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Advances in Real-Time Aerodynamic Model Identification

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This paper describes the development of an in-flight, near real-time, aerodynamic model identification (RAMI) technique, for fixed-wing aircraft. This technique can be used to develop and validate an aerodynamic model to the Federal Aviation Administration AC 120 Level D flight simulator aerodynamic model criteria; and initial demonstrations of its capabilities are taking place on the National Research Council Falcon 20 research aircraft. As part of the RAMI development, innovative, self-contained software algorithms and hardware processing have been designed for onboard use. As well, novel hardware and software techniques are being applied to calibrate fundamental in-flight measurements, such as air data, in real time. The RAMI technique uses the "2-3-1-1" (alternating control input steps in seconds) maneuver, executed in each of the pitch, roll and yaw axes. These maneuvers are flown in flight conditions that span the entire flight envelope of interest. At each flight condition, the small perturbation stability and control derivatives (point model) are determined in real time. An automatic curve-fit process then combines the point models to develop a global aerodynamic model of the aircraft. In addition, an online model validation process is executed to confirm the integrity of the developed model, by comparing the model response to flight data. Excellent aircraft model fidelity has been demonstrated using the RAMI technique.

Introduction

SEVERAL years ago, the Flight Research Laboratory (FRL) of Canada's National Research Council (NRC) launched a research program to address the challenges in the real-time aircraft aerodynamic modeling process. These challenges include 1) integrating high-speed PC computing hardware into the Falcon 20 research aircraft (Fig. 1); 2) developing efficient computing algorithms for data quality checking and aircraft model identification; 3) implementing an automatic procedure to develop a global aircraft model in flight; and 4) developing a capability, based on MATLAB®, Simulink® and the Aerospace Blockset®, to validate the resulting global model in flight.

In recent research, Jategaonkar and Moennich[1] have applied offline system identification methods for a Dornier 328 commuter aircraft and generated aerodynamic databases meeting the Federal Aviation Administration (FAA) Level D qualification Criteria. In-flight model identification research has been performed by Breeman et al.[2]; however, the online procedure only yields a linear model valid for each individual test condition. Real-time parameter estimation in the frequency domain was used by Morelli[3] to compute sequential real-time estimates of dynamic model parameters. Real-time aerodynamics model identification (RAMI) has performed real-time, time-domain parameter estimation to obtain the linear model and is expected to identify the nonlinear flight dynamics and validate the global model in flight.

The primary objectives of this paper are to 1) describe the development of the RAMI in-flight parameter estimation software and associated techniques; 2) describe the global model development and validation; and 3) address the issues in the development of the trim routines, the automatic nonlinear dynamic effects optimizer, and the automatic proof-of-match (POM) process.

Overview of RAMI

The flight-test data suite for aircraft model development and verification includes standard aircraft response parameters and differential global positioning system (DGPS). Fundamental air-data sensors (i.e., pitot-static air data and airflow angles) are calibrated using an efficient, near real-time technique relying on DGPS measurements.[4] The identification and calibration of the dynamic upwash and sidewash effects are accomplished by the analysis of a special set of wind-box flight maneuvers. In this manner, air-data calibrations are determined during dedicated flights in preparation for the execution of the model development and model verification test points. The resulting dynamic responses of the aircraft model are then evaluated in the time domain. The development of a real-time aerodynamic model identification procedure, and the efficient air-data calibration method as applied to flight test, are intended to reduce flight-test time and cost.

The real-time parameter estimation procedure uses a maximum likelihood estimator as the core of the optimization algorithm.[5] To support this efficient algorithm, a high-speed PC is used for the floating-point computations, using the Visual FORTRAN software environment and FORTRAN 77 or FORTRAN 90.

Aircraft and Associated Instrumentation

The NRC Falcon 20 research aircraft has been developed to be a general-purpose, fixed-wing flight mechanics research facility. The current roles for the aircraft include the testing and evaluation of precision instrument approaches using augmented GPS systems for guidance, the determination of aircraft performance characteristics on winter contaminated runways, the examination of the behavior of wing contaminants in flight, and microgravity work for the Canadian Space Agency. With an extensive onboard data-acquisition system, the aircraft can also be used for head-up display development, airborne geoscience studies, avionics research, and aircraft-based sensor research.

Aircraft Instrumentation

The NRC Falcon 20 aircraft has a dedicated research data-acquisition system. All data are digitally sampled onboard at 32 Hz and are available for in-flight analysis or recorded for postflight analysis. For this project, a dual-processor 733-MHz Intel Pentium III Xeon system from Compaq was added to perform the near real-time parameter estimation process.

The Falcon 20 research data-acquisition system is connected to the following carefully selected individual sensors: 1) a triad of linear accelerometers; 2) a two-axis vertical gyro and a directional gyro; 3) a triad of angular rate gyros; 4) a total temperature probe; 5) a PC-mounted GPS; 6) air data from either the nose mask[6] or a

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Fig. 1 NRC Falcon 20 aircraft.

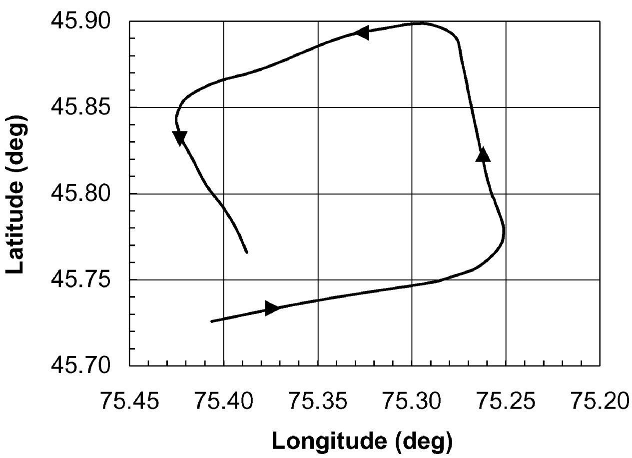

Fig. 2 Wind-box pattern as flown by the Falcon 20 research aircraft.

cruciform configuration flush hole air-data system; 7) control positions; and 8) engine parameters.

In-Flight Air-Data Calibration

Several years ago, the FRL developed an off-line technique[4] for the simultaneous determination of pitot-static position error correction and the calibrations of angle of attack α and angle of sideslip β. The technique was called SCADS (simultaneous calibration of air-data systems) and used DGPS data, together with attitude/heading, angular, rate and air-data parameters, to estimate the air-data calibration errors. More recently, a real-time SCADS technique,[7] using a Kalman filter approach, has been developed for use onboard an aircraft.

The following wind-box air-data calibration maneuver is used in the real-time SCADS technique; it is flown once in each flap setting and landing-gear configuration: 1) a 1-min leg at constant heading, accelerating from 150 to 250 kn airspeed; 2) 90-deg turn with bank angle of 20 deg; 3) a 1-min leg at constant heading, decelerating from 250 to 150 kn airspeed; 4) a 90 deg turn, accelerating up to 185 kn; 5) a series of beta sweeps for 1 min while maintaining constant speed and track angle (i.e., slowly increasing angle of sideslip from 0 up to 10 deg in each direction); 6) another 90-deg turn, accelerating up to 225 kn; and 7) another set of beta sweeps with amplitude of 10 deg while maintaining 225 kn airspeed.

Figure 2 shows a typical horizontal flight track for the Falcon 20 while executing the wind-box pattern.

The fundamental philosophy underlying this particular flight maneuver is to ensure adequate variations in α, β, and true airspeed for proper estimation of the associated calibration coefficients, and to ensure that the horizontal wind components are observable by varying the aircraft heading as shown in Fig. 2. For a typical wind-box maneuver, as just described, α varies between 4 and 10 deg as airspeed decreases from 250 to 150 kn.

RAMI Process

To achieve a true real-time aerodynamic model identification, the various steps shown in Fig. 3 need to be addressed. There are several key components in the process of developing an aerodynamic model in flight:

1) It requires dedicated self-contained high-speed computing hardware to extract the flight data from the host aircraft and automatically process the data.

2) A data quality checking process is required to ensure data integrity.

3) The resulting data are then used in the maximum likelihood estimator (MLE) to compute aircraft parameters that define the point models.

4) The next step is the in-flight automatic global model determination that integrates the point models into a continuous model.

5) Aircraft cross-axis and/or nonlinear dynamics are determined automatically using the nonlinear dynamics optimizer algorithms.

6) The final step is to validate the global model in flight, based on POM software developed using the MATLAB/Simulink/Aerospace Blockset.

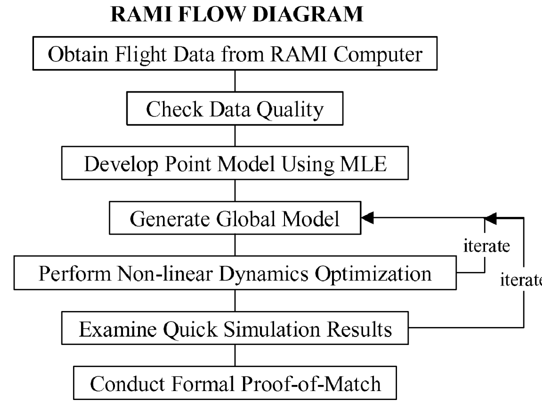

Fig. 3 Real-time aerodynamic-simulator model identification system flow diagram.

Flight Data Acquisition from RAMI Computer

In this step, the raw data are extracted from the sensor suite using high-speed computing hardware and saved to the resident hard drive for immediate processing.

Data Quality Verification

The data quality check process has been developed by integrating the flight-path reconstruction routines, regression checks for correlation, checking minimums and maximums, and signal dropout inspection. Because the Falcon 20 aircraft is a dedicated aircraft for this project and all parameters are functional, the data quality check is optional.

Point Model MLE Identification

The point model consists of the stability and control derivatives that describe the small perturbation dynamics of the aircraft around a specific trim condition. These are obtained by the process illustrated in Fig. 4. The MLE parameter estimation technique is used to generate these derivatives in an automatic process. This point model and the average trim states of the aircraft (2 s prior to the beginning of the control input) are compiled into a trim data file. To obtain these values in near real time, the processing computer performs the calculations at the conclusion of any single set of maneuvers.

The modified 2-3-1-1 (M2311) maneuver provides adequate information to allow the estimation of the stability and control derivatives at a test condition. It was developed to reduce data contamination from cross-coupled inputs and to avoid excessive deviations from trim conditions. The M2311 inputs were conducted with the yaw damper off and with the stability augmentation system (SAS) off. With the SAS off, while in forward flight, the aircraft remained stable during the main axis control inputs, and virtually no cross-axis control inputs were required. During the M2311, the pilot alternated step inputs, in 2-3-1-1 s, with the input size of the 3-s segment reduced to $\frac{2}{3}$ of the magnitude of the other three segments. Secondary

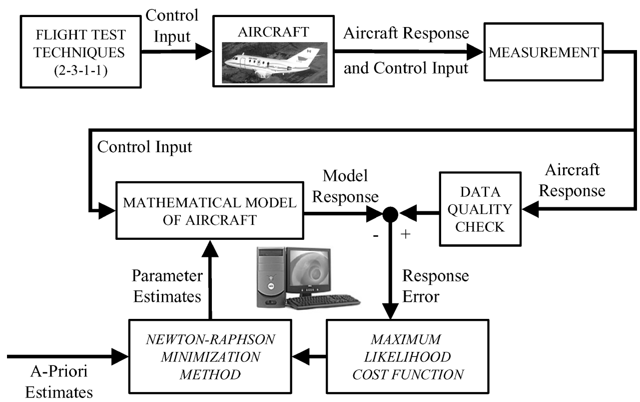

Fig. 4 Parameter estimation concept.

axis pulse control inputs were applied to prevent large deviations in the cross axis. To start the maneuver, the pilot maintains a 5-s trim period and then performs the M2311 maneuver using the elevator in the longitudinal axis, and the aileron followed by the rudder in the lateral axis. After each M2311 maneuver, the pilot lets the aircraft have a control free response for 5 s and then retrims the aircraft for 5 s to complete the maneuver. Care is also taken, during the M2311, to ensure that the pilot does not generate large amplitude inputs at higher frequencies. The M2311 maneuvers are then repeated throughout the aircraft's flight envelope.

In Fig. 4, the M2311 control input excites the mathematical model of the aircraft to generate the model responses that compare to the flight data to produce an error response cost function. The maximum likelihood technique is used to minimize this cost function by iterating the stability and control derivatives until the change in the cost function is below a chosen small error bound.

The technique developed by NRC for in-flight parameter estimation satisfies the near real-time requirement and has numerous advantages. By examining the results after the maneuvers, immediate feedback can be provided to the pilot as to how well the maneuver has been performed. This provides confirmation of the maneuver quality, allowing iterative modification, or improvements to the maneuver, to be made in flight. In addition, no postflight processing is required, which has the potential to shorten the overall flight-test program. However, all sensors must be calibrated before flight, with the exception of the air-data systems, which are calibrated in flight. The workload for the flight-test engineer is also increased by the requirement to examine the incoming data for anomalies.

The initial development of the in-flight parameter estimation technique[8] used the concept of minimal intrusion to the host aircraft's data-acquisition system. It was implemented as an additional system that received data parameters from the existing aircraft data-acquisition system. The results should be the same as those generated by the standard off-line processing. The in-flight parameter estimation system was completely self-contained and removable. Each flight test maneuver was self-contained, and information from past flight maneuvers was not required.

Global Model Development Process

Although the point model accurately describes the aircraft dynamics at any particular trim condition, thereby accounting for Mach effects, thrust effects, and flap setting, it does not provide the ability to predict the Mach or thrust contributions embodied in a given set of stability derivatives. Additionally, the point model does not describe the dynamics encountered with aircraft configuration changes. These weaknesses are addressed in the development of the global mathematical model. To develop a global mathematical model of the NRC Falcon 20, curve fitting and nonlinear dynamics optimization were used to construct a comprehensive aerodynamic model in an iterative process. After completing this process, the global model was verified using a proof-of-match technique.

Curve-fit identification follows from the point model of the stability and control derivatives, which are derived from small perturbation maneuvers around a trim condition, covering various aircraft configurations and flight conditions. In this type of identification, the derivatives are combined into functions. In general, these functions are formulated using Mach number M, α, β, and coefficient of thrust C_t. This process is repeated for all flap settings. For the Falcon 20, a set of equations was developed for each of the flap positions. The global model interpolates in between flap settings to compute aerodynamic forces and moments. By combining the point model results, an aerodynamic model valid over a broader range of the flight envelope is derived.

As mentioned earlier, each derivative is formulated as a function of aircraft flight conditions at different configurations in order to form a global model. The MATLAB® regression process is used to formulate all of the derivatives from the trim data file as a function of α, β, C_t, and M in linear, quadratic, product, and multiple regressor modes. The coefficient of correlation is used to determine the best fit to finalize the equation. If the coefficient of correlation value is less than a predetermined value, the average value of that derivative is used to represent its equation. This curve-fit process is automatic, but the end user has the option to override any equations based on subjective judgement. The six aerodynamic modules (X, Y, Z, L, M, N) that were generated then entered the nonlinear dynamics optimization and the POM process.

The analysis of the aerodynamic model was based on six dimensionless coefficients for each of the rigid-body degrees of freedom of the aircraft. The force coefficients C_D, C_L, C_Y were chosen in the wind axes reference frame, and the moment coefficients C_l, $C_m C_n$ were defined in the body axes reference frame. To obtain the aerodynamic drag C_D, a thrust model was required. This thrust model was developed using the original equipment manufacturer (OEM) performance manual and needed to be validated during the flight test phase.

The global model error in the three components of forces and moments was estimated using the 2-3-1-1 and Qualification Test Guide (QTG) maneuvers trim flight data. The error statistics derived from both the force coefficients and moment coefficients show the robustness of the model for the full envelope of the flight data. Model error was measured as either the equivalent control input required to compensate for the error, or the angle of attack, or sideslip spread necessary to perfectly trim the simulated aircraft.

Nonlinear Dynamics Optimization

Nonlinear dynamics optimization is a regression technique that identifies the cross-axis and nonlinear dynamics by minimizing the force and moment residual errors resulting from applying the curve-fit identification force and moment coefficients to actual aircraft time histories. By analyzing unique maneuver time histories such as approach to stall, landing-gear extension, or flap retraction, parameters to describe these nonlinear dynamics can be identified.

Examples of recent use of the nonlinear flight regimes/dynamic optimization technique to obtain global models to reach FAA Level D standards are listed next. This technique has been implemented in RAMI. From Refs. 9 and 10, in postflight data processing the following strategies were used to estimate the cross-axis stability and control derivatives, landing-gear dynamics, stall, one-engine-inoperative (OEI) dynamics, ground effects, and other related effects, for a high-performance jet and turboprop aircraft:

1) Develop a complete model, based on the 2-3-1-1 maneuvers, and compute the residual forces and moments for cross-axis effects.

2) Use the existing model, and maneuvers such as OEI, to identify differential thrust effects.

3) Use multiple regression to identify the effects of stall dynamics, including nonlinear effects.

4) Use flight-path reconstruction to correct the measured α and β for ground effects, leading to a ground-effects model.

References 9 and 10 show the off-line techniques to estimate the nonlinear dynamics from the simple cross-axis stability and control derivatives caused by the complicated stall-related effects. Most of the off-line processes have been converted into an automated form to estimate the nonlinear dynamics in a close to real-time process. Further development is required to expand this automatic process to include flap, gear, OEI, and stall dynamics.

Simulation—Global Aerodynamic Model Evaluation

This simulation process does not contain a trim routine, so that it cannot find a trim solution that optimizes the trim variables for each maneuver. Instead, force and moment offsets in the aircraft model are averaged before the maneuver starts and eliminated from the model before simulating. It also graphically offsets the controls to values equivalent to the model error for the pitch, roll, and yaw axes, in order to give the user an indication of the model trim error. This simulation step is optional and will only be used during the initial model development. Once sufficient trim points are collected, or the model reaches maturity, this process is not required.

Proof of Match

The RAMI POM is performed using the MATLAB, Simulink, Aerospace,® and Stateflow® blocksets. The atmospheric model and the standard aircraft equations of motion are included in the Aerospace blockset as a standard library. Also, Simulink provides many standard functions for simulation, called the S-function, which facilitate the building of the simulation model. To build the Falcon simulation model, the global model has been divided into six aerodynamic modules that are composed of three force (X, Y, Z) and three moment (L, M, N) S functions in MATLAB M-files. The advantage of using Simulink and the blocksets is to build the aerodynamic simulation model using commercial-off-the-shelf software, with flow diagram blocks that are easy to understand.

In the POM step, the FAA AC 120 40B[11] tolerances are used as criteria in the QTG trajectories to complete the Level D flight model requirements. The aircraft trim routines, based in MATLAB, are being further developed for robustness and streamlined into a relatively automatic process to trim the aircraft in the POM simulated flight environment.

After the global model is finalized and converted into MATLAB format, a trim routine, developed in the MATLAB/Simulink environment and using the sequential-quadratic-programming algorithm, determines the trim conditions of the aircraft. The model computes the forces and moments of the aircraft and finds its nearest trim position.

The global model was validated by using the POM process. For a given maneuver, a test definition file (TDF) was set up to obtain the initial conditions of the aircraft. The trim routine finds the trim conditions of the aircraft by determining the aircraft control positions and the initial states of the aircraft. Minor adjustments of the initial conditions might be required to ensure that the simulated responses of the aircraft are within the FAA 120 40B tolerances.

For this paper, these simulations are driven by the measured control surface deflections. In the future, the flight controls will be integrated to the control sticks such as pilot force inputs.

RAMI Flight-Test Program

Early development of the point model for the Falcon 20 research aircraft involved flight testing in October 1999 and January 2000. The goal of these flights was to obtain data for postflight air-data systems calibration and aerodynamic model identification. During the third flight test, a near real-time aerodynamic model identification flight test was conducted. M2311 control inputs were used as the primary test maneuver. In the fall of 2002, during the fourth flight test flight data were collected and used to validate the aerodynamic model. The aircraft configurations and selected altitude for the flight test are documented next.

The four flights were performed in calm air conditions, on different days, at pressure altitudes of 10,500 ft (3,200 m). The aircraft was flown from 150 to 225 kn, inclusive, using 25-kn increments with flaps and landing gear up. The elevator δe, aileron δa, and rudder δr control inputs were performed at each speed. The takeoff weight of the aircraft was 24,287 1b (11,016 kg). The flight test consisted of two types of maneuvers. The first was the wind-box formation, described earlier (see Fig. 2), which was used to calibrate the air-data systems, and the second maneuver type was 2-3-1-1 control inputs.

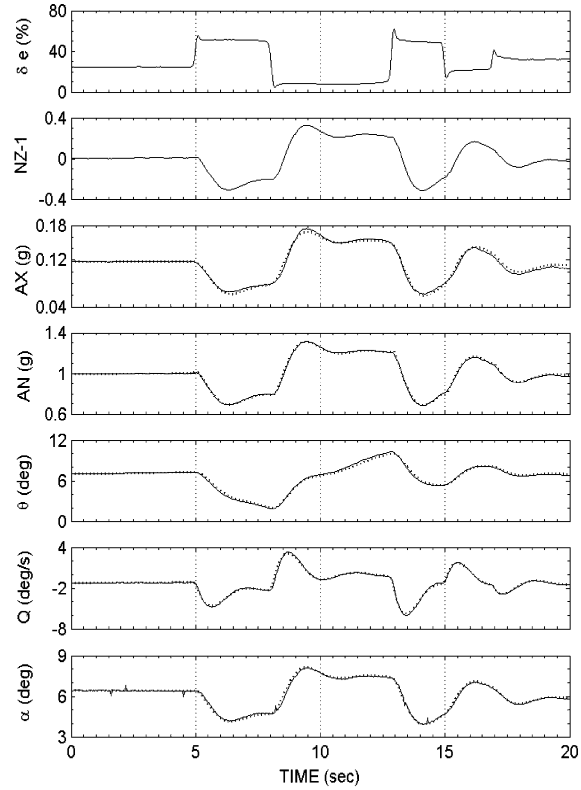

Fig. 5 NRC Falcon 20 point identification: longitudinal match for 160 kn and 10,000 ft; ——, flight data; and - - - -, model results.

Results from Using RAMI Process

Point-Model Identification Results

To examine the fidelity of the point model, the model responses and flight data were plotted.

Figure 5 shows one of the Falcon 20 longitudinal elevator responses. An excellent match occurs, and no difference could be found when the maneuver was analyzed again, in postflight processing.

Figure 6 shows a plot of the lateral maneuver case, which was analyzed with the separate aileron and rudder cases being concatenated. Because any lateral control inputs excite the same lateral stability matrix, this concatenation allows the estimation of the stability matrix while the control contains both the aileron and rudder control matrix. Again, an excellent match was found for the lateral acceleration, yaw and roll rates, bank angle, and angle of sideslip.

Global Model Development Process

Figure 7 shows an example of the point-model estimates of $C_{l\beta}$ (rolling moment caused by sideslip angle derivative) plotted vs α.

As mentioned earlier, each derivative is regressed as a function of α, β, C_t, and M. Using the trim data, the dependencies of each derivative on the preceding parameters pertaining to each derivative were identified. For example, the $C_{l\beta}$ derivative is given by

$$C_{l\beta} = C_{l\beta 0} + C_{l\beta\alpha}\,\alpha$$

This formulation was then compared to the derivatives determined by the modified MLE (MMLE) process. Figure 8 shows a comparison of $C_{l\beta}$. ($C_{l\beta c}$ is the computed value, and $C_{l\beta m}$ is the point-model value.) The 45-deg slope of the line that fits the data implies a good agreement between the two quantities $C_{l\beta c}$ and $C_{l\beta m}$.

All model error statistics were nominally within the tolerance of ± 1 deg for the controls and ± 0.5 deg for the attitudes.

The global model process develops a set of force and moment equations for each flap setting. In the next section, the nonlinear dynamics optimizer identification of the rigid-body aerodynamics

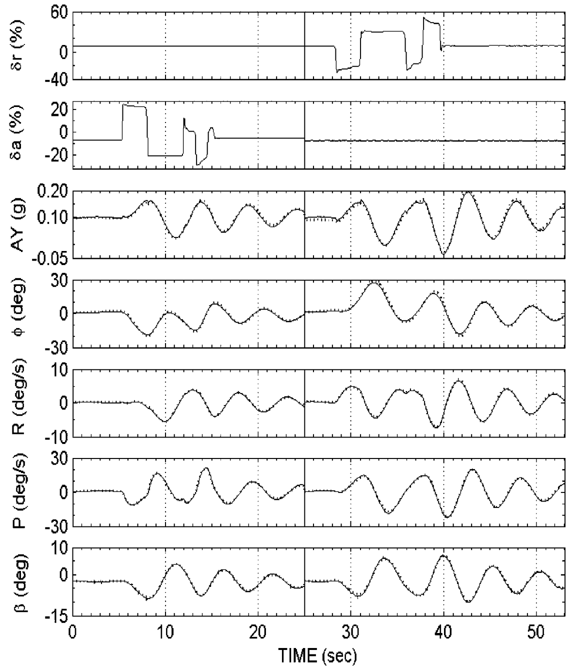

Fig. 6 NRC Falcon 20 point identification: lateral match for 175 kn and 10,500 ft; ——, flight data; and - - - -, model results.

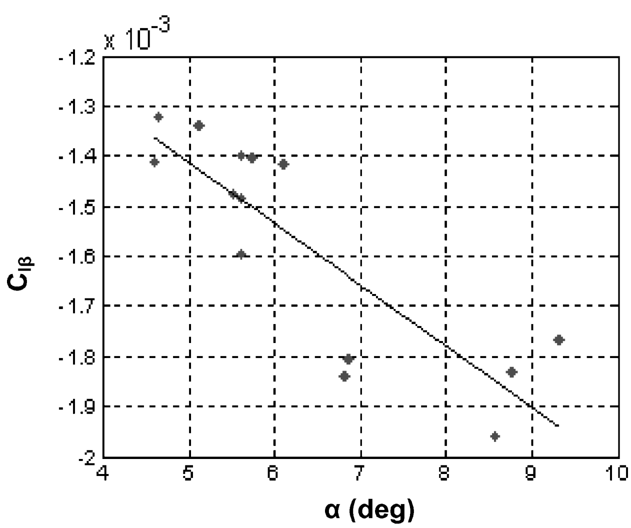

Fig. 7 Change of derivative of roll caused by sideslip with angle of attack.

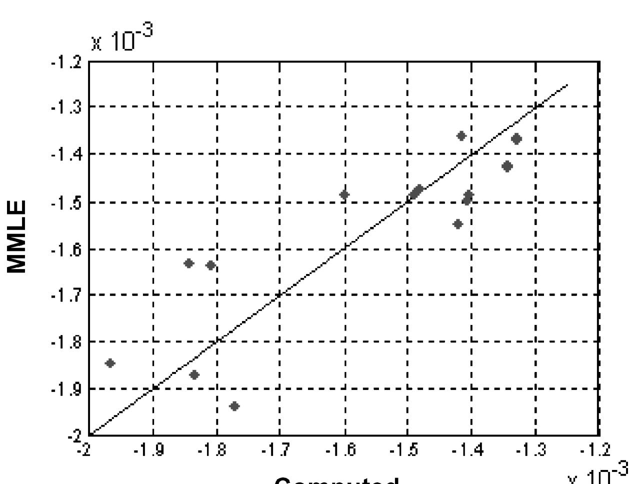

Fig. 8 $C_{l\beta}$ function—MMLE vs computed.

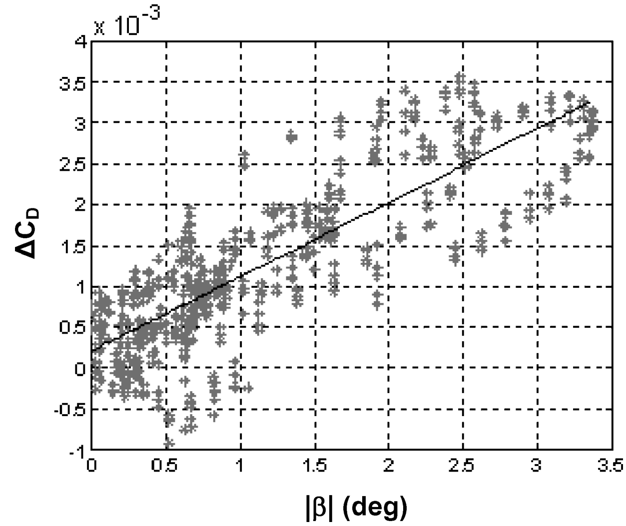

Fig. 9 ΔC_D vs $|\beta|$ from the nonlinear dynamics optimization process.

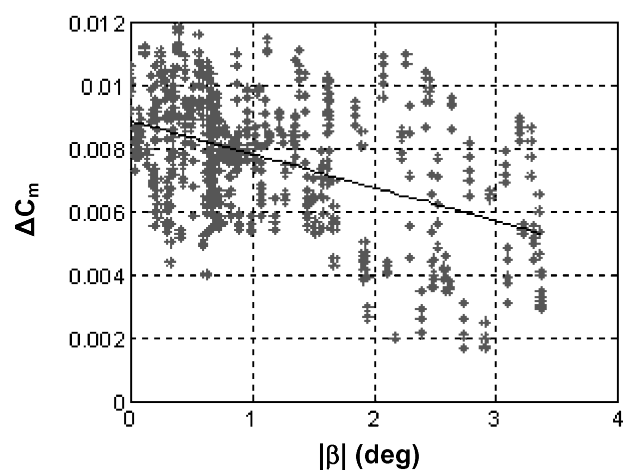

Fig. 10 ΔC_m vs $|\beta|$ from the nonlinear dynamics optimization process.

yields a set of derivatives for each flap setting that are combined into a single model by incorporating a linear interpolation, dependent on flap settings. The sequence followed in the POM process was to match the 2-3-1-1 maneuvers, and then the single-axis control maneuvers followed by the high angle of attack, engine dynamics, takeoff, and landing.

At the end of this process, the six-degrees-of-freedom (X, Y, Z, L, M, N) aerodynamic model equation files were automatically created for model validation.

Nonlinear Dynamics Optimizer Results

Figure 9 shows the cross-axis term of the coefficient of drag force caused by the absolute value of the angle of sideslip, which was found by using the optimization technique in an automatic process. Because of either small sensor error or modeling error, ΔC_D was nonzero at β equals zero.

From experience, for most aircraft the cross derivative $C_{m\beta}$, which is the coefficient of pitching moment caused by absolute value of angle of sideslip, is usually significant. Figure 10 shows the relationship between ΔC_m and the absolute value of the angle of sideslip. For the NRC Falcon 20 aircraft, the pitching moment caused by sideslip is weak. Similarly, because of either small sensor error or modeling error, ΔC_m was nonzero at β equals zero.

Simulation—Global Aerodynamic Model Evaluation

The simulation process provides a quick and easy way to evaluate the model fidelity. The simulation is a six-degrees-of-freedom equation of motion solver written in a MATLAB script.

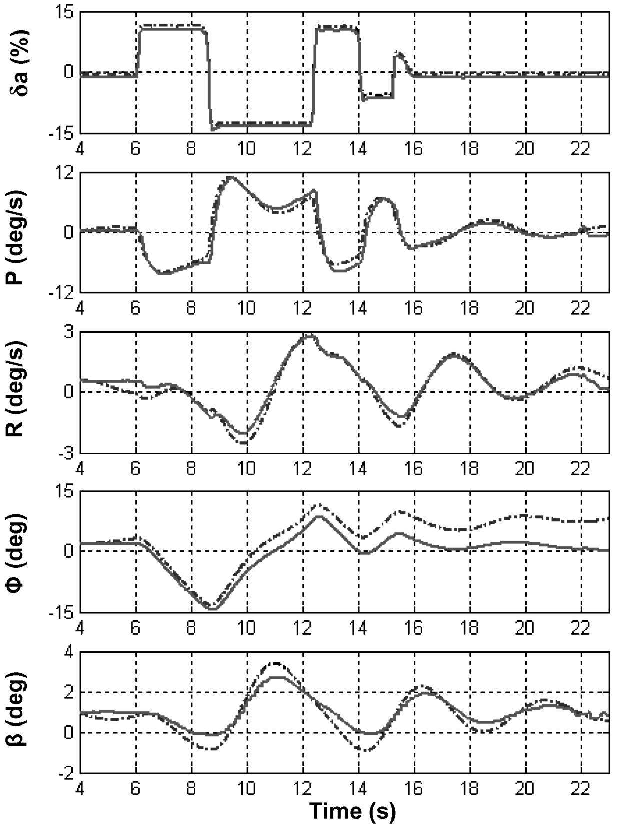

Fig. 11 NRC Falcon 20 simulation results at 120 kn IAS: ——, flight data; and - - - -, model results.

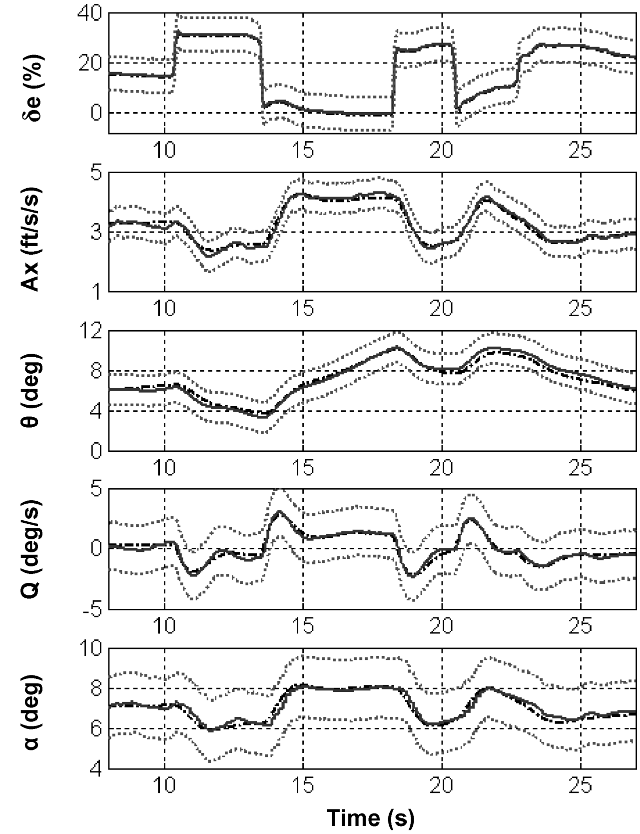

Fig. 12 NRC Falcon 20 elevator control input POM results at 160 kn IAS: ——, flight data; - - - -, model results; and . . . ., specification bounds.

The simulation process is used after the automatic process of curve fitting the stability and control derivatives and the nonlinear aerodynamic optimization process. It provides a measure of the model fidelity in both the control trim tolerances and the aircraft responses when the model responses are compared to the flight data. Also, it shows the trends in the (possibly) missing dynamics. Usually, nonlinear aerodynamics optimization and the simulation processes are used, in an iterative fashion, to capture the significant dynamics for fixed-wing aircraft. Figure 11 shows the model responses and the flight data for a 2-3-1-1 control maneuver at 120 km indicated airspeed (AS). The residual forces and moments in the trim period (first 2 s) were used. These residuals were nulled out by changing the control positions and holding the original derivative values. The aileron position shows a change of less than 1% (0.15 deg). Currently, engineering judgement is used to accept the model fidelity. For this case, it is concluded that the model responses match well with the flight data, except for bank angle Φ. At this point, the developing model is accurate enough to be validated by the POM process.

POM of the Aerodynamic Model

Figures 12 and 13 show the Falcon 20 aircraft elevator and aileron responses, respectively, comparing the flight data to the model responses. The FAA 120 40B tolerance limits are added in the plots as dotted lines. The initial conditions of the rates were derived from the trim segment of the flight data and put in the TDF. In Fig. 12, the pitch rate Q was adjusted slightly by the end user. However, the adjustment of the rates is within the accuracy tolerances ($\pm 0.25^\circ$/s) of the sensors.

Figure 12 indicates that the elevator position in the model trim position is slightly different from the measurement. Also, the small difference between the model response and the flight data, for force and moment, is because of instrumentation error and/or modeling error. The other states, (for example, α and pitch attitude) are determined by the aircraft equations of motion. The model generates a high-fidelity match to the flight data, and all of the model responses

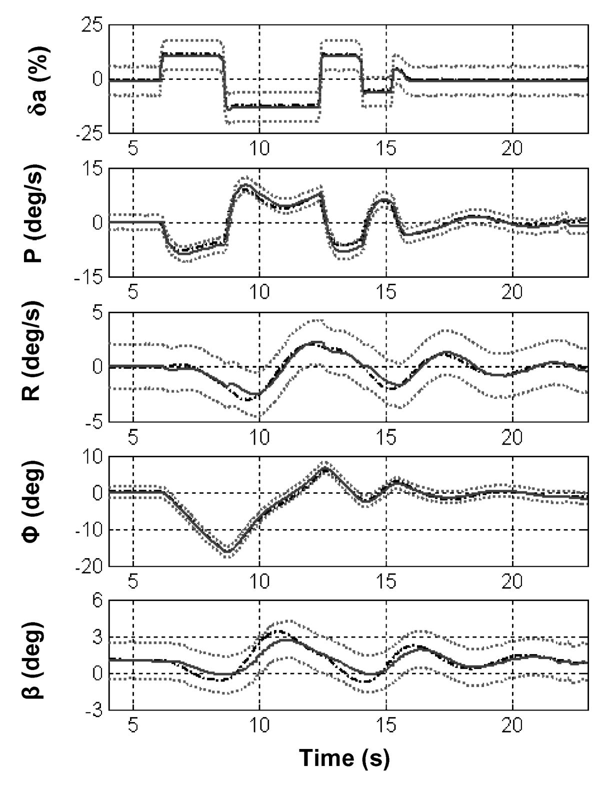

Fig. 13 NRC Falcon 20 aileron control input POM results at 210 kn IAS: ——, flight data; - - - -, model results; and . . . ., specification bounds.

Table 1 In-flight parameter estimation program timings

Axis	Flight maneuver length, s	Computation time, s
Longitudinal	20	2.094 max
	20	1.484 min
Lateral	Aileron: 20	7.359 max
	Rudder: 25	
	Aileron: 20	4.281 min
	Rudder: 25	

Table 2 In-flight global model development timings

Process	Data length	Computation time, s
Curve fit	20 cases	6–8
Nonlinear dynamics	54 s	2–3
Simulation	19 s	1–2
Proof of match	20 s	6–8

are within the tolerance bounds. Figure 13 also indicates that the aileron control input β and Φ are within the tolerance bounds.

Time Requirement

The onboard data system on the Falcon 20 transmitted a set of 24 aircraft parameters to the RAMI computer at a 32-Hz rate, via a serial link. The modified onboard parameter estimation program received and processed the data and then computed the model parameters. Maximum and minimum processing times to compute the model parameters were obtained and are given in Table 1. Identification of the derivatives for the longitudinal and lateral axes required a maximum of 2 and 8 s, respectively.

Table 2 shows the elapsed computing time required for the curve fit, nonlinear model dynamics, simulation and POM. The total time required is 15 to 21 s. Both the nonlinear dynamics and simulation processes might be required if a maneuver is proven to produce a poor match at the POM step.

Future Work

Ongoing developments will provide faster and higher quality aircraft global mathematical models. The following near-term goals have been identified: 1) a flight-test engineering interface to flag data and maneuver problems; 2) validation of the nonlinear flight regimes in flight; 3) an improved automated curve-fitting process; 4) an efficient identification of nonlinear terms; 5) generation of model interface routines to allow automated simulation and POM steps; 6) development of graphics definition file and table look-up functions; and 7) total elapsed time reduced by a factor of two.

In the real-time application of the mathematical model for control law development, the operating system and parameter estimation software will need to be upgraded for higher performance.

Conclusions

The following summarizes the main conclusions and lessons learned while developing the onboard RAMI technique to identify a mathematical model of the NRC Falcon 20 aircraft:

1) The near real-time point model requires approximately 2 and 8 s to identify the longitudinal and lateral axes, respectively.

2) The total computation time required for the in-flight global model development process is 15–21 s.

3) The simulation evaluation provides a quick and easy assessment of the developing model.

4) A trim routine has been developed, and the POM process provides the validation of the aerodynamic model to the tolerance limits of Federal Aviation Administration 120 40B.

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