29th Congress of the International Council of the Aeronautical Sciences
St. Petersburg, Russia; September 7-12, 2014

APPROACHES FOR FLIGHT TESTS AIRCRAFT PARAMETER IDENTIFICATION

O.N. Korsun*, B.K. Poplavsky **
**State Institute of Aviation Systems*
Moscow, Russia
***Gromov Flight Research Institute*
Zhukovsky, Russia

Keywords: *flight tests, aircraft parameter identification, system identification*

Abstract

The report presents an example of identification techniques , which proved to be effective in processing of considerable quantities of flight test data within the admissible range of flight parameters. The techniques have been successfully applied to the aerodynamic parameter identification of a number of aircrafts in the process of flight tests.

1 Introduction

The system identification methods form an important part of flight test data analysis. Through these methods accurate aircraft parameter estimation may be obtained, that meets the requirements of numerous applications, such as simulators and flight control systems design, aircraft modernization and so on.

The aircraft parameter identification incounters the following principal difficulties:

inevitable differences between the physical object and the adopted mathematical models;

the essential incorrectness of the identification problem (in A.N. Tichonov's sense) [1,3].

The presented techniques are to overcome these difficulties, using the system approach. It means that identification problem is treated as an integral multistage system, designed according to certain basic principles.

These principles are:

every stage includes a verification procedure;

the decomposition of the general problem to minor subproblems;

the systematic search for all useful information in the relevant disciplines;

the important role of human operator cognitivity.

The stages of the identification are discussed further.

The presented techniques are based on the theoretic results achieved due to the support by Russian Fund for Fundamental Research, project 12-08-00682.

2 Identification input data

2.1 Data on the aircraft and control system

Required data includes geometric, weight, inertial parameters of the aircraft, a priori aerodynamic and trust coefficients, censors coordinates, control system algorithms, parameters of flight rated values.

This information is necessary for flight experiment design, flight safety, precise investigation of measurement errors.

2.2 Flight Tests Data

The requirements for flight parameters registration are common. The identification doesn't need anything beyond the usual set of parameters, registered in the flight tests. The registration frequency must be greater or equal 16 Hz.

3 On-land experiments

One of the ways for decomposition of the general identification problem is to determine the constant errors of angular velocities, overloads, control surfaces deviations measurements in on-land experiments.

3.1 Estimation for constant errors of angular velocities measurements

The experiment is carried out as follows.

The aircraft is settled in the maintenance position, the registration system is turned on for an interval of 2…3 s. Since the aircraft stands still, its angular velocities are equal to zero. Therefore, the measurements and registered values are equal to constant measurements errors coupled with the noises. To surpress the noises the mean through the registration interval should be taken as a constant measurement error estimate.

3.2 Estimation for constant errors of overloads measurements

The experiment is carried out like in the previous case with an addition: the registration is turned on after the adjustment of the on-board inertial system. It is required to provide the precise values of angles of pitch and roll which are not equal to zero. In this case for the aircraft standing still the true overloads values are

$$
\begin{aligned}
n_{y0} &= \cos\gamma_0 \cos\upsilon_0 ,\\
n_{z0} &= -\sin\gamma_0 \cos\upsilon_0 ,\\
n_{x0} &= \sin\upsilon_0 ,
\end{aligned}
\qquad (1)
$$

where υ_0, γ_0 - angles of pitch and roll.

The estimates for overloads measurements constant errors are

$$
\begin{aligned}
\Delta n_y &= n_{y\,изм} - n_{y0} ,\\
\Delta n_z &= n_{z\,изм} - n_{z0} ,\\
\Delta n_x &= n_{x\,изм} - n_{x0} ,
\end{aligned}
\qquad (2)
$$

where

$n_{y\,изм}, n_{z\,изм}, n_{x\,изм}$ - overloads measured values.

In order to diminish the noises influence the means through the registration interval should be used like in the case before.

3.3 Estimation for constant errors of control surfaces deviations measurements

The aircraft is settled in the maintenance position. It's required that the hydraulic feeding is supplied. The control surfaces are set approximately to neutral position. Then their actual deviations from neutral are measured directly with the accuracy not less than 0,05 degrees. The on-board registration system is turned on for 2…3 s.

The constant error, for example, of the rudder deviation measurement is estimated according to the formula:

$$\Delta\delta_H = \delta_{H\,изм} - \delta_{H0}, \qquad (3)$$

where δ_{H0} - actual rudder deviation, provided by the angular measuring device,

$\delta_{H\,изм}$ - rudder deviation, registered by the on-board registration system.

The other control surfaces are treated in the same way.

4 Flight experiment design

At this stage the ranges of altitude, velocity, angle of attack and aircraft configurations are determined. The recommended forms of the test input signals [9] are presented in fig. 1.

The basic flight modes are the horizontal flight and the turn at constant angle of roll.

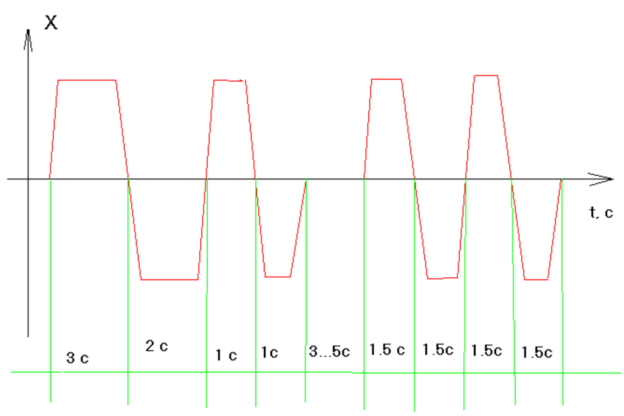

Fig. 1. Forms of pilot controls deviations

5 Data compatibility check

At this stage the following equations, taken from the general model of the aircraft three-dimensional movement [1, 3, 9], are used. These equations doesn't include the aircraft aerodynamic parameters, so the check of the on-board measuring and registration system may be separated from the aircraft parameter identification problem. It gives an example of the way the principle of decomposition is carried out.

$$\frac{d\alpha}{dt} = \omega_z - \frac{1}{\cos\beta} \cdot \left[\left(\frac{a_x}{V} - \omega_y \sin\beta \right) \sin\alpha + \left(\frac{a_y}{V} + \omega_x \sin\beta \right) \cos\alpha \right]$$

$$\frac{d\beta}{dt} = \frac{a_z}{V}\cos\beta - \left(\frac{a_x}{V}\sin\beta - \omega_y \right)\cos\alpha + \left(\frac{a_y}{V}\sin\beta + \omega_x \right)\sin\alpha, \qquad (4)$$

$$\frac{dV}{dt} = a_x \cos\alpha\cos\beta - a_y \sin\alpha\cos\beta + a_z \sin\beta,$$

$$\frac{d\upsilon}{dt} = \omega_y \sin\gamma + \omega_z \cos\gamma,$$

$$\frac{d\gamma}{dt} = \omega_x - tg\,\upsilon\,(\omega_y \cos\gamma - \omega_z \sin\gamma),$$

where a_x, a_y, a_z - :

$$a_x = g\,(n_x - \sin\upsilon),$$

$$a_y = g\,(n_y - \cos\upsilon\cos\gamma), \qquad (5)$$

$$a_z = g\,(n_z + \cos\upsilon\sin\gamma).$$

The equations (4), (5) form the object model. The observed vector includes angles of attack and slide α and β, velocity V, angles of pitch and roll υ and γ. The input signals for this model are angular velocities $\omega_x, \omega_y, \omega_z$ and overloads n_x, n_y, n_z. Then a parameter identification algorithm, for example, Maximum Likelihood Estimation (MLE) [2], is applied. The vector of identified parameter includes constant errors of angular velocities and overloads. The estimates of the same parameters, obtained in the on-land experiment, serve as a priori values.

It should be noted that in this algorithm the dynamic measurement errors caused by the shift of censors from aircraft mass center, must be taken into account.

The necessary formulas for overloads and angles of attack and slide, are presented in [1].

The above mentioned algorithm is very effective for detecting dynamic measurement errors. The fig. 2 presents an example of detecting the time lag in the measured values of angle of attack. In this case the additional analyses revealed that this lag was caused by the low frequencies filter which the measurement system model hadn't accounted for.

A very good match was achieved after the filter equations being added to the initial model (fig. 2).

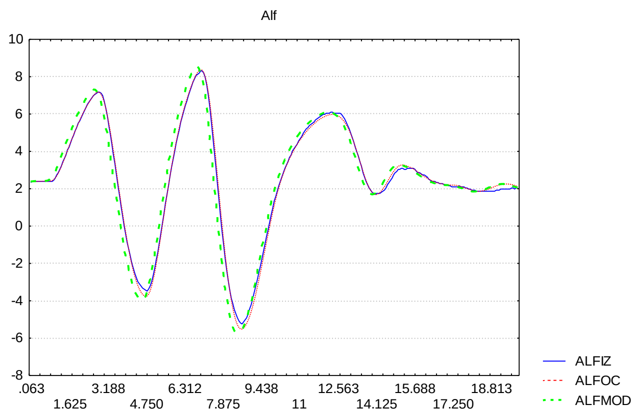

Fig. 2. The lag detection in the angle of attack measured values

When the on-board measurement and registration system functions correctly, the obtained match between simulated and flight experiment signals is remarkable.

Fig. 3 presents examples for angles of pitch and roll and fig. 4 - for velocity and angle of slide.

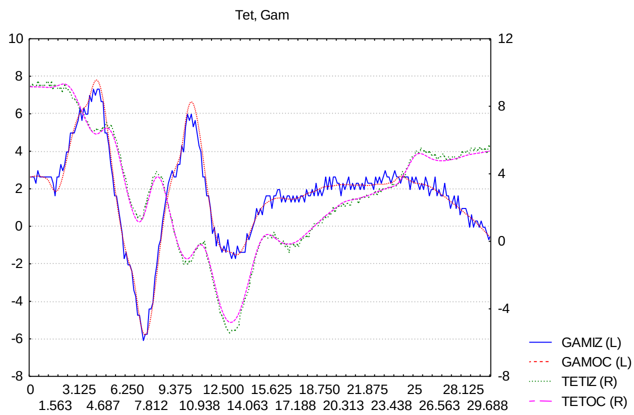

Fig. 3. Angles of pitch and roll simulated and experiment values match (on-board measuring system functioning correctly)

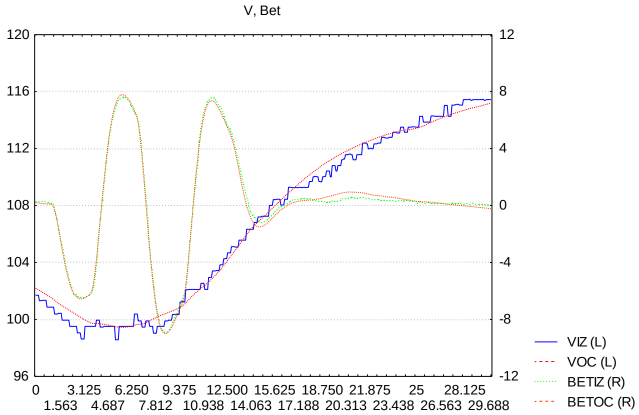

Fig. 4. Velocity and angle of slide simulated and experiment values match (on-board measuring system functioning correctly)

6 Mathematic models of aircraft movement and aerodynamic coefficients

For the purposes of parameter identification non-linear three-dimensional model of aircraft movement is recommended [1].

On the one hand, this model is not very sophisticated, and on the other, it provides an accurate description of the relation between the parameters of flight. Thus the linearization errors are excluded.

For the coefficients of aerodynamic forces and moments the traditional linear models may be adopted, especially within the domain of moderate angles of attack. The non-linear aerodynamic effects require a polynomial or spline approximation. The parameters of these approximations are included into the identified parameters vector.

7 Analyses of the wind tunnel tests data

In the problem of aircraft aerodynamic parameter identification the wind tunnel tests data serve as *a priori* information, which is to be précised according to the flight tests results. The experience show that a considerable part of this *a priori* information is true, especially when the general character of aerodynamic parameters as functions of Mach or angle of attack, is concerned. So it's very useful to begin with the careful analyses of the wind tunnel information in order to detect some general features of the aerodynamic data. At this step the information of the aircraft flight configurations and control system should be taken into consideration.

An example of this analyses is presented at fig. 5. It shows the pitch moment coefficient as a function of the angle of attack at various Mach numbers.

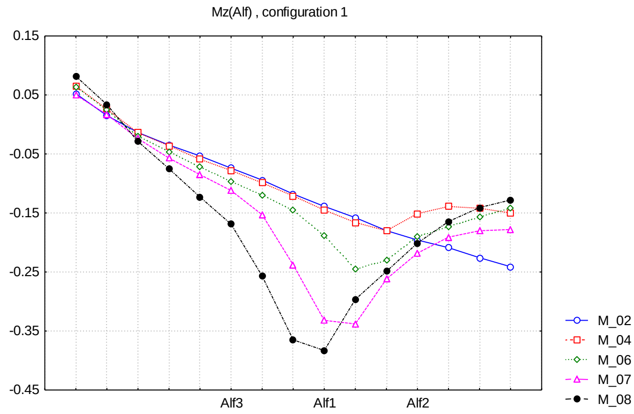

Fig. 5. An example of the wind tunnel data analyses

At first sight the function is strongly nonlinear. But it should be remembered that at angles of attack greater than ALF1 the control system automatically changes the flight configuration.

So, within the range of $\alpha <$ ALF1, which is achievable in flight and which is subject to the identification, the function is linear for M=0,2…0,6, and at higher Mach numbers may be approximated by two linear functions, that is a first-order spline with the knot ALF3.

8 Flight tests data processing

Although there are a great number of identification algorithms, the presented techniques deal only with a few of them.

A method, which proved to be very effective at processing a great part of the flight data, is Maximum Likelihood Estimation (MLE) [2]. For more specific cases some special algorithms have been developed.

The discrete-continuous identification method [4] , based on the principles of Kalman filtering, is recommended for processing data containing the atmospheric turbulence (object noise). The similar results may be obtained by coping MLE [2] with discrete-continuous Kalman filter [3].

The parameter identification of statically unstable aircrafts should be carried out by the parallel model method [6]. The cases of slightly unstable aircrafts may be dealt also with MLE coupled with the Kalman filter [5]. The method [7] combines the advantages of time and frequency domain identification algorithms. At last, the invariant method identification [8] proved to be effective in cases of deterministic noises of the known form and unknown amplitude.

9 Identification results analyses

The joint analyses of identification estimates, obtained by processing different flight data sets, improves considerably the final results.

Fig.6 shows the identification estimates of a parameter $m_z^{\delta_B}$ for 32 flight intervals at different Mach numbers.

The regression line is close to horizontal. It shows, that the considered parameter doesn't depend on the changes of M. The correspondent statistical test also indicates at insignificance of the correlation.

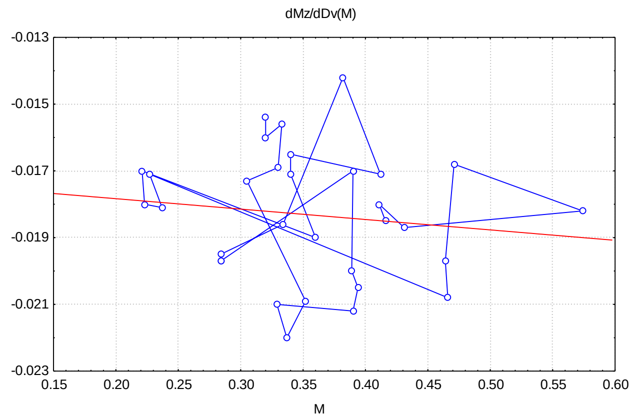

Fig. 6. Detection of the correlation between identification estimates and Mach number

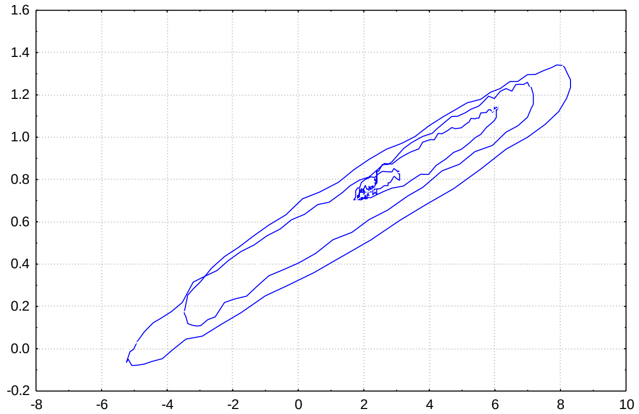

Fig. 7. False aerodynamic hysteresis of $c_y(\alpha)$ estimates caused by the lag in the angle of attack measurements

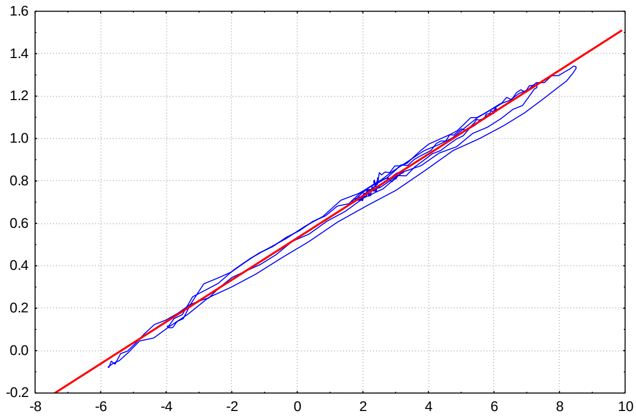

Fig. 8. The $c_y(\alpha)$ estimates after correction of the lag in the angle of attack measurements

Another example is presented at fig.7. It shows the estimates of the lift coefficient c_y as a function of the angle of attack. This graph produces an impression of aerodynamic hysteresis. The impression is false, because the additional analyses has shown that the true source of this effect was the lag in the measurements of the angle of attack. The next figure presents the same data after this lag has been corrected.

10 The final model verification

The graphic match between the simulated and experiment output signals is the necessary requirement, that the model should meet after the identification is over.

The fig. 9 shows such an example for a pitch movement. It should be kept in mind that a good match, being necessary, never can guarantee that the model is true. That's why presented techniques, based on the principle of system approach, is necessary.

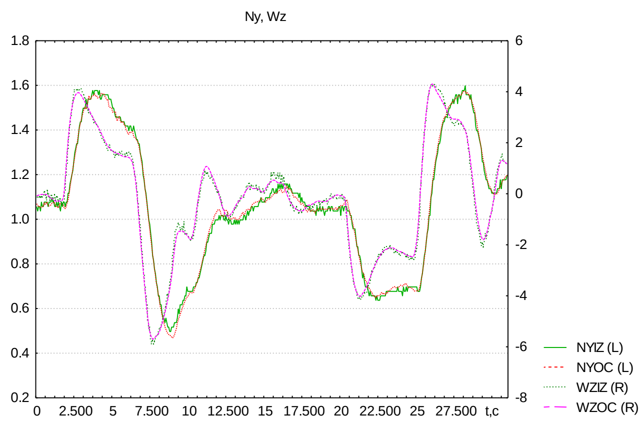

Fig. 9. The match between experiment and simulated values of normal overload n_y and pitch angular velocity ω_z

Conclusion

The presented techniques proved to be effective being applied to flight tests data processing of several modern aircrafts in recent years.

References

[1] Васильченко К.К., Леонов В.А., Пашковский И.М., Поплавский Б.К. *Летные испытания самолетов.* – М.: Машиностроение, 1996.

[2] Maine R.E., Iliff K.W. *Identification of Dynamic Systems. Theory and Formulation.* – NASA RP 1138, 1985.

[3] Васильченко К.К., Кочетков Ю.А., Леонов И.А., Поплавский Б.К. *Структурная идентификация математической модели движения самолет*а. – М: Машиностроение, 1993.

[4] Кулифеев Ю.Б. Дискретно-непрерывный метод идентификации непрерывных систем. – *Известия АН СССР. Механика твердого тела,* 1981, № 5, с.47–55.

[5] Исаев С.А., Корсун О.Н. Идентификация параметров математической модели статически неустойчивого самолета в интересах оценивания характеристик траекторного движения. – *Радиотехника,* 1996, № 10, с. 92-97.

[6] Корсун О.Н. Идентификация продольного движения статически неустойчивого самолета, основанная на использовании параллельной модели. – *Известия академии наук. Теория и системы управления*, 2001, № 3, с. 34-39.

[7] Корсун О.Н. Алгоритм идентификации динамических систем с функционалом в частотной области. – *Автоматика и телемеханика*, 2003, № 5, с. 111-121.

[8] Леонов В.А., Поплавский Б.К. Метод линейных преобразований идентификации динамических систем. – *Изв. АН СССР. Техническая кибернетика, 1990, № 2, с. 163- 170.*

[9] Klein V. Estimation of aircraft aerodynamic parameters from flight data // Prog. Aerospace. Sci. 1989. № 26. P. 1–77.

Contact Author Email Address

mailto:marmotto@rambler.ru

Copyright Statement