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A STUDY ON MODELING TECHNIQUES FOR FUEL BURN ESTIMATION BASED ON FLIGHT SIMULATOR EXPERIMENT DATA

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ABSTRACT

The ever-increasing demand for global air travel has created many daunting challenges for the aviation industry. The estimation of fuel consumption is integral to the evaluation of aircraft performance, which is in turn vital to developing key components of future air traffic management systems. In this study, a framework for the quantitative estimation of fuel burn was established with the objective of developing a modeling technique for accurately assessing aircraft performance. Data from a series of continuous descent operations simulations conducted on a full-flight simulator were used as reference data. Base of Aircraft Data (BADA) (aircraft performance model data) provided by Eurocontrol were used together with point mass dynamics to estimate the fuel flow for both clean and non-clean aircraft configurations. Results revealed that it could accurately estimate the total fuel consumption to within ±6% of the actual value, and the cruise and descent fuel consumptions to within ±6% and ±10%, respectively.

1 INTRODUCTION

The increasing demand for global air travel has created many daunting challenges for operators, regulators, and air navigation service providers. This has prompted the undertaking of various research and development projects toward a global transition from the current airspace-based air traffic control (ATC) system to a more flexible and reliable air traffic management (ATM) system. Collaborative Actions for Renovation of Aircraft Systems, commonly known as CARATS, is the Japanese counterpart of the NextGen of the United States and the Single European Sky ATM Research (SESAR) of Europe. It is a long-term research entity for the renovation of Japan's national air transportation system (Study Group for the Future Air Traffic Systems 2010). One of the key challenges in a future Japanese ATM system is to increase the operational capacity of the Tokyo International Airport, which has the fifth highest annual passenger enplanements in the world (Airports Council International 2015). 4D-Trajectory Based Operations (4D-TBO) and Continuous Descent Operations (CDO) are two of the core technologies proposed in the roadmap to increasing the efficiency and reliability of a possible future system. 4D-TBO defines flight trajectories optimized for space and time, expected to maximize the performance of each airplane. Conversely, CDO is a concept in which an airplane performs a continuous descent from the Top of Descent (ToD) to the destination, eluding the mid-flight level-off segments and thus achieving significant fuel savings compared to conventional operation. Authors have contributed towards the improvement of CARATS through evaluation of the potential benefits of a future ATM system in an ideal operational environment via trajectory optimization (Wickramasinghe et al. 2016) and proposition of optimal arrival methodologies for addressing the challenges facing terminal and airport surface operations (Toratani, Wickramasinghe, and Itoh 2017).

Modeling of aircraft motion and referencing to aircraft performance data are crucial to accurate evaluation of aircraft performance for the above-mentioned purposes. Precise modeling of aircraft performance in a non-clean configuration or low-altitude operation is particularly critical. Extensive studies have been conducted in recent years on the accurate modeling of aircraft performance. Trani et al. (2004) used a neural network approach to estimate fuel burn, with the process requiring referencing a large database of aircraft operations and state data. Patterson et al. (2009) conducted a preliminary analysis of the accuracy of fuel burn models by comparing their results with real-time aircraft flight data and data from the International Civil Aviation Organization (ICAO) time-in-mode method. Results showed that fuel flow-rate patterns for a majority of flights differed from ICAO standard data. This was confirmed by Chati and Balakrishnan's (2014) analyses of aircraft fuel burn and emissions during landing and take-off, based on FDR data. Senzig, Fleming, and Iovinelli (2009) proposed a thrust specific fuel consumption (TSFC) model based on an airplane manufacturer's data, and showed that its estimations were accurate to within ±5% from field elevation up to 10,000 ft. However, the requirement for detailed data from the manufacturer limits general application of this model. Oaks, Ryan, and Paglione (2010) proposed a fuel burn model for prototype application. The fuel consumption estimations of the model were found to be +2% during ascent, +4.7% during cruise, and -37.1% during descent compared to data obtained from a flight data recorder (FDR). Chatterji (2011) introduced a detailed model for estimating fuel burn and showed its estimation deviation to be less than ±1% compared to FDR data for a single flight. Unavailable aircraft performance data were generated by scaling the average values obtained from performance data for other aircraft and fitting the parameters through trial and error to achieve accuracy of the model. The application of an estimator based on a proportional-integral-derivative (PID) controller also enabled reduction of the noise in the estimated parameters. However, the utilized type of high-order estimator requires significant computations for the definition of appropriate gain values. Harada et al. (2013) used a point mass approach to quantitatively evaluate the fuel consumption, achieving an accuracy of ±5% for clean configuration only. Most of these studies referenced the Base of Aircraft Data (BADA) Family 3 database of Eurocontrol because of its vast coverage of currently operated aircraft, simplicity, and availability. The developed models are well adapted for large-scale, high-level performance simulations that mainly utilize substantial accumulative data. However, for extensive review of the entire flight envelope of a specific aircraft, it is very important to reference a performance database that features in-depth performance data for all configurations. The BADA Family 4 database provides such a platform and was employed in the present study.

Fuel burn estimation models developed for various purposes have contributed to the investigation of this key performance indicator of aircraft performance. This paper provides a framework for the quantitative evaluation of fuel burn toward enhancing aircraft performance evaluation through accurate assessment of fuel consumption. Data obtained through a series of full-flight simulator (FFS) experiments performed for CDO demonstrations were used to validate the estimates of the proposed model. Point mass dynamics was also used in conjunction with the BADA Family 4 database to develop a computationally efficient and accurate aircraft performance model. The proposed model was also used to perform phase-wise fuel burn computations and the deviation of the results from measured values were statistically reviewed to investigate the validity of the model. This study also involved the development of a generalized and accurate platform for fuel consumption estimation for various aircraft performance evaluation purposes at the Electronic Navigation Research Institute (ENRI).

The rest of this paper is structured as follows. Section 2 introduces the reference data and the proposed aircraft performance model, including the mathematical formulation and model structure used in its application. Section 3 presents the fuel consumptions in different flight scenarios computed by the proposed model, as well as the results of the statistical analysis of the model accuracy. Section 4 discusses the results of the study and the scope of further improvements of the model. Finally, a summary of the study and the conclusions drawn from it are presented in Section 5.

2 DATA SOURCES AND MODELS

This section introduces the reference data used in the present study and discusses the employed fuel flow estimation procedure based on a mathematical formulation of the aircraft motion and integration of the developed model with the BADA database. Because the reference data were obtained by FFS experiments, the International Standard Atmosphere (ISA) conditions were utilized in the analysis.

2.1 Full-Flight Simulator Data

Flight data obtained by a series of flight experiments conducted in a FFS with the collaboration of a national airline were used as reference data in this study. The data is henceforth referred to as "measured data". FFS affords a highly technical platform for the training of pilots in a high-fidelity virtual environment. The platform was used in this study to review the operational feasibility of CDO procedures (Itoh et al. 2016). The performed experiments considered various conventional procedures such as optimal profile descent (OPD), vectoring, and adjustment of required time of arrival (RTA), as well as concept-based procedures such as fixed-flight path angle (FPA) descent and continuous climb operations (CCO). The experiments also addressed operational scenarios encountered at the Tokyo International Airport (ICAO code: RJTT) and Kansai International Airport (ICAO code: RJBB). A total of 48 flight trials was corroborated for a twin-engine wide body jet passenger aircraft. The obtained data series provided a broad platform for the modeling of the aircraft performance under different configurations. Figure 1 shows examples of the arrival routes assigned to RJTT and RJBB in the experiments. Data related to the aircraft state were used to estimate the aerodynamic drag, engine thrust, and fuel flow rate, while the performance parameters were used to validate the proposed model.

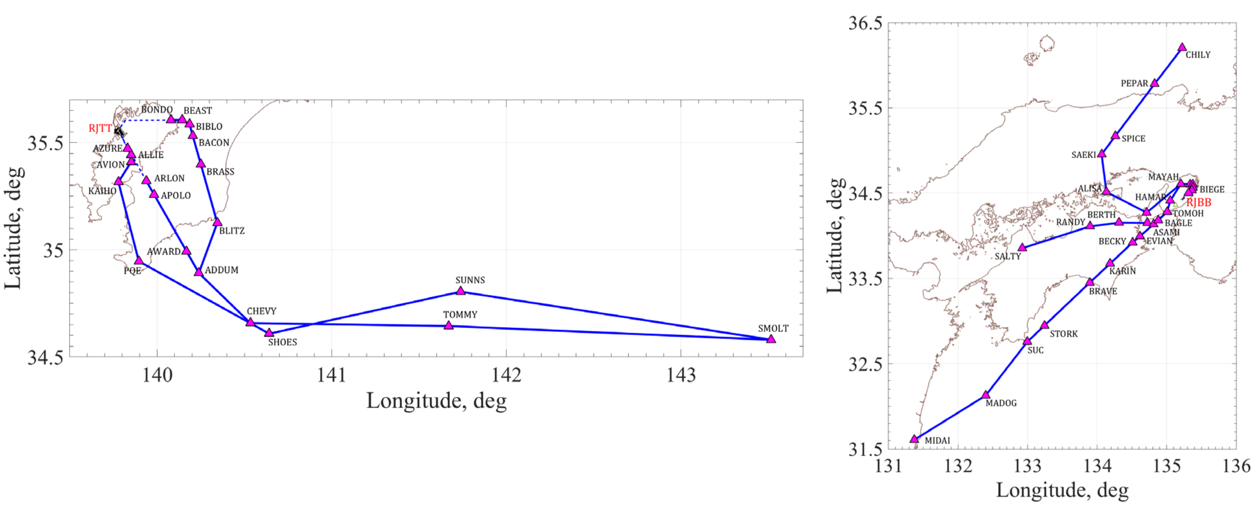

Figure 1: Arrival routes at Tokyo International Airport (RJTT) and Kansai International Airport (RJBB) obtained from the experiments.

2.2 Meteorological Data

As noted earlier, the ISA conditions were applied to the present experiments. Wind data obtained by the Global Spectral Model (GSM) was used for the simulations, in which the wind magnitude and direction were set at four levels of pressure altitude through the simulator's main computer. The setting of the wind conditions was based on the linear approximations illustrated in Figure 2, in which the wind speed and direction are plotted against the pressure altitude obtained by a flight simulation conducted at the RJBB. The wind magnitudes were defined at altitudes of 39,000, 29,000, 10,000, and 6,000 ft, respectively.

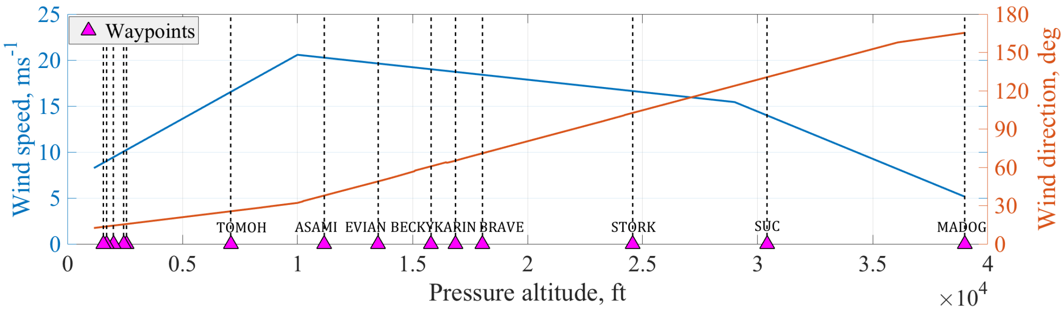

Figure 2: Setting of wind magnitude and wind direction.

2.3 Mathematical Formulation of Aircraft Motion

Point mass approximations were used in this study to model the aircraft's 3-D translational motion. The following three governing equations regarding the longitude θ, latitude ϕ and geometric altitude h are generally used to describe an aircraft's motion:

$$\dot{\phi} = \frac{1}{R_0 + h}(V_{TAS}\cos\gamma_a\cos\psi_a + W_{SN}) \tag{1}$$

$$\dot{\theta} = \frac{1}{(R_0 + h)\cos\phi}(V_{TAS}\cos\gamma_a\sin\psi_a + W_{EW}) \tag{2}$$

$$\dot{h} = V_{TAS}\sin\gamma_a \tag{3}$$

where R_0 is the mean radius of Earth, V_{TAS} is the airmass-relative speed or true airspeed, γ_a and ψ_a are respectively the airmass-relative flight path angle and azimuth angle, and W_{EW} and W_{SN} are respectively the zonal and meridional wind components acting on the aircraft.

The definition of the aircraft's acceleration under the forces acting on its body varies with the coordinate frame of reference. Previous studies have shown that the adoption of an inertial coordinate frame introduces significant noise into the estimated inertial speed (Harada et al. 2013). The noise originates from the measurement noise of the ground speed and is amplified by the use of the time derivative. Hence, an airmass-relative coordinate frame was employed in this study, and the airmass-relative acceleration of the aircraft was determined using

$$m\frac{dV_{TAS}}{dt} = T - D - mg\sin\gamma_a - m\left(\frac{dW_{EW}}{dt}\sin\psi_a + \frac{dW_{SN}}{dt}\cos\psi_a\right)\cos\gamma_a \tag{4}$$

where m is the aircraft mass, T is the required thrust, D is the aerodynamic drag, and g is the gravitational acceleration with an assumed angle-of-attack of zero. If the vertical component of the wind is assumed to be negligible, an apparent force corresponding to the rate of change of momentum of the wind would act on the moving coordinate frame. Because (4) represents the force equilibrium in the direction of the true airspeed vector, the apparent force component can be included in the equation, as contained in the parentheses. To reduce irregularities in the true airspeed, a weighted difference approximation is introduced, as expressed in (5), which gives the time derivative of the true airspeed at time t_i. The subjected time interval used in the study was $\pm$5s ($n = 5$).

$$\frac{dV_{TAS}}{dt}(t_i) = \sum_{j=1}^{n} \frac{2}{n}\left(\frac{n+1-j}{n+1}\right)\frac{V_{TAS}(t_{i+j}) - V_{TAS}(t_{i-j})}{2j\Delta t} \tag{5}$$

2.4 Aircraft Performance Model

The BADA Family 4 database was used as the primary reference for the aircraft performance model in this study. BADA consists of a aircraft performance models based on mass-varying, kinematics (Eurocontrol Experiment Centre 2016). Unlike BADA Family 3, BADA Family 4 defines its aerodynamic, thrust, and fuel flow models in the form of polynomial expressions with extensive reference to different flight profiles and aircraft configurations. Another significant distinction of BADA Family 4 is that most of its mathematical models are derived as functions of the Mach number M.

The aerodynamic drag D is generally computed based on the drag coefficient C_D using the following mathematical expression

$$D = \frac{1}{2}\kappa p_0 S \delta M^2 C_D \tag{6}$$

where κ is the adiabatic index, p_0 is the standard atmospheric pressure at the mean sea level, δ is the pressure ratio (ratio between the pressure at aircraft's position and p_0), and S is the wing reference area. C_D is computed as a function of the lift coefficient C_L, the position of the high-lift devices δ_{HL}, and the speed brakes δ_{SB} and M:

$$C_D = f(C_L, \delta_{HL}, \delta_{SB}, M). \tag{7}$$

The general formulation of the fuel flow rate can be expressed as

$$FF = \delta \cdot \theta^{\frac{1}{2}} W_{MTOW} \cdot a_0 \cdot L_{HV}^{-1} \cdot C_F \tag{8}$$

where θ is the temperature ratio (ratio between the temperature at the aircraft's position and the temperature at the mean sea level in ISA), W_{MTOW} is the maximum take-off weight, a_0 is the speed of sound at the mean sea level in ISA, L_{HV} is the fuel lower heating value and C_F is the fuel coefficient. C_F is usually computed based on the engine's non-idle or idle thrust rating, as follows:

$$C_F = \begin{cases} C_{F,idle} & \text{idle ratings is used} \\ \max(C_{F,gen}, C_{F,idle}) & \text{non} - \text{idle ratings is used} \end{cases} \tag{9}$$

where $C_{F,idle}$ is the idle fuel coefficient and $C_{F,gen}$ is the non-idle or general fuel coefficient. Because the engine rating flag is not included in the reference data, the maximum value is applied to the entire process. Thus, $C_{F,idle}$ and $C_{F,gen}$ are generally expressed as

$$C_{F,idle} = f(M, \delta, \theta) \qquad C_{F,gen} = f(M, C_T) \tag{10}$$

where C_T is the thrust coefficient and can be computed from

$$T = \delta \cdot W_{MTOW} \cdot C_T \tag{11}$$

For a turbofan engine, C_T is generally expressed as a function of the Mach number and throttle parameter for non-idle ratings (maximum cruise, maximum climb, and maximum take-off) and no rating (direct throttle parameter input), and as a function of the pressure ratio and Mach number for idle ratings. These equations are used for trajectory modeling, although (11) was used in the present study because the engine thrust had already been estimated. Considering that the reference data was obtained at a frequency of 1 Hz, the total fuel consumption (TFC) was determined as the time integral of the fuel flow rate, expressed as (12) where Δt is the time interval, and t_f is the terminal time of the flight.

$$TFC = \sum_{t=0}^{t_f} FF(t) \cdot \Delta t \tag{12}$$

3 ANALYTICAL RESULTS

This section discusses the validity of the proposed aircraft performance model based on a quantitative evaluation of its fuel burn estimations. Figures 3 and 4 illustrate two examples. The first example (Flight 35) concerns a smooth descent with no speed restrictions, while the second example (Flight 15) concerns a series of speed commands given during descent. The two examples respectively represent a standard performance modeling and performance modeling under largely varying conditions.

In each of Figures 3 and 4, the top panel shows the pressure altitude and the measured and estimated fuel flow rates while the bottom panel shows the positions of the speed brake lever, flaps, and landing gear extension. All the parameters are plotted against the flight time. Flight 35 included the deployment of speed brakes and flaps at 5°, and the flight simulation was implemented only up to the initial approach fix (IAF). Flight 15 involved FPA descent with speed control as a demonstration of flight-deck interval management (FIM). There were large fluctuations in the fuel flow rate due to various speed commands given to the pilot. The fuel flow rate increased significantly just before the flight termination due to the full deployment of the flaps and landing gear, which considerably increase the aerodynamic drag. Both figures reveal that the fuel flow rate instantly increases with the deployment of the flaps, and the landing gear in the case of Flight 15. The speed brakes are deployed to decrease the airspeed, but this does not affect the fuel flow rate because of the idle thrust conditions. The recorded position of the landing gear is usually between 0 and 1, but the value was multiplied by 20 in this study for better visibility in the plots. Comparison of the time histories of the measured and estimated fuel flow rates reveal that the proposed model reproduces the aircraft's behavior with a very high degree of accuracy. Figure 3 also shows that the relaxed conditions of the aircraft were modeled with a high accuracy, although with a slight deflection at the deployment of the flaps. Figure 4 further shows that the proposed model takes the speed variations into consideration, with excellent tracking of the high fuel flow ratings. However, there are significant differences between the descent-phase fuel flow rate and the results of previous work that utilized the BADA 3 model. In addition, the top panels in Figures 3 and 4 show that the descent fuel flow rate tends to be inversely proportional to the flight altitude. This is due to the increase in the air density with decreasing altitude. Harada et al. (2013) and Wickramasinghe et al. (2016) showed that the estimated descent fuel flow rate significantly deviated from measured data, even in the clean configuration, due to the simplified function of the geopotential altitude defined in the BADA 3 model of the fuel flow rate under idle thrust conditions. In the case of the BADA 4 model, the idle rating fuel flow rate is determined by (10), which considers not only the altitude (pressure and temperature ratios), but also the speed. This affords a high-accuracy modeling under idle thrust conditions, as can be observed from the two examples presented in this paper. The measured TFC for Flight 35 was 1833kg, which represents a difference of 55kg compared with the 1778kg determined by the proposed model (estimation error = -3.1%). The measured and estimated TFCs for Flight 15 were 2195 and 2047kg, indicating a difference of 148kg (estimation error = -6.7%). The TFC estimation error was obtained as

$$err_{TFC} = \frac{TFC_{est} - TFC_{data}}{TFC_{data}} \times 100\% \tag{13}$$

where err_{TFC} is the estimation error, TFC_{est} is the estimated and TFC_{data} is the measured TFC.

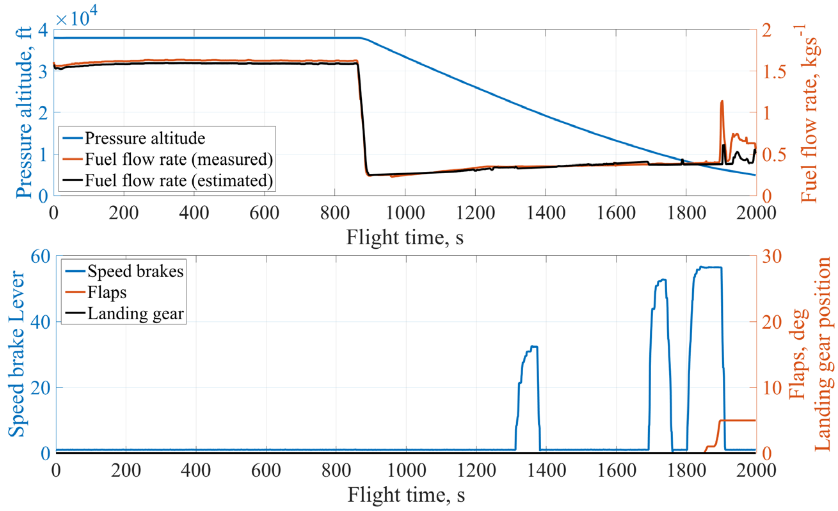

Figure 3: Time histories of estimated fuel flow rate and related parameters for Flight 35 (top: pressure altitude, and measured and estimated fuel flow rates. bottom: speed brake lever, flaps, and landing gear).

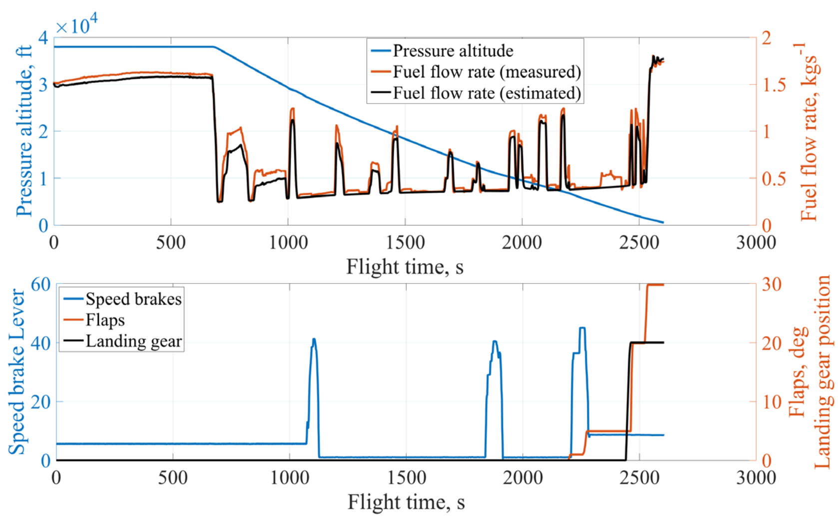

Figure 4: Time histories of estimated fuel flow rate and related parameters for Flight 15 (top: pressure altitude, and measured and estimated fuel flow rates. bottom: speed brake lever, flaps, and landing gear).

Figure 5 provides a statistical review of the estimation errors. The top panel is a whisker plot presentation of the fuel flow rate estimation errors at all the data points for all the simulated flight cases. The red horizontal line in each box indicates the median value, while the upper and lower edges of the box indicate the 1st and 3rd quartiles (enclosing 50% of the normal population). The interquartile range (IQR) is given by the data between the 1st quartile and 3rd quartiles. The lower and upper whiskers cover 99.3% of the normal population, namely the data between “1st quartile – (1.5×IQR)” and “3rd quartile +

(1.5×IQR).” The extremals or outliers are indicated by the red markers which are beyond the lower or upper limits of the whiskers, respectively. Results indicate that the average median of the estimation errors for all flights is -0.023 kg/s, while the average IQR between -0.035 and -0.050 kg/s. For most of the flight cases, the outliers are within ±1kg/s. The bottom panel of Figure 5 shows the root mean square error (RMSE) and mean error of the flow rate estimations for each flight case. The average RMSE and mean error for all the 48 flights are 0.091 and -0.028kg/s, respectively. This shows that the BADA 4 model is highly accurate for modelling the aircraft performance and estimating the fuel burn. However, the obtained results indicate that the proposed model tends to underestimate the instantaneous fuel flow rate. It is also noteworthy that the determined aircraft performance may differ with the engine models used in the FFS and BADA 4 database. Furthermore, data smoothing used for the range calculations is also considered as a contributing factor to the difference in fuel burn estimation.

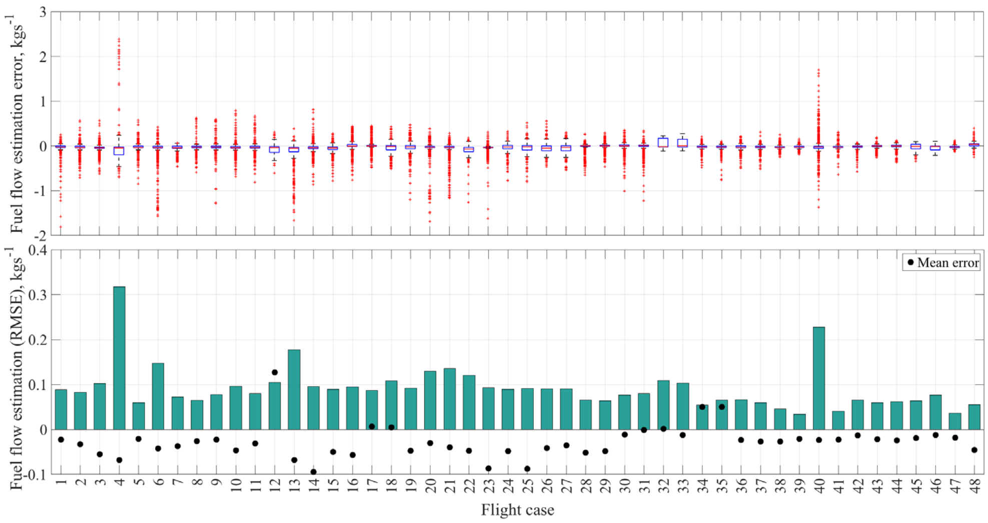

Figure 5: Estimation errors of the fuel flow rate (top: boxplot. bottom: root mean square error (RMSE) and mean error).

Furthermore, a phase-wise estimation error evaluation was conducted to examine the effect of the configuration setting on the fuel burn estimation. The take-off and climb phases were not considered in the experiments, and only the fuel flow rates during cruise and descent phases were investigated. Figure 6 shows the results. The error bars in the figure indicate the standard deviation for the different estimation errors. The standard deviation of the estimation error, σ_{err}, was obtained as follows:

$$\sigma_{err} = \sqrt{\frac{1}{n-1}\Sigma\{FF_{err}(t) - \overline{FF_{err}}\}^2} \tag{14}$$

where FF_{err} is the estimation error and $\overline{FF_{err}}$ is the mean estimation error. The solid lines with markers in Figure 6 represent RMSEs of the estimation errors for the respective phases. The overall results show that the fuel flow rate estimation during the descent phase contributes more to the estimation error in Figure 5. One reason for this is the commencement of each flight experiment constituting a short segment. However, a more evident reason is the deployment of the high-lift devices, speed brakes, and landing gear in the descent phase, compared to the clean configuration of the cruise phase. The average standard deviation and RMSE of the cruise phase estimation errors were determined to be 0.041 and 0.07kg/s respectively, while the corresponding values for the descent phase were 0.087 and 0.098kg/s, respectively.

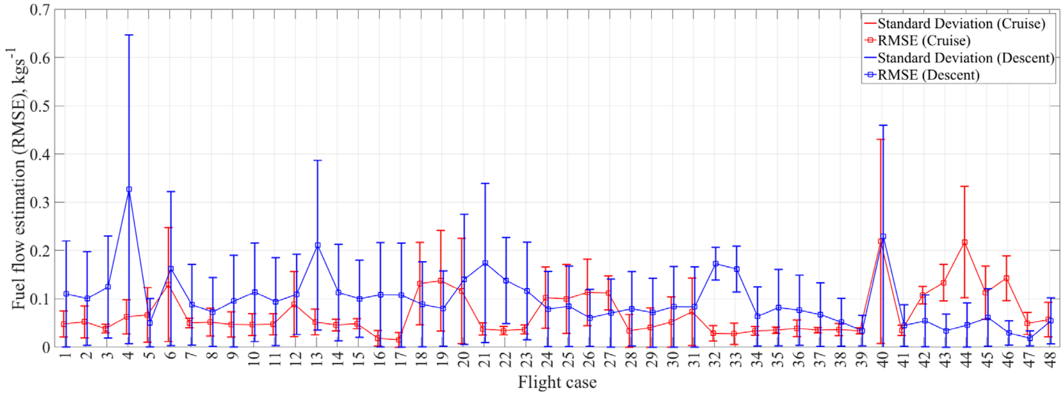

Figure 6: Phase-wise evaluation of the fuel flow rate estimation errors.

Finally, the profiles for overall and phase-wise fuel consumption estimation errors were compared as shown in Figure 7. The average TFC estimation error was determined to be -3.67%, with the TFC observed to be accurately estimated within ±6%, excepting the cases of Flights 4, 10, 13, and 22. The corresponding values for the cruise phase were determined to be -3.089% and ±6% (excepting the same four flights). There were only two irregular cases (Flights 32 and 33) in the estimation results of the descent phase fuel consumption, as indicated by large positive deviations from the measured data. The estimation errors for the other cases were determined to be within ±10%. The two irregular flight cases are excluded from the discussion below.

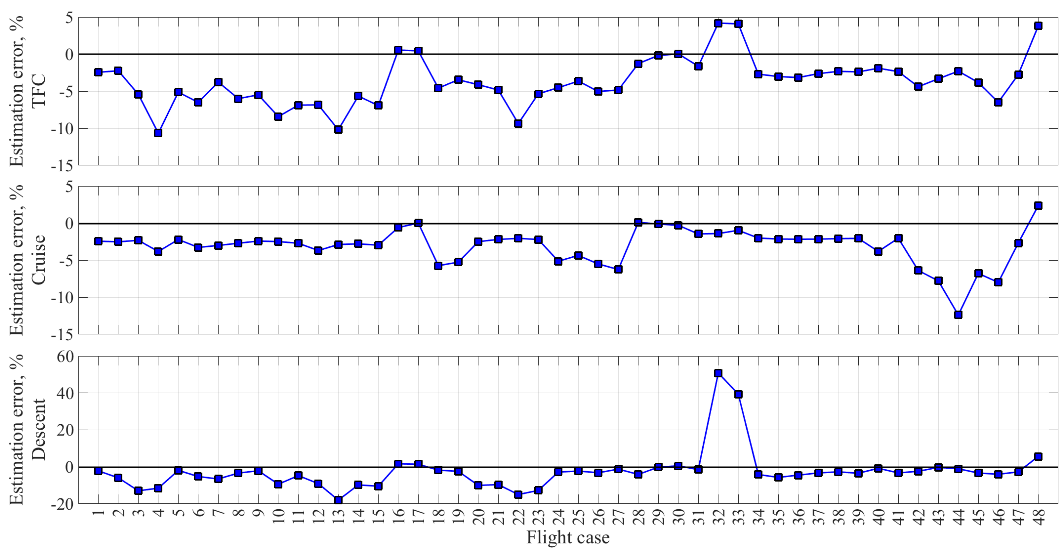

Figure 7: Comparison of the estimation errors of the TFC and the cruise phase and descent phase fuel consumptions.

4 DISCUSSION

The results presented in Section 3 show that the proposed aircraft performance model is sufficiently accurate for both clean and non-clean configurations. Here, we consider possible modifications that could be used to broaden the applicability of the model as a platform for reviewing the aircraft performance (Kageyama and Akinaga 2017; Toratani et al. 2017). One such improvement is the introduction of a six degree-of-freedom motion of the aircraft into the mathematical formulation of the model. This would potentially reduce the estimation error at low altitudes which include large heading variations and vectoring. In addition, further analysis is required to determine how the FMS computations are integrated with the physical motion of the aircraft and the procedure settings. In the present study, some significant partial deviations were observed between the measured and estimated fuel flow rates for some flight cases, attributable to conflicts between the governing dynamics of the proposed model and the flight procedure settings in the FMS. For example, as can be seen from the performance parameter time histories of Flight 4 in Figure 8, there is a sudden partial deviation of the estimated fuel flow rate in the in the descent phase relative to the measured value. Terms 1-5 in the figure correspond to the thrust components in (4), as follows:

$$\text{Term 1} = D, \quad \text{Term 2} = mg\sin\gamma_a, \quad \text{Term 3} = m\frac{dV_{TAS}}{dt}$$

$$\text{Term 4} = m\frac{dW_{EW}}{dt}\sin\psi_a\cos\gamma_a, \quad \text{Term 5} = m\frac{dW_{SN}}{dt}\cos\psi_a\cos\gamma_a$$

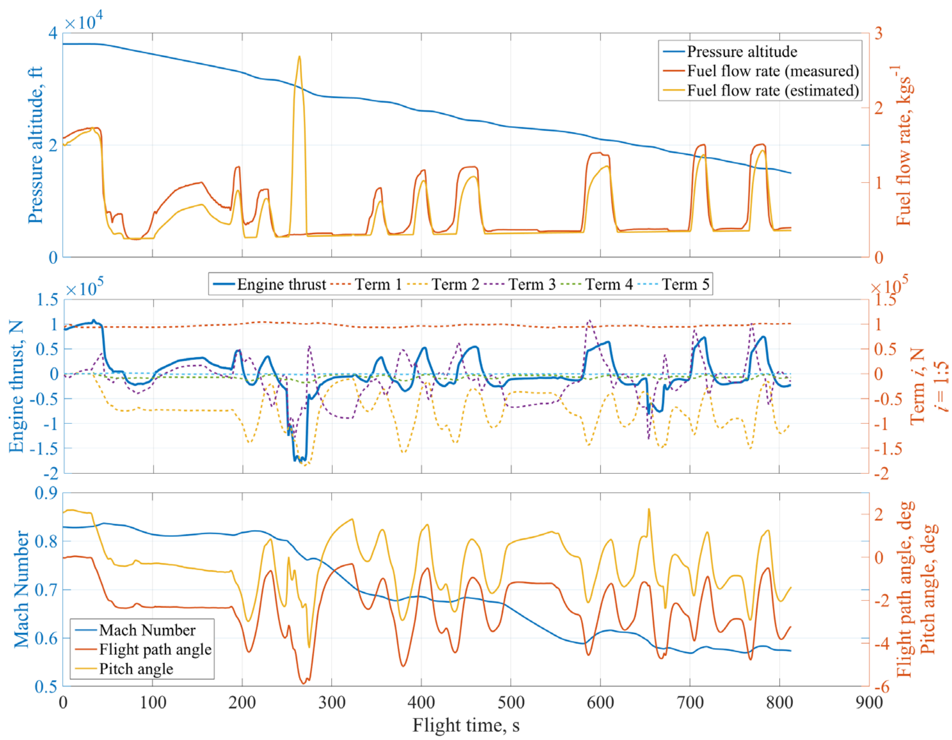

Figure 8: Time histories of performance parameters of Flight 4 (top: pressure altitude and measured and estimated fuel flow rates; center: thrust components; bottom: Mach number, flight path angle, and pitch angle).

Overall, the trends in Figure 8 are similar to those in Figures 4 and 5. However, the estimated fuel flow rate rapidly and significantly peaks relative to the measured fuel flow rate just before 300s. This coincides with sharp changes in the flight path and pitch angles and a decrease in the Mach number, resulting in Term 2 assuming a large negative value, and hence the development of a negative thrust. Consequently, the expression of the general fuel coefficient as a function of the thrust coefficient, which is computed as a polynomial of the thrust, causes the estimated fuel flow rate to increase rapidly. However, an aircraft usually remains in the state of idle thrust during descent, and the procedure settings prevent the measured fuel flow rate from fluctuating with the changes in the aircraft dynamics. A means of integrating the procedure settings into the proposed model is an issue requiring further study. Furthermore, a specific aircraft type was considered in this study, and there is the need to broaden the scope of the proposed model by applying it to experiments performed using other aircraft types. This would also afford a means of investigating the effect of the engine model on the estimation process. For this purpose, data obtained from a cockpit quick access recorder (QAR) can be used as reference data for obtaining the total flight profile under non-ISA conditions. This would enable a comprehensive examination of the feasibility of applying the model to aircraft performance from take-off to landing.

5 CONCLUSION

This paper proposed a model of aircraft performance based on a quantitative evaluation of the estimated fuel burn. Data obtained through a series of flight experiments conducted in an FFS was used as reference data for investigating the accuracy and validity of the proposed model. Point mass approximations were used to model the aircraft dynamics and the BADA 4 model was used as the primary aircraft performance database. The fuel burn was estimated for a total of 48 flights and a statistical analysis of the estimation errors was conducted. The analytical results showed that the proposed model was capable of estimating the fuel flow rate with an average error of -0.028 kg/s, indicating a tendency to under-estimate. The difference between the engine models used in the flight simulator and the BADA 4 model is considered to be the one reason for the discrepancy. There is, however, the need to test the model using other aircraft types to clarify this issue. Further, phase-wise examination of the estimation errors revealed that the descent phase dominantly contributed to the overall estimation error, due to the non-clean configuration of the aircraft. The proposed model was found to be capable of estimating the TFC to within ±6% of the actual value, while the fuel consumption during cruise and descent phases were estimated to within ±6% and ±10% respectively. The scope of the proposed model is expected to be enhanced by applying it as a platform to review aircraft's performance in other applications.

LICENSE AGREEMENT

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