THE FORTY-FOURTH MEETING OF THE
INFORMAL PACIFIC ATC CO-ORDINATING GROUP
(IPACG/44)

(Honolulu HI, United States 21 – 22 August 2018)

Agenda Item 6: Air Traffic Management (ATM) Issues

A Study on the influence of Weather Prediction Error upon DARP Operational Benefits Evaluation

(Presented by the Electronic Navigation Research Institute, Japan)

SUMMARY

This paper provides a quantitative study on the weather prediction error and its influence on the evaluation of DARP operational benefits. A series of QAR data from DARP operated aircraft with corresponding flight plans are used to estimate the prediction discrepancies of wind and temperature by comparing with numerical weather prediction data acquired from the Global Spectral Model (GSM). The study further focuses on the estimation discrepancies of fuel consumption due to these prediction errors.

1. Introduction

1.1. The ever-growing demand for air travel is a daunting challenge for the aviation industry and has propelled R&D activities worldwide to seek plausible solutions. Traffic forecasts predict a significant increase in international flights in the Fukuoka FIR, and a large proportion of these flights connect East Asia with North America along routes based on the North Pacific route system (NOPAC) or the Pacific Organized Track System (PACOTS). User Preferred Routes (UPR) were introduced to overcome the drawbacks of NOPAC and PACOTS by enhancing the flexibility of airline operators to develop wind-optimal routes tailored for each flight. Dynamic Airborne Reroute Procedures (DARP) was introduced as a part of the UPR enhancement plan, and All Nippon Airways (ANA) is currently the sole Japanese operator using DARP.

1.2. DARP is a procedure for re-route clearance which contributes towards the performance improvement of an individual flight leading to cost savings (Fuel and flight time) by implementing dynamic lateral-route alterations from an initial flight plan upon considering updated atmospheric conditions. Current DARP operations are focused on routes between Tokyo (Haneda and Narita) and Honolulu, and from Tokyo to Los Angeles, San Francisco and San Jose. DARP operations have a low implementation rate of 3% (384 flights out of 12,422 DARP applicable flights between October 2012 and August 2017).

1.3. The relatively low benefit of some DARP weighed against its costs of additional workload for pilot/dispatcher and pilot/air traffic control (ATC) coordination is considered to be the main contributing factor for this situation. Also, discrepancies between ground-based estimates of DARP benefit and actual realized benefit further contributes to the issue of whether DARP can be considered as a potential enhancement for future oceanic operations. Weather prediction error (that is, the accuracy of forecasts) and uncertainty in performance estimation methodologies are the key factors that affect the precision of ground-based DARP benefits estimation.

1.4. As a part of a research study on 4D- Trajectory Based Operations (4D-TBO) and free routing conducted at the Electronic Navigation Research Institute (ENRI), this information paper focuses on clarifying the above-mentioned uncertainties through a quantitative evaluation of weather prediction error and its influence on the estimation discrepancies of aircraft performance, specifically fuel consumption. This kind of an approach is considered to be critical for promoting the greater implementation of DARP application by providing operators with a broader picture on fleet performance for better situational awareness, eventually leading to improved decision-making in such procedures.

2. Discussion

2.1. This analysis of weather prediction error looks at estimation errors of horizontal wind velocity and air temperature by comparing in-flight-measured data with estimations using the numerical weather prediction (NWP) forecast/nowcast data used in the ground-based performance estimations. In contrast to traditional charts, NWP data consist of atmospheric parameters on a "grid" of points at various pressure altitudes. Furthermore, the analysis on the impact of wind prediction error upon aircraft performance estimation focuses on the estimation error of fuel flow by comparing in-flight measured data and estimations using NWP data. A statistical evaluation is conducted to present the results.

2.2. In collaboration with ANA, ENRI has acquired a set of Quick Access Recorder (QAR) data from 36 DARP operated flights between November 2016 and July 2017, shown in Fig. 1. Analyzed data also include original and DARP-revised flight plans of each flight generated by the airline's ground system. In-flight-measured data related to time histories of aircraft dynamics, aircraft performance and atmospheric conditions are obtained from the QAR data while the flight plan data provide information on NWP forecasts utilized in the trajectory generation process and the time at which this process is initialized.

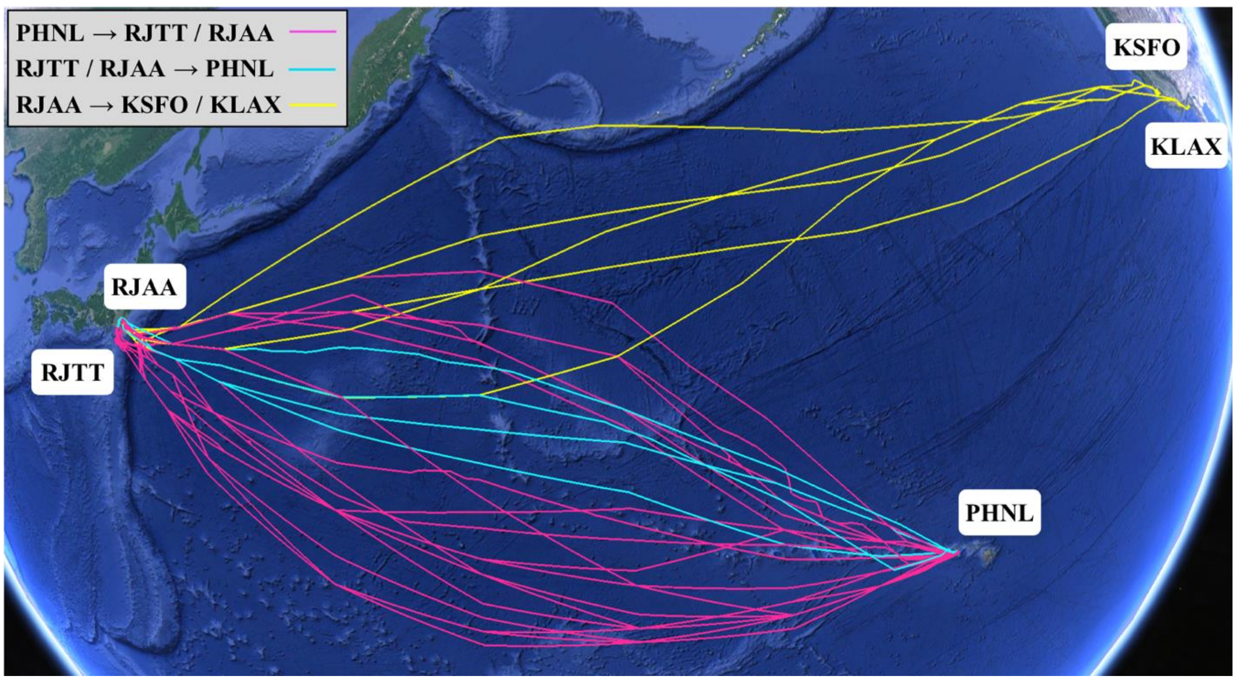

Fig. 1. DARP operated flights used in the study.

2.3. NWP data from the Global Spectral Model (GSM) distributed by the Japan Meteorological Agency are used to acquire necessary forecast/nowcast data for the analysis. These are gridded at 0.5-degree intervals of latitude and longitude in the altitude range of flight operations. Forecasts are published four times a day at 0000Hrs. UTC, 0600Hrs. UTC, 1200Hrs. UTC and 1800Hrs. UTC, and include forecasts for the publication time (called "nowcast") and for various "look-ahead" times at 6-hour intervals.

2.4. Analysis on weather prediction error

2.4.1. Zonal & meridional wind velocity components and static air temperature (SAT) at each data point on the aircraft's actual trajectory (that is, latitude, longitude and altitude) are generated by the following methods;

"Original": Weather data are estimated by NWP forecast data based on the time information provided in the original flight plan. This is a single fixed time value for generating the "wind aloft" data provided in the flight plan. Time interpolation is applied to generate the forecast weather data at this time. Forecast data are applied accordingly.

"DARP": Weather data are estimated by NWP forecast data based on the time information provided in the DARP-revised flight plan. The definition of time information is the same as the "Original" method but the time value for generating wind aloft data for DARP-revised flight plan is used here. Time interpolation is applied by using the corresponding forecast data.

"Nowcast": Weather data are estimated by NWP "nowcast" data. In this method, data are interpolated according to the time history666 of each data point derived from QAR data.

2.4.2. Table 1 shows an example on how these data were used in the analysis for a flight departed from PHNL on XX day at 1924Hrs. (UTC) and arrived in RJAA on XX+1 day at 0456Hrs. (UTC).

Table 1. An example on the usage of NWP forecast/nowcast data in the analysis.

Method	Weather forecast/nowcast Data		Time Information
	Weather data	Forecast "look-ahead" time	
Original	XX day, 0600Hrs. UTC	12 Hrs. 18 Hrs.	Wind aloft data generated time: XX day, 1920Hrs.
DARP	XX day, 1200Hrs. UTC	06 Hrs. 12 Hrs.	Wind aloft data generated time: XX day, 2114Hrs.
Nowcast	XX day, 1800Hrs. UTC XX+1 day, 0000Hrs. UTC XX+1 day, 0600Hrs. UTC		Time history from QAR data: XX day, 1924 Hrs. ~ XX+1 day, 0456Hrs.

2.4.3. The estimation error (considered as the observed value) from each method is evaluated as the Root Mean Square Error (RMSE) considering the in-flight-measured data as the predicted value. Defined in Eq. 1, RMSE is a measure to determine residuals (difference between the observed value y_i and the predicted value $\hat{y}_i$) of a n population. It is expected that 68% of the population distribution is within one RMSE value and 95% of the population distribution is within two RMSE values.

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(\hat{y}_i - y_i)^2}{n}} \quad (1)$$

2.4.4. Results are shown in Fig. 2. From top to bottom, RMSE of static air temperature (SAT), zonal wind component and meridional wind component are respectively denoted for all flight cases. RMSE of Nowcast are illustrated in khaki bar plots while the RMSE of Original and DARP are blue and red marker-line plots respectively. As expected, the results show that weather prediction error is inversely proportional to the forecast time (that is, the longer the forecast look-ahead time, the lower its accuracy), and that weather prediction error data can be reduced by using nowcast forecasts in aircraft performance estimations. Average and range of RMSE values obtained from each method are given in Table 2. These numerical results also clarify that weather prediction error largely vary due to the use of forecast data and it could be significantly reduced by applying nowcast data in performance estimations.

Table 2. RMSE values of weather prediction error.

	Zonal wind (m/s)		Meridional wind (m/s)		Static air temperature (K)	
	Average	Range	Average	Range	Average	Range
Original	4.98	2.57 ~ 7.63	5.79	3.10 ~ 14.26	1.76	1.15 ~ 3.44
DARP	4.41	2.78 ~ 6.23	4.83	2.72 ~ 11.23	1.62	0.82 ~ 2.94
Nowcast	3.46	1.96 ~ 4.95	3.69	2.42 ~ 6.78	1.34	0.58 ~ 2.69

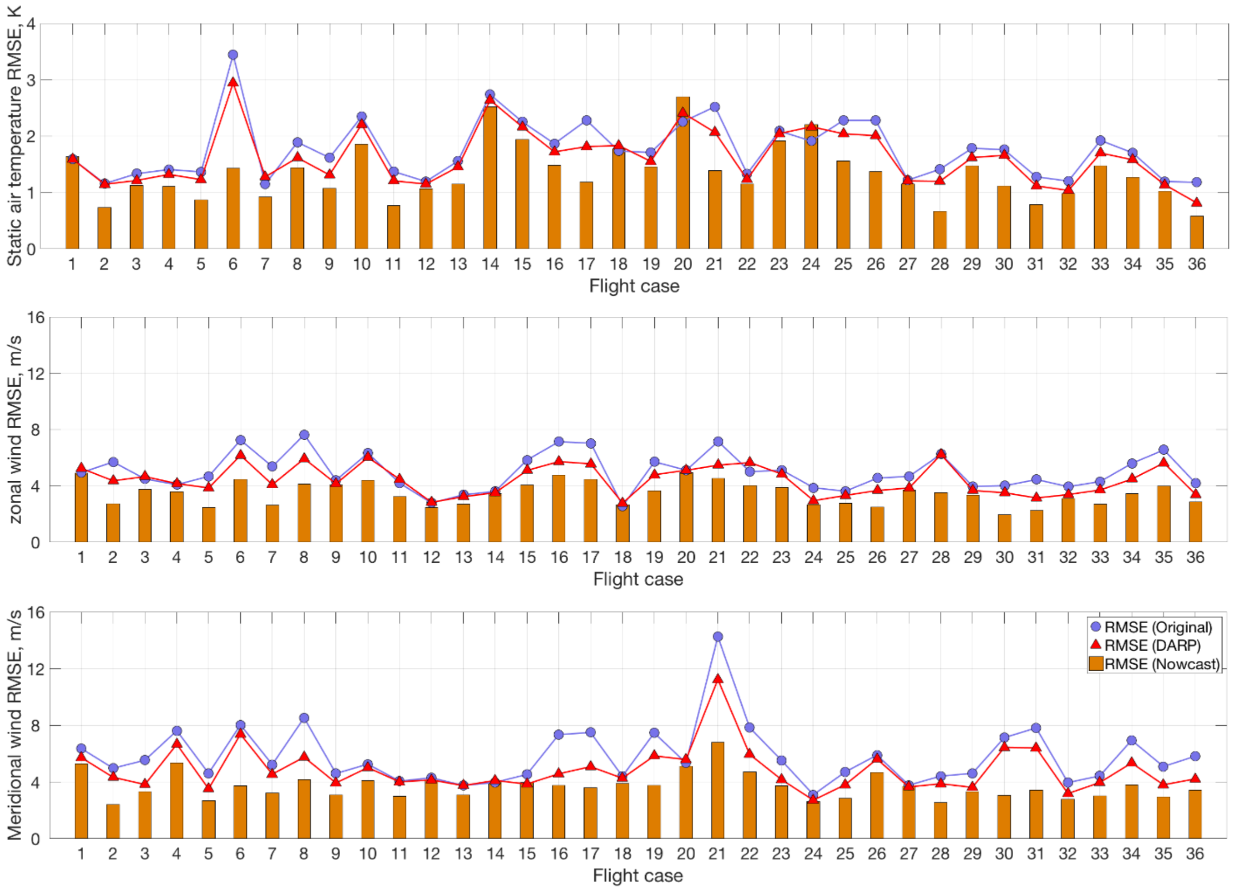

Fig. 2. Root Mean Square Error (RMSE) of wind and static air temperature (SAT) estimation.

2.5. Analysis on the impact of weather prediction error upon aircraft performance estimation

2.5.1. This section focuses on how weather prediction error influence the discrepancies occur in aircraft performance estimation. Fuel consumption is used here as the key parameter that represents the performance of an aircraft. Hence, this study is conducted by reviewing the estimation error of fuel flow evaluated using the forecast data subjected in section 2.4 and comparing them with in-flight-measured data.

2.5.2. In order to conduct this study, ENRI has developed a tool which has the capability of addressing various aircraft performance characteristics called the ENRI Aircraft Performance Model (EAPM). EAPM models the fuel consumption of an aircraft by integrating aircraft dynamics, aircraft performance data and atmospheric data. Aircraft performance data are acquired from the Base of Aircraft Data (BADA) Family 4, developed and maintained by EUROCONTROL.

2.5.3. Figure 3 depicts the accuracy of EAPM through a boxplot presentation. The box represents

50% of the distribution, called the Interquartile Range (IQR), in which the horizontal line within the box represents the Median. The range between upper and lower whiskers represents 99.3% of the population distribution. The average Mean of fuel flow estimation error records at -0.025 kg/s which is approximately 1.16% of total fuel consumption. The two black-dotted lines enclose the range between minimum and maximum whiskers falling within -0.16 kg/s and 0.16 kg/s. Hence, it is considered that EAPM has sufficient accuracy to be used in this study for performance comparison.

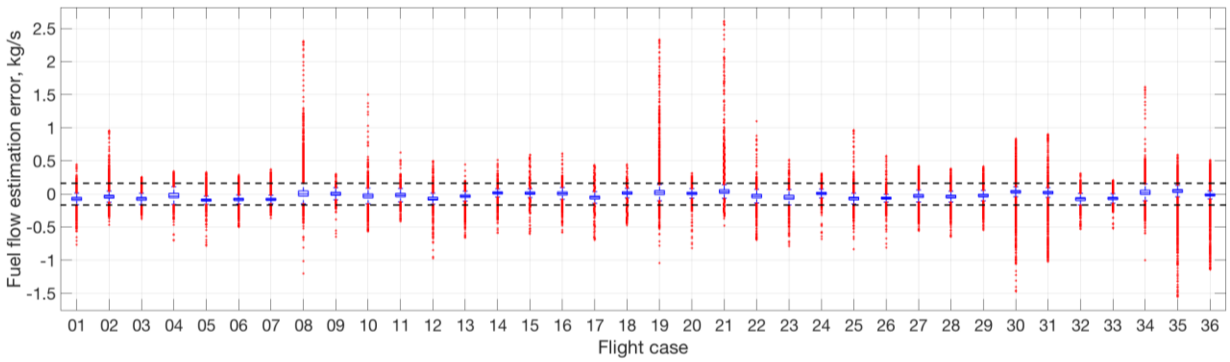

Fig. 3. Boxplot presentation of EAPM estimation accuracy.

2.5.4. This model is used to estimate the fuel flow of each flight by utilizing the weather data acquired by Original, DARP and Nowcast methods. These estimations are then compared with the actual fuel flow from QAR data to review the impact of weather prediction error on fuel flow estimation. In this study, the ground speed is assumed to be identical to the values obtained from QAR data which results the true airspeed of the aircraft to deviate from the QAR values due to the variation in weather data, hence causing discrepancies in fuel flow estimation. Model error is assumed negligible since the identical is used to estimate the fuel flow in all three methods. Obtained results are illustrated in Fig. 4.

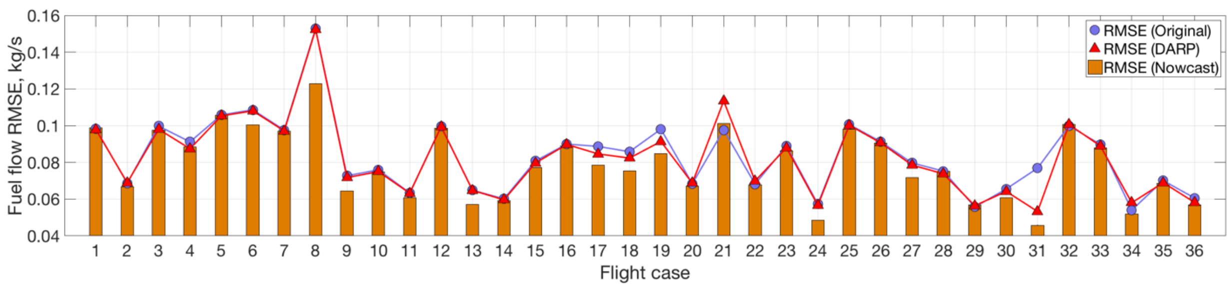

Fig. 4. RMSE of fuel flow estimation.

2.5.5. Results reveal somewhat a direct impact of weather prediction error on fuel flow estimations. In most cases, it is apparent that fuel flow estimation error is proportional to weather forecast time. Table 3 presents the numerical values of the fuel flow estimation errors.

Table 3. RMSE values of fuel flow estimation error.

	Fuel flow (kg/s)	
	Average	Range
Original	0.083	0.054 ~ 0.152
DARP	0.082	0.053 ~ 0.152
Nowcast	0.074	0.045 ~ 0.122

2.5.6. Though many flights cases support the fact that fuel flow estimation error is proportional to weather forecast time, numerical results show similar characteristics in estimation errors from Original and DARP methods while the estimation error is reduced by using the Nowcast method. The difference in fuel flow estimation error between Original/DARP and Nowcast methods ranges from 0.01 kg/s to 0.03 kg/s. Considering a nine-hour flight, this difference may result an estimation error of approximately 700 lbs. to 2150 lbs. of fuel.

3. Summary and Future Work

3.1 This information paper presents a quantitative evaluation of weather prediction error and its impact on aircraft fuel burn estimation. A series of QAR data from DARP operated flights were acquired including flight plan information on both pre-flight and DARP flight planning. Numerical weather prediction forecast and nowcast data were used to estimate zonal/meridional wind components and static air temperature and were compared with the cockpit-measured data to investigate the weather prediction error. Results showed that by applying nowcast weather data in ground-based performance estimation could help to reduce the prediction error significantly. These estimated data were then integrated to an aircraft performance model developed by ENRI to review the impact of weather prediction error on fuel flow estimation error. Results reveal that weather prediction error has a direct impact on fuel flow estimation which can result discrepancies in fuel consumption estimations, negatively contributing towards decision-making in DARP implementation.

3.2 The scope of this study is to be enhanced according to following measures;

- Obtained results will be used to compare with the output from the ground-based system to investigate the impact of the difference in evaluation methods on performance estimation discrepancies.
- Enhancing the QAR database will provide further information on tendencies of weather prediction error (impact on different flight phases, impact due to seasonal changes etc.) and help improving the accuracy of the EAPM.
- Investigating the possibilities on enhancing DARP operational benefits through dynamic 3D-rerouting (4D-TBO).

4. Conclusion

4.1 The meeting is invited to note the information provided.