ASIA AND PACIFIC INITIATIVE TO REDUCE EMISSIONS

2011 ASPIRE ANNUAL REPORT

PERFORMANCE METRICS APPENDIX

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Introduction

Welcome to the ASPIRE Annual Report's Metrics Appendix. The purpose of this appendix is to provide details and an explanation of important metrics that were mentioned only briefly in the Annual Report. Herein we discuss our data sources, methodology, and the results of our studies of the fuel burn benefits provided by improvements in Air Traffic Management (ATM). We focused on several areas that are of interest to the ASPIRE Partners. First, we take a historical look at benefits in the South Pacific Region, to account for past success. Second, we look at the potential benefits of future ATM improvements in the Pacific Region. Third, we present and explain the benefits that could be achieved by reducing separation minima from the current 30/30. We conclude by discussing the benefits obtained by flights taking advantage of the Dynamic Airborne Reroute Procedure (DARP).

Gathering, compiling, processing, and analysing data is crucial to quantify the benefits of ATM improvements. The partners recognise the necessity of developing shared metrics, one of the five pillars of ASPIRE. This work was made possible through data-sharing agreements with ASPIRE partners.

South Pacific Historical Analysis

Over the last 10 years, there have been significant improvements in oceanic air traffic control capabilities. The incremental efficiency gains from these changes have been captured in this analysis by using today's traffic. Because the most innovative changes occurred in the South Pacific area, the analysis focused on flights between San Francisco/ Los Angeles and Auckland/Sydney. These city pairs experienced the greatest separation reductions: longitudinal separation has been reduced from 15 minutes to 30 nautical miles (NM), lateral separation has been reduced from 100 NM to 30 NM, and Reduced Vertical Separation Minima was introduced as illustrated in Figure 1. In addition, flight paths moved from fixed great circle paths to wind-optimised flex tracks to user-preferred routes. Users can now offset for a climb-through operation and dynamically reroute if on a sub-optimal path given updated wind information.

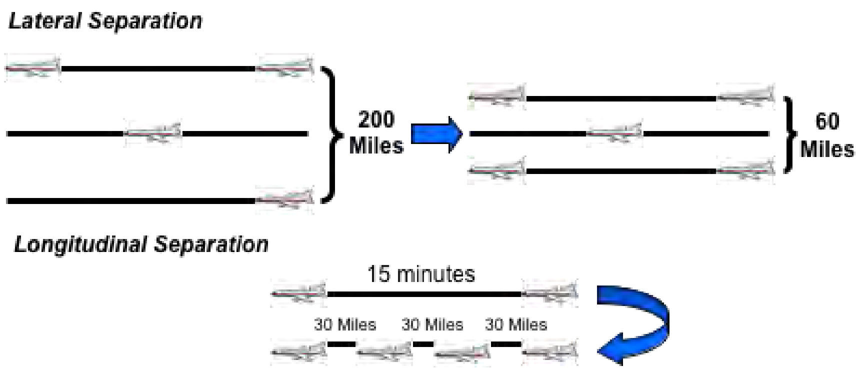

Figure 1: Separation Changes in the Oceanic Airspace

To simulate these changes, the flight plans from November 2007 were chosen as the demand, and a baseline of fixed great circle paths was generated. The entire month of flights with filed flight plans in Oakland oceanic airspace was used to capture all potential flight interactions during modelling. Using Dynamic Ocean Track System (DOTS) and available meteorological data, wind-optimised flex tracks were created for 10 days. For the other days, assumptions were made on the appropriate track to use for routing. The International Civil Aviation Organization (ICAO) filed flight plan was assumed to be the User Preferred Route (UPR).

Each scenario's traffic was processed through a tool that checked for conflicting trajectories and whether there would be a better altitude-speed combination along a given path. The scenarios were processed to capture the changes in winds throughout the day. In the later scenarios when flights can deviate from the input path (great circle, flex track, user preferred route), the functionality was added to check if a lateral offset would improve fuel burn as part of the dynamic rerouting. The check for a more efficient path occurred about every three hours with lateral offset checking when considering a blocked climb.

Table 1: Benefits from Incremental Improvements in the Oceanic Environment Compared to the Baseline Scenario

	Cumulative Benefit	
	Westbound	Eastbound
10 Minutes Longitudinal	0.1%	0.1%
Wind Optimised Flex Tracks (B747 model)	0.3%	0.6%
Reduced Vertical Separation Minima (RVSM) 1000 ft.	0.6%	0.9%
50NM lateral	0.7%	0.9%
50NM longitudinal	0.7%	0.9%
User Preferred Routes	1.4%	1.5%
Dynamic Reroutes	1.9%	1.8%
30/30	2.2%	2.0%

Each of the improvements include the previous scenario changes; for example, the Reduced Vertical Separation Minimum (RVSM) scenario includes benefits from both the 10 minutes longitudinal and flex tracks improvements. These are average benefits, and it should be noted that actual benefits depend on both the origin-destination of a flight and the aircraft type. For example, for some less congested city pairs (e.g., San Francisco–Auckland), using preferred routes removed most of the system constraints on fuel efficiency, and thus the gains from 30/30 were smaller than on more congested routes. Additionally, since the flex tracks were designed specifically for the Boeing 777-400 (B744), the transition to UPRs provided smaller benefits for the B744 than for other aircraft types, such as the Boeing 777-200 (B772).

Available Benefit in the Pacific Region

Abstract

One of the key components of ASPIRE is the development of performance metrics. These metrics are designed to quantify the incremental improvements in efficiency proved by the Air Traffic Management (ATM) operations. The Civil Aviation Bureau of Japan (JCAB), Airways New Zealand, the United States Federal Aviation Administration (FAA), and Airservices Australia have shared data to support construction of efficiency metrics. This study presents total available benefits in the Pacific ATM environment, given current technology. Available benefits are approximately 4.3% and vary depending on origin-destination and aircraft type.

Introduction

Trajectory-based fuel efficiency is a key metric to measure the effectiveness of ATM operations in the oceanic environment. There have been many estimates of the potential savings from more fuel efficient operations. Often these estimates are based on supposition, but in this study, we measure this potential by comparing the modelled fuel burns from an optimised trajectory and from the actual trajectory. The fuel-optimised trajectories provide an ideal flight benchmark of the best achievable fuel burn. The actual trajectories provide a snapshot of the fuel burn performance within the current capabilities of the air traffic management and the airlines' cost indices. The available pool of benefits, in terms of fuel savings, can be calculated by comparing the fuel burn of fuel-optimised trajectories to the fuel burn of the actual trajectories. This benefit is evaluated by origin-destination and airframe on flights between the United States and Australia/New Zealand.

Methodology

In order to estimate the available benefit in the Pacific Region, fuel burn was calculated from modelled trajectories of the actual flight paths and the ideal flight paths. This study was limited to origin-destination pairs that had trajectory data provided by ASPIRE partners.[1] Future studies may include additional origin-destination pairs as data-sharing agreements are expanded.

Data Sources

The flight trajectory (latitude, longitude, altitude, and time) and aircraft information (aircraft type) for each flight is obtained through data-sharing agreements with the partnering Air Navigation Service Providers (ANSPs).[2]

Since fuel burn depends upon an aircraft's loaded weight, ideally this loaded weight would be used as an input for all fuel burn calculations. Unfortunately, since each airline considers this to be proprietary information, this study uses the average payload information provided by the airlines to the Bureau of Transportation Statistics (BTS).

The University Corporation for Atmospheric Research (UCAR)[3] was the source of the reanalysed winds, which provides historical global wind information (rather than forecasts). This analysis used the National Center for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) Reanalysis Project[4] "R1 pressure level" product, which provides wind information at six-hour intervals every 2.5 degrees across the globe at 17 pressure levels.

Data Processing

Given the multiple data sources for this analysis, the first step to process the data was to change the provided data into a format that could be used with the CSSI fuel burn model, Optimal Tragectory Generator (OPGEN). Text messages can be translated to specific formats or database files queried. Trajectories were built by combining partner ANSPs' data with data from the FAA trajectories using the Oceanic Flight Constructor (OFC). The OFC parses the data from the multiple ANSPs and combine them to make the trajectory files for the flights.

Having been built by the OFC, the initial trajectories for the sample were next inputted into the OPGEN preprocessor. In the OPGEN preprocessor, the trajectories are reformatted and have points filled in between current points (if the need arises). After obtaining the reformatted trajectories from the OPGEN preprocessor, the trajectories were then run through OPGEN Core.

Fuel Burn Modelling

Once the trajectories are in the same consistent format, they are then processed through OPGEN to determine fuel burn. OPGEN has two commonly-used settings: 'fuel_only' and 'full optimisation' modes; the 'fuel_only' mode approximates the as-flown fuel consumption, while the 'full optimisation' mode calculates the minimum fuel burn for each trajectory. OPGEN uses backward integration for this process. Starting from the oceanic exit point, it follows discrete steps as specified by a trajectory. At each step it calculates the required fuel to fly a segment, defined as the airspace between two consecutive waypoints; variables considered include aircraft weight at the lastly observed waypoint, average airspeed, wind, and the optimal vertical profiles between the two waypoints. The sum of fuel required at each segment is the total fuel consumption. The 'fuel_only' mode runs the inputted trajectory and calculates the fuel burned along the path. No changes are made to the path, so the outputted trajectory is the same as the inputted. In the 'full optimisation' mode, the optimisation is unconstrained in regards to the following: conflicts, convective weather, or cost index beyond fuel (i.e. no overflight fees). In addition, the optimised flight time can only be 10% longer than the actual. This means that with full wind information, aircraft may fly at unusual altitude to achieve a better wind performance.[5]

Certain flights violated performance constraints during the modelling of the actual trajectories. Performance constraints include limits on airspeeds at altitude, limits on fuel flow, limits on weight and maximum altitude constraints. In order to accurately model these flights, the trajectories for these flights were subjected to a cleaning process. This process required the trajectories outputted from OPGEN Core to be run through a program that removed the points that violated the performance constraints. The speeds were then recalculated, and the trajectories were rerun through OPGEN. Trajectories were only run once through the cleaning process, as overcleaning could result in removing large portions of the trajectories.

The final and cleaned baseline trajectories were run through OPGEN Core's 'fuel_only' mode again. Then, the same trajectories were run through OPGEN Core's 'full optimisation' mode to establish the ideal flight benchmark.

Once all of the OPGEN runs were completed, an analysis on the output data was performed. Some of the flights in the sample were dropped due to various reasons. There were some flights that only had one record for that Origin-Destination-Aircraft (ODA) pairing. Some flights were dropped because the generic weights used from the Bureau of Transportation Statistics (BTS) data were too heavy to be optimised correctly. Flights were also removed because of optimisation errors and unusual aircraft performance. Outliers of the sample (flights with fuel burn that lay outside of two standard deviations of the mean of the ODA) were also removed.

Results

Savings provided by allowing the modelled flight to fly the most fuel-efficient path vary depending upon the ODA combination. Overall, there was an average 4.82% available savings for US-Australia ODAs and 3.38% for US-New Zealand ODAs. Table 1 shows the average potential fuel savings by aircraft type for the study period, March 2010-May 2011. This is followed by tables presenting the complete results by ODA combination by month. These detailed tables allow for detection in trends over time, as well as seasonality.

Table 1: Average Potential Fuel Savings Compared to the Baseline Scenario by Aircraft Type,

% Fuel Savings	Average US-Australia City Pairs	Average US-New Zealand City Pairs
A332	N/A	3.46
A388	4.33	N/A
B744	4.43	2.91
B772	N/A	3.57
B77W	7.51	6.40

Table 2: Potential Fuel Savings Compared to the Baseline Scenario for US-Australia City Pairs by Aircraft Type, March-September 2010

% Fuel Savings	March 2010	April 2010	May 2010	June 2010	July 2010	August 2010	September 2010
A388							
YSSY KLAX	5.20	5.14	5.32	5.16	5.45	5.12	5.02
KLAX YSSY	4.05	3.78	4.17	4.46	4.55	4.15	4.95
YMML KLAX	5.45	5.31	5.95	5.05	4.56	3.99	5.10
KLAX YMML	3.54	4.17	3.08	2.96	3.59	3.17	3.01
B744							
YSSY KLAX	5.71	5.12	5.75	5.15	5.59	5.25	4.78
KLAX YSSY	4.59	4.22	4.28	4.40	4.60	3.87	4.01
YMML KLAX	4.94	5.94	5.61	5.96	5.34	5.31	4.96
KLAX YMML	4.50	4.55	4.20	5.39	5.19	3.39	3.69
YSSY KSFO	5.44	4.10	3.31	3.45	3.94	3.53	3.57
KSFO YSSY	4.60	4.18	3.66	4.58	5.42	4.37	4.46
B77W							
YMML KLAX	*	7.32	8.04	*	*	*	8.31
KLAX YMML	4.61	5.57	4.49	5.94	6.80	6.87	6.06
YBBN KLAX	8.06	8.29	8.97	8.42	8.00	7.07	7.90
KLAX YBBN	6.63	6.75	6.87	6.16	6.67	7.45	7.47

***Indicates months where fewer than five flights met the ODA combination.**

Table 3: Potential Fuel Savings Compared to the Baseline Scenario for US-Australia City Pairs by Aircraft Type, October 2010- May 2011

% Fuel Savings	October 2010	November 2010	December 2010	January 2010	February 2010	March 2011	April 2011	May 2011
A388								
YSSY KLAX	4.58	*		3.16	3.76	4.61	4.81	5.15
KLAX YSSY	4.31	*		4.67	4.04	3.22	3.81	3.16
YMML KLAX	4.72	*		*	*	5.00	4.83	4.47
KLAX YMML	4.31	*			*	*	2.69	2.48
B744								
YSSY KLAX	4.25	5.75	4.99	4.94	4.49	4.83	5.62	5.36
KLAX YSSY	4.56	3.26	4.11	5.42	5.28	4.19	4.16	4.51
YMML KLAX	4.87	5.55	4.98	4.54	4.67	4.58	5.73	5.77
KLAX YMML	3.90	3.15	3.30	5.35	4.80	4.00	2.38	3.41
YSSY KSFO	2.89	4.74	3.75	4.42	3.71	3.80	4.84	3.82
KSFO YSSY	4.29	4.51	4.57	5.25	5.81	3.21	3.83	3.61
B77W								
YMML KLAX	6.95	5.55	6.32	7.21	6.99	7.80	8.01	8.59
KLAX YMML	7.34	4.38	5.97	6.05	6.35	5.94	5.41	4.81
YBBN KLAX	8.51	8.24	7.55	8.02	7.32	6.80	8.32	8.61
KLAX YBBN	7.27	6.15	6.85	8.35	7.63	5.99	6.57	6.51

***Indicates months where fewer than five flights met the ODA combination. A blank cell indicates that there were zero flights for the given ODA.**

Table 4: Potential Fuel Savings Compared to the Baseline Scenario for US-New Zealand City Pairs by Aircraft Type, March-September 2010

% Fuel Savings	March 2010	April 2010	May 2010	June 2010	July 2010	August 2010	September 2010
A332							
NZAA KLAX					3.9	3.9	3.8
KLAX NZAA					3.5	2.5	3.2
B744							
NZAA KLAX							
KLAX NZAA	2.5	2.0	1.9	1.7	2.0	1.7	2.8
NZAA KSFO	*						*
KSFO NZAA	*						*
B772							
NZAA KLAX	*	3.5	3.7	4.9		*	4.7
KLAX NZAA	*	6.5	5.6	4.8			6.3
NZAA KSFO	2.3	2.3	3.1	2.1	1.9	2.0	1.8
KSFO NZAA	4.9	4.2	4.0	3.7	4.2	4.9	4.4
B77W							
NZAA KLAX							
KLAX NZAA							

***Indicates months where fewer than five flights met the ODA combination. A blank cell indicates that there were zero flights for the given ODA.**

Table 5: Potential Fuel Savings Compared to the Baseline Scenario for US-New Zealand City Pairs by Aircraft Type, October 2010- May 2011

% Fuel Savings	October 2010	November 2010	December 2010	January 2010	February 2010	March 2011	April 2011	May 2011
A332								
NZAA KLAX	3.4	3.8	4.0	3.7	3.8	4.2	4.5	4.5
KLAX NZAA	3.4	3.0	3.6	2.8	2.7	2.6	2.7	2.6
B744								
NZAA KLAX	2.3	3.2	3.3	2.8	3.3	3.5		
KLAX NZAA	2.6	2.5	2.5	2.5	2.4	2.2	*	
NZAA KSFO		*			*	*	3.0	2.5
KSFO NZAA		*			*		1.5	1.5
B772								
NZAA KLAX	5.4	2.9					3.1	3.1
KLAX NZAA	1.5	7.7	1.7		5.9		5.2	4.8
NZAA KSFO	0.8	1.8	2.1	1.5	1.8	1.6		
KSFO NZAA	5.3	4.5	5.5	4.8	4.7	4.3	7.9	
B77W								
NZAA KLAX				7.9	8.3	8.2	8.6	7.7
KLAX NZAA				*	6.5	6.2	5.8	4.5

***Indicates months where fewer than five flights met the ODA combination. A blank cell indicates that there were zero flights for the given ODA.**

Conclusions

Unique data-sharing agreements among ASPIRE partners allowed for development of shared performance metrics. This study calculated the remaining pool of possible benefits in the oceanic environment by comparing the current modelled fuel burn with the ideal modelled fuel burn, given current technology. Across all city pairs and aircraft types, the average potential fuel burn savings is 4.3%. This represents the maximum possible savings given the current aircraft mix.

Benefits of Reducing Aircraft Separation below the Current Standard

Abstract

Although traffic density in oceanic airspace is significantly lower than in control areas nearby to major airports, a minimum separation must be maintained between aircraft when flying all oceanic routes. Flights compete for the most fuel-efficient routes because only a certain number of flights can be on the same route at the same time. The current standard calls for a minimum 30/30 separation (lateral/longitudinal separation in nautical miles) or greater, depending on the aircraft and equipage. If the minimum separation could be reduced, more flights could fly on the same routes. This work looks to see how the reduction in separation can bring about benefits and if research into enabling technologies should be undertaken.

For this analysis, the aircraft are assumed to have the necessary equipment to maintain the specified separation. A sample of aircraft in 2010 was taken, trajectories were created from actual recorded data, and a simulation containing the sample flights was run. Different scenarios were considered to estimate the potential benefits of reducing the separation standard given increasing traffic density—first with non-optimised and then with optimised trajectories. The non-optimised trajectories were created from actual, as-flown data and are meant to mimic current conditions. The optimised trajectory scenarios were designed to show the fuel burn for the ideal, minimum fuel burn User Preferred Routes (UPRs), an important consideration given the increasing prevalence of UPRs in recent years. The results from the simulation showed that the reduction in separation standard caused an increase in average fuel burn savings benefits. As traffic density was increased (two- and three-fold), the benefits increased as well, just not linearly. Separation reduction resulted in negligible benefits for the optimised trajectories. While this analysis was done for a small sample (63 days), using a larger sample would show whether or not the trend in benefits would be consistent in the long run. Certain regions can be isolated from the sample in order to examine the benefits of those areas. Given the relatively small benefits achievable by reducing the separation standard below 30/30, before changing the current standard it would be judicious to first reach an operating environment where all aircraft can maintain 30/30.

Introduction

In oceanic airspace a minimum lateral and longitudinal separation of 30 nautical miles (NM) and 1,000 feet vertical must be maintained between aircraft; aircraft without suitable equipment have even greater separation requirements. The minimum separation is essentially a cylinder with 30 NM radius and 1,000 feet height surrounding each aircraft. While the oceanic airspace is vast, there is significant competition for fuel-efficient routing. As many oceanic flights fly great distances, small changes can have a significant impact. In particular, there have been many questions raised about the financial impacts of the current separation standard. What would be the benefits of applying radar separation minima in the oceanic environment?

For the sake of this analysis, we will assume that the technology to allow aircraft to safely operate up to 5 NM apart in the oceanic airspace would be available.[6] Furthermore, we will also assume a 100% equipage rate in all scenarios.

This high-level benefits analysis looks to answer whether the potential benefits of such a reduction warrant research into enabling technologies and under what conditions. To evaluate various separation standards, the separation standards were incrementally reduced by 5 NM from 30 NM in five-mile increments. This paper creates six scenarios that will test if changes to the system will be beneficial or not. The six scenarios are as follows:

1) Current traffic using actual flight plans as input

2) Current traffic plus duplicate set of flights (shifted by five minutes from the original flight plans)

3) Current traffic with two sets of duplicated flights (shifted by five and 10 minutes)

4) Scenario 1 with fuel-optimised trajectories

5) Scenario 2 with fuel-optimised trajectories

6) Scenario 3 with fuel-optimised trajectories

Each of these scenarios was run through a program simulating the behaviour of the aircraft and their interactions with each other. After all six scenarios were processed, the results were analysed.

Data Sources

This section describes the data that was used to create the input for the simulation analysis. Data was collected from March 2010 to September 2010. Rather than run every day in that time period (the simulation runtime would have taken too long[7]), nine days from each month were selected to create a random sample of every day of the week. The nine days chosen for each month were starting from the 3rd and going to the 27th, by intervals of three days.[8]

Input Trajectories

Flight plans filed in Oakland and Anchorage oceanic airspaces were extracted from the FAA Ocean21 off-line data tables.[9] These flight plans were processed using the Filed Flight Plan Processer (FFPP)[10] to create an estimate of the 4D trajectory with information on the origin, destination, airframe, and call sign into the correct format for the Optimal Trajectory Generator (OPGEN)[11] preprocessor. The OPGEN preprocessor used the origin, destination, airframe, and airline information to estimate the weight of the aircraft using information from the Bureau of Transportation Statistics (BTS) Air Carrier Statistics database (T-100 database).[12]

Optimised Input Trajectories

The input trajectories were also processed by OPGEN to create fuel optimal flight paths based on the wind. These trajectories were the basis of the second set of scenarios.

Payload

BTS data was used to obtain an average value for payload. The average payload values were calculated for each airline, aircraft type, and origin-destination combination. This did not take into account seasonal variation.

Wind

The University Corporation for Atmospheric Research (UCAR)[13] was the source of the reanalysed winds, which provides historical global wind information (rather than forecasts). This analysis used the NCEP/NCAR Reanalysis Project[14] "R1 pressure level" product, which provides wind information at six-hour intervals every 2.5 degrees across the globe at 17 pressure levels.

Methodology

Figure 1 maps the general process that was executed for this analysis. A more detailed explanation of the steps follows.

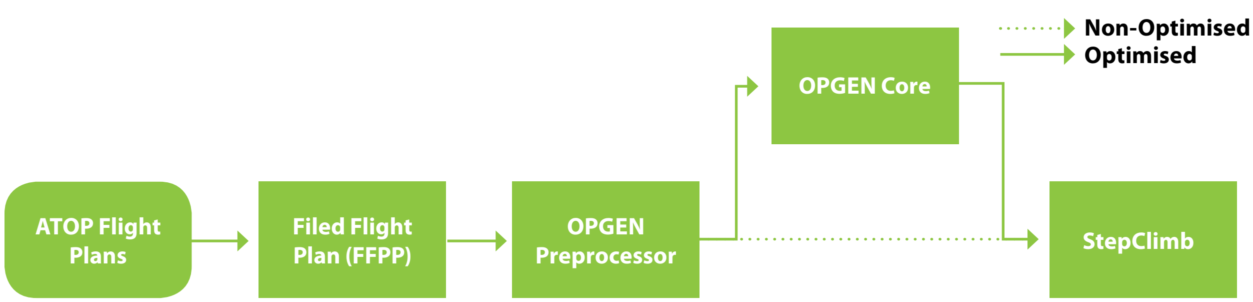

Figure 1. Overall Mapping of Methodology.

Once the sample dates were chosen, the next step was acquiring the flight plan from the Advanced Technologies and Oceanic Procedures (ATOP) database and processing it with the FFPP. This step converted the flight plan data into trajectory files that could be used by the OPGEN preprocessor. The next step was running the generated files through the OPGEN preprocessor. The OPGEN preprocessor is a subprogram of OPGEN that reformats the trajectory and fills in points along the trajectory when necessary. The input files for OPGEN Core and StepClimb were obtained after running the preprocessor. StepClimb is a simulation program of air traffic on and off the oceanic track system. An important aspect of the program is that the separation constraint between aircraft can be changed to meet the user's needs. Flights are rerouted or subjected to altitude changes to minimise flight cost. Flights can also be dynamically rerouted if needed. It is assumed that all aircraft are fully equipped to maintain the separation standard. At the conclusion of the simulation, the fuel burn for each flight is contained in the output and can be used for analysis purposes. OPGEN's fuel burn module is used in StepClimb, as well OPGEN's optimisation. At this point, the analysis for optimised and non-optimised trajectories split paths.

For the non-optimised trajectories, the output files from the preprocessor are taken and the duplication process occurs. All of the flights are copied and their start time is shifted by five and 10 minutes. By doing this, the input files for single, double, and triple traffic are created. The three traffic cases were then run through StepClimb, varying the setting of lateral and longitudinal separations. The separations that were considered were 30/30 (lateral [NM]/longitudinal [NM]), 25/25, 20/20, 15/15, 10/10, and 05/05. This was done for each day in the sample.

For the optimised trajectories, the output trajectories from the preprocessor were run through OPGEN Core, so that the trajectories became optimised. The flights were optimised by OPGEN Core. OPGEN is a program that takes in trajectory information for a flight, optimises the trajectory (minimises fuel burn), and then outputs the optimal trajectory. A genetic algorithm is used to find the minimum fuel consumed path for the flight. Performance and operational constraints are used when determining the optimal trajectory. Revision 333 of OPGEN was used to perform this analysis. Base of Aircraft Data (BADA) was used for aircraft information in OPGEN. All aircraft are mapped using BADA 3.8.

Any flights that caused errors during the optimisation process were removed from the sample. The flights were removed from the non-optimised sample as well, so as to keep the same flights in both optimised and non-optimised cases when running StepClimb. The optimised trajectories were then converted into the input type that was needed to run StepClimb. Once again double and triple traffic cases were created by duplicating and shifting the start time of the flights. All the traffic cases were run through StepClimb for all the separation cases.

The StepClimb output files were now in hand for all of the cases (optimised and non-optimised, all traffic cases, and all separation cases). With the fuel burn for each flight, the analysis was able to be performed. After the analysis was done, a filter was implemented to remove flights that had extreme decreases in benefits. Any flight that had a decrease of more than 2% from one separation case to another was filtered out. This was to remove flights that may have similar saving for most cases, but in a certain case it burned a lot more fuel for some reason (mostly from not being able to achieve the same altitude it had in the other cases). With the samples filtered, the results were able to be analysed and conclusions drawn.

Results

In order to see the effect of reducing aircraft separation, StepClimb was run with six different separation settings. The following table is the result of the non-optimised case using current traffic levels:

Table 1. Percent En-Route Fuel Burn Savings for Reduced Separation Standards for Current Traffic, Non-Optimised Scenario

Separation standard (lateral/longitudinal) in nautical miles						
	30/30	25/25	20/20	15/15	10/10	05/05
Marginal Benefits		0.07%	0.05%	0.06%	0.04%	0.06%
Cumulative Benefits		0.07%	0.12%	0.18%	0.22%	0.28%

This table compares the average fuel burn from each of the separation cases. The step benefits row contains the benefits seen from reducing the separation to the next case (for example, reducing separation from 25/25 to 20/20 resulted in a 0.05% savings of average fuel burn). The base benefits row is the benefit of going from 30/30 to the specified separation (30/30 to 10/10 would be a savings of 0.22% of average fuel burn).

To simulate an increase in traffic levels, two additional traffic scenarios were created. These scenarios were designed to estimate the magnitude of the benefits for reduced separations standards given marked increases in traffic levels. This analysis considers scenarios that have double and triple the level of current traffic. These traffic levels would not be reached for 14 and 22 years, respectively, even if traffic were to increase uninterrupted at 5% annually, or for 35 and 55 years with a 2% annual growth rate. To create the double traffic scenario, all of the original flights were duplicated and their times shifted by five minutes. The duplicated flights plus the original flights made up the scenario of double traffic. The scenario of triple traffic contains the original set of flights, plus two sets of duplicated flights (five and 10 minute time shifts from the originals).

The following tables present the results of the double and triple traffic scenarios:

Table 2. Percent En-Route Fuel Burn Savings for Reduced Separation Standards for Double Traffic, Non-Optimised Scenario

Separation standard (lateral/longitudinal) in nautical miles						
	30/30	25/25	20/20	15/15	10/10	05/05
Marginal Benefits		0.12%	0.09%	0.09%	0.09%	0.09%
Cumulative Benefits		0.12%	0.21%	0.30%	0.39%	0.48%

Table 3. Percent En-Route Fuel Burn Savings for Reduced Separation Standards for Triple Traffic, Non-Optimised Scenario

Separation standard (lateral/longitudinal) in nautical miles						
	30/30	25/25	20/20	15/15	10/10	05/05
Marginal Benefits		0.15%	0.12%	0.12%	0.12%	0.12%
Cumulative Benefits		0.15%	0.27%	0.39%	0.50%	0.63%

From the results it can be seen that as the traffic density increase, so does the average fuel burn savings. The increase in average fuel burn savings is not proportional to the traffic increase (i.e. double traffic does not mean double savings):

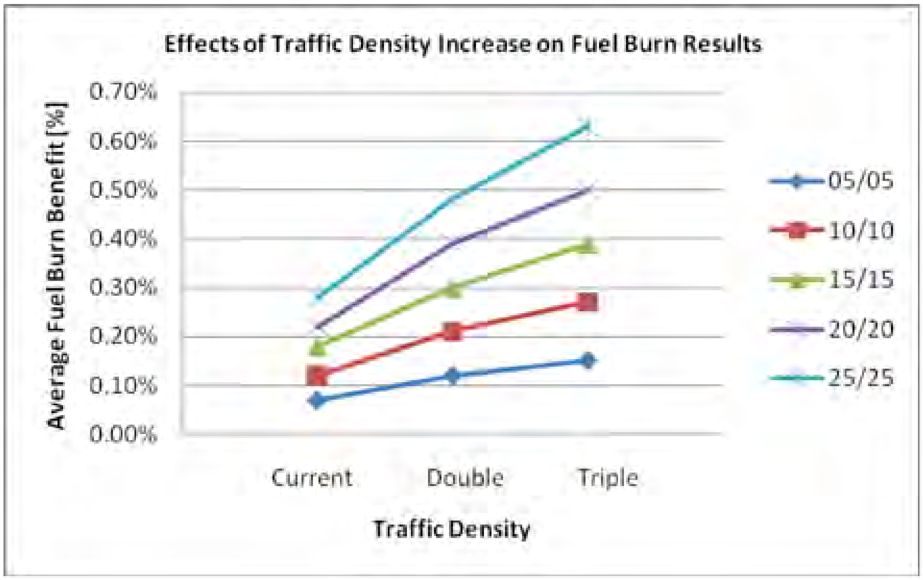

Figure 2. Effects on Average Fuel Burn Benefits by Changing Traffic Density.

Flight Optimisation

All of the aforementioned results have been non-optimised flights. All of those cases were modelled a second time as optimised flights in order to see the effects of optimising the flights' trajectories. The first scenario looked at was the separation reduction for the optimised flights:

Table 4. Percent En-Route Fuel Burn Savings for Reduced Separation Standards for Single Traffic, Optimised Scenario

Separation standard (lateral/longitudinal) in nautical miles						
	30/30	25/25	20/20	15/15	10/10	05/05
Marginal Benefits		0.00%	0.00%	0.00%	0.00%	0.00%
Cumulative Benefits		0.00%	0.00%	0.00%	0.00%	0.01%

As seen in Table 4, the saving that results from reducing the separation for the optimised sample of flights is negligible. The results are very similar with the double and triple traffic scenarios.

An interesting result to see is the comparison of the optimised and non-optimised flights in regard to average fuel burn. The following table summarises the results for all the scenarios:

Table 5. Percent Difference in Average Fuel Burn Between Optimised and Non-Optimized Trajectories Cases

Separation standard (lateral/longitudinal) in nautical miles						
	30/30	25/25	20/20	15/15	10/10	05/05
Single	1.10%	1.04%	0.98%	0.93%	0.91%	0.88%
Double	1.33%	1.21%	1.11%	1.02%	0.94%	0.90%
Triple	1.48%	1.36%	1.24%	1.08%	0.96%	0.90%

As could be expected, in all of the cases, the optimised flights averaged a better fuel burn than the non-optimised flights.

Selected Regions

With the results of all the scenarios in hand, one is able to select certain regions and see the effects of separation reduction specific to that region. This can be done by listing the Origin-Destination (OD) pairs for the region and filtering the results to include only the selected OD pairs. Besides the results for all the flights (shown above), a few regions were selected and the results of the triple traffic non-optimised case is presented.

NOPAC

The Northern Pacific (NOPAC) Route System contains five Air Traffic Services (ATS) routes between Alaska and Japan. The five routes are R220, R580, A590, R591, and G344. Searching through the flight plan files, the city pairings using these routes were found. The results were then filtered by the NOPAC OD pairs and the triple traffic non-optimised results are as follows:

Table 6. Percent En-Route Fuel Burn Savings for Reduced Separation Standards for Triple Traffic, Non-Optimised NOPAC Scenario

Separation standard (lateral/longitudinal) in nautical miles						
	30/30	25/25	20/20	15/15	10/10	05/05
Marginal Benefits		0.23%	0.18%	0.18%	0.16%	0.16%
Cumulative Benefits		0.23%	0.40%	0.59%	0.74%	0.90%

PACOTS

The Pacific Organized Track System (PACOTS) consists of chosen tracks between certain origin and destinations. For example, some PACOTS routes (about 13 general routes) are Hawaii to Japan, Japan to North America, etc. The OD pairs associated with the routes were found and the filtered results were found:

Table 7. Percent En-Route Fuel Burn Savings for Reduced Separation Standards for Triple Traffic, Non-Optimised PACOTS Scenario

Separation standard (lateral/longitudinal) in nautical miles						
	30/30	25/25	20/20	15/15	10/10	05/05
Marginal Benefits		0.26%	0.20%	0.20%	0.18%	0.18%
Cumulative Benefits		0.26%	0.47%	0.66%	0.84%	1.02%

PACOTS – Hawaiian City Pairs Only

The sample of flights from the separation reduction cases was filtered to only include PACOTS flights involving Hawaii. By doing so, the benefits can be seen from the separation reduction for the tracks that involved Hawaiian airports. The PACOTS Hawaiian results are as follows:

Table 8. Percent En-Route Fuel Burn Savings for Reduced Separation Standards for Triple Traffic, Non-Optimised PACOTS-Hawaii Scenario

Separation standard (lateral/longitudinal) in nautical miles						
	30/30	25/25	20/20	15/15	10/10	05/05
Marginal Benefits		0.07%	0.11%	0.06%	0.09%	0.10%
Cumulative Benefits		0.07%	0.18%	0.23%	0.32%	0.43%

PACOTS – Without Hawaii

With the removal of the Hawaiian flights, the results for the rest of the PACOTS flight can also be seen:

Table 9. Percent En-Route Fuel Burn Savings for Reduced Separation Standards for Triple Traffic, Non-Optimised PACOTS-No Hawaii Scenario

Separation standard (lateral/longitudinal) in nautical miles						
	30/30	25/25	20/20	15/15	10/10	05/05
Marginal Benefits		0.32%	0.23%	0.23%	0.21%	0.20%
Cumulative Benefits		0.32%	0.55%	0.78%	0.98%	1.18%

Conclusions

By creating aircraft trajectories from the filed flight plans and inputting them into the simulation program StepClimb, the effects of the separation reduction were seen through analysis. Multiple scenarios were created and processed, which allowed seeing the effects of changing certain factors of the system. The results of the analysis are as follows:

1) The modelling tolerance of programs such as OPGEN and Stepclimb is about 0.3%. The results of this analysis fall close to that modelled tolerance, but vary anywhere from 0.0% (the optimised flights) to ~0.6% (non-optimised triple traffic). While this analysis is representative of the months selected, it may not be representative of the full year, as seven months were used.

2) It can be noted that the benefit from further separation reduction can be similar to the benefit of flying more fuel optimally (slower). However, our analysis of flying more fuel optimally (slower) does not take into consideration the additional costs that come with flying longer (crew costs, aircraft utilisation). In order to see if the benefits of flying longer were similar to separation reduction, further research would need to be pursued.

3) A difference in regions can be seen with the results of this analysis. For example, certain track systems (PACOTS, NOPAC) were extracted from the results, and the potential benefits for those track systems can be seen. The same can be done with any set of Origin-Destination pairs that are found within the results. By doing this, it is possible to see the effects of separation reduction on congested tracks.

4) This paper assumes that everyone starts at 30/30. It would be reasonable to work to equip all aircraft for the 30/30 separation standard first before reducing the separation standards further given the limited benefits. By then, traffic may have increased enough to justify the further reductions in the separation standard.

Savings from the Dynamic Airborne Reroute Procedure Initiated in Oakland Airspace

Abstract

The Dynamic Airborne Reroute Procedure (DARP) allows airborne flights to modify their flight trajectory to achieve fuel savings by taking advantage of favourable winds and flying more direct routes. In addition, DARP can be used to avoid adverse weather. While DARP has been available in select Oakland, California, airspace since June 2006, relatively few flights have taken advantage of this procedure. This report fills the gap between anecdotal evidence and theoretical conjecture about the true fuel savings of DARP. This investigation focuses on flights that requested an airborne reroute via DARP, using Controller-Pilot Data Link Communication downlink message 24 (CPDLC DM24) between 1 May 2009 and 15 February 2011 in the Oakland Oceanic Flight Information Region (FIR). The fuel savings provided by DARP was calculated by comparing modelled fuel burn for each planned trajectory with the modelled fuel burn for the corresponding rerouted trajectory. A total of 138 planned and reroute trajectory pairs were modelled, with an average savings of 110 kg for each DARP. Considering only those flights that had a positive savings, the average per DARP was 440 kg. This analysis was performed by extracting and identifying DARP requests and responses from historical CPDLC messages from the FAA Ocean21 offline data tables.

Introduction

While DARP has been available in select Oakland airspace since June 2006, relatively few flights have taken advantage of this procedure. To date, systematic analysis of the fuel savings benefits of airborne reroutes has not been made publicly available.

The ICAO Global Operational Data Link Document recommends using a REQUEST CLEARANCE DM 24 for all DARP requests; these requests should be made at least 20 minutes prior to the start of the proposed reroute, as well as one hour prior to the FIR boundary. The current system allows aircraft to request minor route modifications using Direct To (DM 22) or free text messages (DM 67). Example requests are listed in the table below.

Table 1: Sample DARP Requests by Downlink Message (DM) Code

DM Code	Sample Message
DM 22	**REQUEST DIRECT TO** 45N140W
DM 24	**REQUEST** Destination Airport: RJBB KISME MONPI 21N14036E A597 TAPOP OTR26 EDDIE 3404N13444E
DM 67	RQST DIRECT ELKEY FOR SADDE6 ARRIVAL

Use of all these route modification requests has gradually trended upwards for the past five years, as shown in the figure below. Note, however, that the use of the full reroute (via the Route Clearance (DM 24) request) has lagged behind the simpler minor reroutes requested via DIRECT TO [position] and free text messages..

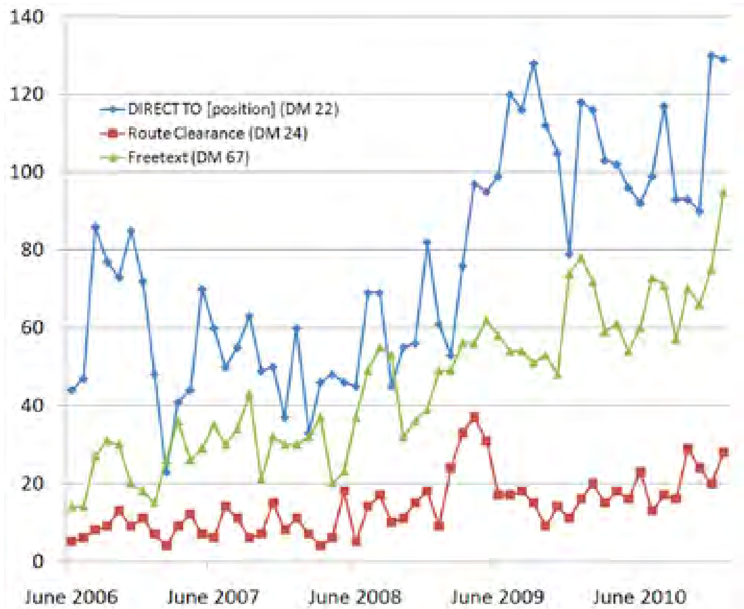

Figure 1: Monthly Reroute and Route Modification Requests, Oakland Oceanic FIR, June 2006-January 2011

The focus of this analysis will be on the fuel savings provided by the REQUEST CLEARANCE (DM 24) requests, as most of the Direct To and free text messages involve only minor changes to the flight plan. Figure 2 (below) illustrates how a DM 24 DARP request can allow for further tailoring of a filed flight plan. The filed flight plan is displayed in grey, while the requested DARP reroute is shown in red.

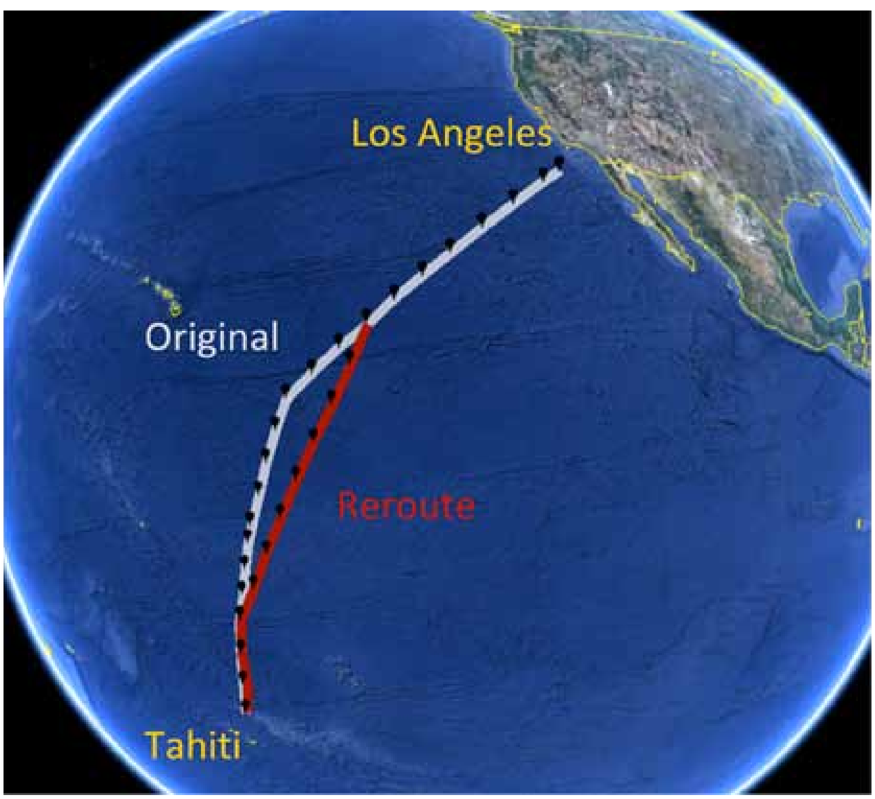

Figure 2: DARP Reroute on a Los Angeles to Tahiti Flight

Methodology

This DARP analysis compares the modelled fuel burn of the planned flight with the modelled fuel burn of rerouted flight. DARP requests and corresponding flight plans were extracted from the FAA Ocean21 offline data tables for the period from 1 May 2009 through 15 February 2011. The ideal experiment would be to have two identical flights leave at exactly the same time, with one flight flying the planned route and one flying the DARP-modified route. Given that this ideal experiment is not physically possible, this analysis uses the next-best option which is to compare the modelled fuel burn of the planned flight (per the flight plan specifications of speeds and routing) to the modelled fuel burn of the planned flight with the DARP spliced in.

Data Processing

The first step in the process was to take the flight plans and DARP requests and convert them into a consistent format and includes latitude and longitude, rather than waypoint names. For example, the following DARP request is converted into a list of latitude and longitude.

24 REQUEST Destination Airport: KLAX BORIC AHNDO 28N30 AUDIA MQO RZS Departure Airport...

15.807,-134.426 24.428,-131.412 34.249,-123.09 34.216,-122.419

Figure 3: Conversion of Reroute Message to Latitude and Longitude

DARP requests that directly mentioned “weather” or “deviate” or “deviation” were excluded from the analysis, as these requests are made for safety reasons, rather than to provide fuel savings.

Once the flight plans and the DARP request points were in a consistent format, a copy of the flight plans was made and modified per the DARP requests points. That is, for a given flight, the flight plan was cut at the point where the first DARP point occurred (the divergence point). The DARP request points were then appended to the truncated flight plan. The schematic below outlines the process.

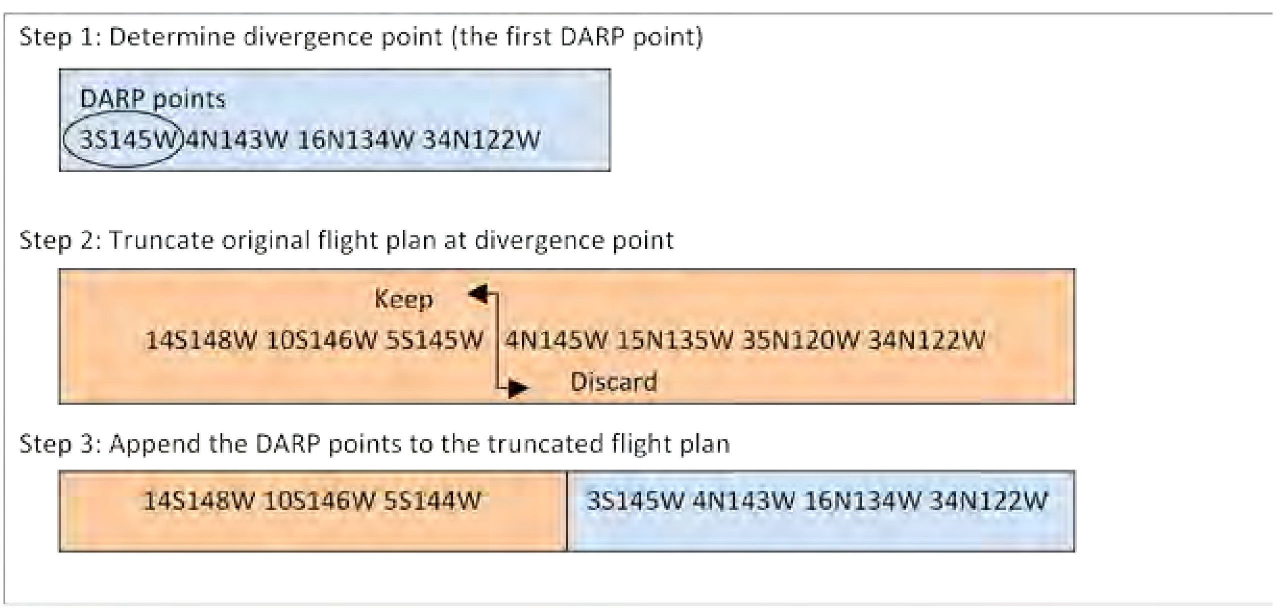

Figure 4: Process to Create Rerouted Flight Trajectory

This process of truncating flight plans and appending DARP points was repeated for all flights. Once all the trajectories had been assembled, the timestamps were adjusted for the each trajectory based on the reported timestamps from the Automatic Dependent Surveillance-Contract (ADS-C) positional reports.

Fuel Burn Modeling

The planned and rerouted trajectories were processed through CSSI's fuel burn modelling program, OPGEN (v 355). In order to estimate the fuel savings of DARP requests, fuel burn from the modelled flight plan trajectory was subtracted from the modelled fuel burn from the rerouted trajectory.

The original sample included 255 flight pairs. Flights were dropped from the sample for the following reasons:

1. Unusual aircraft performance.[15] (Flight pairs excluded: 7).

2. If the reroute resulted in a change in distance less than one nautical mile. This step was taken to ensure that the requested reroute was in fact a reroute and not simply a reconfirmation of the previously approved flight plan. (Flight pairs excluded: 44).

3. Reroutes that were initiated less than two hours from top-of-descent were similarly excluded. Reroutes near the end of the flight are generally not reroutes meant to take advantage of changing wind conditions. (Flights pairs excluded: 28)

4. Flights where the flight plan route and rerouted route contained differences in altitude. Any flight where the rerouted flight was modelled at altitude different than the flight plan flight for more than 30 minutes was eliminated. (Flights pairs excluded: 32).

5. Flight pairs where the fuel burn savings were outliers. Outliers were defined as flight pairs where the fuel burning savings was more than two standard deviations from the mean. (Flights pairs excluded: 6).

The final sample included 138 flight pairs.

Results

Following the modelling and cleaning process, the fuel burn of the rerouted trajectory was compared to the fuel burn of the planned trajectory. Of the 138 planned and reroute trajectory pairs modelled, 81 rerouted flights or 59% showed a fuel savings from the original flight plan. Overall, the average savings for each DARP was 110 kg, a average savings of 0.35% of en-route fuel burn. Considering only those flights that had a positive savings, the average per DARP was 440 kg, a savings of 0.94% of en-route fuel burn. The fact that 41% of flights during our study period did not have positive fuel savings indicates that these reroutes provide other benefits to the airlines, whether it is time savings or avoiding congestion or weather events.

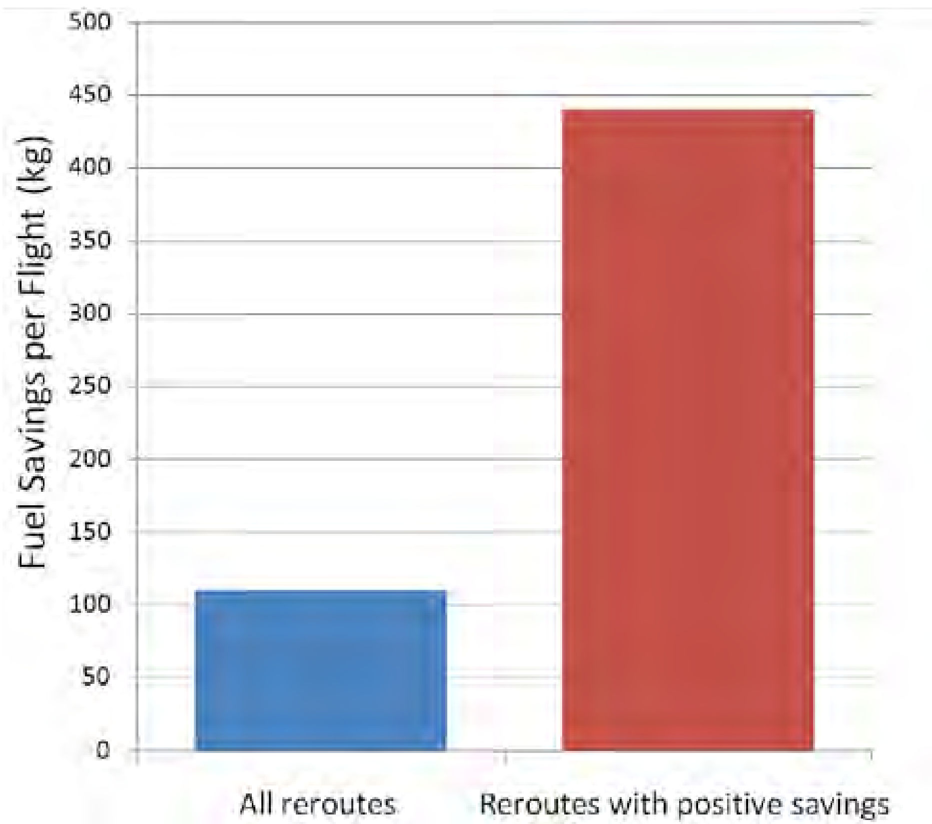

Figure 5: Average Fuel Savings per DARP Reroute

Conclusion

DARP allows airborne flights to modify their flight trajectory to achieve fuel savings by taking advantage of favourable winds and flying more direct routes. This investigation focused on flights that requested an airborne reroute via the DARP, using CPDLC DM24 between 1 May 2009 and 15 February 2011. This analysis showed that the majority of flights that reroute experience fuel savings. The fuel savings provided by DARP was calculated by comparing modelled fuel burn for each planned trajectory with the modelled fuel burn for the corresponding rerouted trajectory. A total of 138 planned and reroute trajectory pairs were modelled, with an average savings of 110 kg for each DARP, which represents 0.35% reduction in en-route fuel consumption. Considering only those flights that had a positive savings, the average per DARP was 440 kg, savings of nearly 1% of en-route fuel.

Notes

1 These OD pairs are: KLAX to/from NZAA, YBBN, YMML, YSSY and KSFO to/from NZAA, YSSY.

2 JCAB, Airways and Airservices; Fiji provided data starting in May 2011.

3 UCAR is a non-profit organization dedicated to atmospheric research (www2.ucar.edu).

4 Kalnay et al., The NCEP/NCAR 40-year reanalysis project, Bulletin of American Meteorological Society, 77, 437-470, 1996.

5 Example: An optimised trajectory may model descending to flight level 320 at the end of a flight to achieve a better tailwind. A pilot would have no way of knowing that the better tailwind is there nor would a pilot descend to check for it.

6 In en route RADAR environments, 5 NM separation is standard. Currently oceanic standards do not allow for 5 NM separation; current ADS-C Climb-Descent Procedure (ADS-C CDP) and ADS-B In-Trail Procedure (ADS-B ITP) trials call for 15 NM minimum separation. We do not suggest here that technology exists to support the 5 NM separation in the oceanic environment, rather we are investigating whether or not benefits exist to support development or pursuit of technology and procedures to further reduce the oceanic separation standards below the current standard of 30/30NM.

7 The runtime for a single day in the fuel burn model (OPGEN Core) is about 15 minutes. The issue with runtime occurs with the trajectory interaction model (StepClimb), which has a runtime of 1-2 hours for a single day (depending on the amount of flights). The runtime for the 63 days in this analysis was about 140 days (63 days to run*1.5 hours of runtime in StepClimb*6 scenarios*6 separations). Had the entire 7 months been ran, it would have taken approximately 480 days of runtime.

8 That is, days 3, 6, 9, 12, 15, 18, 21, 24, 27 of each month were included.

9 Documentation available in Advanced Technologies and Oceanic Procedures (ATOP) Computer Program Functional Specifications (CPFS) System Recording (SREC) Document Number: FAA-ATOP-2003-0276

10 CSSI, Inc., "Filed Flight Plan Parser User Guide", 9 June 2011.

11 CSSI, Inc., "OPGEN User Manual", revised 4 March 2010; Mondoloni, S., A Genetic Algorithm for Determining Optimal Flight Trajectories, AIAA Guidance, Navigation and Control Conference, Boston, Massachusetts, 10-12 August 1998.

12 Information about the T-100 data bank is available on the BTS website at www.transtats.bts.gov/DatabaseInfo.asp?DB_ID=110

13 UCAR is a non-profit organization dedicated to atmospheric research (www2.ucar.edu).

14 Kalnay et al., The NCEP/NCAR 40-year reanalysis project, Bulletin of American Meteorological Society, 77, 437-470, 1996.

15 If modelling constraint violations were greater than .3 for any of the six constraints in the OPGEN fuel modeling program.

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