2. DARP 運用における気象予測誤差の影響に関する検討

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1 Introduction

Increasing demand for air travel has propelled research & development projects in a global scale to seek new solutions for enhancing the efficiency of the current air transportation system. Studies predict that that larger portion of air traffic would increase over the Japanese airspace due to long-haul flights, in other words international flights and overflights.

Figure 1 illustrates the complex structure of airspace around Japan.

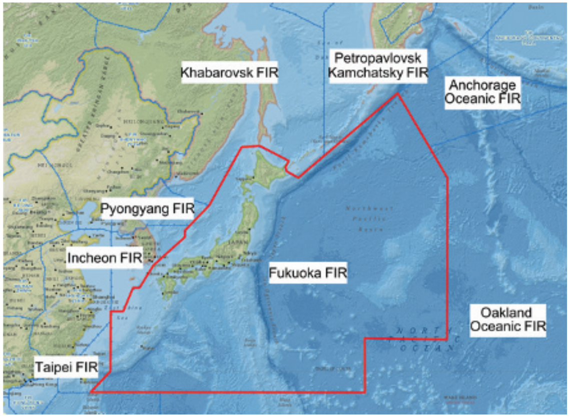

Fig. 1 Fukuoka FIR and adjacent foreign FIRs[1].

Oceanic air routes over the Fukuoka FIR (Flight Information Region) are mainly consist of NOPAC (North Pacific) routes and PACOTS (Pacific Organized Track System) routes. NOPAC routes are five parallel air routes located between Fukuoka and Anchorage FIRs bordering the Khabarovsk and Petropavlovsk-Kamchatsky FIRs. These routes were designed in the 1980s and since then have not undergone any major modifications nor improvements. On the other hand, PACOTS are optimized routes for high-altitude wind conditions published by either FAA or JCAB in the daily NOTAM or track message. Currently, 9 tracks are published for eastbound flights while 11 tracks are published for westbound flights[2,3]. PACOTS are generated by considering the average take-off weights and departure times of used aircraft in the operations. These drawbacks are addressed recently with the introduction of UPRs (User Preferred Routes) due to,

- The possibility of designing operator-oriented flight routes by the operators.
- The improvement of ground-based ATC (Air Traffic Control) support systems.
- Introduction of modern aircraft types which are capable of operating at reduced separation margins.

UPRs are custom-designed for each flight according to its departure time and take-off weight, since more operator-friendly compared to conventional PACOTS. Yet, UPRs too have operational constraints such as

- Aircraft on UPRs have to maintain at least 50NM of lateral separation from certain PACOTS routes.
- Aircraft on UPRs do not have priority on selecting the desired flight altitude.

Hence, DARP (Dynamic Airborne Reroute Procedures) Operations are introduced as one of the strategies to meet these challenges in the UPR implementation for Northern and Southern Pacific regions.

1.1 DARP Operations

DARP is a procedure for re-route clearance which contributes towards more efficient traffic flow and cost savings by implementing dynamic lateral-route alterations from the initial flight plan upon considering updated weather conditions[2,4]. Figure 2 denotes the workflow from flight plan generation to departure. Generally, a flight plan is prepared 3 ~ 4 hours before the departure with the latest weather forecast data. Weather forecast data are updated every six hours starting from 0000Hrs UTC. Hence, it can be noted that the aircraft does not possess an optimal flight plan since the weather conditions can be changed by the time of departure.

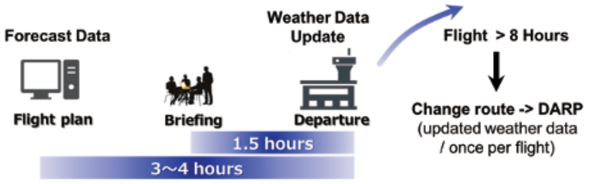

Fig. 2 Workflow from flight plan generation to departure.

Then, the flight deck weather data is updated before the departure with the latest forecast data. DARP route is calculated only once for the entire flight and is uplinked to the flight deck by the ground operator. Depending on the situation, pilot decides whether to implement the DARP route or not. DARP operations have an implementation rate of 3.1% (384 flights out of 12,422 DARP intended flights) since October 2012 to August 2017 with a reduction of 376,500 lbs. of fuel and 26 Hrs. 50 Min. of flight time [5]. Average benefits through DARP implementation are not notable due to many challenges concerning DARP operations. One is the dispatcher's workload in implementing DARP process. This includes DARP route calculation, data link process and coordination with the pilot. Also, it is difficult to accurately estimate the DARP benefits at the time of implementation since the flight profile is updated only once with the weather data obtained by the ground operator for a flight that lasts more than 10 hours. In order to broaden the application scope of such procedures which would eventually increase the benefits in a future system, reviewing the KPIs (key performance indicators) that have significant influence in implementing the procedure is of great importance.

Electronic Navigation Research Institute (ENRI) is involved in various research studies among which analyzing / optimizing oceanic tracks including arrival routes and Full-4D operations are two major projects assigned to seek solutions to improve the current ATC system. The former project investigates the impact of innovative procedures such as continuous descent operations (CDO), flight-deck interval management (FIM) and airborne surveillance application systems (ASAS), while the latter project reviews the challenges towards the application of 4D- optimal trajectories into the system. These studies show that weather data contribute significantly towards the implementation of such procedures.

This paper emphasizes the influence of weather data in DARP operations through information regarding a series of DARP implemented flights provided by a national airline company. These data are used as reference to show the operational benefits by applying DARP procedures which reflect the influence of weather in such operations. Performance parameters are calculated by applying meteorological data from the Japan Meteorological Agency (JMA)[6] and aircraft performance data from the Base of Aircraft Data (BADA) data from the EUROCONTROL[7]. Obtained results are used to discuss the improvements that can be proposed for oceanic routes and issues to overcome in validating such proposals in a real operational environment. A comprehensive discussion on the enhancement of this research scope is provided in future work.

2 Reference Data

This section introduces different data types that are used to present the preliminary results.

2.1 Aircraft Position Data

In this study, information regarding a series of DARP implemented flights provided by a national airline company is used as reference data (indicated as 'reference data'). The flights are originated from the Honolulu International Airport (ICAO Code: PHNL) and the destinations are the Tokyo International Airport (ICAO Code: RJTT) and Narita International Airport (ICAO Code: RJAA). The 3D-position data required for analysis are acquired through the integration of Oceanic Air Traffic Control Data Processing System (ODP) data and Radar Data Processing System (RDP) data. ODP data are generated according to flight plan data and position reports downlinked by the aircraft. RDP data are radar data tracked by the Oceanic Route Surveillance Radars (ORSR) and Air Route Surveillance Radars (ARSR). The data are further processed by a smoothing algorithm to treat irregular data patterns and data loss[8].

Performance parameter estimations are considerably sensitive to weather data and time histories of the position data. Furthermore, access to ODP and RDP data are limited. Hence, general review is made based on overall data (18 flights) while the sensitive calculations are conducted based only on accessible data, five flights in total. Flight plan data are available as 3D trajectory profiles with waypoint data and, altitude and speed assigned at each waypoint. Hence data interpolation is necessary to generate trajectories for performance estimation. On the other hand, ODP data is updated at a 1-minute interval compared to the 10-second interval of RDP data. These dissimilarities have influenced to adopt following assumptions in trajectory preparation in order to implement a fair analysis on operational performance between predetermined flight plans and corresponding DARP. The context of this paper refers to trajectories generated based on flight plan data as 'plan tracks' and trajectories generated based on airline provided information as 'DARP tracks'.

- Aircraft performs at a cruising speed of Mach 0.80. This is the standard airline procedure value defined in the BADA model for the subjected aircraft.
- Aircraft performs from the initial point of reference data to the initial point available from ODP data at the cruising altitude identical to the altitude at the initial point of ODP data.
- The aircraft follows the vertical profile acquired by the corresponding ODP and RDP data in both plan tracks and DARP tracks.
- Aircraft passes the merging point of plan track and DARP track at the same time, hence the starting time between the two tracks are not identical. The difference of weather conditions due to this reason is considered negligible.

2.2 Meteorological Data

JMA distributes a variety of numerical weather prediction (NWP) grid point value (GPV) weather forecast data on global and local atmospheric conditions. The Global Spectral Model (GSM) nowcast data is used in the analysis, of which the forecast data is updated at an interval of 6 hours. The precision of forecast data is already validated in a previous study[6].

2.3 Aircraft Performance Data

Aircraft performance calculations of conventional and optimal operations are based on the BADA (version 3.12) model data. As aircraft mass data is unknown, aircraft mass at the initial point of each flight is estimated as a ratio of the maximum take-off mass defined in the BADA model. The ratio is considered based on the fact that fuel consumption is approximately proportional to flight time[9]. Table 1 shows the flight time estimated from the plan tracks with total flight time in brackets, acquired by flight plan data, and the estimated initial mass value for each flight case.

Table 1 Estimated Aircraft Initial Mass

Flight	Flight time (s)	Initial mass (kg)
F01	23,280 (33,000)	133,704
F02	23,610 (33,600)	131,928
F03	15,390 (32,880)	88,154
F04	22,350 (32,520)	131,655
F05	19,670 (26,640)	137,985

3 Analytical Results

Figure 3 shows the lateral route deviations of DARP tracks for all the flights compared to the corresponding plan tracks. Deviations are plotted with respect to longitude. Most of the DARP operations are initiated around the 180°E meridian except for two flights which record the largest deviation of 7 degrees.

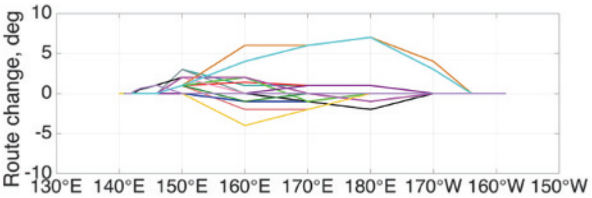

Fig. 3 Lateral deviation due to DARP operations.

3.1 Benefits Assessment of DARP

This section compares the aircraft performance, mainly fuel consumption between plan tracks and DARP tracks to understand the benefits obtained by implementing DARP. Flight time is the other key parameter which is compared to review the benefits obtained through implementing DARP operations. Table 2 denotes the numerical values of total fuel consumption, flight time and flight range for the five subjected flight cases.

Table 2 Aircraft Performance of Planned and DARP Flights

Flight		Fuel (kg)	Time (s)	Range (m)
F01	plan	25,584	23,280	5.489×10^6
	DARP	24,723	22,640	5.334×10^6
F02	plan	25,109	23,610	5.474×10^6
	DARP	24,969	23,480	5.510×10^6
F03	plan	12,331	15,390	3.344×10^6
	DARP	11,986	15,090	3.412×10^6
F04	plan	23,579	22,350	5.376×10^6
	DARP	23,128	22,000	5.303×10^6
F05	plan	22,066	19,670	4.747×10^6
	DARP	21,870	19,500	4.705×10^6

Numerical results show that DARP operations were successful in reducing fuel consumption for all flights by considering the updates in weather forecast data. Figure 4 shows the bar plot for fuel consumption difference for each flight. Flight F02 records the lowest fuel difference since the DARP track has deviated significantly from the plan track and has recorded the largest positive range difference among the subjected five flights. Hence, it is assumed that a larger amount of fuel was reduced when considering the total flight. Figure 5 depicts the percentage of fuel consumption difference with respect to flight range difference. Similar to Fig. 4, both parameters are evaluated based on plan track performance parameters.

It is considered that tradeoff with longer flight path has paid off well in reducing fuel consumption for flights F02 and F03. It is considered that tradeoff with longer flight path has paid off well in reducing fuel consumption for flights F02 and F03. It is also considered that airline companies are eager to implement DARP operations when dynamic re-routing provide benefits on fuel burn and/or flight time. Effect on flight time due to DARP operations is not reviewed in this study, because the time parameter was not available in the acquired DARP information.

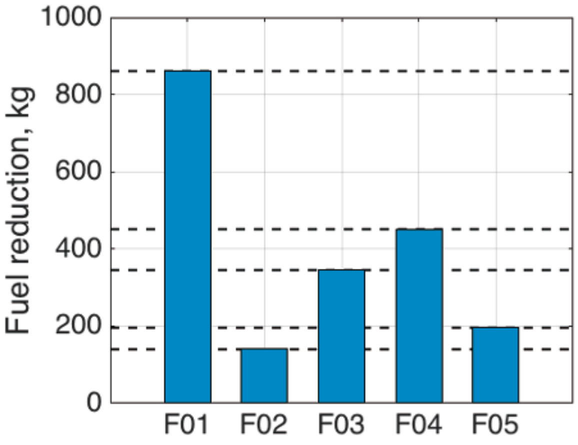

Fig. 4 Fuel Consumption Reduction with DARP.

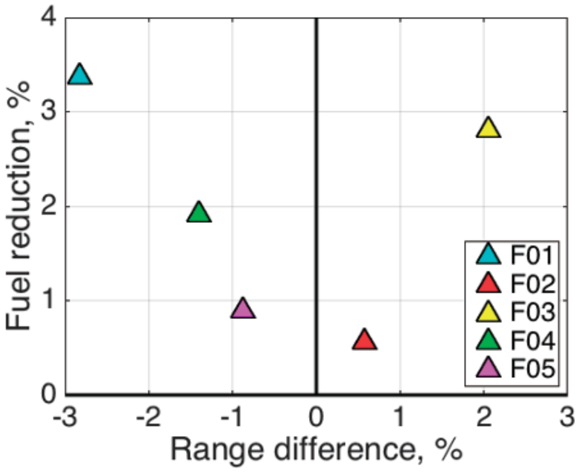

Fig. 5 Tradeoff between Fuel and Range with DARP.

3.2 Benefits Assessment of 4D-TBO

A trajectory optimization model based on the Dynamic Programming (DP) method has been developed by the authors which minimizes fuel consumption according to given arrival time constraints by exerting maximum aircraft performance. This section focuses on the 4D- TBO with free arrival time. These results are based on the assumption that fuel consumption could be reduced by allowing the aircraft to optimize its trajectory through considering real-time weather conditions in an ideal 3D- operational environment. Table 3 denotes the numerical values of fuel consumption and flight time corresponding to each optimal flight.

Table 3 Optimal Performance with 4D-TBO

Flight	Fuel (kg)	Time (s)	Range (m)
F01	20,442	21,051	4.991×10^6
F02	20,523	21,431	5.064×10^6
F03	10,418	14,889	3.287×10^6
F04	21,132	22,027	5.121×10^6
F05	20,756	20,622	4.640×10^6

Figures 6 and 7 show fuel consumption difference and fuel difference percentage versus flight range difference between optimal tracks and DARP tracks respectively. It is understood that a significant reduction of fuel consumption was obtained through trajectory optimization. These results include the assumption errors in trajectory generation for DARP flights. Yet, it can be speculated that even without considering the assumption errors, the optimizer could reduce fuel consumption compared to the subjected DARP flights. Results also show that flight range was also reduced for all five flights. It is considered that this difference has mainly caused the reduction of fuel consumption. Figure 8 shows that the optimal track selects the minimum distant track, commonly known as the Great Circle Route compared to its counterpart. Contours represent the wind distribution at 250 hPa pressure altitude (approximately 33,000 ft). The maximum fuel reduction is recorded at about 17% while the maximum range reduction is recorded at approximately 8%. Results show that dynamic re-routing according to weather conditions provide fuel saving benefits to airline operators. It is speculated that, though fuel savings from a standalone flight would not be so significant, cumulative evaluations would show that DARP could bring significantly positive impact to airline operators. Results also show that 4D- TBO applications considering updated weather data conditions in oceanic flights record significant fuel savings compared to conventional procedures and arrival time management capability added 4D- TBO would be a potential enhancement for oceanic operations.

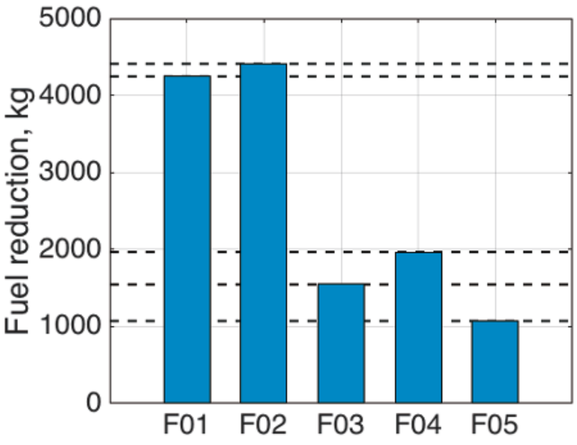

Fig. 6 Fuel Consumption Reduction with 4D-TBO.

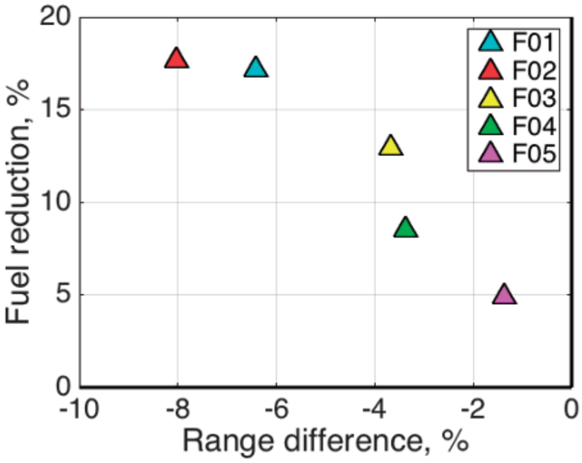

Fig. 7 Tradeoff between Fuel and Range with 4D-TBO.

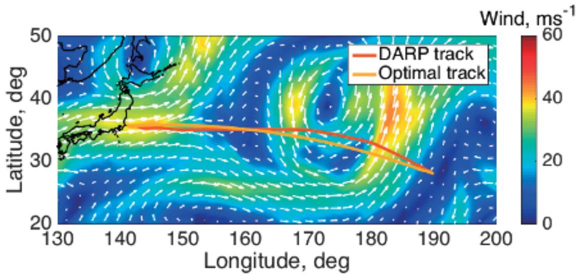

Fig. 8 Lateral Route Profile Comparison.

4 Future Work

Preliminary results discussed in this paper are based on information that had to be gathered in heaps and integrated due to the lack of data resources. In order to implement a more comprehensive review on the impact of weather data forecast error, we need more reliable data on original flight planning and real time aircraft performance. The scope of this research is expected to be enhanced with a series of QAR (Quick Access Recorder) data and corresponding filed flight plan data that had been acquired from a national airline company between May 2015 and July 2017. Figure 9 illustrates the acquired QAR data. Data are mainly based on flights between PHNL and RJTT / RJAA, and flights from RJTT / RJAA to San Francisco (ICAO code: KSFO) / Los Angeles (ICAO code: KLAX). It is clear from the color distinction that DARP flights are mainly concentrated on inbound flights to Tokyo from Honolulu and outbound flights from Tokyo to the West coast of the United States.

Flight plan data generated by airline operators consist of wind aloft data that include wind magnitude, wind direction and atmospheric temperature at different flight levels along the planned flight route. Also, DARP flight plans include the same weather data parameters along the updated flight route. As QAR data provides real time measured data of the above parameters, a comprehensive and quantitative evaluation can be conducted on the forecast error on weather data. This will provide a concrete platform to review the deviation of aircraft performance from actual values due to performance calculations based on forecast weather data. Evaluations are planned to be conducted for deviations on operational benefits and enhanced benefits from 4D-TBO application. Obtained results would pave the way to a more realistic understanding on the benefits due to current and future improvements in operational procedures while emphasizing the challenges of the current system that have to overcome in order to meet the future expectations.

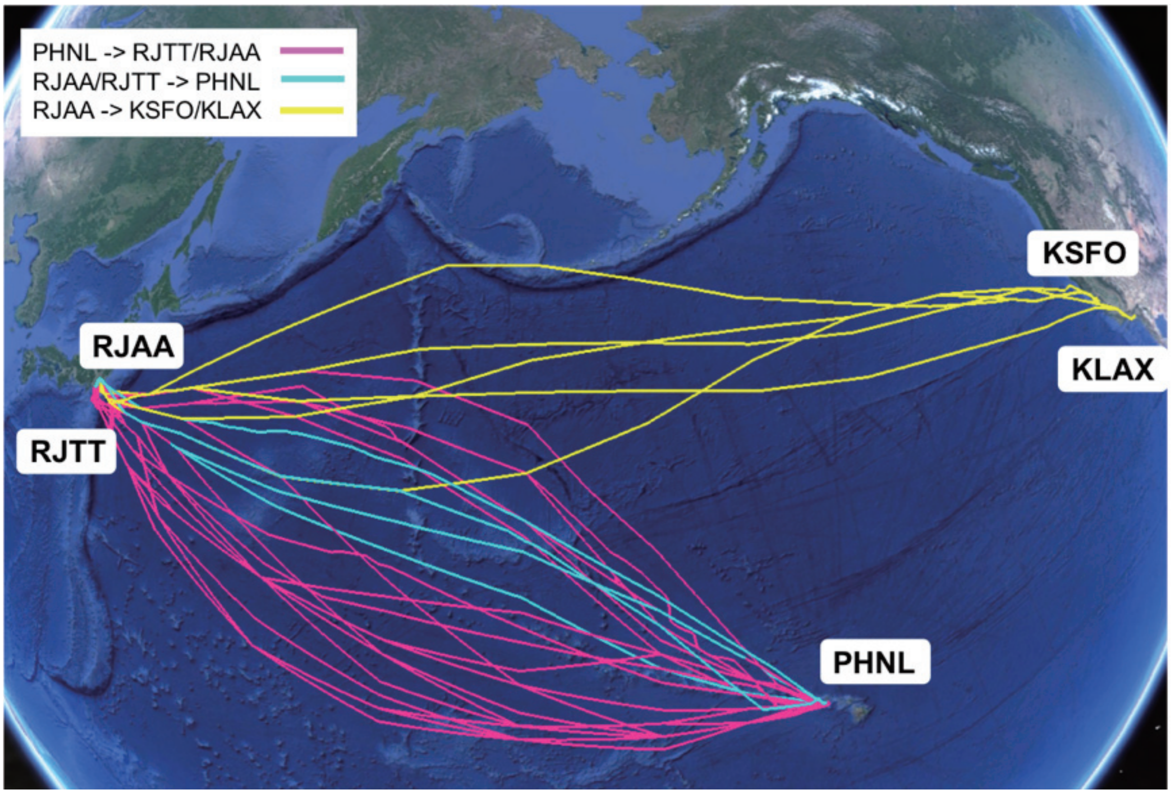

Fig. 9 QAR data on DARP flights.

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