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IDENTIFICATION OF THE AIRCRAFT CONTROL BASING ON THE LINEAR AND ANGULAR ACCELERATIONS RECORDED

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A method for identification of the aircraft control based on the recorded linear and angular accelerations is presented in the paper. The aircraft accelerations have been calculated by means of numerical simulation of a flight for specified deflections of the control surfaces. These values have been also applied to reconstruction of the manual control. The computations were made for the I-22 IRYDA M93 aircraft.

Key words: flight dynamics, flight control, flight simulation

1. Introduction

Crash recorders are often used in aviation, despite the fact that they do not allow for recording of all flight parameters, storing only a few significant ones. It is very difficult to reconstruct the crash sequence basing on these parameters. Some recorders allow for storing also linear and angular accelerations, however without control surface deflections and revolutions of engines.

When we have all data: relative 3D aircraft position, initial flight parameters, and we are provided with a fully identified aircraft dynamical model, we can reconstruct the flight trajectory, its velocity, control surface deflections and revolutions of engines to reconstruct the manual control. It can be used not only in reconstruction of aircraft crash, but in pilot training too.

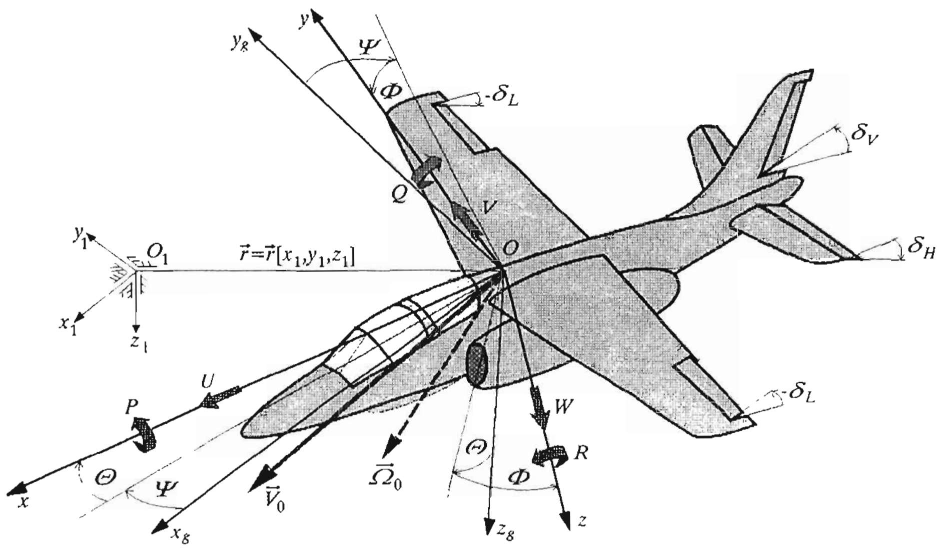

Fig. 1. Co-ordinate system

2. Physical and mathematical aircraft models

2.1. Physical model

The following assumptions have been accepted for the physical aircraft model to be constructed:

- Aircraft is a rigid body with six degrees of freedom
- Aircraft has a geometrical, aerodynamic and mass plane of symmetry
- Aircraft flies at a subsonic velocity in a standard atmosphere without turbulence
- Aircraft control surfaces are weightless (their deflections affect changes in aerodynamic forces and moments of forces)
- Quasi stationary aerodynamic model is employed.

2.2. Mathematical model

The two main co-ordinate systems have been assumed:

- Body-fixed system $Oxyz$ – non-inertial system
- Earth-fixed system $O_1x_1y_1z_1$ – inertial system.

The dynamic equations of motions were derived in the body-fixed system using the Boltzman-Hamel equations for mechanical systems with the holonomic constraints imposed.

The mathematical model of aircraft employed is commonly used in aviation (Maryniak, 1993; Goszczyński, 1998; Pyrz and Maryniak, 1998). The equations assume the following matrix form

$$\widetilde{\mathbf{M}}\dot{\boldsymbol{V}} + \mathbf{KM}\boldsymbol{V} = \boldsymbol{Q}^* \tag{2.1}$$

where

$\mathbf{M}$ – matrix of inertia

$$\mathbf{M} = \begin{bmatrix} m & 0 & 0 & 0 & S_Z & 0 \\ 0 & m & 0 & -S_Z & 0 & S_X \\ 0 & 0 & m & 0 & -S_X & 0 \\ 0 & -S_Z & 0 & J_X & 0 & -J_{XZ} \\ S_Z & 0 & -S_X & 0 & J_Y & 0 \\ 0 & S_X & 0 & -J_{XZ} & 0 & J_Z \end{bmatrix}$$

$\widetilde{\mathbf{M}}$ – modified matrix of inertia (Maryniak, 1993; Goszczyński, 1998), $\widetilde{\mathbf{M}} = \mathbf{M} + \mathbf{M}_{\dot{w}}$

$\mathbf{K}$ – matrix of rigidity

$$\mathbf{K} = \begin{bmatrix} 0 & -R & Q & 0 & 0 & 0 \\ R & 0 & -P & 0 & 0 & 0 \\ -Q & P & 0 & 0 & 0 & 0 \\ 0 & -W & V & 0 & -R & Q \\ W & 0 & -U & R & 0 & -P \\ -V & U & 0 & -Q & P & 0 \end{bmatrix}$$

$\boldsymbol{V}$ – vector of velocities, $\boldsymbol{V} = col[U,V,W,P,Q,R]$

$\dot{\boldsymbol{V}}$ – vector of accelerations

$\boldsymbol{Q}^*$ – vector of the external forces and moments of forces, $\boldsymbol{Q}^* = col[X,Y,Z,L,M,N]$

The components of external forces and moments of forces vector (Goszczyński and Pyrz, 1997; Goszczyński, 1998; Pyrz and Maryniak, 1998) read

$$\boldsymbol{Q}^* = \boldsymbol{Q}^a + \boldsymbol{Q}^g + \boldsymbol{Q}^T + \mathbf{U}^\delta \boldsymbol{\delta} \tag{2.2}$$

where

$\boldsymbol{Q}^a$ – vector of the aerodynamic forces and moments of forces
$\boldsymbol{Q}^g$ – vector of the gravity forces and moments of forces
$\boldsymbol{Q}^T$ – vector of the forces and moments of forces due to engine
U^δ – matrix of the forces and moments of forces due to aerodynamic control
$\boldsymbol{\delta}$ – vector of control surfaces deflections, $\boldsymbol{\delta} = col[\delta_h, \delta_v, \delta_l, \alpha_{zh}, n_L, n_P]$
δ_h – angular deflection of the elevator
δ_v – angular deflection of the rudder
δ_l – angular deflections of the ailerons
α_{zh} – angle of the tail plane incidence
n_L – revolutions of the left engine
n_P – revolutions of the right engine.

The following kinematic relations have been also employed (Goszczyński, 1998)

$$\dot{\boldsymbol{r}}_1 = \boldsymbol{\Lambda}\boldsymbol{V} \tag{2.3}$$

where
$\dot{\boldsymbol{r}}_1$ – vector of velocity, $\dot{\boldsymbol{r}}_1 = col[\dot{x}_1, \dot{y}_1, \dot{z}_1, \dot{\Phi}, \dot{\Theta}, \dot{\Psi}]$
$\boldsymbol{\Lambda}$ – matrix of transformation.

The above equations create a full mathematical model of the aircraft in a 3D flight.

3. Solution to the simple inverse problem of dynamics

Before solving the simple inverse problem of dynamics, we should know the vector of linear and angular accelerations $\dot{\boldsymbol{V}}$ and the state vector $\boldsymbol{A}$ for each instant of the flight, for which we calculate components of the control vector

$$\boldsymbol{A} = col[U, V, W, P, Q, R, x_1, y_1, z_1, \Phi, \Theta, \Psi] \tag{3.1}$$

To this end:

(a) having the state vector $\boldsymbol{A}$ at the instant t_0, we have to calculate from Eq (2.3) the component of $\dot{\boldsymbol{r}}_1$ at the same moment of time ($\boldsymbol{V}$ is a component of $\boldsymbol{A}$),

(b) knowing the vector of accelerations $\dot{\boldsymbol{V}}$ at the instant t_0 and having calculated $\dot{\boldsymbol{r}}_1$, ($\dot{\boldsymbol{A}} = col[\dot{\boldsymbol{V}}, \dot{\boldsymbol{r}}_1]$) we have to integrate numerically $\dot{\boldsymbol{A}}$, as a result we obtain the state vector $\boldsymbol{A}$ at the instant $t_1 = t_0 + \delta t$. The iterative procedure is performed to calculate the state vector $\boldsymbol{A}$ at any instant $t_{i+1} = t_i + \delta t$.

(c) in the next step rewrite Eq (2.1) as follows

$$\widetilde{\mathbf{M}}\dot{\boldsymbol{V}} + \mathbf{KM}\boldsymbol{V} - \boldsymbol{Q}^* = 0 \tag{3.2}$$

Having known $\boldsymbol{A}$ and $\dot{\boldsymbol{A}}$ at the instant t_i, as well as the identified dynamic model of the aircraft (Goszczyński, 1998) at our disposal, we have to solve a system of six non-linear equations in the components of the control vector $\boldsymbol{\delta}$. To this end we have used numerical programs with standard library routines.

4. Results of calculations

The computations were made for the aircraft I-22 M93 "Iryda" as the test object at the following two stages:

Stage 1. The simulation of flight was performed the specified deflections of control surfaces and engine revolutions. The initial components of the state vector $\boldsymbol{A}$ and histories of linear and angular accelerations $\dot{\boldsymbol{V}}$ (Fig.2) were determined.

Stage 2. For the following input data:

- Vector $\boldsymbol{A}$ at the instant t_0

$$\boldsymbol{A} = \begin{bmatrix} 149.6582\ \frac{\mathrm{m}}{\mathrm{s}} \\ 0\ \frac{\mathrm{m}}{\mathrm{s}} \\ 10.12057\ \frac{\mathrm{m}}{\mathrm{s}} \\ 0\ \frac{\mathrm{rad}}{\mathrm{s}} \\ 0\ \frac{\mathrm{rad}}{\mathrm{s}} \\ 0\ \frac{\mathrm{rad}}{\mathrm{s}} \\ 0\ \mathrm{m} \\ 0\ \mathrm{m} \\ -2000\ \mathrm{m} \\ 0\ \mathrm{deg} \\ 3.87069\ \mathrm{deg} \\ 0\ \mathrm{deg} \end{bmatrix}$$

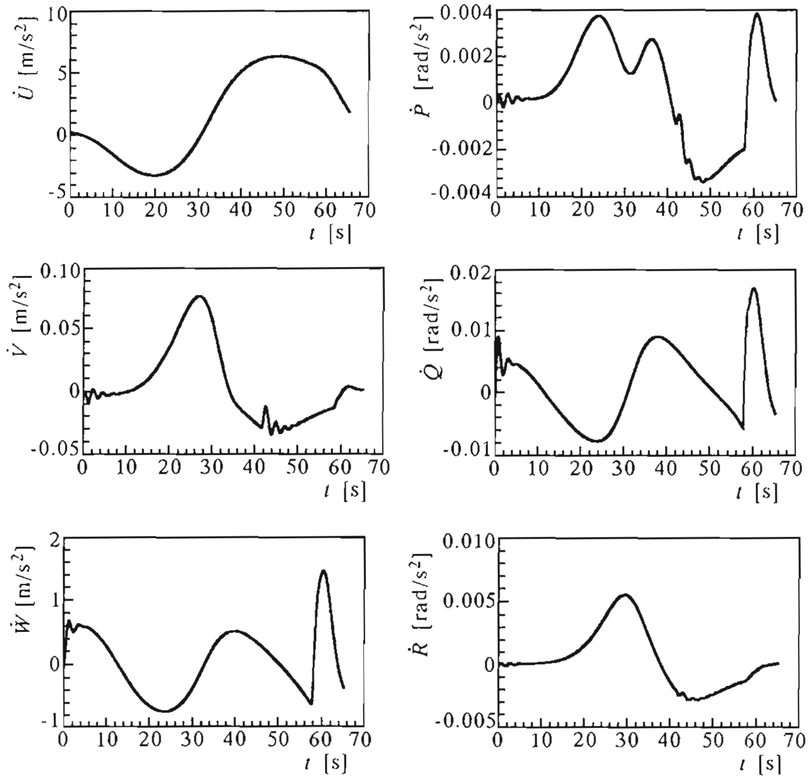

Fig. 2. Historis of the acceleration vector

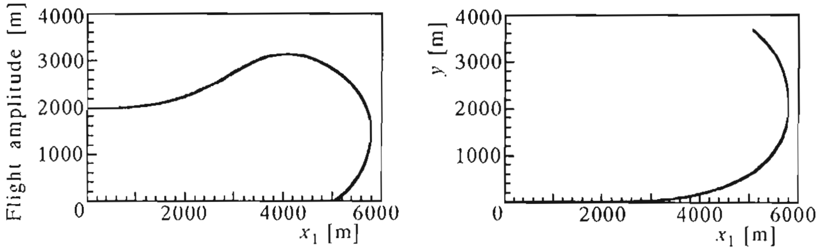

Fig. 3. Flight trajectories on the planes: (a) $O_1x_1z_1$, (b) $O_1x_1y_1$

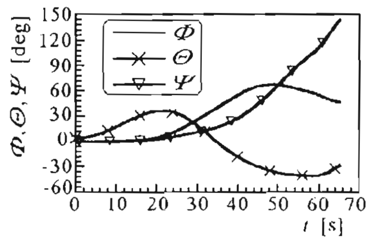

Fig. 4. Eulerian angles

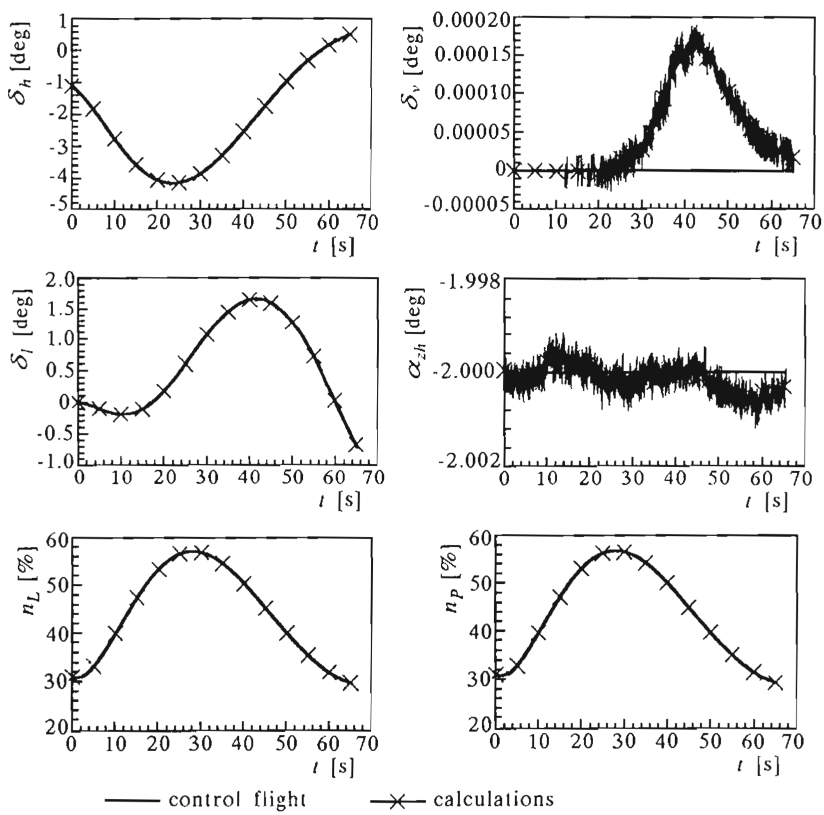

Fig. 5. History of vector of controls

- Vector $\dot{\boldsymbol{V}}$ at any moment of the simulation process the calculations were made in two steps:

(a) in the first step the components of the state vector $\boldsymbol{A}$ were determined at an arbitrary moment (according to Section 3, p.a,b), including the flight trajectory (Fig.3 and Fig.4);

(b) in the second step the control vector $\boldsymbol{\delta}$ (according to Section 3 p.c) was determined. In Fig.5, the solid line denoted as "control" represents the specified deflections of control surfaces and engine revolutions, while the broken line denoted as "calculations" represents the values of components of the control vector resulting from the solution to the inverse problem of dynamics.

5. Conclusions

From the results presented above a good agreement can be seen between the control surfaces deflections and engine revolutions resulting from simulation and the calculated components of the control vector obtained from the solution to the inverse problem of dynamics.

The analysis carried out have proved that knowing initial values of the components of the state vector as well as the values of linear and angular accelerations recorded during the flight, one can reconstruct the realised trajectory and velocity of flight.

We know that, it is impossible to reconstruct unequivocally the control vector realised during the flight by a pilot. Hypothetically, there may be more than one method for the aircraft control which yield the same trajectory of flight at the same velocity. In that case on the basis of the presented method various hypotheses concerning the aircraft control may be investigated.

The assumed values of components of the state vector considered as the initial conditions for solving numerically non-linear system of equations may affect the obtained results.

Acknowlegment

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Wyznaczanie sterowania samolotu na podstawie zarejestrowanych przyspieszeń liniowych i kątowych

Streszczenie

W pracy przedstawiono metodę wyznaczania kątów wychyleń powierzchni sterowych oraz sterowania zespołem napędowym na podstawie zarejestrowanycj przyspieszeń liniowych i kątowych samolotu.

Przyspieszenia działające na samolot zostały wyznaczone w drodze symulacji numerycznej lotu samolotu przy z góry zadanym sterowaniupowierzchniami sterowymi oraz obrotami silnika. Następnie, wykorzystując tą samą metodę, przeprowadzono próbę odtworzenia tych sterowań. Obliczenia zostały wykonane na przykładzie samolotu I-22 Iryda M93 jako obiekcie testowym.

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