Data Processing Consideration and Model Validation in Flight Vehicle System Identification

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Abstract. There are four steps in system identification. Data Processing constitutes the first and most essential step. In this paper an overview of the flight data processing for reaching a sound set of data is presented. It includes the analysis of the types of data available, the method of exclusion of outliers and noise, bias corrections, and filtering of disturbances. Filtering include time domain and frequency domain processing. On the other hand, model validation is considered the final step for aircraft identification. This was accomplished for an innovative model of elevator hinge moment (EHM) in a turboprop aircraft equipped with a mechanical control system. Here, optimization of the identification design has been achieved by iteratively estimating the unknown model parameters.

Keywords: Data Processing, Model Validation, Hinge Moment Parameters, Parameter Identification.

1 Introduction

It is a standard practice in industry and academic communities to use flight test data for system identification. The results are used for developmental purposes as well as design validation [1]. There are four steps to be followed for system identification: data gathering, model postulate, parameter identification and model validation. Data gathering is considered as the first and essential part in identification terminology, used as the input for the model which is prepared later. It consists of selecting an appropriate data set, pre-processing and processing them for the work [1], [2], [3], and [4]. It involves the implementation of the known algorithms together with the transcription of flight tapes, data storage and data management, calibration, processing, analysis and presentation. Moreover, Model validation is necessary to gain confidence in, or reject a particular model. In particular, the parameter estimation and the model validation are integral parts of the system identification. Validation refers to the process of confirming the conceptual model and demonstrating an adequate correspondence between the computational results of the model and the actual data. Identification for control is defined when modeling a dynamic system (e.g. EHM system) with identification techniques (like Maximum Likelihood (ML)

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Estimation Techniques based on an Optimization Cost Function). In doing so, a model of limited complexity (like Elevator surface control model) is used specially for feedback and feed forward control design (e.g. a control loader system) and evaluation purposes (e.g. by the use of raw flight recorded data and sensors' outputs) [5]. In what follows the special requirements and techniques for EHM identification will be discussed for each of the data processing and the model validation steps.

2 Choosing Appropriate Types of Data Sets

Flight data acquisition can be done by any of the two methods: first is through a preplanned flight test program during which attempts are made to perform the test in a proper and orderly manner as well as using adequate equipment for this purpose. Second is based on gathering normal flight data from their advance digital flight data recorders after each flight. Due to estimate the parameters, appropriate data sets are considered as flight test data, but availability of such a data from the second method requires a necessary pre-processing step in order to reach appropriate data sets for estimation process [4]. Dealing with normal flight data, *outliers* are series of points out of range by a wide margin and do not follow a normal trend. They may be produced by either sensor or related circuits installed for data acquisition. It may cause divergence problems when used for estimation purposes. However, selection of suitable criteria is of utmost importance since it could result in useful data losses. Fig. 1 shows the ψ angle data points taken by digital flight data recording devices from a normal flight. Points highlighted with circle seem to be outliers. Here, an innovative method has been coded in MATLAB software to omit them. The right side plot indicates a considerable improvement in the range of variations of the ψ angle [4].

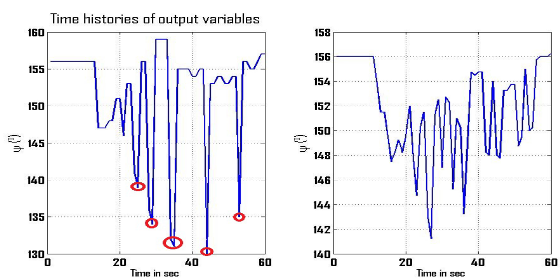

Fig. 1. Demonstration of the effect of outlier omission on a set of data [4]

2.1 Data Compatibility Check

There are techniques such as Flight Path Reconstructions (FPR) used when dealing with bias corrections. This is necessary when position and installation errors occur in aircraft construction, e.g. in accelerometers or rotational measuring instruments like rate gyros [1].Here, the instrument bias errors are the unknown parameters in pre-processing procedure; that is, Kinematic equations concerning measured quantities like linear accelerators, Euler angles and their angular rates can be corrected by considering their related bias parameters (such as Δa_X , Δa_Y and Δa_Z for accelerometers, and Δp , Δq and Δr for rate gyros) [1]. Fig. 2 shows convergence of bias parameter estimates with error bounds for a specified set of data by Output Error Method (OEM) [4], demonstrated for three accelerometers and angular rates. Order of magnitudes for angular rates is of small range about one thousandth or smaller, in comparison with those of accelerometers which is of about one tenth or a bit more [4].

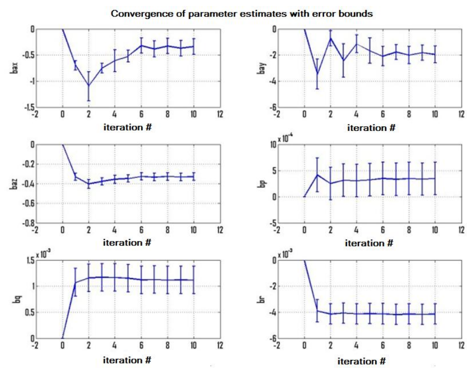

Fig. 2. Convergence of bias estimates with error bounds, ended in 10 iterations [4]

2.2 Disturbance and Noise

In general, there are two kinds of errors in parameter identification: measurement errors and the process noise. Some estimating algorithms like filter error method (FEM) based on ML Method consider both in their formulations. Others like OEM consider only measurement noise and are sensitive to the presence of process noise. However, preprocessing techniques can also help to eliminate it.Process noise, like the effect of Turbulence and gust loads, are unwanted inputs to the system and may enter the dynamic model via recorded flight data. However, dealing with normal FDR needs either sufficient knowledge about the allowable frequency domains of the sensors, called frequency bandwidth, or good understanding of the disturbance. Obviously, unavailability of both may cause the procedure useless. Experimental observations over several series of flight data points reveal that range of frequency domain for presence of process noise is usually less or equal than 0.5 Hz and for measurement noise is equal or larger than 10 Hz [6]. Hence, to decrease the turbulence effect with a lack of sufficient knowledge, implementation of such approximation may sounds good [4].Here, an innovative technique has been created in a MATLAB; it works based on weighted coefficients depending on the number of selected points to be smoothed over the whole data trend. Fig.3 shows the effect of filtering techniques for a normal FDR, in which red plots on the right are smoothed plots and the blue ones on the left are ordinary. Digital signatures are acceptable.

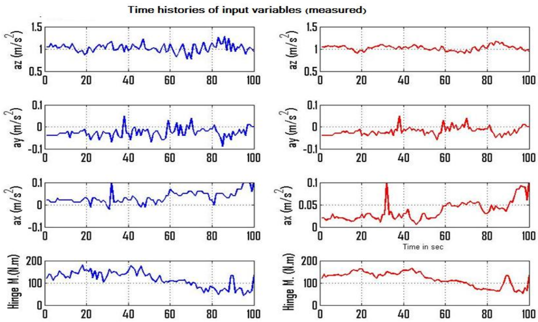

Fig. 3. Effect of smoothing techniques on filtering data points by FDR [4]

3 Model Validation

Validation procedure in flight identification can be divided into two parts. The first is the compatibility check between the system response (measured) and the mathematical model computed response (estimated). The second includes the numerical convergence of the specified estimation techniques [4].

3.1 Inverse Simulation in Identification of EHM

Here, an inverse simulation of elevator control surface has been designed for hinge moment identification. That is, the measured EHM can be supposed as system model response and the EHM coefficients may be defined as desired control inputs instead of elevator deflections themselves. The relationship between the known variables and the unknowns is formulated as [4]:

$$\begin{cases} C_{he} = \dfrac{HM_m}{qS_e \bar{C}_e} \\ C_{he} = C_{h\alpha}\alpha_t + C_{h\delta e}\delta_e \end{cases} \tag{4}$$

in which HM_m (the measured EHM), q (dynamic pressure), S_e (elevator control surface area), C_e (mean elevator chord), α_t (tail angle of attack), δ_e (measured elevator deflection) are the known variables and $C_{h\alpha}$ and $C_{h\delta e}$ are the unknowns. However, such equation can be written for any control surface. Figs.4.a and 4.b show the compatibility between the measured EHM and the estimated HM, in turn, done by the two estimation techniques of ML method. As it is observed, both plots admit the good tracking of the input hinge data points by the estimated ones during the off-line simulation [4].

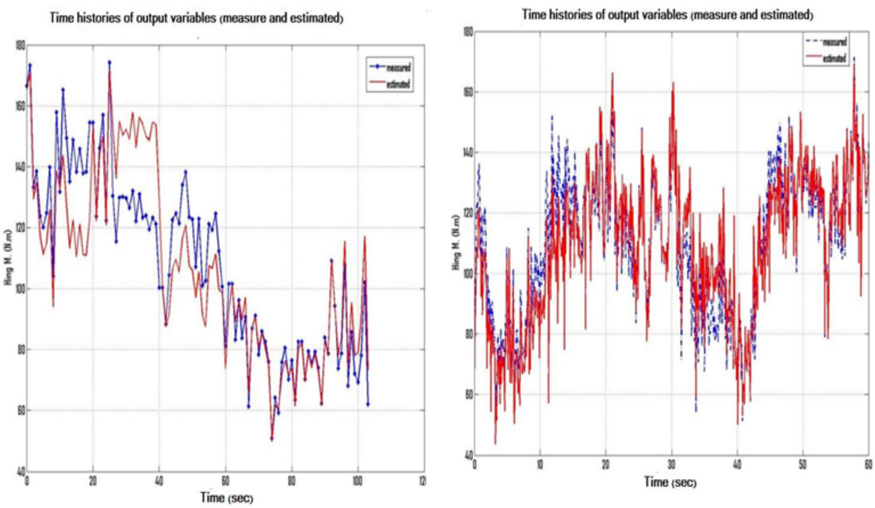

Fig. 4. Validation of HM: the measured (blue trend) and estimated (a) OEM, (b) FEM

3.2 Hinge Moment Validation via Cost Function Minimization

In an optimal based strategy algorithm like ML, a cost function (e.g. determinant of covariance matrix of the residuals) has been defined to be minimized. Better estimation results go with the lowest values obtained. Table 1 shows the feasibility of convergence procedure in the FEM applying for HM coefficients identification. Other values include the number of iterations, the numerical method of Levenberg-Marquardt algorithm, and the convergence tolerance magnitude. Numerical simulation confirms the identification process [4].

Table 1. FEM Convergence Procedure for Hinge Moment Identification [4]

Iter no	detR Correction of F (Updated R)	Iter no	detR Correction of F (Updated R)
0	5.1417e-021	7	4.4398e-029 Correction of F - 4.4243e-029
1	1.4533e-026		
2	2.4406e-027	8	4.4208e-029 Correction of F - 4.4096e-029
3	1.1412e-027 Correction of F - 8.3886e-029	9	4.4079e-029 Correction of F - 4.4002e-029
4	6.5701e-029 Correction of F - 4.8878e-029	10	4.3994e-029 Correction of F - 4.3942e-029
5	4.5131e-029 Correction of F - 4.4893e-029	11	4.3937e-029 Correction of F - 4.3902e-029
6	4.4624e-029 Correction of F - 4.451e-029	12	4.3899e-029

4 Conclusion

In the present paper, identification procedure of HM parameters for a control surface was presented. The pre-processing and validation steps of the whole process were analyzed in details. After choosing an appropriate set of flight data, instrument errors were considered as bias parameters in sensor modeling; then, pre-processing was introduced by FPR. Time and frequency domain techniques were introduced to decrease the measurement and process noise effects. Several criteria in validation procedure for EHM were performed on an innovative HM model. Depicted results classified in two categories, graphical and analytical outputs, showed satisfactory and acceptance of the whole HM identification [4]. Future work will be devoted to design a control technique, through which the position control of the hydro or electro mechanical system, namely control loader system, is to be achieved by the input identified parameters [7].

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