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Abbreviations

ADS-B	Automatic Dependant Surveillance-Broadcast
ADS-B IN	Automatic Dependant Surveillance-Broadcast (receive)
ADS-B OUT	Automatic Dependant Surveillance-Broadcast (transmit)
ASAS	Airborne Separation Assistance System
ATC	Air Traffic Control
ATM	Air Traffic Management
ATOL	Airspace and Traffic Operations Laboratory
ATSA	Airborne Traffic Situation Awareness
ATSP	Air Traffic Service Provider
BADA	Base of Aircraft Data
CDTI	Cockpit Display of Traffic Information
CPDLC	Controller Pilot Data-Link Communication
d_a	Distance of aircraft A to common point
d_b	Distance of aircraft B to common point
d_{ITP}	ITP distance
DME	Distance Measuring Equipment
Eurocae	European Organization for Civil Aviation Equipment
ft	Feet
FL	Flight level
FMS	Flight Management System
GFS	Global Forecast System
HITL	Human-In-The-Loop
HF	High Frequency
ICAO	International Civil Aviation Organization
ITP	In-Trail Procedure
kts	Knots
LaRC	Langley Research Center
Lbs/hr	Pounds per hour
NASA	National Aeronautics and Space Administration
NATOTS	North Atlantic Organized Track System
NLR	National Aerospace Laboratory (Netherlands)
nmi	Nautical miles
NOAA	National Oceanic and Atmospheric Administration
NOTAM	Notice to Airmen
OCA	Oceanic Control Area
PACOTS	Pacific Organized Track System
RADAR	Radio Detection and Ranging
RFG	Requirements Focus Group
RTCA	Radio Technical Commission for Aviation (formerly)
SA	Situation Awareness
SASP	Separation and Airspace Safety Panel
SOPAC	South Pacific
SPR	Safety, Performance and Interoperability Requirements
TCAS	Traffic alert and Collision Avoidance System
TDA	Traffic Density Analyzer
TMX	Traffic Manager (NLR/NASA)
U	NATOTS track Uniform
V	NATOTS track Victor

VHF	Very High Frequency
W	NATOTS track Whiskey
X	NATOTS track X-ray
Y	NATOTS track Yankee
Z	NATOTS track Zulu

Definitions

Automatic Dependent Surveillance-Broadcast (ADS-B). A system by which airplanes can constantly broadcast state, environment, and intent information. This can include: current position and altitude, category of aircraft, ground speed, flight number, whether the aircraft is turning, climbing or descending, and integrity indicators over a radio datalink.

Flight Level. A surface of constant atmospheric pressure, which is related to a specific pressure datum of 29.92 inches of mercury (1013.2 hectopascals), and is separated from other such surfaces by specific pressure intervals. Each is stated in three digits that represent hundreds of feet (ft). For example, flight level (FL) 370 represents a barometric altimeter indication of 37,000 ft.

Following Climb or Descent. A Same Track climb or descent performed by an aircraft when following a Reference Aircraft.

Ground Speed Differential. The difference between the In-Trail Procedure (ITP) Aircraft's ground speed and a Reference Aircraft or Same Direction Potentially Blocking Aircraft's ground speed.

In-Trail Procedure (ITP). A procedure employed by an aircraft that desires to change its flight level to a new flight level by climbing or descending in front of or behind one or two Same Track, Potentially Blocking Aircraft which are at an Intervening Flight Level.

Initial Flight Level. The flight level of the ITP Aircraft when it determines a climb or descent is desired.

Intermediate Flight Level. Any flight level between the Requested Flight Level and the Initial Flight Level of the ITP Aircraft.

Intervening Flight Level. Any Intermediate Flight Level that has Same Direction aircraft whose ADS-B report data are available to the ITP Aircraft.

ITP Aircraft. An aircraft that is fully qualified (from an equipment, operator, and flight crew qualification standpoint) to conduct an ITP and whose flight crew is considering a change of flight level.

ITP Criteria. A set of conditions that must be satisfied prior to initiating an ITP request or executing an ITP clearance.

ITP Distance. The distance between Reference or Potentially Blocking Aircraft and the ITP Aircraft as defined by the difference in distance to a common point along each aircraft's track. For the special case of parallel tracks, an along-track distance measurement would be used to determine this value.

ITP Equipment. Equipment needed on the ITP Aircraft that provides ADS-B information on Potentially Blocking Aircraft with regard to ADS-B data qualification (i.e., information sufficient to determine if ADS-B data are, or are not, Qualified ADS-B Data), Same Direction, ITP Distance, Ground Speed Differential, flight level, and aircraft identification.

ITP Separation Minimum. The longitudinal separation minimum between the ITP Aircraft and Reference Aircraft. The ITP Separation Minimum is based on the International Civil Aviation Organization (ICAO) Distance Measuring Equipment (DME) separation method and is 10 nautical miles (nmi).

ITP Speed/Distance Criteria. A specified set of maximum positive Ground Speed Differential and minimum ITP Distance values between a Same Direction Potentially Blocking Aircraft and the ITP Aircraft, required to be met prior to requesting or initiating an ITP with that aircraft as a Reference Aircraft.

Leading Climb or Descent. A Same Track climb or descent performed by an aircraft when ahead of a Reference Aircraft.

Positive Mach Difference. A difference in Mach between the ITP Aircraft and the Reference Aircraft that would result in a decrease in the ITP Distance between them.

Potentially Blocking Aircraft. Aircraft at an Intervening Flight Level whose ADS-B report data are available to the ITP Aircraft.

Qualified ADS-B Data. Received ADS-B data that meet the accuracy and integrity requirements determined to be required for the ITP.

Reference Aircraft. One or two Same Direction, Potentially Blocking Aircraft with Qualified ADS-B Data that meet the ITP Speed/Distance Criteria and that will be identified to Air Traffic Control (ATC) by the ITP Aircraft as part of the ITP clearance request.

Requested Flight Level. A flight level above (for a climb) or below (for a descent) all Intervening Flight Levels that is no more than 4,000 ft from the Initial Flight Level.

Same Direction. Same direction tracks are intersecting tracks or portions thereof, the angular difference of which is less than 45 degrees or more than 315 degrees.

Same Track. Same direction tracks and intersecting tracks or portions thereof, the angular difference of which is less than 45 degrees or more than 315 degrees, and whose protection areas overlap (i.e., without lateral separation).

Abstract

Automatic Dependant Surveillance-Broadcast (ADS-B) equipment can enable the use of new ground and airborne procedures, such as the NASA-developed In-Trail Procedure (ITP), the first of several new procedures to go through the International Civil Aviation Organization (ICAO) approval process. This paper discuses a computerized batch processing experiment designed to examine the operational impacts of the introduction of ADS-B equipment and the ITP to the North Atlantic Organized Track System. The ITP will make use of improved surveillance in the local surrounding airspace of ADS-B-equipped aircraft to enable more efficient oceanic flight level changes. The experiment was conducted using the Traffic Manager (TMX), a desktop simulation capable of simulating airspace environments and aircraft operations. The collected data were analyzed with respect to multiple, operationally relevant parameters, including fuel burn, request approval rates, and the distribution of fuel savings across aircraft and the North Atlantic Organized Track System (NATOTS). The experiment showed that operational improvements and benefits could be achieved through the use of ADS-B or ADS-B and the ITP.

Introduction

The United States, Australia and Europe have established programs to develop and implement Automatic Dependant Surveillance-Broadcast (ADS-B) to improve Air Traffic Management (ATM). [1-3] Benefits of ADS-B include increased surveillance range and a more extensive message set compared to previous technology. The National Aeronautics and Space Administration (NASA) Langley Research Center (LaRC) is developing a new airborne procedure that leverages the benefits of ADS-B to provide a means for pilots to make more informed requests of Air Traffic Service Providers(ATSPs) and enables altitude changes that previously would not have been approvable. Intended for use in non-radar (radio detection and ranging) airspace that employs procedural separation, the In-Trail Procedure (ITP) uses airborne ADS-B data, onboard tools, and a new separation standard based on these data and tools. In order to support development of the ITP, NASA researchers conducted several experiments, including human-in-the-loop (HITL) studies evaluating both pilot and controller aspects of the new procedure, safety analyses, and computerized batch processing studies investigating the operational impacts of the use of the ITP.

The objective of this paper is to present the results of the computerized batch processing study and discuss some of the operational benefits that can be gained with the ITP. The paper is organized as follows: presentation of background on why there is a need for the ITP, a description of the ITP, description of the simulation program used in the batch processing experiment and the development of enhancements required to conduct the experiment, descriptions of the experiment, simulation validation and scenarios, assumptions and configurations, results and analysis. The paper closes with some concluding remarks summarizing the results of the experiment.

Background

The ITP is designed for use in non-radar procedural airspace. Accordingly, the North Atlantic Organized Track System (NATOTS) was selected for this experiment . On a typical day, approximately 800–1,000 aircraft cross the North Atlantic. Of these, about 400-600 aircraft fly on the NATOTS. Thus, the NATOTS is one of the most heavily utilized oceanic regions in the world. Other flights operate on non-structured, uniquely designed "random" routes, which are created upon request. In addition to large numbers, the oceanic environment accommodates the majority of aircraft traveling across the ocean in a relatively small window of time. This is done for scheduling reasons by the airlines to accommodate curfew restrictions at destination airports and customer travel times that are most in demand. Most traffic is comprised of similar aircraft types. During peak crossing times, traffic produces local congestion at the most common crossing altitudes. This congestion generally requires some aircraft to fly at altitudes different from those requested. Unfortunately, the new altitudes may be less fuel efficient. The problem is exacerbated by the separation standards used. In the North Atlantic, the separation standard is a 10-minute Mach number technique. This separation standard compares the Mach number of two sequential aircraft in order to account for the closure during flight when a faster aircraft is following a slower aircraft. Based on the difference in Mach numbers and the distance to be traveled along the NATOTS track being flown in nautical miles (nmi), the separation time increases beyond the 10-minute standard. Table 1, from the Application of Separation Minima for the North Atlantic Region [4], shows the additional separation time values (in minutes) used for this technique.

Table 1: 10–minute Mach number technique used to separate aircraft in the North Atlantic

Difference in Mach	Distance to Fly/Additional Separation required at common point to ensure at least minimum separation at exit/divergence/limit point				
	001-600nmi	601-1200nmi	1200-1800nmi	1801-2400nmi	2401-3000nmi
0.01	01	02	03	04	05
0.02	02	04	06	08	10
0.03	03	06	09	12	15
0.04	04	08	12	16	20
0.05	05	10	15	20	25
0.06	06	12	18	24	30
0.07	07	14	21	28	35
0.08	08	16	24	32	40
0.09	09	18	27	36	45
0.10	10	20	30	40	50

Although some aircraft climb and descend to more optimal altitudes during North Atlantic oceanic crossings, most aircraft do not make altitude change requests during the crossing, despite the fact that openings are often available at desirable altitudes. The reason is that pilots today have no way to determine where the openings are located and, thus, have no way to determine the best time to initiate a new request. One factor that contributes to this problem is the limited local surveillance available to pilots. As a result, only about 6% of aircraft perform an altitude change (although this number seems to be increasing. – B. McPike [NATS UK] personal communication, October 28, 2004.) In contrast, the increased range of ADS-B allows for improved surveillance of surrounding traffic and is greater than the current separation standards employed in the NATOTS. The ability to receive ADS-B transmissions (ADS-B IN) can provide pilots with a means of identifying potential climb or descent opportunities by increasing situation awareness (SA) of surrounding traffic. The increased SA can be achieved through the use of a graphical Cockpit Display of Traffic Information (CDTI). Although a CDTI is not required for the ITP, it can provide additional benefit to an ITP installation. An example of a possible ITP display is shown in Fig. 1. The display was used in one of the ITP HITL experiments [5].

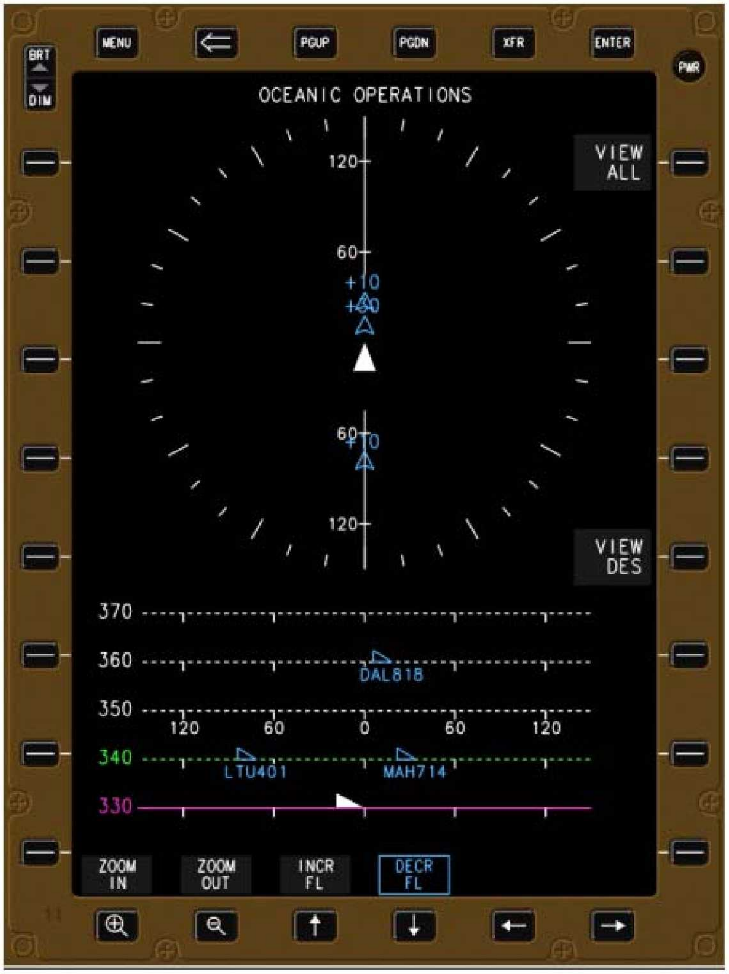


Figure 1: Final ITP display as used in HITL experiment

While an increase in SA can provide benefits, the ITP goes further to establish new procedures and a proposed new separation standard that can enable altitude changes that are not possible under current operations. The ITP is designed to take advantage of ADS-B technology that can enable inter-aircraft transmission and reception of position and other relevant aircraft information [6], [7]. The details of the ITP are explained in the next section.

In-Trail Procedure

Development of the ITP is sponsored by the RTCA/EUROCAE (Radio Technical Commision for Aviation (formerly)/European Organization for Civil Aviation Equipment) Requirements Focus Group (RFG) and the International Civil Aviation Organization (ICAO) Separation and Airspace Safety Panel (SASP). A complete description of the procedure is available in the *Safety, Performance and Interoperability Requirements (SPR) Document for* the Airborne Traffic Situation Awareness ITP (ATSA-ITP) application [8].

The ITP is intended to enable altitude changes that are otherwise blocked when aircraft are spaced at less than current separation standards at altitudes between the current and desired altitudes of a requesting aircraft. This capability is enabled through the use of ADS-B, onboard tools, and the new ITP. While using the ITP, standard separation is required between all aircraft at the current and desired altitudes. Prior to requesting an ITP, specific initiation criteria must be met with each Reference Aircraft. ITP initiation criteria include that each Reference Aircraft must meet one of two conditions:

1) If the ITP distance to a Reference Aircraft is greater than, or equal to, 15 nmi, then the groundspeed differential must be less than, or equal to, 20 knots (kts) between the two aircraft

or

2) If the ITP distance to a Reference Aircraft is greater than, or equal to, 20 nmi, then the groundspeed differential must be less than, or equal to, 30 kts between the two aircraft.

ITP distance is defined as the distance between a Reference Aircraft and the ITP aircraft. It is calculated as the difference in distance to a common point along each aircraft's track. There is no requirement that the common point be co-located with any form of navigational waypoint. This is shown graphically in Fig. 2.

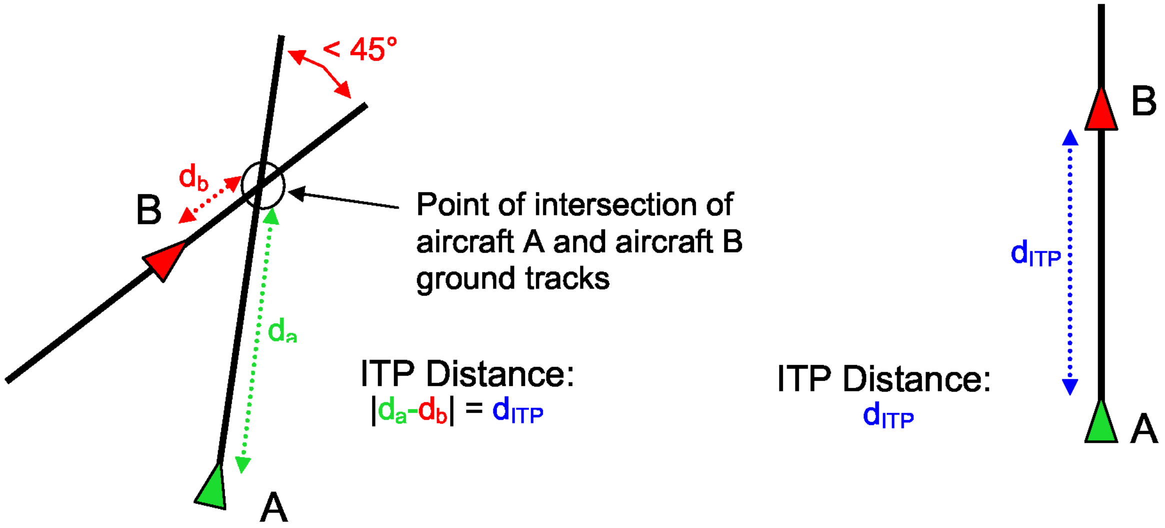


Figure 2: Calculation of ITP distance

Using on-board tools, the ITP aircraft makes use of ADS-B reports from nearby aircraft and determines which aircraft have qualified ADS-B data and meet the ITP initiation criteria. ADS-B reports must meet specific limits for the accuracy and integrity of the data in order to be used for the ITP. In order for the ITP to be requested, both the ITP aircraft and any Reference Aircraft must be Same Direction, and the initiation criteria must be met between the ITP aircraft and any Reference Aircraft. If these conditions are met, the flight crew may make an ITP request to Air Traffic Control (ATC). An air traffic controller must review the request using all available information to ensure that separation will exist with all aircraft not involved in the ITP and that ITP requirements are met. In order for a controller to approve an ITP, the following conditions must be met:

1. The ITP aircraft cannot be a Reference Aircraft for another ITP clearance.
2. The ITP aircraft and each Reference Aircraft must be classified as Same Track.
3. The Reference Aircraft cannot be in the process of maneuvering or be expected to maneuver.
4. The ITP and Reference Aircraft Mach numbers must be within 0.04 Mach of each other if one aircraft is closing on another.

Upon receiving an ITP clearance from ATC, the flight crew must confirm that the initiation criteria are still met with each Reference Aircraft identified in the clearance prior to accepting the clearance and initiating the altitude change. Once the altitude change is completed, the ITP aircraft must report level at the cleared altitude.

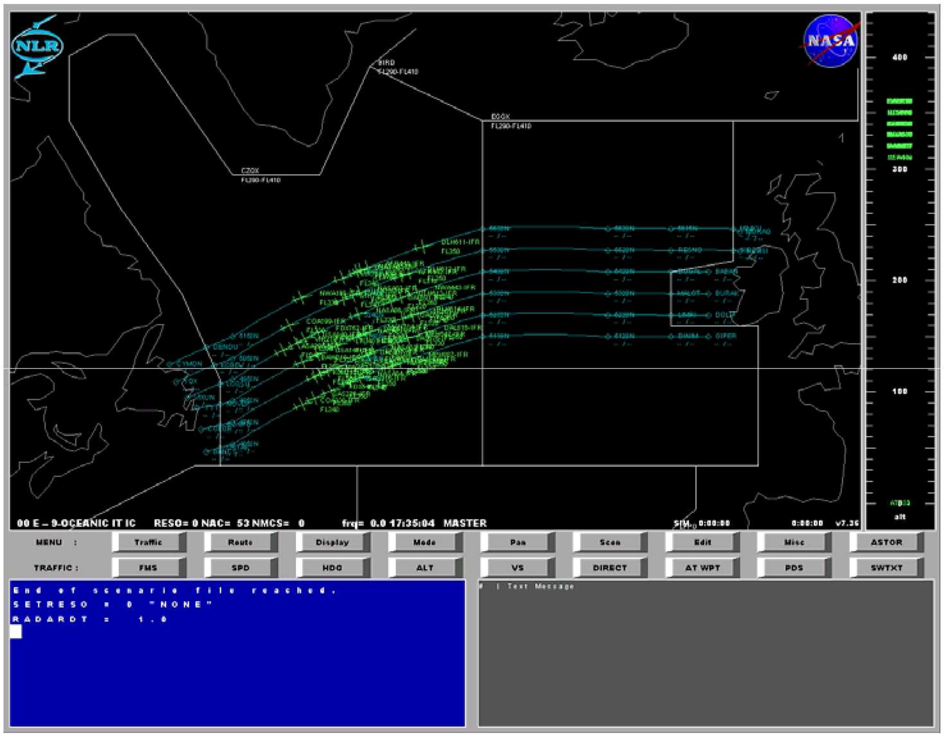
The ITP can be applied equally during climb or descent maneuvers. Provided that all ITP criteria are met, any of the following aircraft configurations can be used:

1. ITP aircraft following one or two Reference Aircraft
2. ITP aircraft leading one or two Reference Aircraft
3. ITP aircraft leading one Reference Aircraft and following one Reference Aircraft

For configurations 1 and 2 with two Reference Aircraft, aircraft must be located on separate intermediate altitudes. For configuration 3, the two Reference Aircraft may be located on the same or separate intermediate altitudes.

Experiment Tool

Traffic Manager (TMX) is a medium-fidelity, desktop simulation application designed for interaction studies of aircraft in present or future ATM environments. Originally developed by the National Aerospace Laboratory (NLR) in The Netherlands, TMX can serve as a stand-alone traffic simulator, scenario generator, scenario editor, experiment control station, data-recording tool, and rapid prototyping environment. Both the NLR and NASA LaRC have continued to enhance and improve TMX, making it a valuable asset to many ATM research projects [9]. TMX was used to simulate the environment for the experiment described in this paper. The simulation environment included the oceanic airspace, the NATOTS, multiple ATC centers, and the individual aircraft. The TMX user interface is shown in Fig. 3.



```
00 E – 9-OCEANIC IT IC    RESO= 0 NAC= 53 NMCS= 0    frq= 0.0 17:35:04 MASTER    SIM 0:00:00    0:00:00 v7.36
```

```
End of scenario file reached.
SETRESO = 0 "NONE"
RADARDT =  1.0
```

Figure 3: Screenshot of Traffic Manager user interface

TMX is capable of simulating up to 2,000 aircraft simultaneously. Each aircraft uses a six-degrees-of-freedom dynamics model augmented with performance parameters from the EUROCONTROL Base of Aircraft Data (BADA) database [10]. Other features include:

- Gate-to-gate operations, including approach and taxi
- Auto Flight Model with basic altitude, heading, and speed modes, plus Flight Management System (FMS) modes with auto throttles and Required-Time-of -Arrival functionality
- ADS-B Model with range limits
- Airborne Separation Assistance System (ASAS) with conflict detection, resolution, and prevention modules that are selectable among multiple variants
- Airborne precision approach spacing for merging and spacing operations
- Pilot Model:, including parameters for reaction time and scheduling of tasks
- Wind Model with 3D "truth" and predicted wind fields
- Weather Model with moving weather cells
- Data logging that is both time- and event-based

TMX supports external connection interfaces that can connect to full motion simulators and integrate with the NASA LaRC Air Traffic Operations Laboratory (ATOL). Depending on the research need, TMX can operate in real-time or fast-time mode. TMX can be modified to accommodate new and changing research requirements or to introduce a new capability to the simulation.

Development

Several enhancements to TMX were required for this research effort. The first enhancement was to create the oceanic flight environment that exists in the North Atlantic. This environment included the addition of Oceanic Control Areas (OCAs), the ability to load National Oceanic and Atmospheric

Administration (NOAA) Global Forecast System (GFS) winds, and the conversion of the NATOTS Notice to Airmen (NOTAM) into TMX route files. Wind data were downloaded from the NOAA National Operational Model Archive and Distribution System. [11] The NATOTS NOTAM with the track definitions for the routes used in this experiment is in Appendix A.

External programs were developed to convert the NOAA GFS winds and NATOTS NOTAM data into the correct format to be read into TMX. It was also necessary to expand and improve the existing Controller Pilot Data Link Communication (CPDLC) functionality in TMX, including the addition of messages for position reports and ITP-required messages, since aircraft can use CPDLC in the North Atlantic.

The next enhancement involved the fuel model and the way in which the model performed fuel flow calculations. The underlying premise was that the core TMX fuel flow calculations (based on a partial implementation of the BADA database) did not align with calculations from tabular or recorded data obtained from actual flights under similar conditions. In order to achieve the desired level of accuracy in the fuel flow model, it was necessary to implement a new calculation method using a 4th order polynomial curve tailored to the data in the airplane performance manual cruise-Mach tables. The new model was applied only during the cruise portion of flight. Due to proprietary restrictions on obtaining appropriate fuel flow data required to implement the new fuel model, many aircraft types in TMX still used the BADA calculations. The improved fuel model was implemented for 10 aircraft types typically flown in the North Atlantic region. These were the only aircraft types used in the experiment.

The next major task was to redesign the pilot model in TMX because the existing model was not capable of performing all of the required tasks related to the ITP and oceanic airspace. For example, the model performed all actions in sequential order but did not perform any automated actions. In addition, the capability to make or react to CPDLC messages did not exist. Redesigning the entire model significantly improved the capability and realism of the pilot model. The new pilot model handled real-world tasks that were performed both manually (e.g., altitude requests) and automatically (e.g., position reports). In addition, automatic actions occurred in parallel with regular pilot actions. The enhanced model will be expanded to accommodate new tasks, as needed. Each aircraft could also create and send position reports automatically.

The last development effort was to create an ATC model in TMX. This development was required because the study needed 1) the ability to simulate aircraft operating in the oceanic environment, 2) the capability to look into the effects of differences in the surveillance information available to pilots and controllers, and 3) the ability to examine the communications involved with each altitude change-request. The ATC model used the same architectural layout as the pilot model and was expandable and multifunctional. The model was based on OCA, with an ATC center created for each sector loaded in the simulation. Aircraft flying in each OCA sent all communications to the appropriate ATC center.

TMX does not currently model inter-center communication. This communication occurs when a maneuver is requested near a boundary or when a boundary transition occurs. However, a limited form of coordination occurs when an aircraft nears the boundary of a sector—i.e., position reports are sent to the adjacent sector(s). The aircraft currently make the appropriate transitional changes and always send communications to the correct ATC center.

Experiment Design

The experiment considered four variables:

1. The ADS-B environment, expressed as (a) the percentage of aircraft in the scenario equipped with the ability to transmit ADS-B messages (ADS-B OUT) and (b) the percentage of aircraft in the scenario equipped with the ability to receive ADS-B transmissions (ADS-B IN)
2. The density of aircraft in the NATOTS airspace

3. The ITP capability, expressed as the percentage of ADS-B IN aircraft equipped with tools required to perform the ITP
4. The request method used for track entry

The levels of ADS-B OUT equipage used were 30%, 60%, and 90% and for ADS-B IN were 10%, 45%, and 80% of all aircraft in the scenario. The two variables together represented an equipage level that provided the surveillance environment for each experiment condition. The experiment assumed that any aircraft equipped with ADS-B IN was also equipped with ADS-B OUT. Therefore, the experiment did not consider cases that would have resulted in a higher ADS-B IN equipage rate than ADS-B OUT equipage rate. This combination of ADS-B OUT and ADS-B IN values yielded six equipage levels. A seventh level was used as the baseline condition in which none of the aircraft were equipped with ADS-B IN or ADS-B OUT.

Four traffic densities were used for the total number of aircraft in the system: 0.5, 1.0, 1.5, and 2.0 times current traffic levels. These traffic densities were referred to as low, medium, high and ultra, respectively, throughout the experiment and in this paper.

Table 2 shows a summary of recorded traffic data from NavCanada's Traffic Density Analyzer (TDA) for the period March 25, 2006–January 23, 2007. This data was used as the basis for the medium density (1.0X) traffic level.

Table 3 shows the average number of aircraft for each traffic density with an approximate ratio to the average number of aircraft from the recorded traffic data (Table 2). Due to the complexities of generating traffic flows with realistic characteristics, the traffic levels generated for the experiment resulted in values that were slightly different from the planned densities. Table 3 shows the generated densities and are used in the remainder of this paper.

Table 2: Real day traffic density level

Minimum # of Aircraft	Maximum # of Aircraft	Average # of Aircraft	Standard Deviation
61	301	232.15	30.59

Table 3: Experiment traffic density levels

	Low	Medium	High	Ultra
Ratio to Real traffic	0.5	1.1	1.4	1.9
Number of aircraft	125	261	318	456

The third variable of ITP capability was 0% (SA) or 100% (SA+ITP) of the ADS-B IN-equipped aircraft. This variable corresponded to aircraft equipped with an ADS-B receiver and CDTI (SA) or that equipment plus onboard tools required for the ITP (SA+ITP). The SA-capable aircraft only used the surveillance aspects of an ADS-B/ITP display, while the SA+ITP capable aircraft combined that information with the increased flexibility of the ITP when making altitude change requests. The use of ADS-B information for situation awareness allowed the pilot model to make more informed altitude change requests, even when not equipped with the tools for ITP. Table 4 shows the relationship of these three variables and the values used.

Table 4: Experiment design matrix

		% ADS-B OUT _ % ADS-B IN												
		0_0	30_10		60_10		90_10		60_45		90_45		90_80	
Traffic Density	Low (0.5X)	SA	SA	SA+I TP	SA	SA+I TP	SA	SA+I TP	SA	SA+I TP	SA	SA+I TP	SA	SA+I TP
	Medium (1.1X)	SA	SA	SA+I TP	SA	SA+I TP	SA	SA+I TP	SA	SA+I TP	SA	SA+I TP	SA	SA+I TP
	High (1.4X)	SA	SA	SA+I TP	SA	SA+I TP	SA	SA+I TP	SA	SA+I TP	SA	SA+I TP	SA	SA+I TP
	Ultra (1.9X)	SA	SA	SA+I TP	SA	SA+I TP	SA	SA+I TP	SA	SA+I TP	SA	SA+I TP	SA	SA+I TP

Table 4 represents half of the experiment design matrix, which was repeated across the remaining experimental variable of the request method used for track entry. The variable of request method determined what altitude an aircraft would request when approaching the entrance of the NATOTS. All aircraft looked at the optimum fuel-flow altitude at a specified look-ahead time (10 minutes) past the entrance of the track. The request method used the optimum fuel-flow altitude (RM0) or added 1,000 feet to it (RM1). The two request methods were based on request methods used by airlines for today's operations—i.e., some airlines conduct flight planning with the expectation of making a climb during the flight, and, therefore, request entry into the track system at the current optimum altitude (RM0). Other airlines do not expect to climb at all, and, therefore, determine a compromise altitude (between optimum at entry and optimum at exit), which usually occurs about 1,000 feet above the optimum altitude at entry (RM1).

The portion of the experiment design matrix shown in Table 4 contains 52 cells. When duplicated, the result is 104 cells for the entire experiment matrix. A statistical power analysis determined 18 replicates as the minimum number needed across all variables of interest. To provide a statistically significant number of samples throughout the experiment, researchers ran 18 replicates in each of the 104 cells. Each replicate represented an independent traffic flow into the NATOTS. Each traffic flow represented a single day, at a specific traffic density, and was randomly generated from a distribution function, such that the desired NATOTS characteristics were simulated (e.g., traffic distribution across the tracks of the NATOTS, distribution of aircraft arrivals into the NATOTS, and total number of aircraft). When accounting for the 18 replicates per experiment cell, a total of 1,872 individual scenarios were run through TMX for data collection.

Simulation Validation and Scenario Creation

The ability to accurately simulate current day operations in TMX was of critical importance in the experiment described in this paper. A significant portion of the development effort focused on modeling current day operations and validating the simulation against data collected during March 7–15, 2005 and March 25, 2006–January 23, 2007. The primary comparisons focused on the distribution of aircraft between the active tracks, the distribution of aircraft in time for the whole NATOTS, and the total number of aircraft that passed through the NATOTS. Data collected from NavCanada's TDA between March 25, 2006–January 23, 2007 were used to determine the average distribution of aircraft between active tracks of the NATOTS, an important aspect of the NATOTS operation since not all tracks are loaded equally—i.e., the NATOTS is designed every 12 hours to make use of the jet stream during eastbound operations or to avoid the jet stream during westbound operations. The result is that most aircraft request entry to the central tracks, which leaves the outer tracks less populated for eastbound flights. Fig. 4 illustrates this distribution for the traffic load on March 7, 2005.

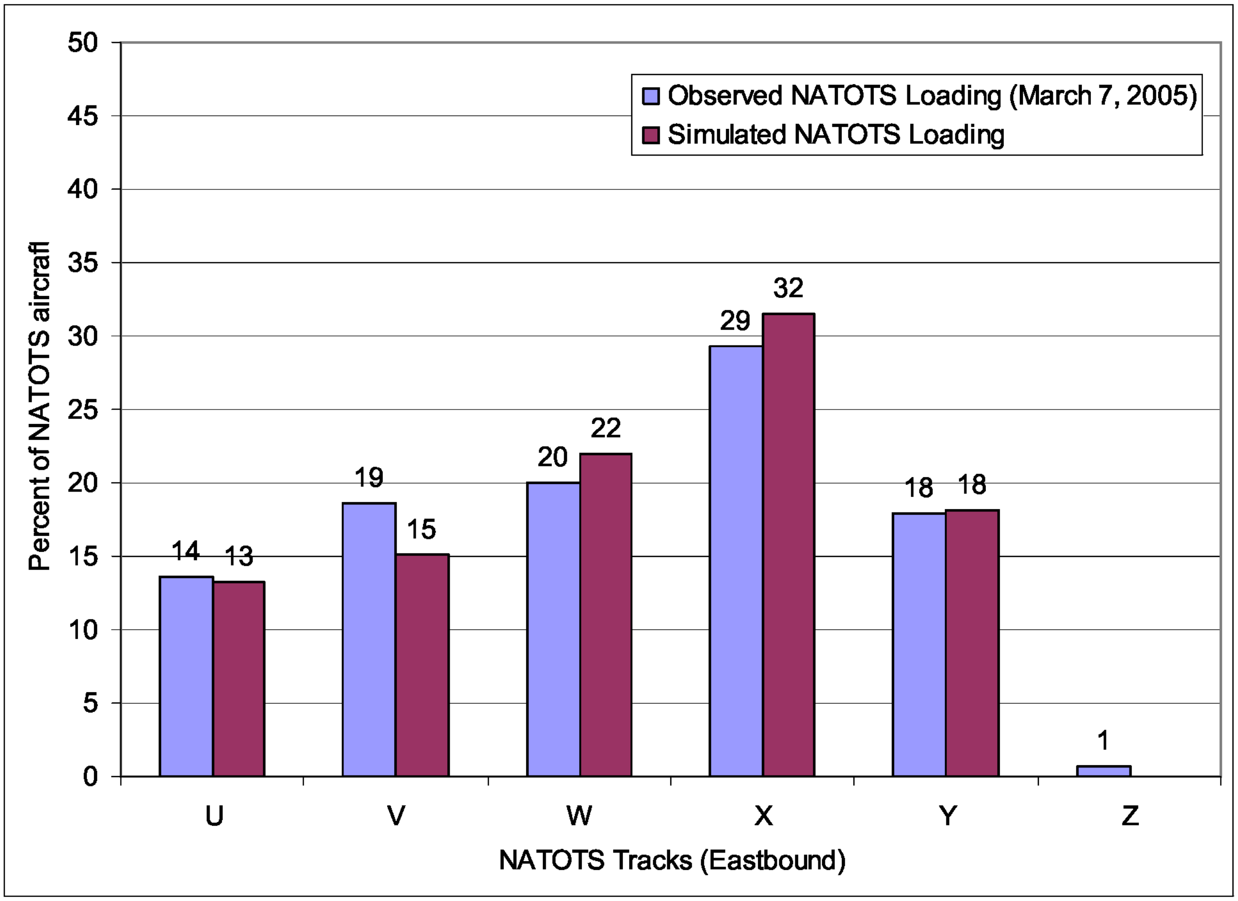


Figure 4: NATOTS loading comparison for Eastbound tracks

Fig. 4 also illustrates how traffic distribution per track averaged across all 18 medium density traffic flows in the experiment. March 7, 2005 is the date used for the NATOTS and the wind field throughout the experiment. Track Zulu (Z) was excluded from the study because the southern-most track experienced a significantly lower aircraft count and occasionally had aircraft join or leave the NATOTS.

Recorded data from Shanwick Oceanic Control for the period March 7–15, 2005 was used to compare the traffic distribution in time. The aircraft in the NATOTS were counted at 60-second intervals. This count showed how the density of aircraft in the system changed with time. The distribution was not uniform between NATOTS active tracks. In order to create scenarios that contained a distribution similar to real-world NATOTS traffic loads, it was necessary to create a distribution function in TMX that could be adjusted using input parameters to achieve the desired traffic density and distribution. This distribution function was based on the generation of an exponentially distributed random number and a nominal creation interval between aircraft, which was performed on a per-track basis. The input parameters were calibrated to create traffic flows with a distribution similar to that of the March 2005 data. The calibration was performed independently for each track used in the experiment. Since the generation process included randomization, it was not assured that every traffic flow generated would have a distribution that matched what was desired. It was necessary to compare the traffic distribution of each flow to data from March 2005 to identify those flows that most closely aligned with the recorded data. The targeted traffic densities based on the data from the TDA were used to ensure that the traffic flows had similar levels of traffic to what was desired. The comparison of both the distribution and the traffic density in the NATOTS was used as the basis for selecting the flows in the experiment. As a result of the selection process, the required 18 traffic flows for each of the four traffic densities of the experiment were identified.

Fig. 5 illustrates how the average distribution of the final experiment traffic flows compared to the average distribution of the March 2005 data. The graph covers the period when the eastbound tracks are active (~12 hours). Each curve includes the count of all active tracks combined. The actual data shown is the average of the nine days worth of data that was collected, and each experiment density is the average of the 18 flows that were simulated. The low-density distribution compared favorably to the actual traffic distribution. The low-density input parameters that defined the scenario-generation function were multiplied by a scalar for the higher traffic density flows. This resulted in an estimate of how the distribution curve scales with increased traffic densities.

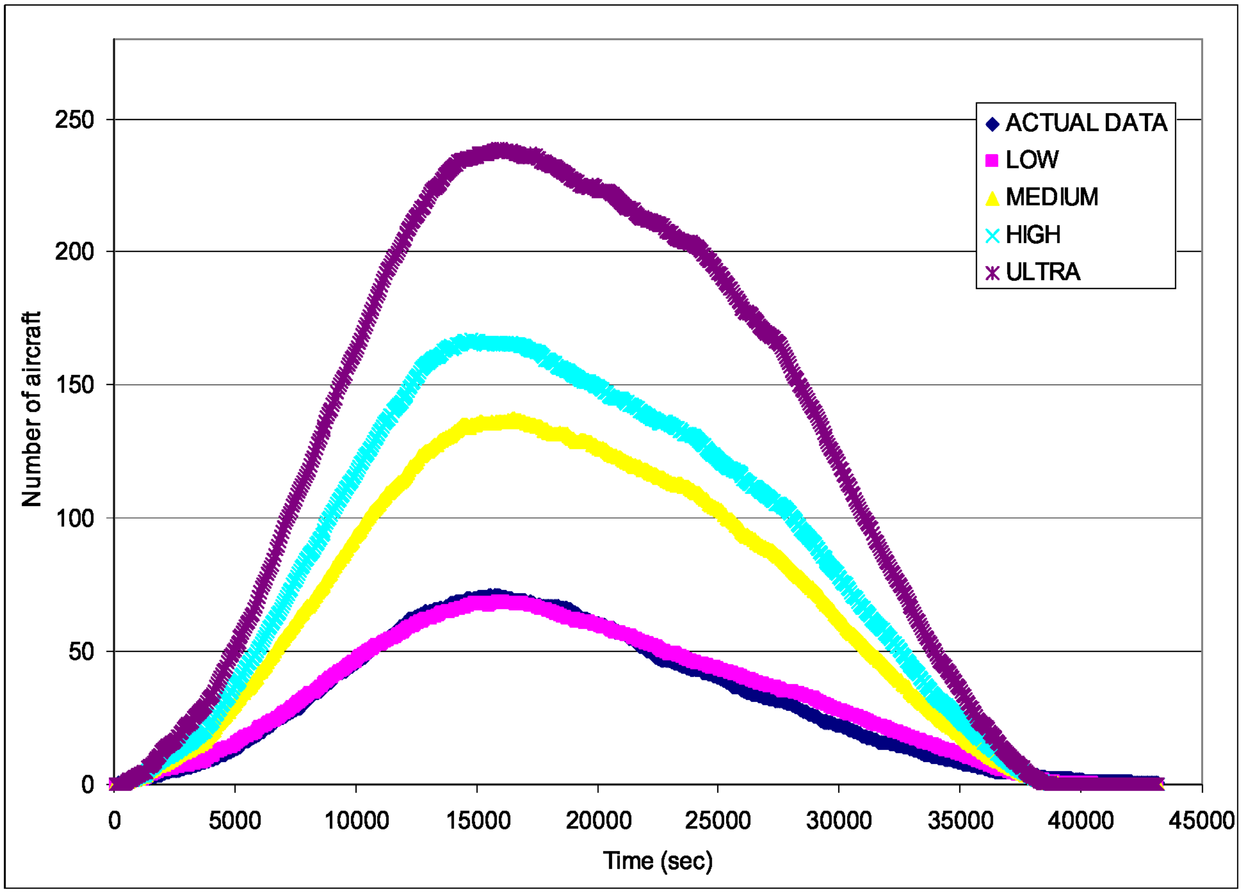


Figure 5: Traffic distribution in Time of aircraft within the NATOTS

Following the selection of the 72 experiment traffic flows (18 flows * 4 densities), each aircraft was loaded onto a track at specific altitudes, such that the required separation was maintained throughout the duration of each flight. This track loading process made use of the ATC model to assign each aircraft a crossing altitude. The assigned altitude was based on the entry-altitude request that each aircraft made to ATC prior to entering the NATOTS. The specific altitude requested by each aircraft was based on the request method (RM0 or RM1) being used. Each of the 72 traffic flows were loaded using both request methods. The ATC model attempted to load each aircraft at its requested altitude. If it was not possible, the ATC model checked for an altitude that could provide required separation in an expanding altitude envelope from the requested altitude. Table 5 shows the altitude assignment sequence that ATC used for loading. The sequence was developed with support from team member observations of track loading operations made during tours of NATOTS control centers for Gander and Shanwick OCAs.

Table 5: ATC altitude assignment sequence

Attempt	Delta from Requested Altitude (ft)
1	0
2	+ 1000
3	+ 2000
4	- 1000
5	- 2000
6	- 3000
7	+ 3000
8	- 4000
9	+ 4000
10	+ 5000

When it was not possible to load an aircraft at an altitude in the sequence while maintaining the required separation, it was removed from the simulation, although this was a rare occurrence and did not significantly impact the average densities of the resulting experiment scenarios. Aircraft could not be assigned an altitude outside the defined NATOTS or flight envelope of the aircraft. The remaining aircraft were recorded into a new scenario. This loading process of the aircraft to a specific altitude created the baseline scenarios for the experiment, which totaled 144 scenarios (72 traffic flows * 2 request methods). These baseline scenarios were then modified to create the remaining experiment scenarios.

Fig. 6 and Fig. 7 illustrate how the density of each traffic flow compared to the recorded TDA data for eastbound tracks (March 2006–January 2007). The number of flights that occurred on the westbound tracks was usually comparable to the number of flights on the eastbound tracks, which together comprised 400–600 NATOTS flights daily. Westbound tracks were excluded from the simulation due to previous unpublished results indicating no significant difference between eastbound and westbound operations. The figures illustrate the 18 traffic flows, per traffic density, when run with the RM0 request method and the RM1 request method, respectively. The figures demonstrate that very few differences occurred when aircraft were loaded into the system using the two request methods.

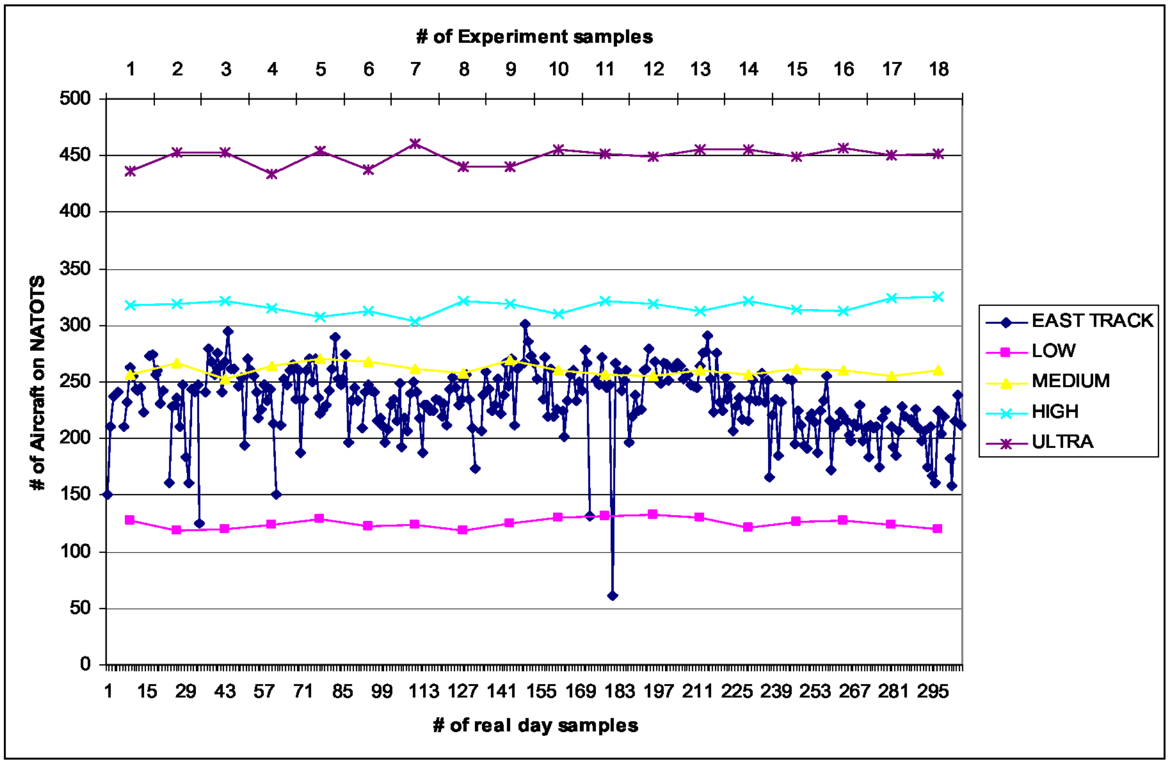


Figure 6: Density comparison for requested entry at optimum altitude (RM0)

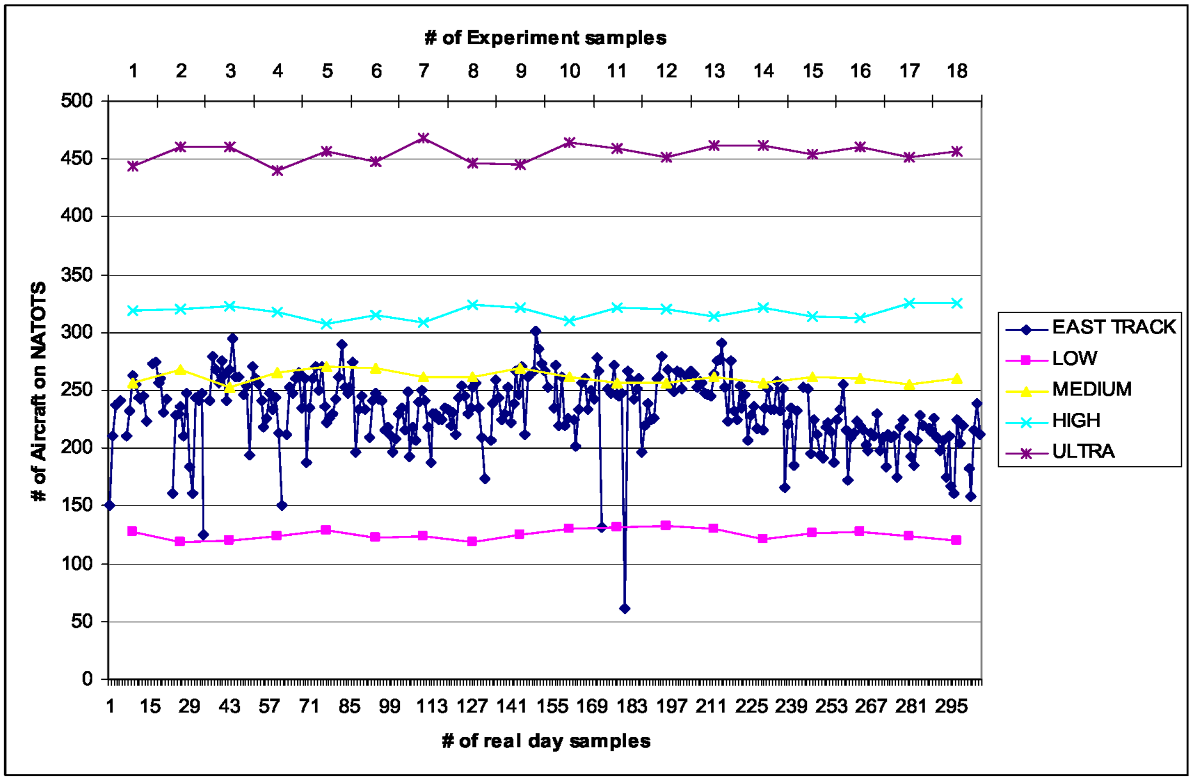


Figure 7: Density comparison for requested entry at compromise altitude (RM1)

The actual data represented in Fig. 6 and Fig. 7 aligns closely with the medium traffic density, while the actual data represented in Fig. 5 align best with the low traffic density. The primary reason for the difference is the dates for which the data were collected. In March 2005, traffic levels in the North Atlantic were lower than in the March 2006–January 2007 time period. Table 6 shows the average number of flights across the two actual data sets and the four experiment densities. The March 2005 data consistently align with the low density for both distribution (Fig. 5) and total number of flights (Table 6).

Table 6: Average number of flights in the NATOTS

	Actual Data Sets		Experiment Data Sets			
	March 2005	March 2006-January 2007	Low	Medium	High	Ultra
Average	128.6	232.2	125.2	260.9	317.2	451.9

The process of a pilot requesting an entry altitude and ATC assigning a crossing altitude was limited to the creation of the baseline scenarios. Baseline scenarios were then used to create the remaining experiment scenarios by adjusting the equipage with which each aircraft was created. The process did not involve the use of TMX, but instead used a stand-alone application with a baseline scenario and a series of random number sequences. For each baseline scenario, there were six groups containing two sequences of random numbers. Each group corresponded to an equipage level in the experiment matrix (30_10, 60_10, 60_45, 90_10, 90_45, or 90_80). One sequence per group contained the numbers for the aircraft that were equipped with only ADS-B OUT, and the other contained the numbers for the aircraft that were equipped with both ADS-B OUT and ADS-B IN. These numbers reference the sequence in which the aircraft were created in the scenario. The random number sequences remained consistent across equipage levels. For example, when an aircraft was equipped with ADS-B OUT (e.g., at the 30% level), it was, at minimum, equipped with ADS-B OUT in any higher equipage environments (i.e., 60% or 90% levels). The same rule held true for the creation of the ADS-B IN equipage sequences. This process only changed the level of ADS-B equipment on each aircraft; it did not affect the creation time, position, or flight plan of the aircraft.

Each ADS-B equipage environment (6 levels) and procedural capability (SA or SA+ITP) generated a new experiment scenario. This resulted in a total of 12 experiment scenarios plus the original baseline scenario. This was repeated for each of the 144 baseline scenarios, yielding all 1,872 scenarios used in the experiment [144 baseline + (12*144) experiment scenarios]. These scenarios were then run through TMX for data collection.

Assumptions and Configurations

In addition to creating scenarios, it was necessary to define certain key assumptions and configuration settings in order to make the simulation operate as a realistic oceanic environment. One assumption concerned the frequency and time when aircraft could make altitude change requests—i.e., no aircraft could make altitude change requests for the first 10 minutes in the track system. This ensured that an aircraft would not be approved for a maneuver that would place it into conflict with another aircraft that had yet to be created in the scenario. This practice was based on current operations, because if an aircraft could change altitude in the first 10 minutes (current required separation), ATC would allow the aircraft to load at that altitude at the beginning of the track. Another assumption restricted aircraft from making requests for the last 100 nmi of the track system. This assumption was made for two reasons. The first reason is that the the required separation is reduced to 5 nmi instead of 10 minutes once an aircraft and a trailing aircraft enter radar coverage near the exit of the track system. In addition, Very High Frequency (VHF) radio coverage is available at that point, making altitude change requests much easier and faster to communicate, as opposed to the High Frequency (HF) coverage available through most of the NATOTS. The second reason to restrict requests near the exit was to avoid conflicts during data analysis. Since aircraft were excluded from the simulation at the track exit, the trailing aircraft could (without this restriction) be cleared for a maneuver that would not be approved if the first aircraft were still in the simulation. The net effect of these assumptions was that aircraft could only make altitude change requests during a period that began 10 minutes after entry and ended 100 nmi before exit.

The frequency with which aircraft could make requests was based on ADS-B IN equipage. Unequipped aircraft (comparable to the vast majority of today's aircraft) could make a single altitude change request when approaching the sector transition between the Gander and Shanwick OCA if the aircraft wanted to move closer to the optimum fuel burn altitude. This transition occurred close to half-way through the NATOTS crossing. This approach to making altitude requests was similar to the way that operations are currently conducted in the NATOTS. Altitude change requests are often made at the same time as the communication checks required at the sector transition. In order to maintain a realistic number of aircraft unequipped with ADS-B IN capability that are performing altitude changes under current operations, a certain number of valid requests were denied. This restriction on valid requests made by unequipped aircraft was intended to result in about 6% of the aircraft being able to maneuver. Requests were approved on a random basis. When a request was determined to be valid, a random number was generated and compared against the target value (used to reach the 6% maneuver rate). If the random number was less than the target value, the request was approved. Otherwise, the request was denied. The actual number of requests approved for aircraft unequipped with ADS-B IN capability was 2%–8%, depending on the particular scenario. This restriction did not apply to aircraft equipped with ADS-B IN capability, where all valid requests were approved. ADS-B IN-equipped aircraft could make altitude change requests at any point during the crossing, provided they had not done so in the prior 10 minutes. Aircraft made follow-up requests when one or more previous requests had been denied, a process that enabled aircraft to get closer to the originally-desired altitude and could be repeated for each altitude available from the cockpit (using the ADS-B IN display). The process ended when available altitudes between present and near-optimum altitudes were depleted or when a request was approved.

Another key assumption concerned the method used in the pilot model to determine the appropriate type of altitude change based on available traffic information. The traffic information was equivalent to the pilot model having a display similar to Fig. 1. There were three possible outcomes that could have resulted from consideration of an altitude change request: 1) no altitude change request, 2) a standard (non-ITP) altitude change request, or 3) an ITP altitude change request. The type of request and amount of available information depended on aircraft equipage. The first step of the process was to determine if an aircraft wanted to make a flight level change in order to fly closer to the optimum fuel-flow altitude. The pilot model assumed that an aircraft always climbed if the optimum fuel-flow altitude was higher than the current altitude. The model also assumed that an aircraft only descended toward the optimum fuel altitude if the difference was greater than 1,000 feet. Since the optimum fuel-flow altitude was always increasing during a flight, making a decent that was too large to catch the optimum would have been inefficient; in some cases, it was better to allow the optimum altitude to come up to the aircraft. Thus, aircraft were not permitted to request an altitude below the requested entry/crossing altitude. An aircraft assigned an altitude at entry that was higher than the altitude requested by the pilot model was permitted to descend, at most, to the original requested entry/crossing altitude.

There were certain conditions in which an aircraft would not request an altitude change. The first condition was when the aircraft was already flying at its fuel-optimum altitude or was not far enough off its current optimum to make a climb or descent maneuver more efficient. The second condition was when conflicting traffic was visible to the aircraft. Both conditions occurred in all scenarios and contributed to a decrease in the percentage of aircraft that made requests.

After determining that an aircraft wanted to change altitude, but prior to making a request, the TMX pilot model checked traffic information from two primary sources: Traffic Alert and Collision Avoidance System (TCAS) and ADS-B. All aircraft in the experiment were equipped with TCAS. Since the effective range of TCAS is approximately 30–40 nmi [12], surveillance of surrounding traffic on the

TCAS display was limited. To simulate this in the experiment, the pilot model of any aircraft could not see TCAS-only equipped aircraft farther away than 40 nmi. In addition, surrounding traffic equipped with only TCAS were not considered "visible" to the pilot model when the aircraft were farther away than 40 nmi. While the use of TCAS was not required and did not enable standard or ITP maneuvers, the use of TCAS information could indicate to the pilot model that a request should not be made. The second means of surveilling surrounding traffic that was available to some aircraft derived from ADS-B information. Surrounding aircraft equipped with ADS-B OUT capability were visible to the pilot model of ADS-B IN aircraft out to 200 nmi.

After determining traffic visibility, the TMX pilot model applied the criteria in Table 7 to control requests.

Table 7: TMX pilot model request availability

Traffic Aircraft Range	Traffic at Desired Altitude	Traffic at Intermediate Altitude
< 15 nmi	None	None
>=15 nmi & < 60 nmi	None	ITP
>= 60 nmi & < 160 nmi	Standard	ITP
>= 160 nmi	Standard	Standard

The criteria in Table 7 were used to evaluate a request based on each visible aircraft; after all visible aircraft were evaluated, the most restrictive request was made. The most restrictive condition was when no requests were possible, followed by an ITP request, and a standard (non-ITP) request. The range differentiation points are as follows:

- 15 nmi was the minimum initiation distance for an ITP request. If there was a "visible" aircraft within 15 nmi, no valid requests were possible.
- 60 nmi was slightly less than the typical separation being used. This was chosen to increase the likelihood of valid requests being made in cases when an aircraft was near the allowable separation limits.
- 160 nmi derived from separation standards used in the North Atlantic and was a practical limit on what could be considered a maximum range required for current separation standards.

In real-world operations, ATC can always approve a less restrictive procedure than the one that is requested. For example, ATC can approve a standard climb if required separation exists, even if an aircraft requests an ITP. ATC cannot approve an ITP if a standard request is made. The reason for this is that even in real-world operations, pilots do not always know the exact separation standard being applied to their aircraft. These limits on requests derive from the idea that if an altitude change is possible, pilots should make the request and try to take advantage of the opportunity.

Results and Discussion

The experiment described in this paper is designed to evaluate the operational impact of introducing the ITP into the NATOTS. Experimental data are evaluated using criteria in three categories:

1. Altitude requests and approval rates
2. Fuel savings
3. Track efficiency

Criteria in each category are compared across four experiment variables:

1. ADS-B equipage level

2. Traffic density
3. Procedural capability
4. Track entry request method

Final Traffic Densities

Before presenting the results of the experiment, it is important to understand that, while both track entry request methods (RM0 and RM1) use the same initial traffic setup, the two methods do not always result in the same number of aircraft being loaded on the track system. Differences between the two request methods result in slightly different traffic densities for some of the traffic flows. Table 8 shows the number of aircraft loaded onto the tracks for each traffic flow and request method, along with the average for each density and how the average compares to the current traffic density. All calculations are based on the value of the average number of aircraft for the appropriate request method and traffic density combination(s).

Table 8: Traffic densities by traffic flow and request method

RM1 Request Method						**RM0 Request Method**				
Traffic flow	LOW	MEDIUM	HIGH	ULTRA		Traffic flow	LOW	MEDIUM	HIGH	ULTRA
1	127	257	319	444		1	127	256	317	436
2	119	268	320	460		2	119	267	319	453
3	120	252	323	460		3	120	252	322	453
4	124	265	318	440		4	124	264	315	434
5	129	270	308	457		5	129	270	307	454
6	123	269	315	448		6	123	268	313	437
7	124	262	309	468		7	124	262	303	461
8	119	261	324	447		8	119	258	322	440
9	125	269	322	445		9	125	269	319	440
10	130	261	310	464		10	130	260	310	455
11	132	256	321	459		11	132	256	321	451
12	133	256	320	452		12	133	255	319	449
13	130	262	314	462		13	130	260	312	455
14	121	257	322	462		14	121	257	322	455
15	126	262	314	454		15	126	262	314	449
16	128	260	313	460		16	128	260	312	456
17	124	255	325	451		17	124	255	324	450
18	120	260	325	456		18	120	260	325	451
Average # of aircraft	125	261	318	455		Average # of aircraft	125	261	316	449
X current density	0.54	1.12	1.37	1.96		X current density	0.54	1.12	1.36	1.93

Altitude Requests and Approval Rates

The first aspect of evaluating the operational benefits of introducing the ITP into the NATOTS involves the number of aircraft able to make altitude change requests, and, of those requests, how many are approved for climb or descent. Fig. 8 shows the average percentage of aircraft that make altitude change requests in the RM1 request method. As would be expected, a higher percentage of aircraft are able to make altitude change requests at lower traffic densities. The data also show that by including the ITP, a higher percentage of aircraft make altitude change requests than do aircraft with the situation awareness aspects of an ADS-B/ITP display alone. The difference between aircraft equipped with SA versus SA+ITP increases directly with the equipage level.

Use of the RM1 request method and the request constraints account for a decrease in requests at the higher traffic densities under the SA condition. By requesting to start 1,000 feet above the optimum, the effect of doubling the traffic density is that more aircraft are loaded off their requested altitude. At higher traffic densities, there are no longer as many opportunities to change altitudes to correct the poor initial loading.

Fig. 9 illustrates the percentage of approved altitude change requests. As more aircraft are equipped with ADS-B IN, the percentage of approved requests at all densities increases. The increase is significantly influenced by the fact that there are fewer requests that cannot be approved as more aircraft are equipped with ADS-B IN. The effect of enabling the ITP does not strongly influence the percentage of requests that are approved, primarily because the number of altitude change requests that use the ITP is small for most conditions, as shown in Fig. 10. The percentage of ITP requests reaches a maximum value of 21% of all requests.

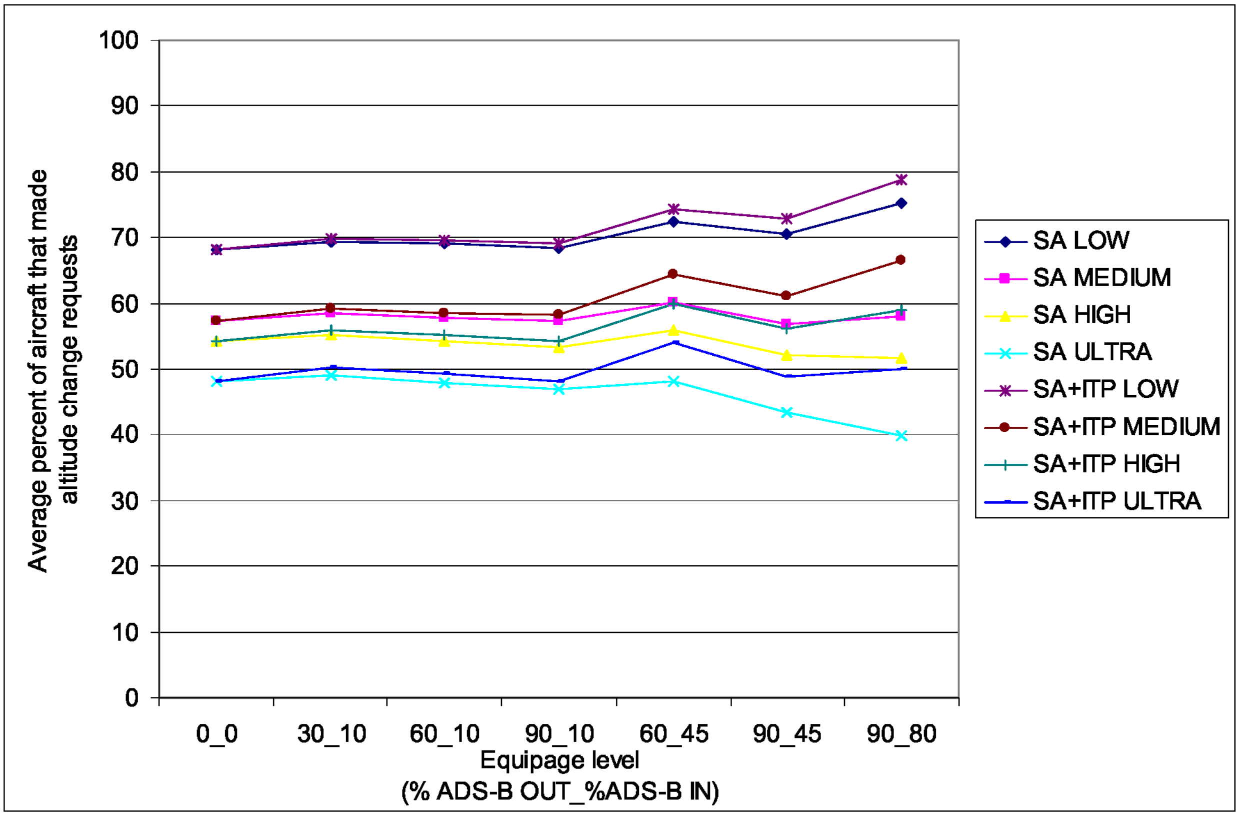


Figure 8: Percentage of aircraft that made altitude change requests (RM1)

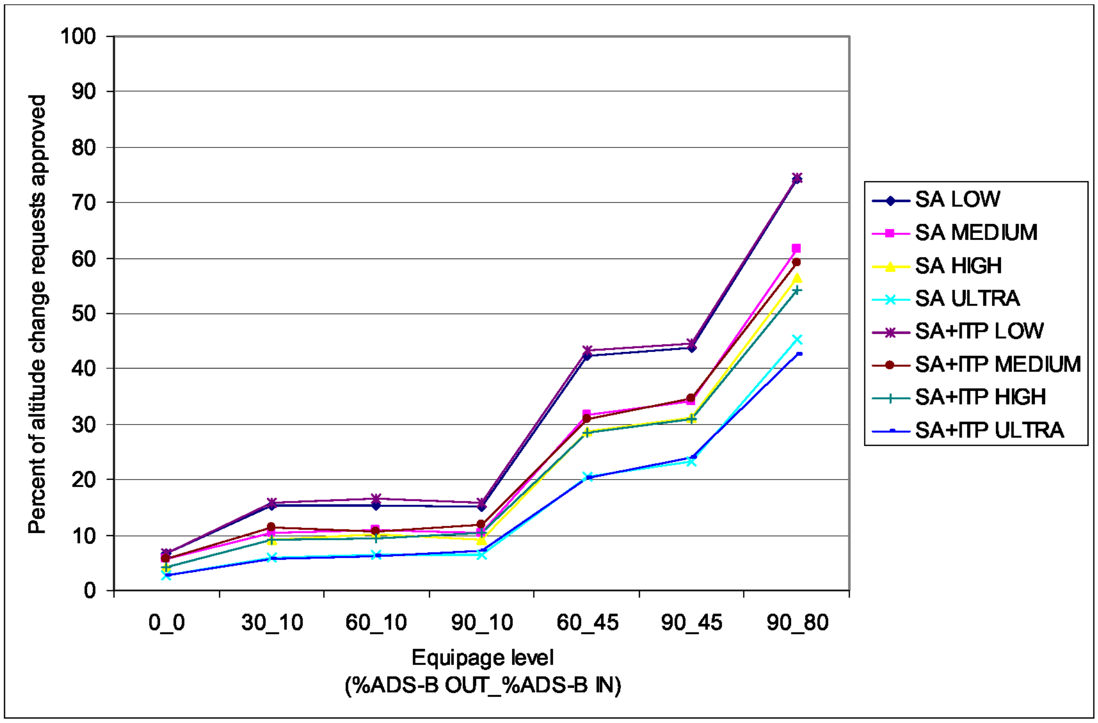


Figure 9: Percentage of altitude change requests approved (RM1)

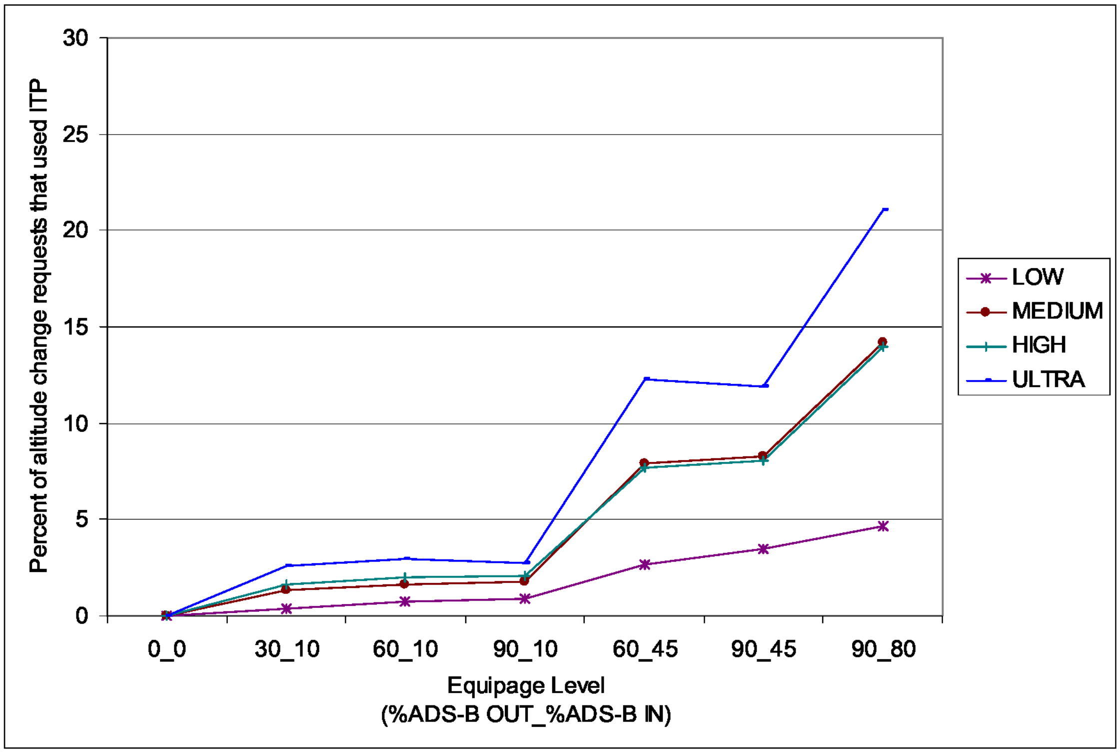


Figure 10: Percentage of altitude change requests that used ITP (RM1)

Data for the RM0 request method are shown in Fig. 11, Fig. 12, and Fig. 13 and indicates an increase in each of the values examined when compared to the RM1 request method. In fact, in nine of the experimental conditions, the average number of requests is greater than the number of aircraft. This means that many aircraft make multiple altitude change requests during the flight across the Atlantic. If a typical flight enters the NATOTS at the optimum altitude and is able to climb 1,000 feet every time it is appropriate, there will ideally be 2-3 step climbs during the crossing.

Under both RM0 and RM1 request methods, the introduction of ADS-B generally improves operations to varying degrees. Under both methods, the introduction of additional ADS-B-IN-equipped aircraft generally increases the number of altitude change requests, as seen by comparing the 90_10, 90_45, and 90_80 equipage levels.

The introduction of additional ADS-B-OUT-equipped aircraft actually decreases the number of altitude change requests. This decrease can be seen by comparing the 30_10, 60_10 and 90_10 equipage levels, or alternatively, by comparing the 60_45 and 90_45 levels. This effect is because, with an increased number of ADS-B-OUT-equipped aircraft, the ADS-B-IN-equipped aircraft observe more aircraft that prevent the completion of a maneuver, and, therefore, do not make requests. This is also why the approval rate of requests does not show the same decline as the percentage of aircraft that make requests.

The effect of ADS-B IN equipage is stronger in the RM0 request method scenarios because of track loading. The aircraft are, on average, loaded several hundred feet lower in the RM0 request method than in the RM1 request method, the number of aircraft that need to climb during the crossing to follow their optimum fuel burn profile increases.

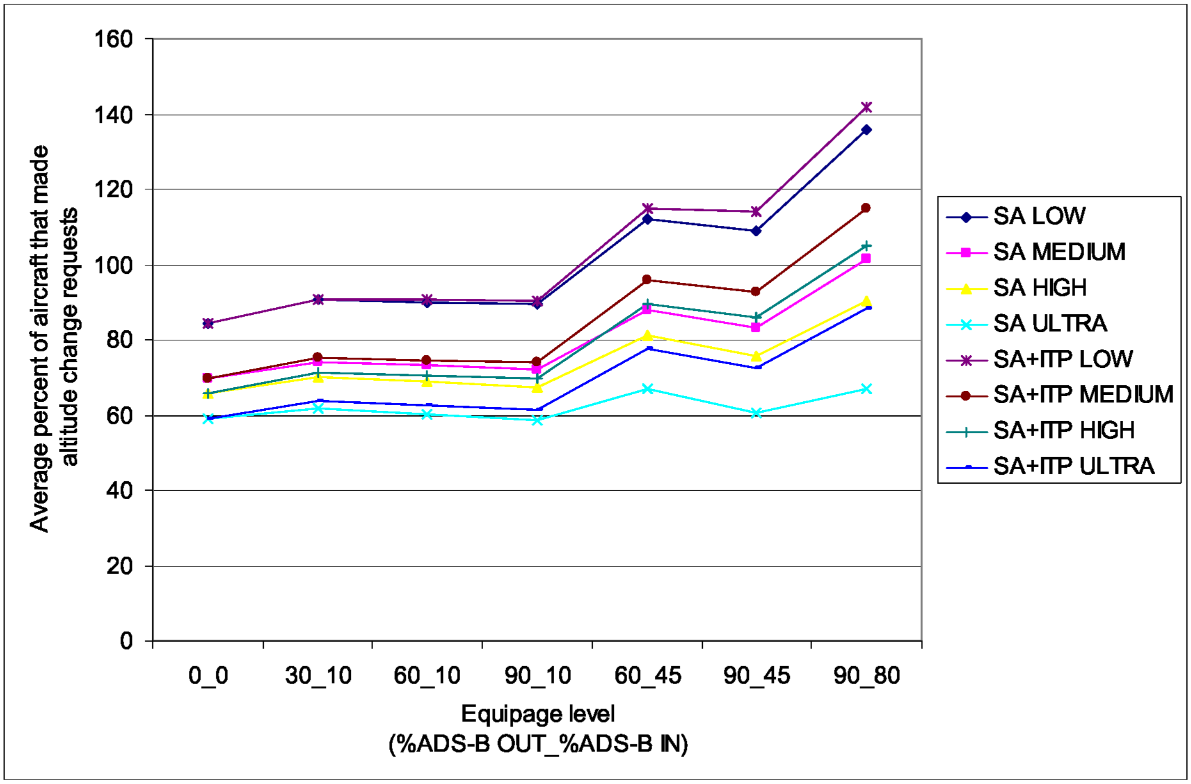


Figure 11: Average percentage of aircraft that made altitude change requests (RM0). Please note that the scale in this figure is not the same as the scale in Fig. 8.

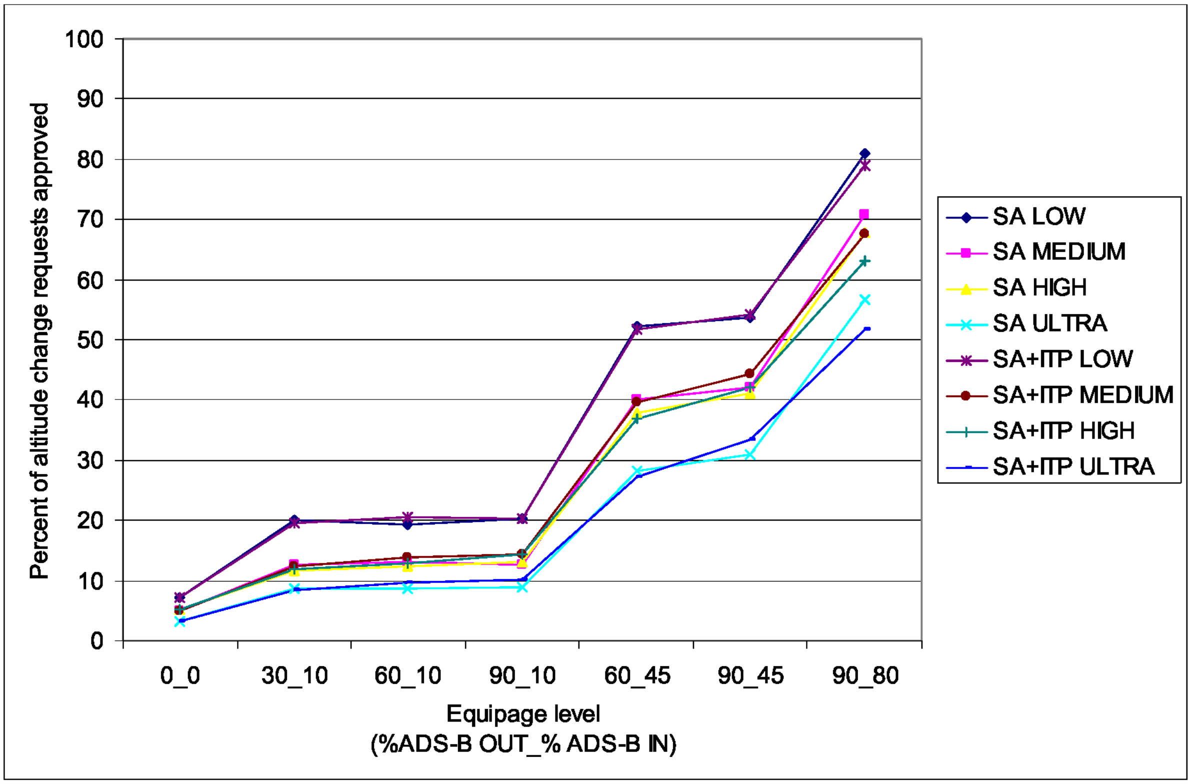


Figure 12: Percentage of altitude change requests approved (RM0)

As shown in Fig. 13, the percentage of the total requests that use the ITP is similar under the RM0 method to that under the RM1 method. The use of the ITP accounts for a higher percentage of requests as the traffic density increases. In most cases, the ITP is used more often under the RM0 scenarios than under the RM1 scenarios. The increased use of the ITP under the higher traffic densities is due to the presence of more aircraft in the NATOTS and the subsequent need to maneuver around them. The ITP allows aircraft to make maneuvers that cannot be performed under current operations, an increase in flexibility that becomes more useful as the density of air traffic increases. The ITP accounts for more than 25% of all requests in the highest equipage case for the RM0 ultra density scenarios.

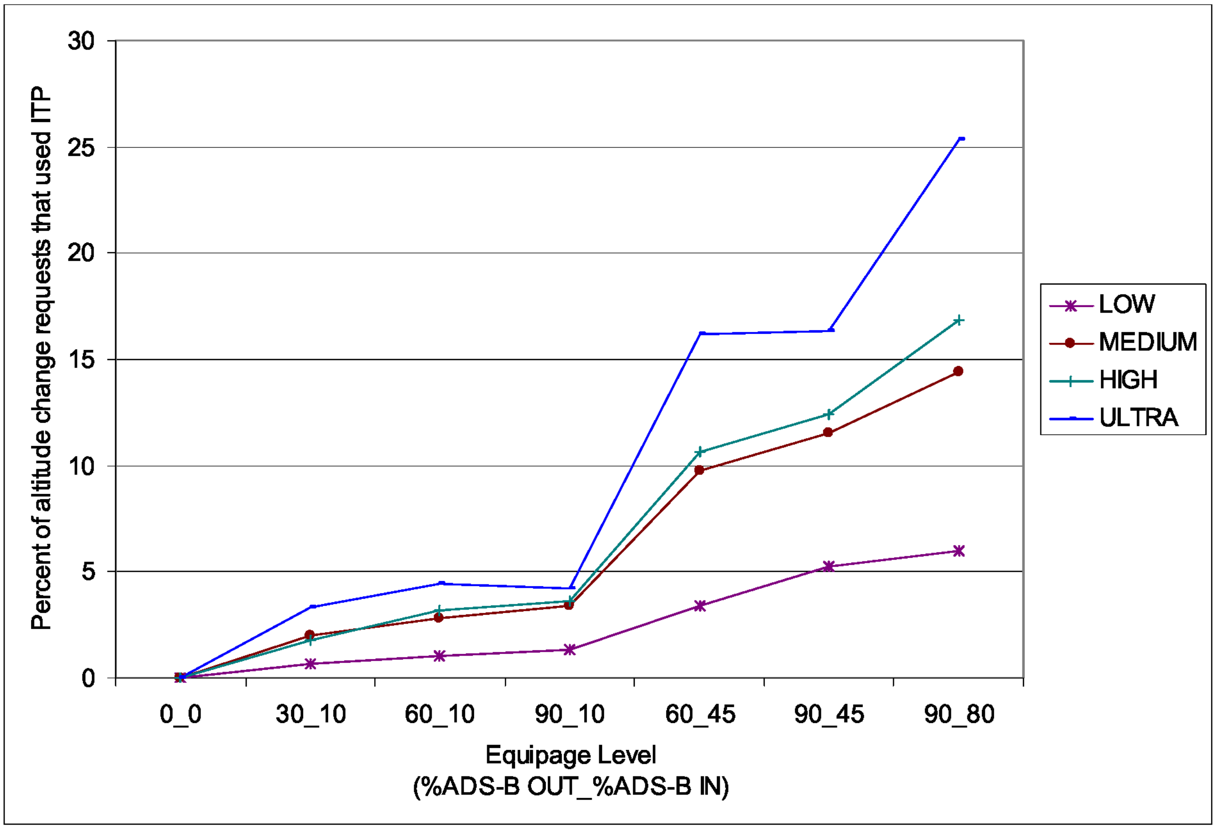


Figure 13: Percentage of altitude change requests that used ITP (RM0)

It should be emphasized that while the data show an increase in request approvals when using ADS-B and the ITP, not all opportunities to climb or descend derive from the increase in aircraft equipage. Under the proper conditions, the use of the ITP can enable more opportunities if there is an available altitude into which an aircraft can climb/descend. **Fig. 14** shows the percentage of requests in the baseline scenarios that can be approved. Fig. 14 includes the requests that are approved and denied *only* to maintain the desired level of approvals for non-ADS-B-IN-equipped aircraft. As previously noted, all aircraft in the baseline are classified as non-ADS-B-IN equipped aircraft. There are more flight level change opportunities under the RM0 request method, and the opportunities vary inversely with traffic density. The reason is that aircraft in the RM1 request method are nominally starting 1,000 feet above their optimum, resulting in a longer period of time before any change will be efficient (from a fuel burn perspective). The decreasing opportunities with increasing traffic density occur because the "openings" on the track into which an aircraft can climb or descend are now being filled from the start of the track with additional aircraft. While similar opportunities exist in today's system, the ATSP would become overwhelmed if every aircraft requests an altitude change every time an altitude change is desired. One conclusion is that in order to take advantage of the opportunities that currently exist, a means by which the pilot can make more informed requests is needed. Introduction of ADS-B technology and the ITP can provide information to assist pilots when making requests and give them increased flexibility when trying to change altitudes.

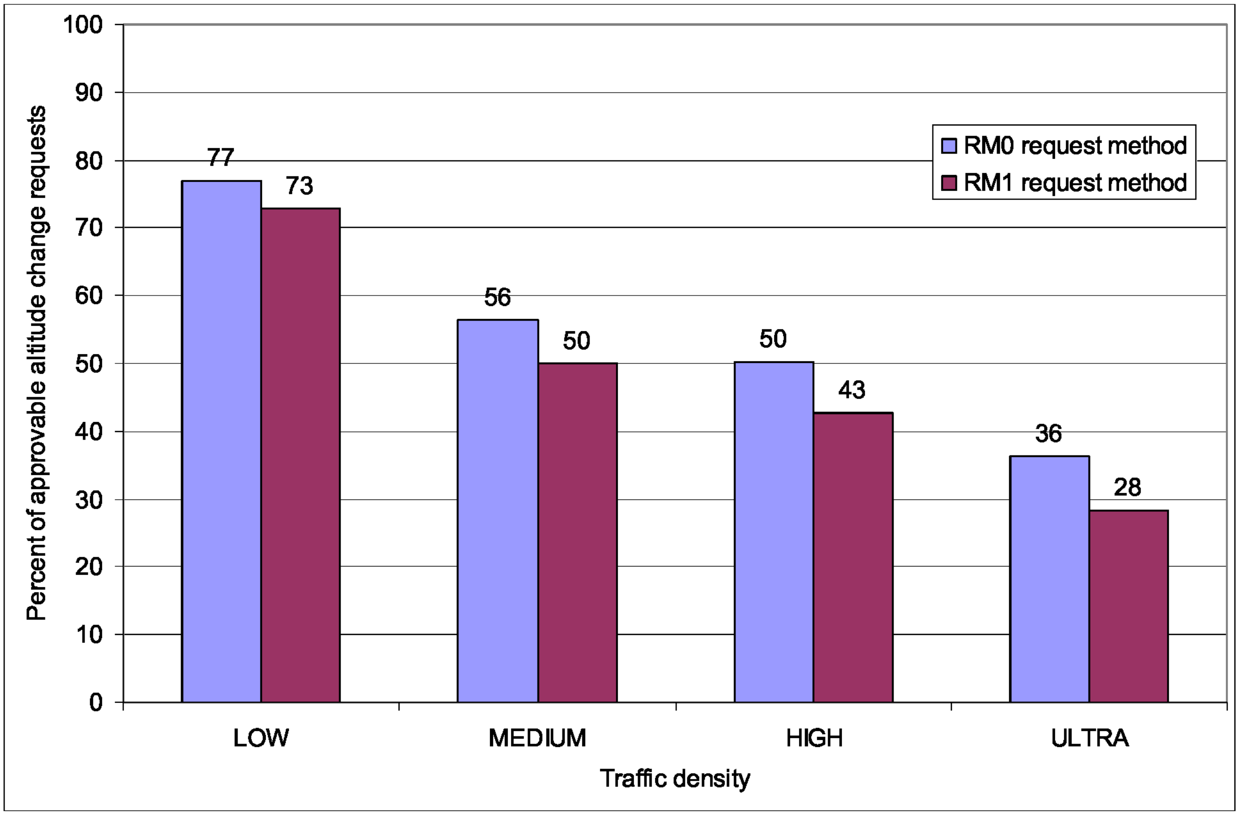


Figure 14: Aircraft capable of maneuvering in the baseline scenarios

Fuel Analysis

The primary variable used for fuel comparisons in the analysis of the data from this experiment is the total fuel burn for a given flight that is normalized by the flight time for that particular flight. The fuel savings for a given flight is then calculated as the difference between the normalized fuel burn for the same flight flown in the baseline (no ADS-B equipage) and the fuel burn for the ADS-B equipage level for each aircraft being investigated. Positive values of fuel savings indicate a reduction in fuel flow compared to the baseline, with negative values indicating an increase or penalty in fuel flow. The normalized fuel burn variable can be compared across equipage levels for each aircraft (to create distributions of how many aircraft experienced a benefit) or averaged together (for a system wide comparison).

Fig. 15 and Fig. 16 show the system-wide averages of fuel savings for all ADS-B IN equipped aircraft for the RM1 and RM0 entry request methods, respectively. Both cases indicate a general trend that aircraft save less fuel when aircraft density increases. The reason is primarily because there are fewer opportunities to make altitude changes as the density of aircraft increases (as shown in the previous section "Altitude Requests ands Approval Rates"). With each increase in traffic density (from low to ultra), a decrease in the average fuel savings occurs when comparing the same experimental conditions. The combination of SA+ITP under the same experimental conditions also proves more efficient than the use of SA alone. In some cases, the use of SA+ITP can allow for increased fuel savings for aircraft at one traffic density higher than for aircraft with SA alone. It can be seen, for example, under the RM0 request method, where high density equipage levels 90-10, 90-45 and 90-80 SA+ITP increased fuel savings compared to medium density SA for the same equipage levels. The contribution in fuel savings attributed to SA is greater than, or equal to, the contribution provided by the ITP; this difference is greater with lower traffic densities. It should be noted that the savings in the RM0 request method are, again, higher than in the RM1 request method.

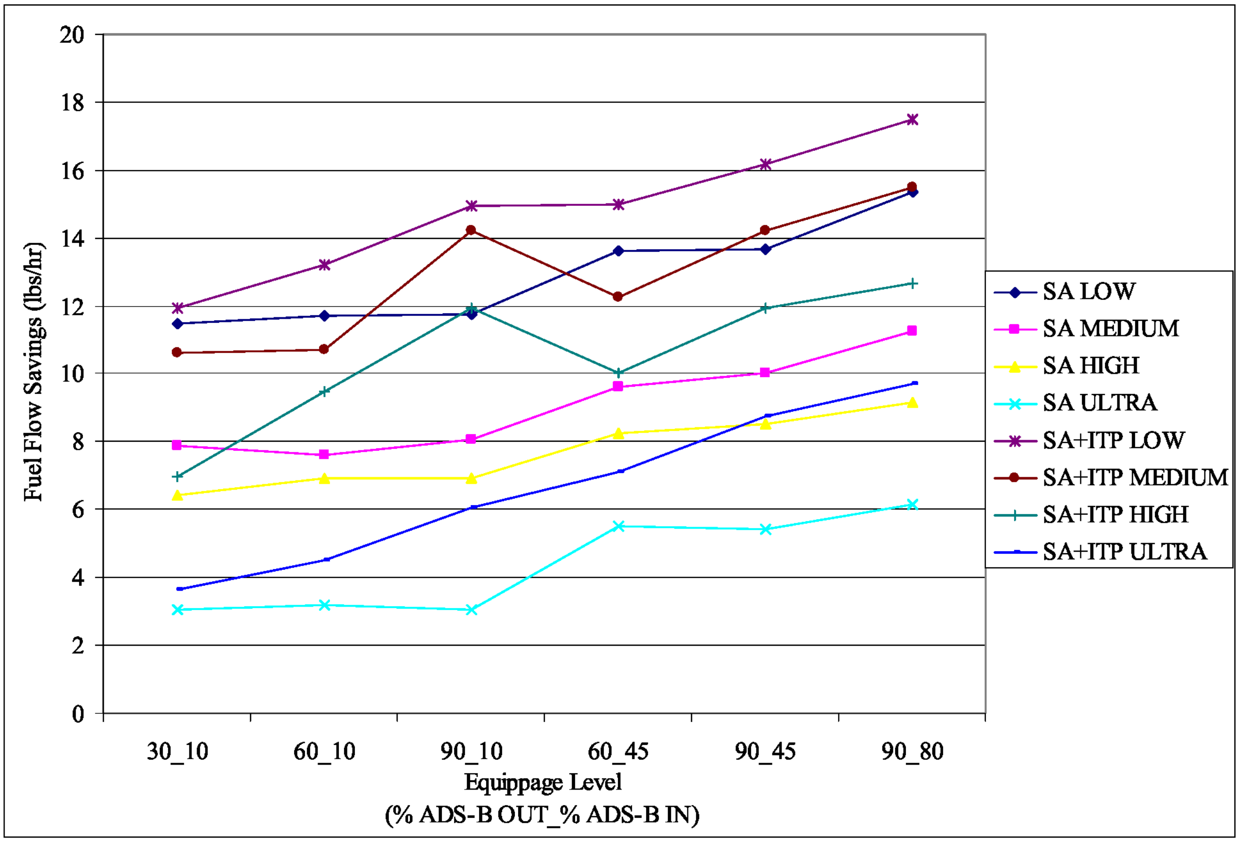


Figure 15: Average fuel flow savings for ADS-B IN equipped aircraft (RM1)

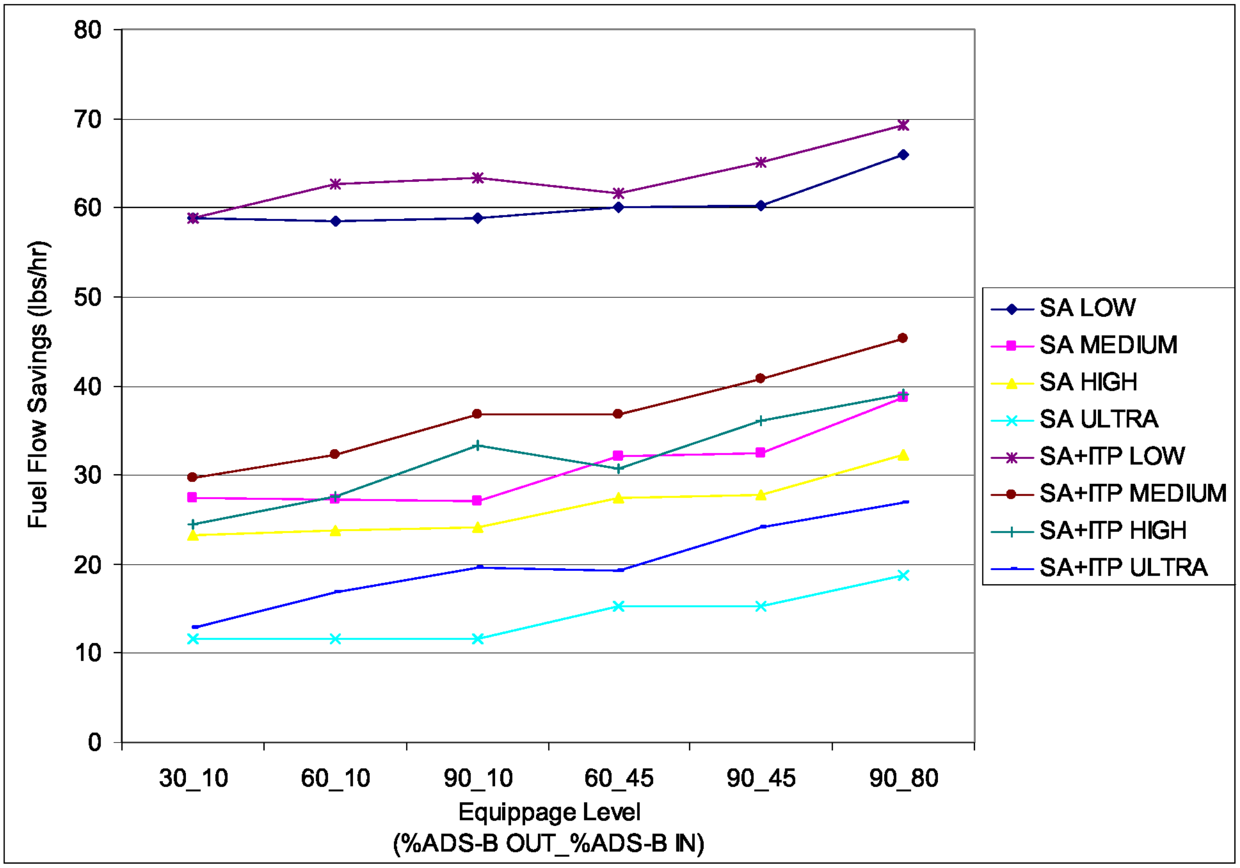


Figure 16: Average fuel flow savings for ADS-B IN equipped aircraft (RM0)

Fig. 15 and Fig. 16 show system-wide averages based on all aircraft equipped with ADS-B IN . The data is analyzed in two ways. The first analysis uses all ADS-B-IN-equipped aircraft. The second analysis uses the ADS-B IN equipped aircraft that has a fuel burn rate that is different from the baseline (i.e., a savings or penalty). Fig. 17 and Fig. 18 show the data for this method. As might be expected, the average fuel savings increases when the data is based only on the number of ADS-B-IN-equipped aircraft that experience a savings or penalty over the baseline flight.

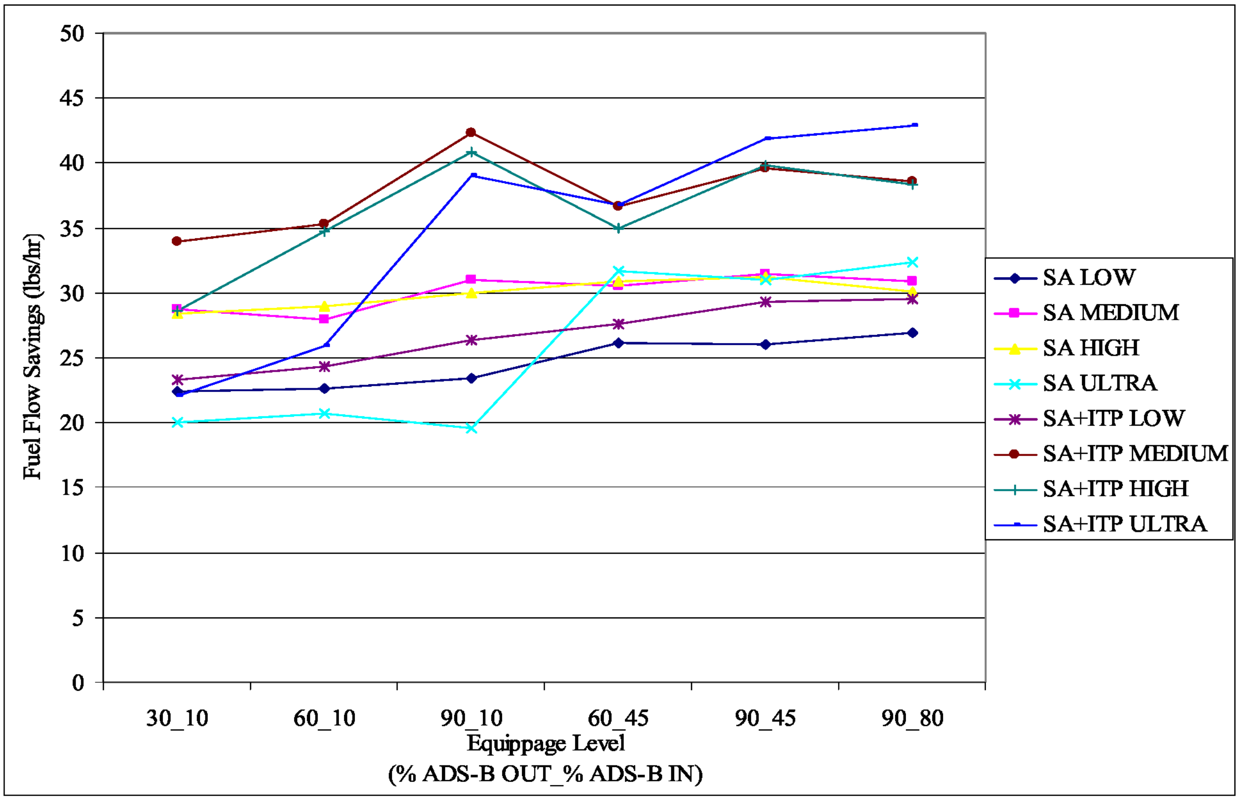


Figure 17: Average fuel flow savings for ADS-B IN equipped aircraft that experienced a difference from the baseline (RM1)

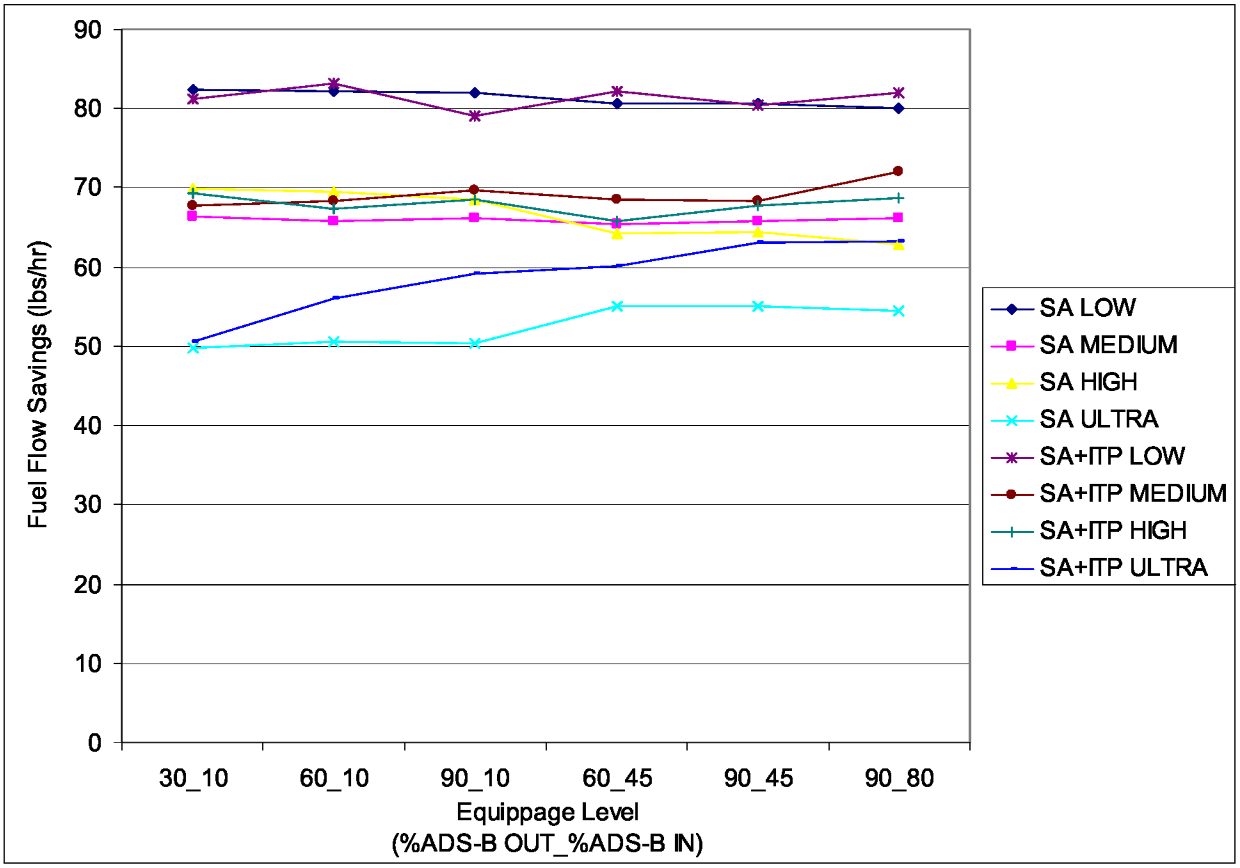


Figure 18: Average fuel flow savings for ADS-B IN equipped aircraft that experienced a difference from the baseline (RM0)

Tables 9 and 10 show the number of flights that experience a fuel savings or a penalty in the RM1 and RM0 request methods, respectively. For reference, Table 8 shows the total number of aircraft in each scenario. A comparison of the data in the two tables reveals a turning point in the number of aircraft that experience a fuel savings or penalty. In most cases, the maximum occurs at the high traffic density. This indicates that there is a maximum where ADS-B and ITP equipage continues to provide an increased benefit with increased traffic density, after which the benefits start to decrease with additional traffic.

Appendix B contains the specific count of aircraft for all conditions. Due to the high volume, the data are not shown here. However, an example is provided below.

An example (medium density, SA+ITP, 60_45, RM0) of a typical distribution of aircraft across savings and penalties is as follows: 117 non-ADS-B IN equipped aircraft and 144 ADS-B IN equipped aircraft, 5.4 non-ADS-B IN equipped aircraft with a fuel savings and 4.7 with a penalty, and 61.9 ADS-B IN equipped aircraft with a savings and 1.0 with a penalty for a total of 73.0. While the specific values change (depending on the experiment conditions), the general trends remain the same. A small number of non-ADS-B IN equipped aircraft experiences a savings or penalty. The savings or penalty is usually about the same number of aircraft. The number of ADS-B IN aircraft that experience a savings is usually significant and the number of ADS-B IN equipped aircraft that experience a penalty is very small.

Table 9: Average number of aircraft with a fuel savings/penalty (RM1)

SA scenarios						SA+ITP scenarios				
Equipage level	LOW	MEDIUM	HIGH	ULTRA		Equipage level	LOW	MEDIUM	HIGH	ULTRA
30_10	17.0	20.8	20.9	18.3		30_10	16.8	22.0	20.6	17.5
60_10	16.9	21.1	21.5	18.9		60_10	17.3	20.4	20.4	18.3
90_10	15.7	20.1	19.5	19.4		90_10	17.0	22.0	22.3	19.5
60_45	35.3	45.9	46.4	41.9		60_45	36.4	46.9	49.8	47.3
90_45	35.2	45.9	47.2	43.0		90_45	37.4	51.0	50.8	49.1
90_80	59.5	79.3	80.0	71.7		90_80	62.3	86.4	87.1	84.6

Table 10: Average number of aircraft with a fuel savings/penalty (RM0)

SA scenarios						SA+ITP scenarios				
Equipage level	LOW	MEDIUM	HIGH	ULTRA		Equipage level	LOW	MEDIUM	HIGH	ULTRA
30_10	23.1	26.0	27.8	25.0		30_10	22.5	25.7	29.4	25.5
60_10	21.7	26.4	29.8	24.4		60_10	23.0	27.7	31.2	27.1
90_10	22.6	25.7	29.8	24.9		90_10	22.3	28.8	33.5	28.4
60_45	49.5	67.7	72.0	65.5		60_45	50.9	73.0	77.9	75.2
90_45	50.7	67.1	73.3	65.4		90_45	54.5	80.6	86.9	87.8
90_80	85.3	125.6	134.9	127.3		90_80	87.7	134.9	148.8	156.4

While the system-wide average is useful for investigating large-scale trends and effects, individual aircraft-level analysis is also useful. By considering the effects on the distribution of savings per aircraft, a more detailed view of the effects can be seen.

The first series in the next sequence of plots represents the savings or penalty (negative values of savings) that aircraft unequipped with ADS-B IN experience. The second series represents the fuel savings that aircraft equipped with ADS-B IN experience. The percentage of each series is calculated independently of the other, so that each series has a total of 100%. Due to the accuracy of the fuel model used for the experiment, fuel savings of less than ±10 pounds per hour (lbs/hr) are not considered when evaluating trends or comparing the results. Fig. 19 (RM1) and Fig. 20 (RM0) show the distribution of the normalized fuel savings, relative to the baseline, for all aircraft in medium density, 60-10 ADS-B equipage level scenarios equipped with SA capability only. Under both RM0 and RM1 request methods, less than 10% of non-ADS-B IN equipped aircraft experience a normalized fuel savings of more than ±10 lbs/hr. These aircraft are spread across both positive and negative values.

By comparison, ADS-B IN equipped aircraft in the RM1 and RM0 request methods experience fuel savings greater than ±10 lbs/hr approximately 20% and 35% of the time, respectively. The majority of ADS-B IN equipped aircraft are distributed with positive fuel savings (two aircraft under RM1 experienced a loss). With the use of ADS-B IN, the probability of an aircraft saving fuel on a flight increases in comparison to the same aircraft without ADS-B IN equipment. An important point is that non-ADS-B-IN-equipped aircraft are still evenly distributed around a savings of 0 lbs/hr—i.e., the increased maneuvering of ADS-B IN equipped aircraft does not cost non-ADS-B-IN-equipped aircraft additional fuel. The distribution is more favorable for ADS-B-IN-equipped aircraft with the RM0 entry request method than with the RM1 entry-request method.

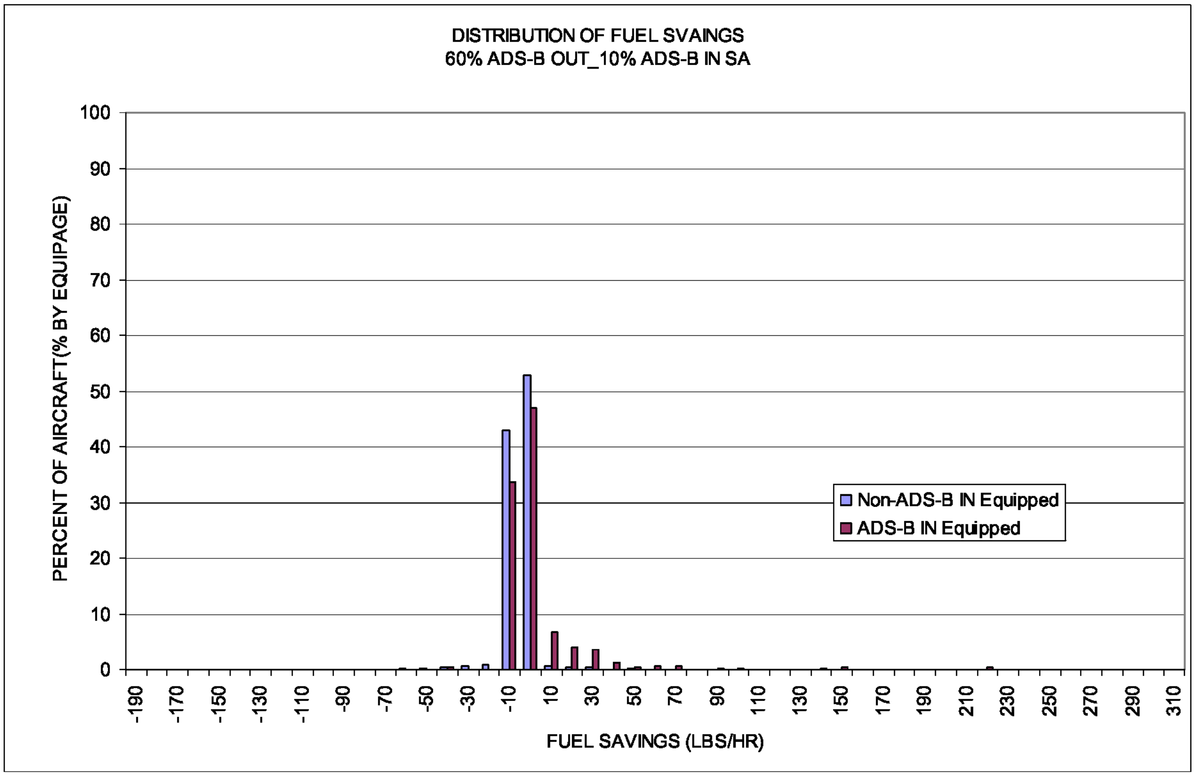


Figure 19: Distribution of normalized fuel savings (RM1, 60_10 SA)

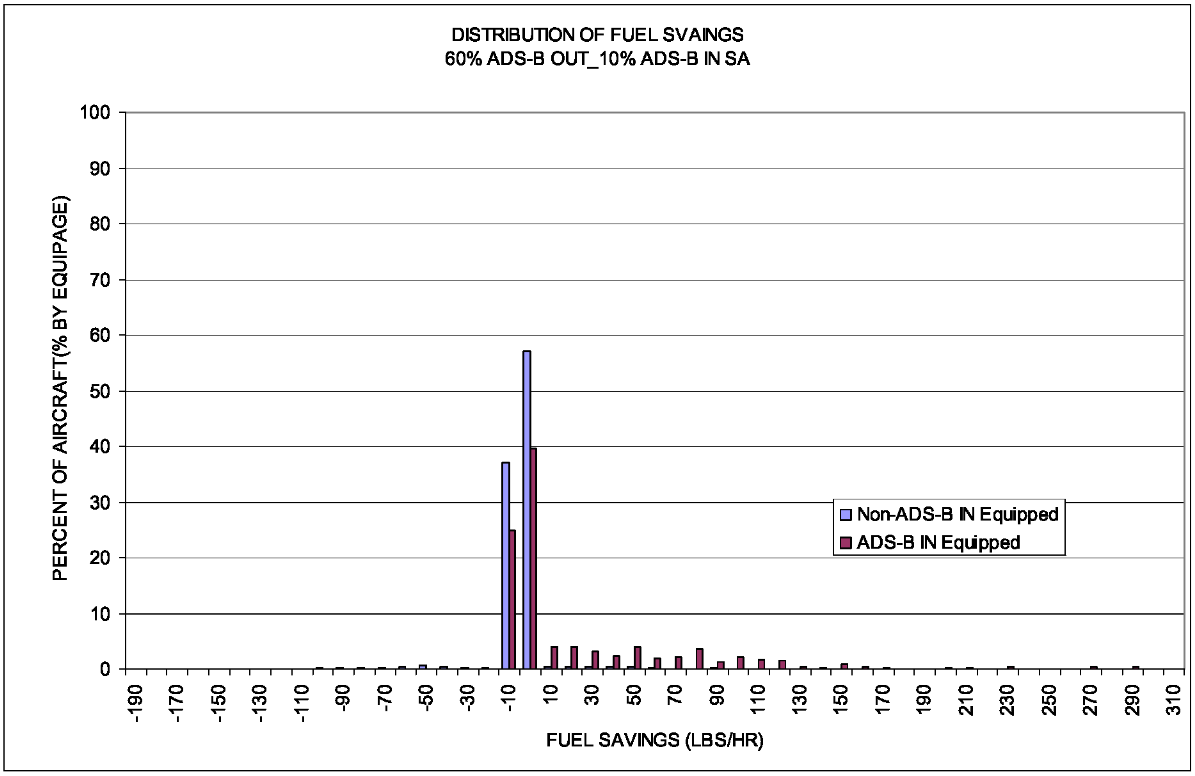


Figure 20: Distribution of normalized fuel savings (RM0, 60_10 SA)

The effect of introducing the ITP into the NATOTS had a larger effect on the fuel savings distribution under the RM0 request method than with the RM1 request method, as shown in Fig. 21. Fig. 21 shows the distribution of fuel savings under the same conditions as those illustrated in Fig. 20, with the addition of the ITP capability. As would be expected, the addition of the ITP to the ADS-B-IN-equipped aircraft has no significant effect on the non-ADS-B-IN-equipped aircraft. The ITP has a small effect on the distribution of ADS-B-IN-equipped aircraft. By allowing aircraft to make use of the ITP, the percentage of the ADS-B-IN-equipped aircraft experiencing fuel savings greater than 10 lbs/hr increases from around 35% to 42%. A similar trend occurs under the RM1 request method but is not as large. Just as a direct relationship between the ADS-B equipage level and average fuel savings occurs (as shown in Fig. 15 and Fig. 16), the percentage of aircraft experiencing fuel savings increases when ADS-B IN equipage increases. Fig. 22 illustrates the SA+ITP 90-80 equipage level under the RM0 request method. Under these conditions, the percentage of the ADS-B-IN-equipped aircraft experiencing fuel savings greater than 10 lbs/hr increases an additional 14% from the 60-10 SA+ITP case.

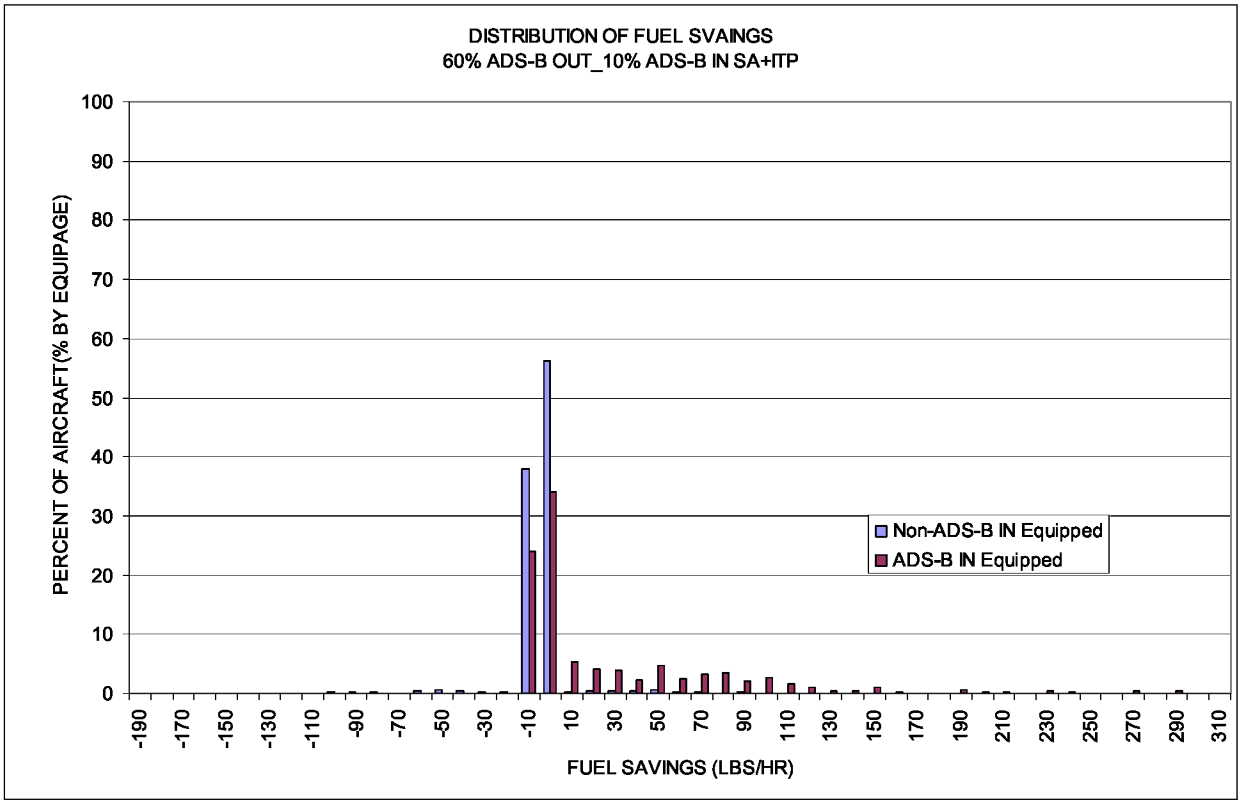


Figure 21: Distribution of normalized fuel savings (RM0, 60_10 SA+ITP)

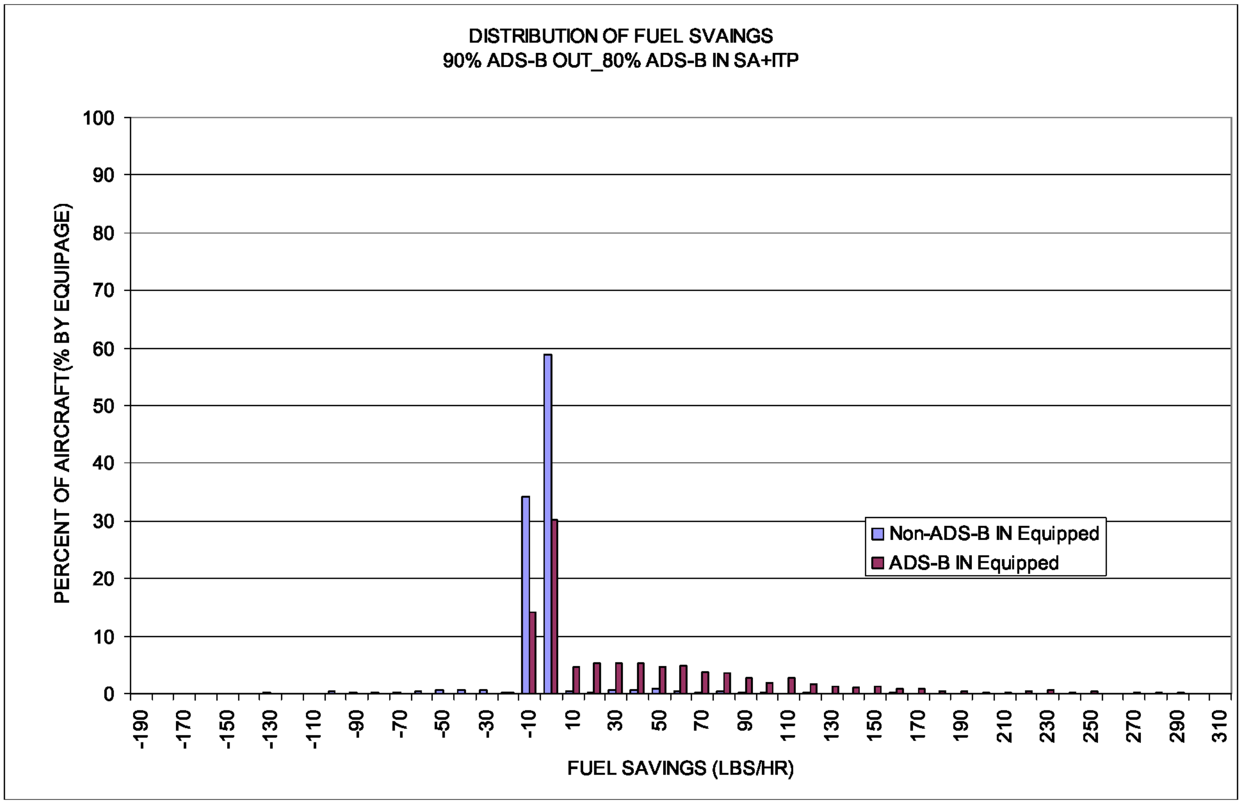


Figure 22: Distribution of normalized fuel savings (RM0, 90_80 SA+ITP)

Track Efficiency

Results discussed in previous sections ("Altitude Requests and Approval Rates" and "Fuel Savings") indicate consistently higher fuel savings and request approval rates with the RM0 entry request method than the RM1 entry request method. There are two main factors: the efficiency of the requested altitude, and the efficiency of the track loading. For each aircraft in a traffic flow, one request method is more efficient than the other and is based on the type of aircraft and the gross weight of the aircraft at the time of the track entry request. The efficiency of the track loading varies slightly with the request method, but both methods use the same process to assign an altitude. The reason for the difference is due primarily to the limitation on the performance data sets available. When an aircraft requests a track entry that is 1,000 feet above its optimum, there are fewer altitudes available above the requested altitude at which it can fly. This often requires the aircraft to load below the requested altitude. Table 11 shows the magnitude of the average altitude (in thousands of feet) that aircraft are loaded from the altitude that is requested. All traffic densities experience more efficient loading under the RM0 entry method than with the RM1 entry method. Under both request methods, the efficiency of the track loading decreases when traffic density increases, as expected, since the simulated ATC needs to fit more aircraft into the same number of available altitudes on the tracks. The magnitude of the decrease with each traffic density increase is very similar for both request methods.

Table 11 also shows the results of the track loading with regard to the magnitude and does not take into account the direction of the offset from the requested altitude. Table 12 shows the average altitude offset for each density when the direction of the offset is included; a negative offset indicates the aircraft are on average loaded lower than the altitude requested. Again, the RM0 request method is more efficient at loading aircraft closer to the request altitude than the RM1 entry request method. The biggest difference in the loading is that the average under the RM0 entry request method is positive and is negative under the RM1 entry request method. This is due in part to the data sets available for some aircraft models and that every aircraft is required to be loaded into the tracks at an altitude within the flight envelope for that particular aircraft model. Requesting 1,000 feet higher at entry means that there are fewer altitudes above the requested altitude for the aircraft to be loaded (even for the most complete aircraft model). Thus, the likelihood of being loaded at a lower altitude than requested increases.

Table 11: Magnitude of average altitude from requested altitude (thousands of feet)

	RM0	RM1	Difference between RM1 & RM0
Low	0.18811	0.425022	0.236912
Medium	0.409294	0.664823	0.255529
High	0.486131	0.724572	0.238441
Ultra	0.673722	0.957504	0.283782

Table 12: Average altitude from requested altitude (thousands of feet)

	RM0	RM1	Difference between RM1 & RM0
Low	0.073647	-0.20674	-0.28039
Medium	0.146237	-0.19906	-0.3453
High	0.136763	-0.21251	-0.34928
Ultra	0.111029	-0.33008	-0.44111

Conclusions

The experiment described in this paper investigated the effects on the NATOTS of implementing the ADS-B ITP. The use of the ITP was tested under various experiment conditions representing the NATOTS today and expected in the near future. These conditions included variations in traffic density, ADS-B equipage environment, the capability of aircraft to use the ITP, and the method used by aircraft to select and request an entry altitude into the NATOTS. The scenarios used in this experiment were specifically designed to accurately simulate traffic patterns and operations based on recorded data from the NATOTS. The design made use of the distribution of aircraft across the individual tracks of the NATOTS, the distribution of the inter-arrival times of aircraft at the entrance to the NATOTS, and the total number of aircraft loaded into the NATOTS. The experiment required the development of new capabilities and enhancements to existing functionality in TMX, the simulation environment. This preparation and design effort allowed for a realistic simulation of the NATOTS and strong confidence in the results presented.

Data collected during the experiment were analyzed across three main categories: 1) altitude requests and approval rates, 2) fuel savings, and 3) track efficiency. Criteria in each category were compared across four variables: 1) ADS-B equipage level, 2) traffic density, 3) procedural capability, and 4) track entry request method.

The first category examined altitude requests made by aircraft and the corresponding request approval rates. Within this experiment, and the current NATOTS, there are many opportunities for aircraft to change altitude. In the baseline scenarios used in this experiment (which were equivalent to current operations in the NATOTS), 25% to 75% of the aircraft could have made desired altitude changes. Unfortunately, the current system does not take advantage of all of these opportunities. Therefore, the simulation did not use all opportunities. The availability to maneuver decreased when traffic density increased. However, the use of the ITP increased when traffic density increased. The percentage of the total requests that made use of the ITP increased from less than 5% under most low density conditions to between 10%–25 % under the higher traffic density conditions. The use of the ITP increased the average percentage of aircraft that made altitude change requests as much as 20% under the ultra traffic density. While the use of the ITP increased the average percentage of aircraft that made a request, it did not significantly increase the percentage of requests that were approved. There were even cases where the approval rate of requests was higher without the use of the ITP. The lack of change in the percentage of approvals is primarily because the use of ITP requests was much less than the use of standard altitude change requests.

The second category examined fuel savings. Analysis of normalized fuel flow data showed that the use of the ITP provided a benefit in fuel savings compared to baseline non-ADS-B simulation runs. However, this fuel savings was not as large as the savings from making standard requests when appropriate. Increased knowledge of when to make a standard request came from an ADS-B IN display. Such a display is likely to comprise part of any ITP installation. The average fuel savings decreased with increasing traffic density, but the portion of the savings that was attributed to the ITP increased with increasing traffic density. The analysis also looked at fuel savings as a distribution across all aircraft. The distribution showed that the majority of the aircraft had no change (less than ±10 lbs/hr) in the flight between an experiment condition and the baseline. The number of aircraft outside the 10 lbs/hr band increased with the use of the ITP and increased even more with increased levels of ADS-B equipage. While there was a shift in the distribution toward larger savings and more aircraft experiencing savings for those aircraft equipped with ADS-B IN or ADS-B IN and ITP, there was no significant change in the distribution of the savings for the non-ADS-B IN equipped aircraft. A significant result is that the voluntary introduction of new technology into the system did not cause a detriment to unequipped aircraft.

The third category examined track efficiency. The analysis looked at data across two track entry request methods used to load the track system. The two methods were based on current airline procedures. The first method (referred to as RM0) assumed that the aircraft will be able to make altitude changes during the crossing. The aircraft therefore requests to enter the track system at the present optimum altitude. The second method (referred to as RM1) assumed that the aircraft would not be able to climb at all during the crossing. In this situation, the aircraft determined a compromise altitude that would place most of the flight at or near the optimum altitude for as much of the flight as possible. The second method also assumed that this compromise altitude would occur 1,000 feet above the optimum at track entry. The analysis showed that the RM0 method of track loading was more efficient than the RM1 method of track loading. This efficiency was judged according to how close to the requested altitude the aircraft were loaded. This result cannot necessarily be directly carried over into actual operations, since a mix of RM0 and RM1 requests occur in the actual NATOTS. Further analysis is needed with an enhanced request method.

The use of the ITP in the NATOTS might be limited. However, the equipment used for the ITP can be used for an entire suite of advanced ADS-B applications, such as merging and spacing, enhanced visual acquisition, or improved ground surveillance. When put together with additional applications, the ITP could provide a very strong component of a suite of ADS-B applications. When the ITP is implemented with a graphical traffic display, the situation awareness that can be gained about surrounding traffic can provide even more benefit. The knowledge of the location of other aircraft in the local airspace can provide a means for pilots to make more informed requests to ATC, even with no change to current day procedures and policies. This aspect of the ITP equipment is what contributes most benefits in the NATOTS environment found in this experiment. This experiment demonstrated that even when aircraft were equipped with the ITP as a capability, most altitude change requests were non-ITP requests. In the North Atlantic, the ITP equipment (if implemented with a graphical display) will provide more benefit than the use of a new procedure and separation standard. The ITP may provide a larger portion of the benefits in a different oceanic region, such as the South Pacific (SOPAC) or the Pacific Organized Track System (PACOTS). These regions experience much lower traffic loads but have similar traffic situations as the NATOTS in that aircraft can be blocked from changing altitude for long periods of time.

References

[1] Federal Aviation Administration. www.faa.gov/about/office_org/headquarters_offices/ato/service_units/enroute/surveillance_broadcast/ Accessed October 30, 2007

[2] Air Services Australia. www.airservicesaustralia.com/pilotcentre/projects/adsb/default.asp Accessed October 30, 2007

[3] Eurocontrol. www.eurocontrol.int/cascade/public/subsite_homepage/homepage.html Accessed October 30, 2007

[4] North Atlantic Systems Planning Group, Application of Separation Minima (North Atlantic Region) v1.0, ICAO European and North Atlantic Office, 29 September 2005

[5] Murdoch, J.L., Bussink, F.J.L., Chamberlain, J.P., Chartrand, R.C., Palmer, M.T., Palmer, S.O., Enhanced Oceanic Operations Human-In-The-Loop In-Trail Procedure Validation Simulation Study, NASA Technical Paper, TP-2008-215313, June 2008.

[6] RTCA, Minimum Operational Performance Standards for 1090 MHz Automatic Dependent Surveillance – Broadcast (ADS-B) and Traffic Information Services Broadcast (TIS-B), DO-260A, Washington, DC, April 10, 2003

[7] RTCA, Minimum Aviation System Performance Standards for Automatic Dependent Surveillance Broadcast (ADS-B), DO-242A, Washington, DC, June 25, 2002

[8] EUROCAE ED-159: Safety, Performance and Interoperability Requirements Document for ATSA-ITP Application, May 2008.

[9] Bussink, F.J.L., Hoekstra, J., Heesbeen, W., *Traffic Manager: A Flexible Desktop Simulation Tool Enabling Future ATM Research*, 24th Digital Avionics Systems Conference, October 2005, Washington DC

[10] 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 Accessed November 14, 2006

[11] NOAA National Operational Model Archive & Distribution System. http://nomads.ncdc.noaa.gov/#ncep_datasets Accessed March 2007-Present

[12] Rockwell Collins. http://www.rockwellcollins.com/ecat/at/ACAS-900_2.html#N27724 Accessed October 30, 2007

Appendix A
NOTAM for NATOTS - March 7, 2005

061401 CZQXZQZX
(NAT-1/2 TRACKS FLS 310/400 INCLUSIVE
MAR 07/0100Z TO MAR 07/0800Z
PART ONE OF TWO PARTS-
U YQX KOBEV 50/50 53/40 55/30 55/20 RESNO NIBOG NURSI
EAST LVLS 320 330 340 350 360 370 380 390 400
WEST LVLS NIL
EUR RTS EAST NIL
NAR N79B N83B N85A-
V VIXUN LOGSU 49/50 52/40 54/30 54/20 DOGAL BABAN
EAST LVLS 320 330 340 350 360 370 380 390 400
WEST LVLS NIL
EUR RTS EAST NIL
NAR N63B N67B-
W YYT NOVEP 48/50 51/40 53/30 53/20 MALOT BURAK
EAST LVLS 320 330 340 350 360 370 380 390 400
WEST LVLS NIL
EUR RTS EAST NIL
NAR N53B N59A-
X COLOR RONPO 47/50 50/40 52/30 52/20 LIMRI DOLIP
EAST LVLS 320 330 340 350 360 370 380 390 400
WEST LVLS NIL
EUR RTS EAST NIL
NAR N43A N49A-
Y BANCS URTAK 46/50 49/40 51/30 51/20 DINIM GIPER
EAST LVLS 320 330 340 350 360 370 380 390 400
WEST LVLS NIL
EUR RTS EAST NIL
NAR N35A N41C-
END OF PART ONE OF TWO PARTS)

061402 CZQXZQZX
(NAT-2/2 TRACKS FLS 310/400 INCLUSIVE
MAR 07/0100Z TO MAR 07/0800Z
PART TWO OF TWO PARTS-
Z CLXTN 38/60 43/50 47/40 50/30 50/20 SOMAX KENUK
EAST LVLS 310 340 380
WEST LVLS NIL
EUR RTS EAST NIL
NAR NIL-
REMARKS:
1.TRACK MESSAGE IDENTIFICATION NUMBER IS 066 AND OPERATORS ARE REMINDED TO INCLUDE THE TMI NUMBER AS PART OF THE OCEANIC CLEARANCE READ BACK.

2.CLEARANCE DELIVERY FREQUENCY ASSIGNMENTS FOR AIRCRAFT OPERATING FROM MOATT TO BOBTU INCLUSIVE:
MOATT TO SCROD 128.7
OYSTR TO CYNON 135.45
YQX TO VIXUN 135.05
YYT TO COLOR 128.45
BANCS TO BOBTU 119.42
3.80 PERCENTAGE OF GROSS NAVIGATIONAL ERRORS RESULT FROM POOR COCKPIT PROCEDURES. ALWAYS CARRY OUT PROPER WAYPOINT CHECKS.
4.OPERATORS SHOULD NOTE THAT NERS IDENTIFIER IS NOT TO BE INCLUDED IN FIELD 15 OF THE FLIGHT PLAN UNDER ANY CIRCUMSTANCES.
END OF PART TWO OF TWO PARTS)

Appendix B
Average count of aircraft experiencing a fuel savings or penalty

Aircraft count for RM1-SA scenarios

	LOW				MEDIUM			
	Unequipped aircraft with		ADS-B IN aircraft with		Unequipped aircraft with		ADS-B IN aircraft with	
Equipage level	Savings	Penalty	Savings	Penalty	Savings	Penalty	Savings	Penalty
30_10	5.5	5.1	6.4	0.0	6.1	7.3	7.2	0.2
60_10	5.5	5.0	6.4	0.0	6.8	6.9	7.2	0.2
90_10	4.6	4.7	6.4	0.0	6.2	6.8	7.0	0.1
60_45	3.3	2.6	29.1	0.3	4.6	4.4	36.1	0.8
90_45	3.1	2.5	29.3	0.3	4.4	4.1	36.7	0.7
90_80	1.2	1.0	56.8	0.6	1.6	1.5	75.0	1.2
	HIGH				ULTRA			
	Unequipped aircraft with		ADS-B IN aircraft with		Unequipped aircraft with		ADS-B IN aircraft with	
Equipage level	Savings	Penalty	Savings	Penalty	Savings	Penalty	Savings	Penalty
30_10	6.9	6.6	7.2	0.2	5.8	5.8	6.4	0.3
60_10	7.9	5.9	7.4	0.3	6.4	5.8	6.4	0.3
90_10	6.2	5.9	7.3	0.1	6.6	5.9	6.5	0.4
60_45	4.1	3.8	37.8	0.7	3.2	3.3	34.2	1.2
90_45	4.3	3.8	38.4	0.7	4.0	3.2	34.6	1.2
90_80	1.3	1.3	76.1	1.3	1.2	1.1	67.0	2.4

Aircraft count for RM1-SA+ITP scenarios

	LOW				MEDIUM			
	Unequipped aircraft with		ADS-B IN aircraft with		Unequipped aircraft with		ADS-B IN aircraft with	
Equipage level	Savings	Penalty	Savings	Penalty	Savings	Penalty	Savings	Penalty
30_10	5.7	4.8	6.3	0.0	7.2	6.7	7.9	0.2
60_10	5.8	4.7	6.8	0.0	6.0	6.6	7.6	0.2
90_10	5.3	4.9	6.8	0.0	6.6	6.8	8.4	0.2
60_45	3.5	2.3	30.2	0.4	3.5	4.4	38.2	0.8
90_45	3.7	2.7	30.6	0.4	4.4	4.8	41.0	0.8
90_80	2.0	0.9	58.7	0.7	1.5	1.4	82.1	1.4
	HIGH				ULTRA			
	Unequipped aircraft with		ADS-B IN aircraft with		Unequipped aircraft with		ADS-B IN aircraft with	
Equipage level	Savings	Penalty	Savings	Penalty	Savings	Penalty	Savings	Penalty
30_10	6.7	6.1	7.6	0.2	5.0	5.3	6.9	0.3
60_10	5.9	6.1	8.2	0.2	5.0	5.6	7.4	0.3
90_10	6.9	6.6	8.7	0.1	6.1	5.3	7.8	0.3
60_45	4.6	4.0	40.4	0.8	4.1	3.7	38.2	1.3
90_45	3.5	4.0	42.7	0.6	3.3	3.3	41.1	1.4
90_80	1.8	1.3	82.4	1.6	1.3	1.1	79.6	2.6

Aircraft count for RM0-SA scenarios

	LOW				MEDIUM			
	Unequipped aircraft with		ADS-B IN aircraft with		Unequipped aircraft with		ADS-B IN aircraft with	
Equipage level	Savings	Penalty	Savings	Penalty	Savings	Penalty	Savings	Penalty
30_10	7.7	6.4	8.9	0.1	8.1	7.3	10.5	0.1
60_10	6.4	6.3	8.9	0.1	8.6	7.2	10.5	0.1
90_10	7.3	6.2	9.0	0.1	7.7	7.4	10.5	0.1
60_45	3.8	3.7	41.7	0.3	5.6	4.6	56.9	0.6
90_45	4.4	4.1	41.9	0.3	4.8	4.7	57.1	0.5
90_80	1.6	1.3	82.0	0.4	2.7	1.6	120.4	0.9
	HIGH				ULTRA			
	Unequipped aircraft with		ADS-B IN aircraft with		Unequipped aircraft with		ADS-B IN aircraft with	
Equipage level	Savings	Penalty	Savings	Penalty	Savings	Penalty	Savings	Penalty
30_10	7.6	9.1	11.0	0.1	8.0	6.8	10.0	0.2
60_10	9.2	9.2	11.3	0.1	7.4	7.0	9.8	0.2
90_10	9.2	8.9	11.5	0.2	7.9	6.9	9.9	0.2
60_45	5.3	5.4	60.5	0.8	5.2	4.5	55.1	0.7
90_45	5.8	5.7	60.9	0.9	5.1	4.4	55.2	0.7

90_80	2.2	2.3	128.8	1.6	2.5	1.7	121.6	1.5

Aircraft count for RM0-SA+ITP scenarios

	LOW				MEDIUM			
	Unequipped aircraft with		ADS-B IN aircraft with		Unequipped aircraft with		ADS-B IN aircraft with	
Equipage level	Savings	Penalty	Savings	Penalty	Savings	Penalty	Savings	Penalty
30_10	7.1	6.3	9.0	0.1	7.2	7.2	11.1	0.2
60_10	7.2	6.3	9.4	0.1	8.4	7.2	11.9	0.2
90_10	6.2	6.1	9.9	0.1	7.7	7.4	13.5	0.2
60_45	4.7	3.9	42.0	0.3	5.4	4.7	61.9	1.0
90_45	4.7	4.2	45.2	0.4	6.0	4.6	68.7	1.3
90_80	1.3	1.6	84.1	0.7	2.3	1.8	128.5	2.3
	HIGH				ULTRA			
	Unequipped aircraft with		ADS-B IN aircraft with		Unequipped aircraft with		ADS-B IN aircraft with	
Equipage level	Savings	Penalty	Savings	Penalty	Savings	Penalty	Savings	Penalty
30_10	8.5	9.1	11.6	0.2	7.6	6.9	10.8	0.2
60_10	8.6	9.1	13.3	0.2	7.5	6.5	12.9	0.2
90_10	8.8	8.8	15.7	0.2	7.1	6.8	14.3	0.2
60_45	5.7	5.5	65.6	1.1	6.3	4.3	63.4	1.2
90_45	5.2	5.4	75.0	1.3	6.2	4.7	75.7	1.2
90_80	2.2	2.1	142.1	2.4	2.4	1.6	150.1	2.3

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14. ABSTRACT

This paper explains the computerized batch processing experiment examining the operational impacts of the introduction of Automatic Dependant Surveillance-Broadcast (ADS-B) equipment and the In-Trail Procedure (ITP) to the North Atlantic Organized Track System. This experiment was conducted using the Traffic Manager (TMX), a desktop simulation capable of simulating airspace environments and aircraft operations. ADS-B equipment can enable the use of new ground and airborne procedures, such as the ITP. ITP is among the first of these new procedures, which will make use of improved situation awareness in the local surrounding airspace of ADS-B equipped aircraft to enable more efficient oceanic flight level changes. The collected data were analyzed with respect to multiple operationally relevant parameters including fuel burn, request approval rates, and the distribution of fuel savings. This experiment showed that through the use of ADS-B or ADS-B and the ITP that operational improvements and benefits could be achieved.

15. SUBJECT TERMS
Automatic Dependant Surveillance-Broadcast; ADS-B; North Atlantic Organized Track System ; In-Trail Procedure; ITP

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