IDENTIFICATION OF FLIGHT PARAMETERS OF LIGHT SPORT AIRCRAFT

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Abstract: In this paper, an identification of flight parameters is described. The identification of aircraft aerodynamic and stability parameters is not a common practice in category of light sport and ultra light aircraft. The results of this identification could be used during the development of safety critical aircraft systems. The identification is presented and compared with vortex lattice method.

Keywords: Aircraft, airplane, identification, flight parameters, stability derivatives, aerodynamic coefficients.

1 INTRODUCTION

The identification process allows the creation of high fidelity simulators for the increase in quality of training and its accessibility. The results of this identification could be used during the development of safety critical aircraft systems. The identification of aircraft aerodynamic and stability parameters is not common practice in the segment of light sport and ultra light aircraft. The necessity of high fidelity identification becomes more important because light sport and ultra light aircrafts are experiencing growth.

This paper is organized as follows. The section 2 presents the identification process. In section 3 the testing aircraft and the data acquisition system are described. The description of testing maneuvers and discussion of test results is shown in section 4.

2 IDENTIFICATION PROCESS

An aircraft is six degrees of freedom object. The motion of aircraft can be divided into superposition of two motions (longitudinal and lateral). The only longitudinal motion is discussed in this article. The longitudinal motion is three degree of freedom motion, which can be described by the set of differential equations (kinematic equations) [3]:

$$\dot{V} = \frac{\bar{q}S}{m}C_D - g\sin(\theta-\alpha) + \frac{T}{m}\cos\alpha \quad (1)$$

$$\dot{\alpha} = -\frac{\bar{q}S}{mV}C_L + q + \frac{g}{V}\cos(\theta-\alpha) + \frac{T}{m}\sin\alpha \quad (2)$$

$$\dot{\theta} = q \quad (3)$$

$$\dot{q} = \frac{\bar{q}S\bar{c}}{I_y}C_m \quad (4)$$

where V is the speed of aircraft with respect to surrounding air, α is the angle of attack, q is the pitch angular velocity, θ is the pitch angle, C_L, C_D are aerodynamic force coefficients in stability coordinate system, C_m is the aerodynamic moment coefficient in aircraft coordinate system, $\bar{c}$ is the length mean aerodynamic chord, I_y is the moment of inertia in the axis y in aircraft coordinate system, g is the gravitation acceleration, S is the wing reference area, $\bar{q}$ is the dynamic pressure, T is the propulsion force and m is the mass of an aircraft.

The aerodynamic model of the aircraft can be expressed in many ways depending on requested precision. The most precise model of longitudinal aerodynamics can be described by set of general functions. For purpose of comparison of aerodynamic model between identification and other methodologies, it has been choosen aerodynamic model based on linear equations:

$$C_D = C_{D_0} + C_{D_\alpha}\alpha + C_{D_q}q^* + C_{D_\eta}\eta \quad (5)$$

$$C_L = C_{L_0} + C_{L_\alpha}\alpha + C_{L_q}q^* + C_{L_\eta}\eta \quad (6)$$

$$C_m = C_{m_0} + C_{m_\alpha}\alpha + C_{m_q}q^* + C_{m_\eta}\eta \quad (7)$$

where C_{D_0}, C_{L_0}, C_{m_0} are aerodynamic coefficients without the effect of elevator in the static state with zero angle of attack , C_{D_α}, C_{L_α}, C_{m_α}, C_{D_q}, C_{L_q}, C_{m_q}, C_{D_η}, C_{L_η}, C_{m_η} are aerodynamic coefficients describing aerodynamic of an aircraft (sometimes called "stability derivatives"), η is the deflection of the elevator, α is the angle of attack and q^* is a dimensionless pitch angular velocity computed from equation:

$$q^* = \frac{q\bar{c}}{2V} \quad (8)$$

The static state is a state where the time derivatives of all state variables are zero. Aerodynamic equations 5, 6 and 7 use superposition of effects of each stability derivative. These equations could be used in simulation without the need of static state.

Whole process of identification consists of the initial estimation of flight parameters and the iterative enhancement of the estimation of flight parameters.

2.1 INITIAL ESTIMATION OF FLIGHT PARAMETERS

The first step in identification process is the differentiation of measured value with low–pass filtering [2]. These differentiated data is used as left–hand side of kinematic equations (1, 2, 3, 4). The expressed coefficients C_D, C_L, C_m are arranged to matrix:

$$\mathbf{Z} = \begin{bmatrix} C_D & C_L & C_m \end{bmatrix} \quad (9)$$

Then the matrix of independent inputs is formulated as:

$$\mathbf{X} = \begin{bmatrix} 1 & \alpha & q^* & \eta \end{bmatrix} \quad (10)$$

where 1 is a vector of ones with the same length as vectors α, q^* and η.

The least squares method is used for computation of the estimate of this matrix. This method is in detail described in [2]. In the case of non–singularity $\mathbf{X}^T\mathbf{X}$, it is possible to find solution as:

$$\hat{\boldsymbol{\theta}} = (\mathbf{X}^T\mathbf{X})^{-1}\mathbf{X}^T\mathbf{Z}^T \quad (11)$$

where x^T is a transposed matrix x and x^{-1} is the inverse of the matrix x.

The result matrix of estimation $\hat{\boldsymbol{\theta}}$ of aerodynamic coefficients is arranged as:

$$\hat{\boldsymbol{\theta}} = \begin{bmatrix} C_{D_0} & C_{D_\alpha} & C_{D_q} & C_{D_\eta} \\ C_{L_0} & C_{L_\alpha} & C_{L_q} & C_{L_\eta} \\ C_{m_0} & C_{m_\alpha} & C_{m_q} & C_{m_\eta} \end{bmatrix} \quad (12)$$

It is possible to replace $(\mathbf{X}^T\mathbf{X})^{-1}\mathbf{X}^T$ by Moore–Penrose pseudoinversion of matrix $\mathbf{X}$ [1]. This approach has better parameters of error detection in comparison with approach with inversion of matrix $(\mathbf{X}^T\mathbf{X})^{-1}$ [2].

2.2 ITERATIVE ENHANCEMENT OF ESTIMATED FLIGHT PARAMETERS

The second step of identification process is iterative enhancement of parameters. The output error method (OEM) is used. The method consists of the simulation of the flight based on the vector of elevator position with respect to time η, initial conditions V_0, α_0, θ_0, q_0 and integration step dt [3]. The simulation is based on commonly used Runge–Kutta 4^{th} order integration method. The integration of the kinematic equations with insertion of the aerodynamic equations gives us output variables matrix $\mathbf{y}$ arranged as:

$$\mathbf{y} = \begin{bmatrix} V & \alpha & \theta & q \end{bmatrix} \tag{13}$$

Let's assume that measured variables can be expressed as the sum of output variables and response error:

$$\mathbf{z}(i) = \mathbf{y}(i) + \boldsymbol{\upsilon}(i) \tag{14}$$

where $\mathbf{z}$ is the matrix of the measured flight data, $\boldsymbol{\upsilon}$ is the response error.

Let's assume that $\boldsymbol{\upsilon}$ has normal distribution $\mathbb{N}(0,\mathbf{R})$ then negative log–likelihood function of the response error takes the form [2]:

$$-\ln[p(\mathbf{z},\boldsymbol{\theta})] = \frac{1}{2}\sum_{i=1}^{N}\boldsymbol{\upsilon}^T(t)\mathbf{R}^{-1}\boldsymbol{\upsilon}(t) + \frac{N}{2}\ln[\det(\mathbf{R})] + \frac{N \cdot n_y}{2}\ln(2\pi) \tag{15}$$

where p is the likelihood function, $\mathbf{R}$ is a covariance matrix, N, n_y are dimensions of the matrix $\boldsymbol{\upsilon}$.

The negative log–likelihood function is used as a cost function J for minimization. In the case of unknown covariance matrix $\mathbf{R}$, the cost function J can be simplified to form [2]:

$$J(\boldsymbol{\theta}) = \det\left[\sum_{k=1}^{N}\boldsymbol{\upsilon}(t_k)\boldsymbol{\upsilon}(t_k)^T\right] \tag{16}$$

After the integration, modified Newton–Raphson method [3] is used to minimize the cost function by changing of the aerodynamic coefficients. The iteration of enhancing the estimation is stopped when the change of parameters $\boldsymbol{\theta}$ decrease under 10^{-4}.

3 TESTING AIRCRAFT AND DATA ACQUISITION SYSTEM

The reference input and state data have been measured on a testing light sport aircraft (SportStar RTC from Evektor Aerotechnik [4] - see Figure 1).

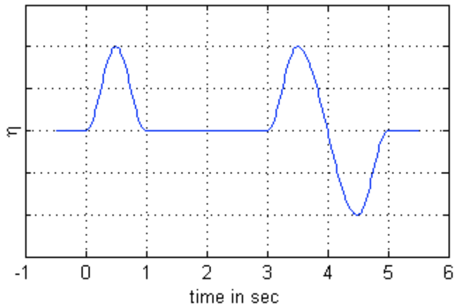
(a) Aircraft used for flight experiment. (b) Data acquisition system installation.

Figure 1: Experimental aircraft Evektor Aerotechnik SportStar RTC.

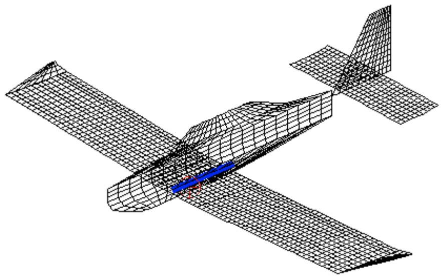
The data acquisition system is based on National Instruments platform CompactRIO [5]. This platform consists of PowerPC controller running Realtime Operating System, chassis with embedded field-programmable gate array (FPGA) and high precision digital analog converters (DAC). This data acquisition system is interconnected by the CANaerospace protocol with attitude heading reference system (AHRS) combined with global position system (GPS) receiver. The data acquisition frequency is 50 Hz.

4 RESULTS OF IDENTIFICATION

Our flight tests consist of two maneuvers (pulse and doublet) executed in five different airspeeds to excite aircraft flight reaction for our identification purposes. The pulse maneuver consists of short duration elevator push–down input with returning to original position. The doublet maneuver consists of two short duration elevator inputs. The first input is push–down, the second input is pull–up. The airspeed for identification was chosen from range between stall speed and cruise speed. The shape of maneuvers is shown on Figure 2(a).



(a) The shape of elevator maneuvers used for identification – pulse (left), doublet (right).



(b) Visualization of the model of the Sportstar RTC in Tornado.

Figure 2: The elevator inputs and the aircraft model in Tornado.

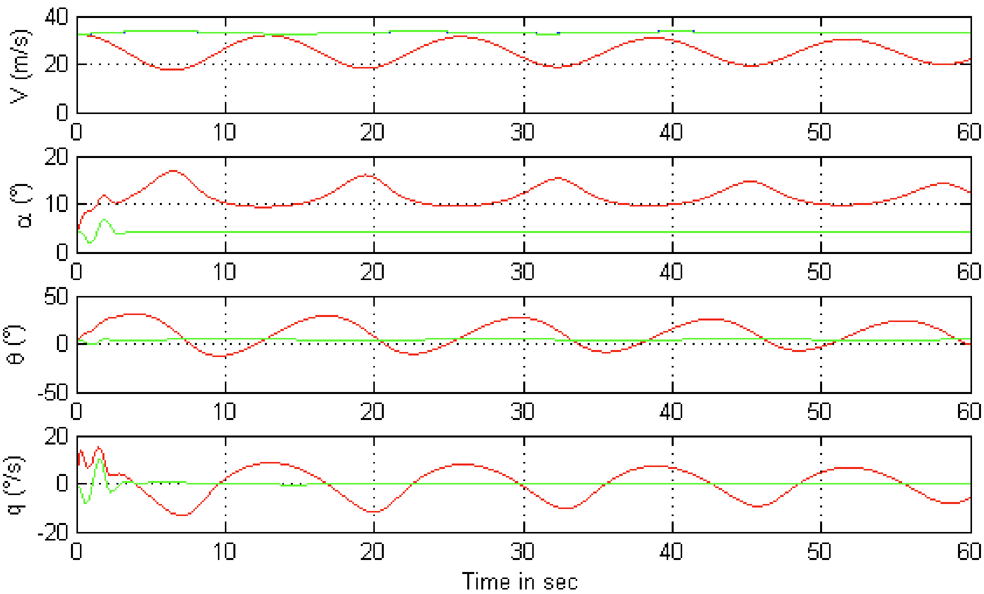


Figure 3: Comparison of measured flight data (blue line), simulated flight data based on identified parameters (green line) and simulated flight data based on predicted parameters from Tornado (red line).

Ten flight maneuvers were initiated in altitude 1200 meters above mean sea level. The flight data was recorded and used as measured variables for identification.All measured data was used for identification. The identified parameters were used for simulation and the simulated data was compared to measured data. For evaluation purposes Tornado software has been used for estimation of aerodynamic coefficients based on geometric property of the aircraft. The Tornado software [6] is commonly used software to predict behavior of aircraft. Tornado is based on vortex lattice method to compute aerodynamic parameters. The model of the geometric property of the Sportstar RTC is visualized on figure 2(b).

Example of measured flight data, simulated flight data based on identification and simulated data based on prediction from Tornado are compared on figure 3. It is possible to see almost full covering of blue line by green line but the red line has slightly different behavior.

5 CONCLUSION

The identification process is described in this paper. The identification is presented on light sport aircraft category. In this category of aircraft identification process is not used for evaluation purposes. The identification can verify predicted models from other methods and can provide increased confidence that aircraft is working within designed limits.

The identification process can be used as source of parameters for high fidelity simulation. This high fidelity simulation can allow precise tuning of certain systems of aircraft. It also delivers possibility of low priced getting of user experience with aircraft before the first flight.

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