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PROGRAM FOR CALCULATION AND STUDY OF STABILITY AND COLTROL OF AIRPLANES

CHƯƠNG TRÌNH TÍNH TOÁN NGHIÊN CỨU ỔN ĐỊNH VÀ ĐIỀU KHIỂN MÁY BAY

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ABSTRACT

For airplanes, two problems of stability and control are concerned each other. In opinion of flight mechanics, the airplane is a solid object moving under the influence of many factors which change the distribution of pressures around the object due to the state of atmosphere, the speed of object, and the requirement of control. This paper presents results of established program for calculating and studying the stability and control of airplanes by solving the small disturbance differential equations of motion with unknowns written in form of harmonic functions. Time response solutions of motions depend on variations of aerodynamic forces. General interface permits to directly input airplane aerodynamic dimensions, coefficients of aerodynamic derivative, and has branch interfaces managing control parameters. With a change of aerodynamic forces, we can correlatively obtain diagrams of response allowing analyses and choices suitable solutions on stability quality. The program can be connected to programs of aerodynamic calculations corresponding with different control objectives.

TÓM TẮT

Đối với máy bay, tính toán ổn định và điều khiển gắn liền với nhau. Trên quan điểm cơ học bay, máy bay là một vật rắn chuyển động chịu tác động của rất nhiều yếu tố làm thay đổi phân bố áp lực khí động theo điều kiện môi trường, theo tốc độ bay và các yêu cầu điều khiển cần thiết. Bài báo trình bày kết quả xây dựng chương trình tính toán nghiên cứu ổn định và điều khiển máy bay trên cơ sở giải phương trình vi phân chuyển động theo lý thuyết nhiễu động nhỏ với các biến được viết dưới dạng hàm điều hòa theo thời gian. Nghiệm đáp ứng theo thời gian của chuyển động phụ thuộc vào biến thiên của lực khí động. Giao diện chính của chương trình cho phép nhập trực tiếp các thông số kích thước khí động của máy bay, các hệ số đạo hàm khí động, và chứa các giao diện nhánh liên quan đến các thông số điều khiển. Mỗi thay đổi của lực khí động, có thể tương ứng nhận được kết quả đồ thị đáp ứng động học cho phép phân tích lựa chọn phương án phù hợp về chất lượng ổn định. Chương trình có thể kết nối với các chương trình tính lực khí động theo các tiêu chí điều khiển khác nhau.

I. INTRODUCTION

In opinion of flight mechanics, airplane is considered as a moving object. However, interaction forces during period of motion are not produced from solid-solid association as we have seen but “invisible” gas-solid association. “Invisible” seemed atmosphere impacts on the airplane with aerodynamic forces which lift this one moving in the atmosphere. The aerodynamic force is a type of distributive force, and changes under every variation of atmosphere, free flow velocity, pitch, roll, elevation controls as desires of man. The controls make change of motion state which concerns variations of geometry or aerodynamic forces for control. Calculations of aerodynamic forces are very complex problems by solving partial differential equations of fluid motion. The method of studying motion fluids is Euler method. Contrary to that, the method of study for flight mechanics is Lagrange method. Therefore, aerodynamic problem and flight mechanics problem are two different types ones on both motion equation type and resolution method, although aerodynamic results are input parameters for stability problems of flight mechanics.

During the transport of airplanes, or by arrangement or by chance, the ones have to be under control or sustain atmosphere turbulences. Under each control or disturbance, a new aerodynamic problem is proposed. In aspect of flight mechanics, it is necessary to calculate static and dynamic stabilities with variations of aerodynamic forces. Aerodynamic parameters are many which concern controls of ailerons for pitch, roll, elevation of airplane and disturbances. This report does not present calculations of aerodynamic forces, but considers these forces being known in coefficient matrix of flight mechanic equations. Coefficients of matrix are input parameters on general interface of program. The program is established by solving motion equation of flight mechanics with output results in numerical values or diagrams permitting evaluations of dynamic stability quality corresponded with each control state of input parameters. This program can connect with program of aerodynamic force calculations or programs of stability calculations of component control systems (hydraulic, electro-hydraulic systems…).

II. METHOD OF RESOLUTION

When considering airplane as a moving object, motion equation of the airplane is written for center of gravity. From the law of momentum variation, equation of forces can be written as follows [1]:

$$X - mg\sin\theta = m(\dot{u} + \omega_y w - \omega_z v) \qquad (2.1a)$$

$$Y + mg\cos\theta\sin\Phi = m(\dot{v} + \omega_z u - \omega_x w) \qquad (2.1b)$$

$$Z + mg\cos\theta\sin\Phi = m(\dot{w} + \omega_x v - \omega_y u) \qquad (2.1c)$$

X, Y, Z are components of external force; m is mass of airplane; u, v, w are velocity components of center of gravity V_C projecting on stability axes fixed to airplane (C, X_b, y_b, Z_b); ω_{xb}, ω_{yb}, ω_{zb} are components of angle velocity; $\dot{u}$, $\dot{v}$, $\dot{w}$ and $\dot{\omega}_{xb}$, $\dot{\omega}_{yb}$, $\dot{\omega}_{zb}$ are derivatives; θ, Φ, ψ are Euler angles (pitch angle, roll angle, yaw angle); (O, X, Y,Z) are absolute fixed axes.

From the law of variation of momentum moment, equations of moment are written as:

$$M_x = I_x\dot{\omega}_{xb} - I_{xz}\dot{\omega}_{zb} + \omega_{yb}\omega_{zb}(I_z - I_y) - I_{xz}\omega_{xb}\omega_{yb} \qquad (2.2a)$$

$$M_y = I_y\dot{\omega}_{yb} + \omega_{zb}\omega_{xb}(I_x - I_z) + I_{xz}(\omega_{xb}{}^2 - \omega_{zb}{}^2) \qquad (2.2b)$$

$$M_z = -I_{xz}\dot{\omega}_{xb} + I_z\dot{\omega}_{zb} + \omega_{xb}\omega_{yb}(I_y - I_x) + I_{xz}\omega_{yb}\omega_{zb} \qquad (2.2c)$$

M_x, M_y, M_z are components of moment; I_x, I_y, I_z and I_{xy}, I_{xz}, I_{yz} are inertial moments

Using hypotheses of small disturbances, equations (2.1) and (2.2) are transformed into matrix form as following [1]:

$$\dot{x} = Ax + B\eta_x + A'\xi_x \quad ;$$
$$\dot{y} = Cy + D\eta_y + C'\xi_y \qquad (2.3)$$

where η is control vector: $\eta_x = (\Delta\delta_e, \Delta\delta_T)^T$, $\eta_y = (\Delta\delta_a, \Delta\delta_r)^T$; A, B, C, D, A', C' are matrices containing aerodynamic derivatives; $x = (\Delta u, \Delta w, \Delta\omega_{yb}, \Delta\theta)^T$, $y = (\Delta v, \Delta\omega_{xb}, \Delta\omega_{zb}, \Delta\Phi)^T$; ξ is disturbance vector due to wind: $\xi_x = (u_g, w_g, \omega_{yb\text{-}g})^T$; $\xi_y = (v_g, \omega_{xb-g}, \omega_{zb\text{-}g})^T$.

The equations (2.3) are called small disturbance equations for longitudinal and lateral motions, and these ones are solved by using Laplace transformation. Above parameters can be written in form of harmonic function:

$$g(t) = a\cos(\omega t + \varphi)\,;\ z(t) = \hat{g}e^{i\omega t} \text{ with } i = \sqrt{-1}\,;$$
$$\hat{g} = ae^{i\varphi}\,;\ g(t) = R[z(t)] \qquad (2.4)$$

where $\hat{g}$ is complex amplitude vector of g(t), a is amplitude and φ angle of phase of g(t)

Replacing g(t) by x(t) we have longitudinal motion and by y(t) we have lateral motion.

Taking x(t) into account, we obtain:

$$\hat{x} = H_\eta\hat{\eta}_x + H_\xi\hat{\xi}_x \qquad (2.5)$$

with $H_\eta = -(A - i\omega I)^{-1}B$; $H_\xi = -(A - i\omega I)^{-1}A'$ and which are called transfer function matrices of output $\hat{x}$ corresponding with input $\hat{\eta}_x$ and ξ_x; I is unit matrix. After Laplace variable, $H_\eta(s) = -(A - sI)^{-1}B$; $H_\xi(s) = -(A - sI)^{-1}A'$.

For programming, η_x is considered as factors of control in longitudinal motion (lateral tail angle) and η_y is factors of lateral control (rudder angle). The variation of aerodynamic forces is corresponding to airplane velocities in compressible regime.

III. RESULTS

Equation (2.3) and (2.5) are solved when coefficient matrices are determined. The coefficients depend on parameters of geometry, structure and kinematics. Results presented in the paper are calculated for airplane Navion with parameters after [2].

Results of time response after long period of longitudinal motion are shown in figure 3.1. Longitudinal stability concerns the fluctuation of velocities u, w, velocity of angle ω_{yb} and angle θ. With reference speed u_o = 53 m/s for long period response, T = 27s, and for sort period response, T = 1,59s. In reality, it is only oscillation with long period which exists, because oscillations with sort period too rapidly damped.

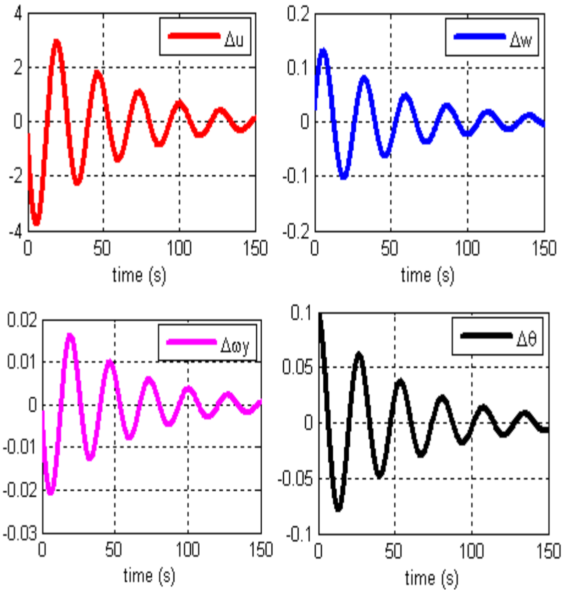

Fig. 3.1 Time response of longitudinal motion ($\Delta u, \Delta w, \Delta\omega_{yb}, \Delta\theta$)

If changing a control parameter, aerodynamic forces are then changed. Figure 3.2 shows that aerodynamic forces are null when angle of aileron is zero, and with angle of aileron taking 5 and 10 degrees, there are differences of pressures on upper and lower of wing profile (Naca 0012) which make aerodynamic forces on wing [3]. When inputting into the program a lateral tail control angle of 10 degrees, we can obtain time response of longitudinal motion after long period presented in figure 3.3. Inputting a disturbance of wind with gust of 5m/s, we have time response of longitudinal motion shown in figure 3.4. Under influence of gust wind, the fluctuation of velocity u changes not very much, while Δw chance considerably.

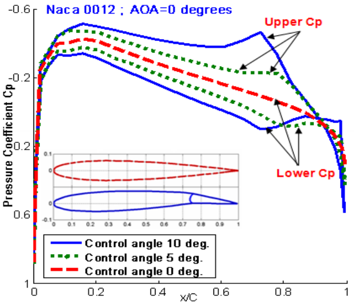

Fig. 3.2 Pressure coefficient with control angles 0°, 5° and 10° (Naca 0012, pivot 25%)[3]

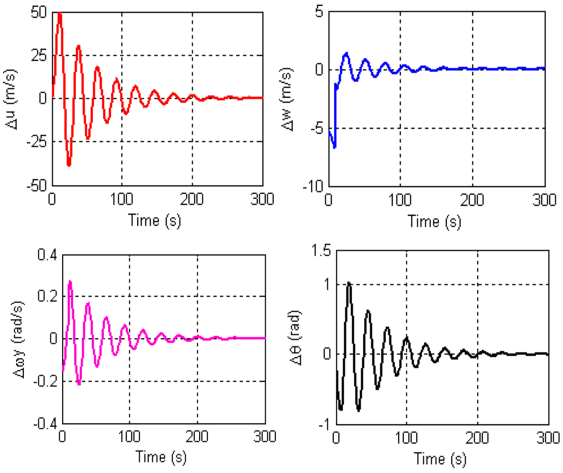

Fig. 3.3 Time response of longitudinal motion with lateral tail angle of 10°

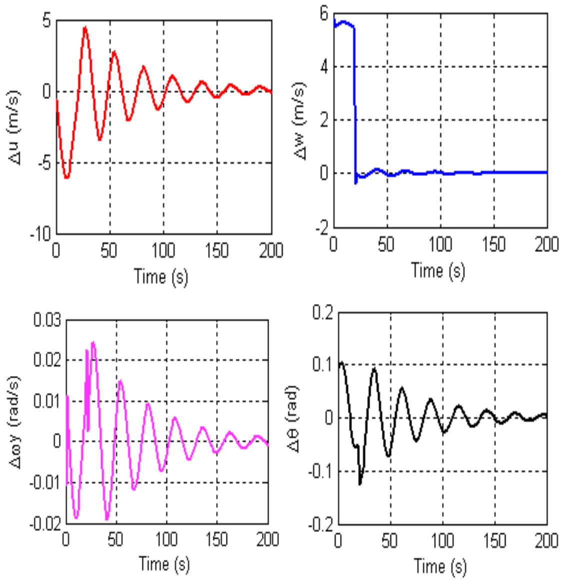

Fig. 3.4 Time response of longitudinal motion with gust wind of 5m/s

If changing speeds of gust wind, we can obtain results of time response equivalently changed. Figure 3.5 presents influences of gust winds on the velocity u in longitudinal motion at Δu = 0.17 m/s. Results in figure show that the greater speed of gust wind is, the longer time is. For speed of gust being greater than 15m/s, the diagram gentler slopes. Influences of lateral tail angle on u in longitudinal motion at Δu = 0.1 m/s are presented in figure 3.6. The diagram is a convex increasing curve.

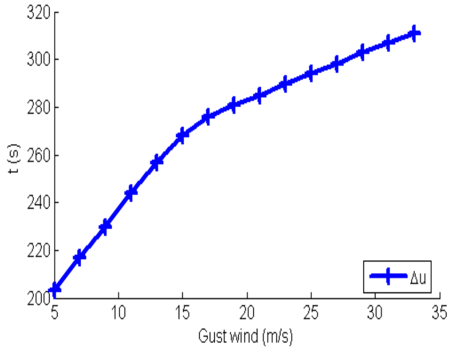

Fig. 3.5 Influence of gust wind on stability of u - response time at u = 0.17 m/s

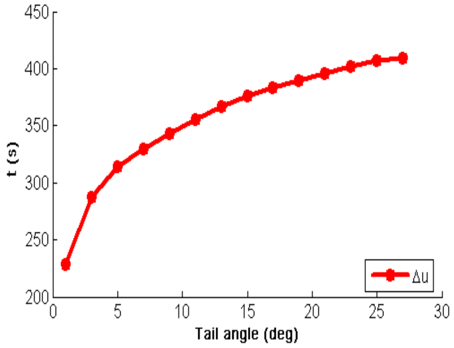

Fig. 3.6. Influence of lateral tail angle on stability of u - response time at u = 0.1 m/s

If changing airplane velocity, damping ratios in longitudinal motion and lateral motion are then changed that are presented in figure 3.7. For parameters of the airplane Navion, the stability of longitudinal motion is established at motion velocities higher than 25 m/s, while the stability of lateral motion is determined at velocities higher than 12 m/s. Numerical results show that for motion velocities lower than 90 m/s (incompressible flow), damping ratio increases after motion velocity in both longitudinal and lateral motions, and flying qualities are good and acceptable at motion velocities around 35m/s and 55m/s (figure 3.8).

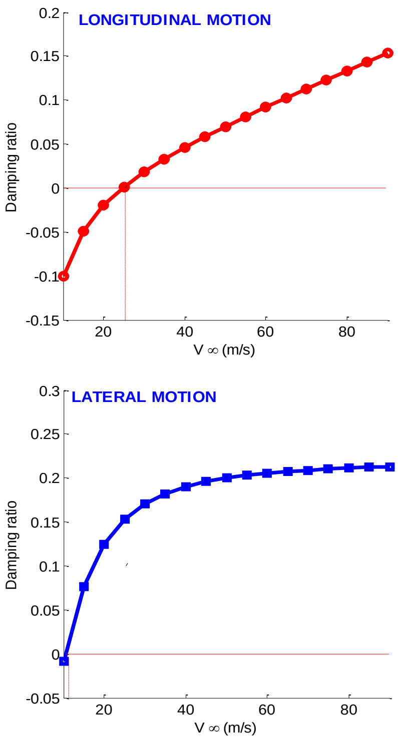

Fig. 3.7 Influences of airplane velocity on damping ratio in longitudinal and lateral motions

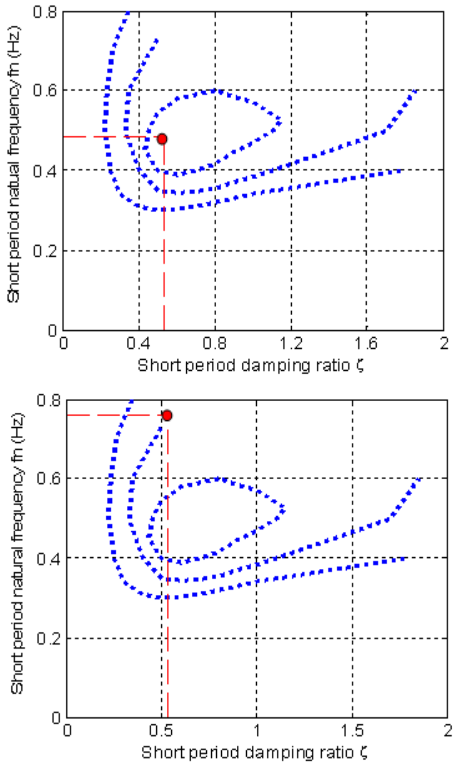

Fig. 3.8 Flying qualities (at V_∞=35m/s and 55m/s)

IV. DISCUSSION

For studying the stability of airplane, it is necessary to calculate both static and dynamic stabilities [4], [5]. Once aerodynamic forces are determined, static stability is calculated by comparing with stability criteria, and calculations of static stability are not represented here. The establishment of program for solving equations of motion by small disturbance theory to investigate dynamic stability combining with the build of interfaces for inputting and outputting facilitate dialogues between users and computers. The evaluation of stability qualities of airplanes without and with presence of control or atmosphere disturbances consists in determinations of aerodynamic forces and their variations. The established program with input and output interfaces permits directly obtaining time responses of characteristics corresponding with a variation of input parameter. When the program is connected with programs for calculations of aerodynamic forces, we can obtain responses of motion after controls.

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