADS-B reports must meet specific limits for the accuracy and integrity of the data in order to be used for the ADS-B ITP. In order for the ADS-B ITP to be requested, both the ADS-B ITP aircraft and any reference aircraft (red aircraft in Figure 1) must be same direction, and the initiation criteria must be met between the ADS-B ITP aircraft and any reference aircraft.

For a complete description of the ADS-B ITP please refer to the Safety, Performance, and Interoperability Requirements (SPR) Document for the ATSA-ITP application (DO-312) document [1]. The ADS-B ITP was initially designed after the currently approved ICAO DME/GNSS climb through procedure, which relies on the pilot to provide information from the cockpit to the controller to be used during the review and approval of an altitude change request. For the ADS-B ITP, this information is obtained through the use of ADS-B technology.

B. Pacific Organized Track System (PACOTS)

The PACOTS is used for the air traffic traveling between Asia and the United States of America. The track definitions are created on a daily basis by Oakland and Fukuoka ATC centers. The minimum lateral separation of the tracks is 50 nmi, the minimum longitudinal separation varies between 30 nmi and 50 nmi based on the airspace operator and aircraft equipage, and the minimum vertical separation is 1000 feet. The eastbound tracks are usually located in Fukuoka airspace for approximately two hours and in Oakland airspace for approximately five hours. This experiment used data from February 4, 2011 along tracks 1, 2, 3, and 14 along the portion of the eastbound tracks that fall within the Oakland airspace boundary and considered both the 30 nmi and 50 nmi longitudinal separation standards. Figure 2 shows a screenshot of a typical traffic flow from a PACOTS controller station.

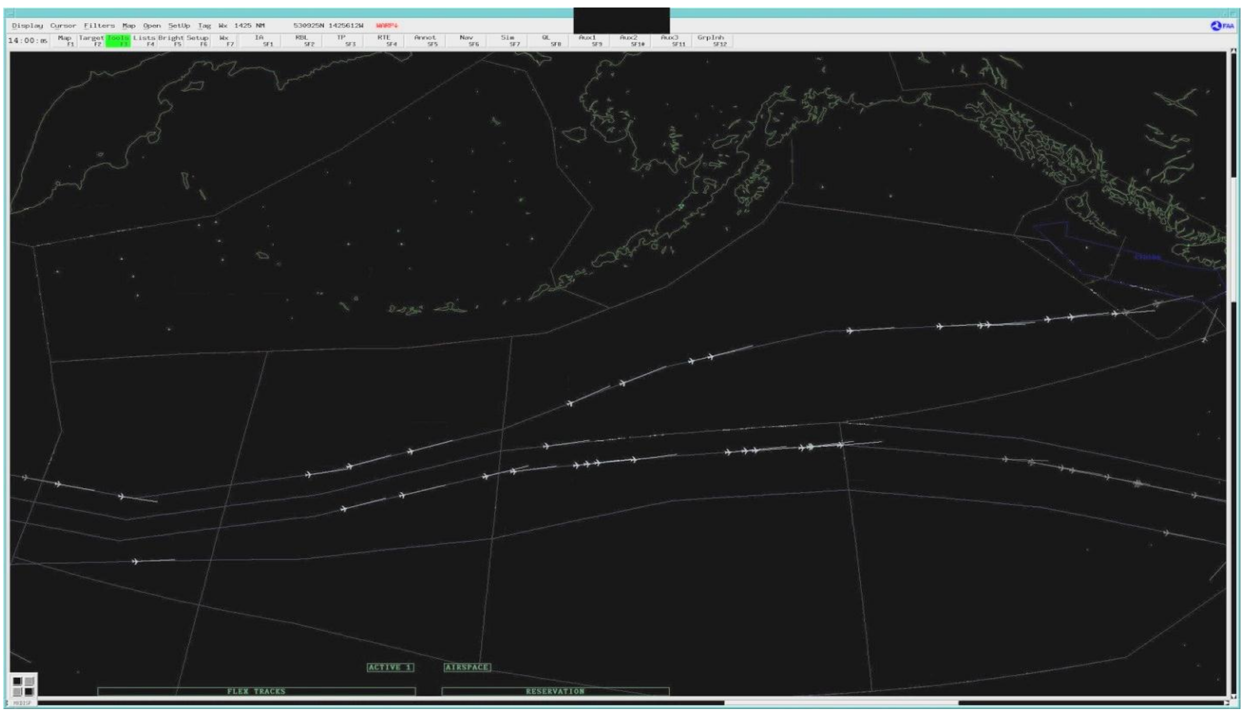

Figure 2: Screenshot of the PACOTS

Previous experiments have shown multiple operational improvements are possible through increased situation awareness (SA) resulting from on-board ADS-B displays and the implementation of the new ADS-B ITP standard. These experiments were focused on other oceanic environments, where many of the benefits were limited by the occasional need for the ADS-B ITP, limited flight time, or traffic densities that were too high to make effective use of the ADS-B ITP [2]. It is expected that the PACOTS will show increased use of the ADS-B ITP over the other oceanic environments due to the traffic patterns, duration of flight time, and separation standards used on the PACOTS. This combination generates a large demand for similar altitudes within the same period of time, forcing some aircraft to fly at undesirable altitudes, which can result in a decrease in fuel efficiency. This experiment examines opportunities for altitude changes created by the ADS-B ITP and estimates the potential fuel savings and beneficial operational impact the ADS-B ITP would have on the PACOTS.

II. Experiment

A. Design

This experiment targeted four parameters as independent variables that could affect the operational impact of the ADS-B ITP and the SA provided by an ADS-B display:

1. the system-wide level of ADS-B equipped aircraft
2. traffic density
3. ITP capability
4. separation standard

The system-wide level of ADS-B equipage is a combination of the percent of aircraft equipped with ADS-B OUT (30, 60, and 90% were simulated) and those equipped with ADS-B IN (10, 45, and 80% were simulated). Because it was assumed that any aircraft equipped with ADS-B IN would also be equipped with ADS-B OUT, no combinations that resulted in a higher ADS-B IN equipage level than ADS-B OUT were considered, yielding a total of six equipage levels. A seventh level of no ADS-B equipage (0%) was used as the baseline to simulate current day operations. The levels of ADS-B equipage are referred to by the percent of ADS-B out equipped aircraft followed by the percent of ADS-B IN aircraft. The two values are separated by a "_". The complete list includes 0_0 (baseline), 30_10, 60_10, 90_10, 60_45, 90_45, and 90_80.

Three traffic densities of 1.0, 1.5, and 2.0 times the number of aircraft in the current PACOTS traffic data were simulated. The third parameter adjusted what information and capabilities for flight level changes could be used by the flight crew. The first level provided the flight crew (pilot model) with increased SA using ITP equipment. The second level expanded the first to include the ability to conduct an ITP (SA+ITP). Pilot models, which were used in lieu of flight crews, were provided with rules to determine under what conditions to request an altitude change based on the proximity to other aircraft. The final parameter of separation standard was set to either 30 nmi or 50 nmi, the two main standards used in Oakland airspace. The relationship of the experiment parameters is shown in Table 1.

Table 1: Experiment Matrix

Separation standard			**30 nmi**			**50 nmi**		
Traffic density			**1.0X**	**1.5X**	**2.0X**	**1.0X**	**1.5X**	**2.0X**
			# Replicates			**# Replicates**		
ITP & ADS-B equipage	**Baseline**	**0_0**	18	18	18	18	18	18
	SA	**30_10**	18	18	18	18	18	18
		60_10	18	18	18	18	18	18
		60_45	18	18	18	18	18	18
		90_10	18	18	18	18	18	18
		90_45	18	18	18	18	18	18
		90_80	18	18	18	18	18	18
	SA + ITP	**30_10**	18	18	18	18	18	18
		60_10	18	18	18	18	18	18
		60_45	18	18	18	18	18	18
		90_10	18	18	18	18	18	18
		90_45	18	18	18	18	18	18
		90_80	18	18	18	18	18	18

B. Simulation Environment

This experiment was conducted in TMX, a medium fidelity desktop flight simulation program originally developed by the National Aerospace Laboratory (NLR) in the Netherlands with continued improvement and functionality expansion by both the NLR and the NASA over many years. TMX is capable of simulating up to 2,000 aircraft at a time, using a six degrees-of-freedom dynamics aircraft model augmented with performance parameters from the

EUROCONTROL Base of Aircraft Data (BADA) version 3.5 [3]. This experiment used enhancements implemented in TMX for a similar ADS-B ITP experiment conducted on the North Atlantic Organized Track System (NATOTS) [2] that included a redesigned pilot model, creation of an ATC model, modeling of the oceanic environment, expansion of the Controller Pilot Data-Link Communication (CPDLC) model, creation of an ADS-B ITP module, and detailed improvements to the accuracy of the fuel flow model. This experiment used the actual National Oceanic and Atmospheric Administration (NOAA) forecast winds and PACOTS route definitions. The traffic flows in the experiment were created by modeling the distribution of recorded traffic data in terms of distribution of aircraft arriving at the track entry in time, total number of aircraft, and aircraft distribution across tracks. Traffic data from February 2011 provided by the FAA was analyzed to provide an overview of current operations in the PACOTS. Data reviewed included: total number of aircraft, distribution of aircraft between tracks, arrival intervals, aircraft type, number, and magnitude of altitude change requests, and track definitions. The results of this analysis provided the information that was used to define the experiment matrix and configure the TMX simulation. Given the fleet mix flying in the PACOTS and the types of aircraft models available in TMX, a selection of eight aircraft types (similar to A330-200, A330-300, A340-300, B747-400, B757-200, B767-200, B767-300, and B777-200) were modeled for this experiment. The selected types cover approximately 77% of the observed aircraft types, with the remainder being primarily cargo carriers, military and business jets. The primary metric taken from the flight data was the distribution and quantity of traffic in the PACOTS. Table 2 shows the average density for the data analyzed along with the data from the baseline condition of the experiment traffic. The average total number of aircraft per day and percent of traffic per track matches closely between the actual and simulated data. Due to the random variations in actual traffic, exact duplication of the number of aircraft was not possible.

Table 2: Comparison of Experiment Baseline

	February 2011	**Experiment Baseline for 1.0x density**
Total number of aircraft per day	65.1	68.7
% on Track 1	28.1	26.6
% on Track 2	30.8	29.5
% on Track 3	29.4	29.7
% on Track 14	11.7	14.2

The simulated traffic flows used in this experiment were also modeled after the distribution of current traffic during the time the tracks are active. The number of aircraft on each track were counted at 60 second intervals to calculate a distribution of the traffic, shown in blue in Figure 3. The modeled distribution is shown in red. The same process was done for all of the baseline scenarios for 1.0x density of the experiment and the data for tracks 1, 2, 3, and 14 are shown in Figure 3. While an exact duplication of the traffic distribution was not possible, the similarity of the simulated data to the actual data indicates this simulation is representative of the PACOTS traffic flow.

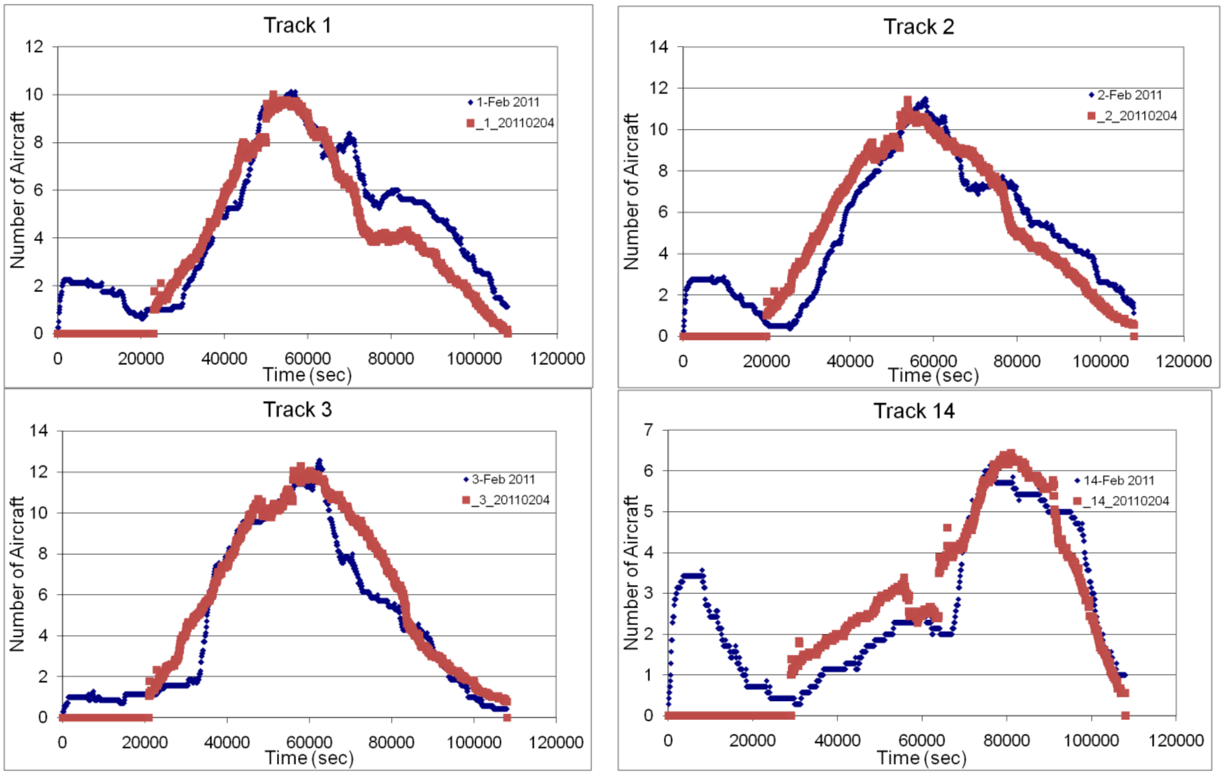

Figure 3: Comparison of actual (blue) and modeled (red) PACOTS Tracks

An analysis of the variation in the magnitude of altitude change requests was completed on the actual data, and was used following the scenario creation to compare the baseline traffic conditions to the actual data. Table 3 includes a comparison of the magnitude of various altitude change requests. Given the accuracy of this comparison, it is important to note that this aspect of the PACOTS was not modeled but emerged from the detailed modeling done on the density distributions and the accuracy of the aircraft models as compared to what is flown in the PACOTS.

Table 3: Comparison of the magnitude of altitude change requests

% Altitude Requests	February 2011	50 nmi / 30 nmi
% of 1000 feet requests	61.0	60.8 / 60.5
% of 2000 feet requests	34.6	28.6 / 29.6
% of 3000 feet requests	2.6	8.5 / 8.3
% of 4000 feet requests	1.5	2.1 / 1.6

III. Results

Throughout the results section of this paper, plots are organized by increasing levels of ADS-B IN and then by increasing levels of ADS-B OUT. The equipage levels are labeled using the syntax of "Percent of aircraft with ADS-B OUT_Percent of aircraft with ADS-B IN". As an example, a label of 30_10 would indicate that 30% of the aircraft are equipped with ADS-B OUT and 10% of the aircraft are equipped with ADS-B IN. Because of the extreme similarity of the data between the 30 nmi and 50 nmi conditions, results will be shown for only the 30 nmi case with differences between the two cases presented as needed. In this section, the terms "fuel savings" and "fuel loss" are used in comparison to each aircraft's respective baseline. When a fuel savings is experienced, it means that the aircraft in that experiment condition used less fuel than the same flight did in the baseline. A fuel loss means that a flight used more fuel for the experiment condition flight than it did for the same baseline flight.

Target density values were 1.0, 1.5, and 2.0 times the current traffic density and the calculated average traffic density for the baseline scenarios is shown in Table 4 with experiment traffic density multipliers shown in parentheses. Due to the random variations in actual traffic, exact duplication of the number of aircraft at higher densities was not possible. Through the rest of the paper, the traffic density conditions will be referred to by the target multiplier values of 1.0x, 1.5x, and 2.0x.

Table 4: Traffic Density of Experiment

Density Name	Average Number of Aircraft per day
ACTUAL	65.1
1.0X	68.7 (1.05 X)
1.5X	93.7 (1.44 X)
2.0X	128.4 (1.97 X)

A. Per Aircraft Fuel Savings and Time at Optimum Altitude

In all non-baseline scenarios, approximately 35% of unequipped aircraft, for both the 30 and 50 nmi separation standards, experienced a fuel savings with no large increases or decreases to the percentage value as the ADS-B or ITP equipage increased. This indicates that the percent of unequipped aircraft that experience a fuel savings or a fuel loss on average does not change with increasing ADS-B or ITP equipage levels. For unequipped aircraft, the distribution of aircraft is nearly equal between aircraft with a fuel savings, aircraft with a fuel loss, and aircraft with no change, a different trend then that experienced by the ADS-B IN equipped aircraft. Nearly all (approximately 95%) of the ADS-B IN equipped aircraft experience a fuel savings. The remaining 5% of equipped aircraft experience a loss.

The largest contributing factor to equipped aircraft fuel savings is the amount of time that they are able to spend at their respective optimum altitudes. All aircraft have an optimum altitude to fly at which is most fuel efficient for the current weight and speed. This altitude changes continually during a flight. During a long flight, similar to those in the PACOTS, an aircraft's optimum altitude could change by as much as 4,000 feet. In order to reduce fuel burned as much as possible, an aircraft should conduct a continuous cruise climb. However, in an organized track system and with the volume of aircraft present, that is not usually possible. In an attempt to follow the cruise climb as close as possible, aircraft perform step climbs periodically as the optimum altitude changes. The more climbs or descents aircraft can make, the higher the fuel savings that can be experienced. In the baseline conditions the unequipped aircraft (100% of the aircraft) spent an average of 28% of the flight time at the optimum altitude. The percent of the flight spent at optimum for the unequipped aircraft did not change as surrounding aircraft were equipped with ADS-B or the ITP.

The percent of time that aircraft spend at their optimum altitude is shown in Table 5. The percent of time that aircraft equipped with ADS-B IN and the ADS-B ITP spend at their optimum altitude ranges between 75% and 79%. This is a significant increase over that of the unequipped aircraft, at 28%. This increase from 28% to 75% of flight time at the optimum altitude is from the aircraft being able to make better and more accurate requests for altitude changes. Having the ITP equipment onboard the aircraft provides increased the SA of the proximate traffic compared to current operations. This additional information allows the flight crew (or pilot model) to make altitude change requests at times when it is more likely that ATC will be able to issue a clearance. The percent of the flight that is spent at optimum is one metric that does change slightly between the use of a 50 nmi separation standard versus a 30 nmi separation standard. The 50 nmi separation condition experienced a smaller increase to 70%-78%. The main reason for this decrease is that when the separation standard is increased, fewer aircraft can fit at any single altitude, resulting in a reduction in opportunities to execute an ITP. In the PACOTS, many of the aircraft will have the same optimum altitude because the aircraft types flown and their weights are usually similar. This creates local conflicts for optimum altitudes which are partially alleviated by the use of a smaller separation standard. For both the 30 nmi and 50 nmi results, the data for ITP equipped aircraft are slightly higher than the data for the SA only aircraft. The benefit of the ITP is offset by the benefit of the smaller separation standard. Also of interest is that under both the 30 nmi and 50 nmi separation standards, there is little variation in the percent of time that equipped aircraft spend at optimum altitude when comparing across the ADS-B equipage levels or traffic density. The primary reason for this insensitivity to ADS-B equipage and density is that the PACOTS is not functioning near a capacity limit. Since all of the aircraft that are equipped with ADS-B and ITP are able to maneuver to their optimum flight levels even at double the current traffic density, it implies that the PACOTS has significant unused capacity available.

Table 5: Percent of Time Spent at Optimal Altitude

	Unequipped	ITP with 30 nmi separation	ITP with 50 nmi separation
Average	27.7%	77.2%	75.0%
Minimum	27.0%	74.6%	70.0%
Maximum	28.4%	79.0%	78.1%

B. Number of Altitude Change Requests and Approvals

As shown in Figure 4, as the ADS-B IN equipage level increases, the average number of requests per aircraft increases from just under two per aircraft in the baseline to over three per aircraft for the highest ADS-B IN equipage level. This increase is primarily due to the increased number of ADS-B IN equipped aircraft, which can make more informed altitude change requests. If the solution was as simple as just making more requests, then that is easy to achieve. Every aircraft in the PACOTS today could start making altitude change requests every time they thought it would be efficient. While this seems like a solution from the perspective of a single aircraft, if all aircraft in the PACOTS were to do this the ATSP could become over loaded. One way to address this is to increase requests using improved SA of the traffic environment (via the on-board display) so that the requests have a higher chance of being approved. Additional requests without accompanying approvals do not increase benefit.

Figure 5 shows that while there is an increase in the number of requests being made by the aircraft (as seen in Figure 4), as the ADS-B IN equipage level increases, the approval rate also increases. In the baseline conditions, an approval rate of just under 70% was experienced by the aircraft, corresponding with the target value from current operations. Even though the number of requests on average increased from 2 per aircraft to 3 per aircraft, the figure shows that the approval rate increased over 20% as ADS-B IN equipage increased to the highest level tested. In general, the number of requests per aircraft were fewer as the traffic density increased. This is because there are fewer openings on the tracks for aircraft to maneuver to with higher traffic density. The approval rate, however, did not show the same consistent trend with density. In the baseline and low ADS-B equipage levels, the approval rate showed only a minor improvement. This is because when only a small portion of the aircraft are equipped with ADS-B OUT, there is less chance for a requesting aircraft to have a complete view of all the aircraft in the local airspace. As the ADS-B level of equipage increased, the approval rates increased significantly. As more aircraft were equipped with ADS-B, the pilot's understanding of the local surrounding traffic increased for the ITP equipped aircraft.

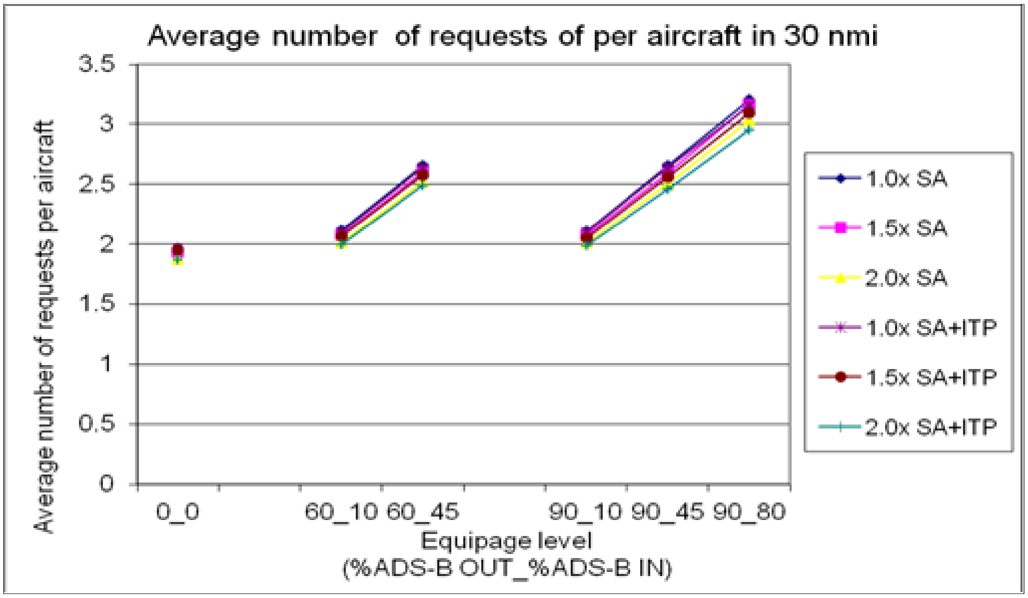

Figure 4: Average requests per aircraft in 30 nmi

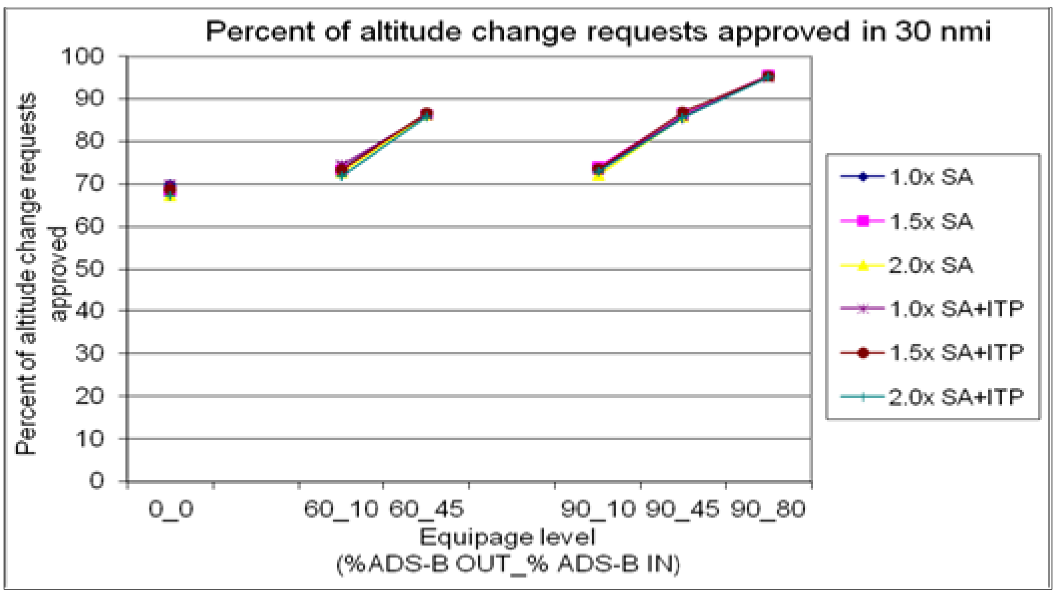

Figure 5: Percent of altitude change requests approved in 30 nmi

C. Number of ITP Approvals

The results presented so far have shown that there are benefits experienced by the ADS-B IN and ITP equipped aircraft. This section will explore what portion of the benefit is attributed to the ADS-B ITP itself. The data on the left in Figure 6 shows the percent of standard ATC clearances at 30nmi granted in response to an ITP request from an ITP equipped aircraft (ITP/STD) with increasing levels of ADS-B OUT equipage across constant ADS-B IN levels. In other words, an ITP equipped aircraft made an ITP request but the ITP procedure was not necessary because standard 30nmi separation was available. These are altitude changes that would have gone unrequested were it not for the increased SA provided by ITP equipment. The data on the right shows the same information but ordered across increasing levels of ADS-B IN while holding ADS-B OUT constant. Figure 7 shows similar data, but for when ATC issued an ITP clearance in response to an ITP request. Both sets of data show a direct relationship in the use of the ITP and the level of ADS-B OUT as seen when comparing the left charts of Figure 6 and Figure 7. For all traffic densities, the percent of approved requests directly increases with the ADS-B OUT equipage level. The effect of increased ADS-B IN equipped aircraft is a general decrease in the percent of aircraft that use the ITP, as seen in the right charts of Figure 6 and Figure 7. As the percentage of ADS-B OUT equipped aircraft increases, so do the number of potential targets to be used as ITP reference aircraft. With more potential reference aircraft, the opportunities to make use of the ITP naturally increases. However, because there are more aircraft equipped with both ADS-B IN and the ITP, there are more aircraft trying to maneuver to a better (often identical) altitude. This results in some ITP aircraft being blocked from making an altitude change, and decreases the percent of aircraft that can take advantage of the ITP.

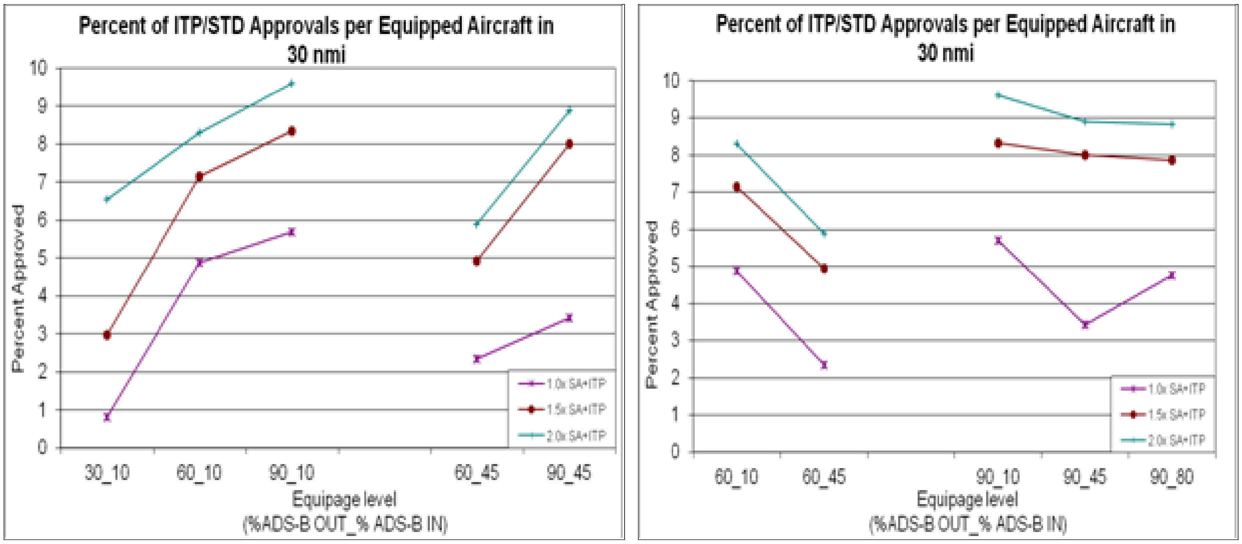

Figure 6: ITP/STD approvals per Equipped Aircraft in airspace using a 30 nmi separation standard

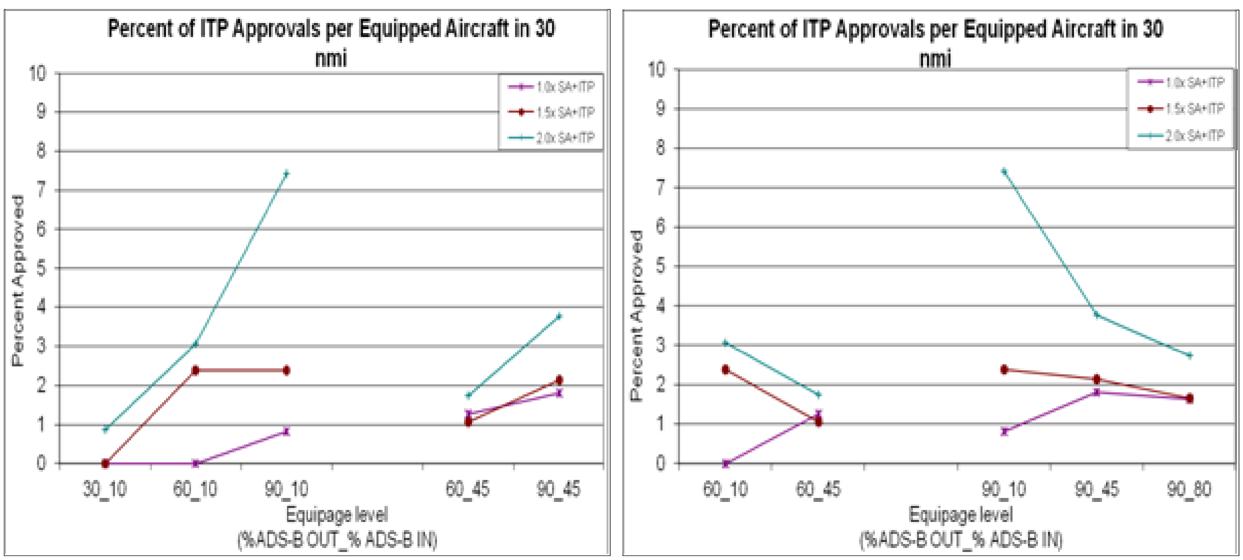

Figure 7: ITP approvals per Equipped Aircraft in airspace using a 30 nmi separation standard

Table 6 shows the average number of ITPs that were approved in a single representative day for both 30nmi and 50nmi separation standards. The number of approved ITPs in a 50 nmi environment was more than double the number in a 30 nmi environment. This increase is directly due to the larger minimum separation standard and the ITP providing greater flexibility compared to it. For both separation standards, the average number of ITPs increased directly with traffic density, ADS-B OUT equipage, and ADS-B IN equipage. This suggests there is benefit for aircraft that are among the first to equip with the ADS-B ITP.

Table 6: Number of Approved ITPs

Separation Standard	30 nmi			50 nmi		
Traffic Density / ADS-B Equipage	1.0X	1.5X	2.0X	1.0X	1.5X	2.0X
30_10	0.0	0.0	0.1	0.1	0.1	0.4
60_10	0.0	0.2	0.4	0.2	0.3	0.9
90_10	0.1	0.2	0.9	0.2	0.4	1.7
60_45	0.4	0.4	1.0	0.8	1.5	2.6
90_45	0.6	0.9	2.2	1.2	2.7	5.2
90_80	0.9	1.2	2.8	2.0	3.8	7.4

D. System-Wide Fuel Savings

Figure 8 shows the average system fuel savings for all unequipped aircraft. Given the number of aircraft in each density (68.7, 93.7, and 128.4) and the duration of the flight (~7 hours), most of the aircraft experience no fuel change from the baseline condition. For example, in the 1.5X condition of the 30_10 ADS-B equipage level, there was a system savings of 973 pounds of fuel. For the 90% ADS-B unequipped aircraft condition, 84.4 aircraft out of the 93.7 total aircraft saved, on average, 11.5 pounds of fuel per aircraft per flight. The majority of the unequipped aircraft though did not experience any significant change in fuel burn as the level of ADS-B and ITP equipage increased.

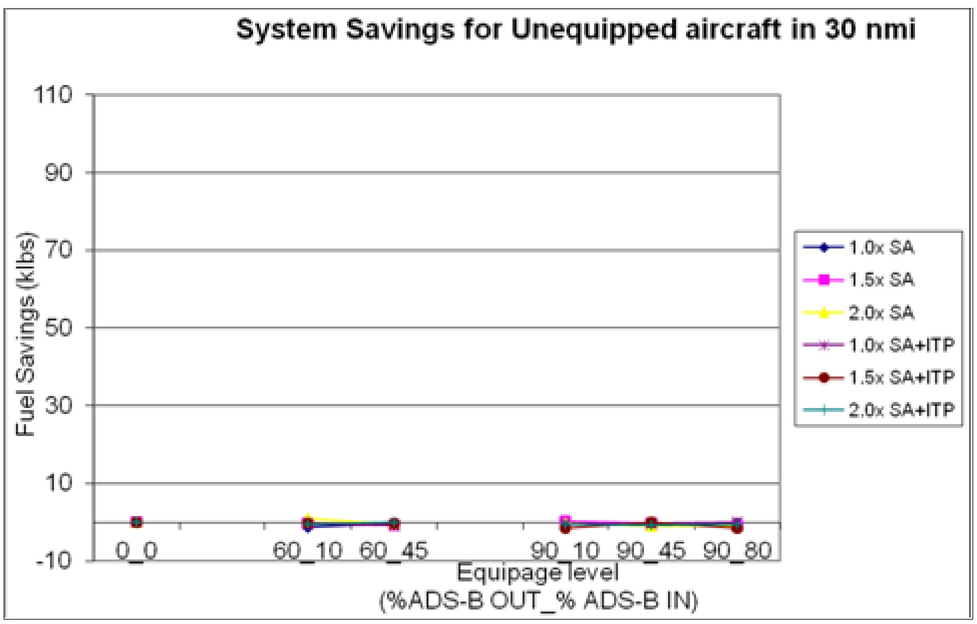

Figure 8: System fuel savings for unequipped aircraft in airspace using a 30 nmi separation standard

Figure 9 shows the average system fuel savings for all equipped aircraft, a very different picture than for the unequipped aircraft. Most visibly, the slopes for all of the data curves are positive indicating that regardless of density or ADS-B equipage, less fuel was burned than in the 0_0 baseline. Finally, there is a clear positive trend with ADS-B IN equipage. For example, a system fuel savings of approximately 9,200 pounds for the 1.5X and 30_10 ADS-B equipage level condition was experienced. Applying this savings to the 9.3 (93.7 * 10%) ADS-B IN equipped aircraft results in just under 1,000 pounds of fuel per aircraft, two orders of magnitude greater than the unequipped aircraft average of 11.5 pounds per aircraft. In terms of SA, the curves for the SA+ITP data are sloped higher than the SA only data. The ITP and separation standard do provide some additional benefit, but it is overwhelmed by the increased ability to make informed requests. The system fuel savings for the 50 nmi environment followed the same trends as the 30 nmi separation environment.

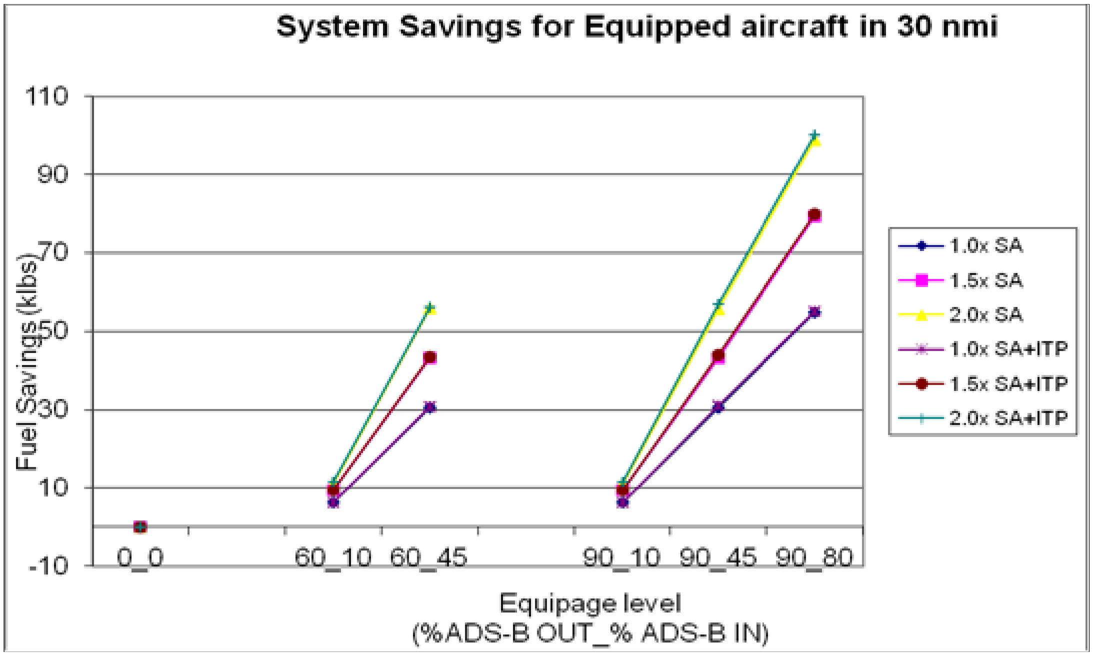

Figure 9: System fuel savings for equipped aircraft in airspace using a 30 nmi separation standard

IV. Conclusions

This study, which simulated the Oakland managed portion of the PACOTS, suggests that there are potential benefits of equipping aircraft with the ADS-B ITP and supporting systems in the PACOTS due to a considerable increase in time spent at optimum altitude and associated fuel savings. The data from this experiment showed that aircraft equipped with the ADS-B ITP and supporting equipment can make more informed requests and subsequently can maneuver more than unequipped aircraft. This ability to maneuver towards the optimum altitude increased the time spent at the optimum for the equipped aircraft from 28% to over 70%. This increased time at the optimum altitude resulted in significantly more fuel savings (1,000 pounds) than experienced by the unequipped aircraft (11.5 pounds). This increased savings is primarily due to the improved SA allowing for more informed altitude change requests. These benefits for the equipped aircraft had no detrimental impact to the unequipped aircraft. The system benefits from the ADS-B ITP increase with increased traffic density, ADS-B OUT equipage, and ADS-B IN equipage. The ADS-B ITP benefits decrease as the minimum separation standard decreases because track capacity (and therefore traffic density) increases enabling fewer opportunities for the ITP.

Acknowledgments

This experiment and analysis was conducted by the National Aeronautics and Space Administration's Langley Research Center for the Federal Aviation Administration's Surveillance and Broadcast Services office.

References

[1] Safety, Performance, and Interoperability Requirements Document for the In-Trail Procedure in Oceanic Airspace (ATSA-ITP) Application, RTCA DO-312, June 19, 2008.

[2] Chartrand et al, Operational Improvements from Using the In-Trail Procedure in the North Atlantic Organized Track System, NASA/TM-2009-215939, October 2009

[3] Nuic, A., 2003, *User Manual for the Base of Aircraft Data (BADA) – Revision 3.5*, Eurocontrol Experimental Centre, Bretigny, France http://www.eurocontrol.int/eec/public/standard_page/ACE_bada.html