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A STUDY ON THE DESIGN OF ALFLEX FLIGHT CONTROL SYSTEM

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Abstracts : Authors have developed ALFLEX simulation program which can implement the flight simulation and control system design of ALFLEX efficiently by using aerodynamic data provided by NAL/NASDA. Then we have designed an example of flight path and altitude control system of ALFLEX. The philosophy of the design method is explained in detail, and a flight simulation result is shown, which verifies the fine performance of the system.

Keywords : ALFLEX, Flight Control, Navigation, Flight Dynamics, Simulation, Space plane

1.INTRODUCTION

There has been a proposal from NAL (National Aerospace Laboratory) to many universities to study the ALFLEX[1)] (Automatic Landing Flight Experiment) together, and in responding to it, authors at first have developed ALFLEX simulation program. The work has been implimented by replacing the dynamics block and aerodynamic data block of GPMS[2)] (General Purpose Tactical Missile Simulation program) which had been developed by authors, by the models of ALFLEX supplied by NAL/NASDA (National Astronautical and Space Development Agency). Next, in order to verify the perfomance of this program, a longitudinal flight control system of ALFLEX is designed as an example and simulation is conducted, which shows the fine efficiency of the program. In this paper the design method is explained in detail, and a simulation result is shown.

2..DERIVATION OF TRANSFER FUNCTIONS

Three axes components of the force worked on the vehicle: lift L, side force C, and drag D are defined as follows

$$L = C_L QS$$
$$C = C_C QS$$
$$D = C_D QS$$

where C_L, C_C and C_D are aerodynamic force coefficients, S is the reference area, Q is the dynamic pressure given by

$$Q = \frac{1}{2}\rho V^2$$

where ρ is the air density and V is the velocity.

The relations between the force components measured in the vehicle body axes F_u, F_v, F_w and these forces are given by

$$\begin{bmatrix} F_u \\ F_v \\ F_w \end{bmatrix} = \begin{bmatrix} -c\alpha c\beta & c\alpha s\beta & s\alpha \\ -s\beta & c\beta & 0 \\ -s\alpha c\beta & s\alpha s\beta & -c\alpha \end{bmatrix} \begin{bmatrix} D \\ C \\ L \end{bmatrix}$$

while, the torques worked on the aircraft three axes M_u, M_v and M_w are given by

$$\begin{bmatrix} M_u \\ M_v \\ M_w \end{bmatrix} = \begin{bmatrix} C_l \cdot Q \cdot S \cdot c \\ C_m \cdot Q \cdot S \cdot c \\ C_n \cdot Q \cdot S \cdot c \end{bmatrix}$$

where C_l, C_m and C_n are aerodynamic moment coefficients, and c is the aerodynamic mean cord length. The vehicle longitudinal transfer functions are derived as follows. The aerodynamic coefficients C_L and C_m are given by

$$C_L = C_{L\alpha} \cdot \alpha + C_{L\delta} \cdot \delta$$

$$C_m = C_{m\alpha} \cdot \alpha + C_{m\delta} \cdot \delta + C_{mq} \cdot \frac{cq}{2V}$$

where δ is the elevator angle. In the actual vehicle, a set of elevon is used as an elevator and an aileron by differently taking the angles of two elevons. The equations of motion in the pitch plane are given by employing the symbols shown in Fig.1 as

$$\dot{\gamma} = f_\alpha \cdot \alpha + f_\delta \cdot \delta$$

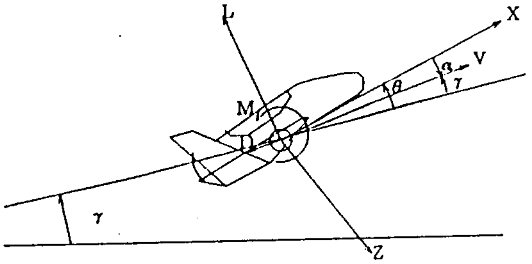

Fig.1 The motion in the pitch plane

$$\gamma = \theta - \alpha$$

$$\ddot{\theta} = m_\alpha \cdot \alpha + m_\delta \cdot \delta + m_{\dot{\theta}} \cdot \dot{\theta}$$

where γ is the flight path angle. Other symbols employed are given by

$$f_\alpha = \frac{QsC_{L\alpha}}{mV}$$

$$f_\delta = \frac{QsC_{L\delta}}{mV}$$

$$m_\alpha = \frac{QscC_{m\alpha}}{I}$$

$$m_\delta = \frac{QscC_{m\delta}}{I}$$

$$m_{\dot{\theta}} = \frac{Qsc^2 C_{m\dot{\theta}}}{2VI}$$

where $C_{L\alpha}$ etc. are aerodynamic derivative coefficients, and I is the moment of inertia about y axis.

From above equations, we can obtain next transfer functions

$$\dot{\theta}(s) = \frac{m_\delta s + f_\alpha m_\delta - f_\delta m_\alpha}{s^2 - (m_{\dot{\theta}} - f_\alpha)s - (m_\alpha + f_\alpha m_{\dot{\theta}})} \cdot \delta(s)$$

$$\dot{\gamma}(s) = \frac{f_\delta s^2 - f_\delta m_{\dot{\theta}} s + f_\alpha m_\delta - f_\delta m_\alpha}{s^2 - (m_{\dot{\theta}} - f_\alpha)s - (m_\alpha + f_\alpha m_{\dot{\theta}})} \cdot \delta(s)$$

by employing next symbols

$$c_1 = -\frac{f_\alpha m_\delta - f_\delta m_\alpha}{m_\alpha + f_\alpha m_{\dot{\theta}}}$$

$$\tau_{\dot{\theta}} = \frac{m_\delta}{f_\alpha m_\delta - f_\delta m_\alpha}$$

$$a_1 = \frac{m_{\dot{\theta}} - f_\alpha}{m_\alpha + f_\alpha m_{\dot{\theta}}}$$

$$a_2 = -\frac{1}{m_\alpha + f_\alpha m_{\dot{\theta}}}$$

$$b_1 = -\frac{f_\delta m_{\dot{\theta}}}{f_\alpha m_\delta - f_\delta m_\alpha}$$

$$b_2 = \frac{f_\delta}{f_\alpha m_\delta - f_\delta m_\alpha}$$

we can express the above transfer functions as follows.

$$\frac{\dot{\theta}(s)}{\delta(s)} = \frac{c_1(1 + \tau_{\dot{\theta}} s)}{1 + a_1 s + a_2 s^2}$$

$$\frac{\dot{\gamma}(s)}{\delta(s)} = \frac{c_1(1 + b_1 s + b_2 s^2)}{1 + a_1 s + a_2 s^2}$$

3.THE AUTOPILOT DESIGN

Figure 2 shows the designed autopilot block diagram. For convenience, let us express the transfer functions as

$$\frac{\dot{\theta}(s)}{\delta(s)} = \frac{c_1(1 + \tau_{\dot{\theta}} s)}{1 + a_1 s + a_2 s^2} = f_b(s)$$

$$\frac{\dot{\gamma}(s)}{\delta(s)} = \frac{c_1(1 + b_1 s + b_2 s^2)}{1 + a_1 s + a_2 s^2} = f_o(s)$$

Then the rate-loop taransfer function; $\dot{\gamma}c(s)$ to $\dot{\gamma}(s)$ is given

$$\frac{\dot{\gamma}(s)}{\dot{\gamma}c(s)} = \frac{K_1}{s} f_o \frac{K_2 f_b}{1 + K_2 f_b f_c} = f_r(s)$$

$$= \frac{1 + b_1 s + b_2 s^2}{(1 + \tau_r s)(1 + \frac{2\zeta_r}{\omega_r} s + \frac{1}{\omega_r^2 s^2})}$$

where

$$f_c(s) = 1 + \frac{K_1}{s}$$

The acceleration-loop transfer function; $a_c(s)$ to $a(s)$ without the altitude feedback loop is given by

$$f_a(s) = \frac{a(s)}{a_c(s)}$$

$$= \frac{1 + b_1 s + b_2 s^2}{(1 + \tau_a s)(1 + \frac{2\zeta_a}{\omega_a} s + \frac{1}{\omega_a^2} s^2)}$$

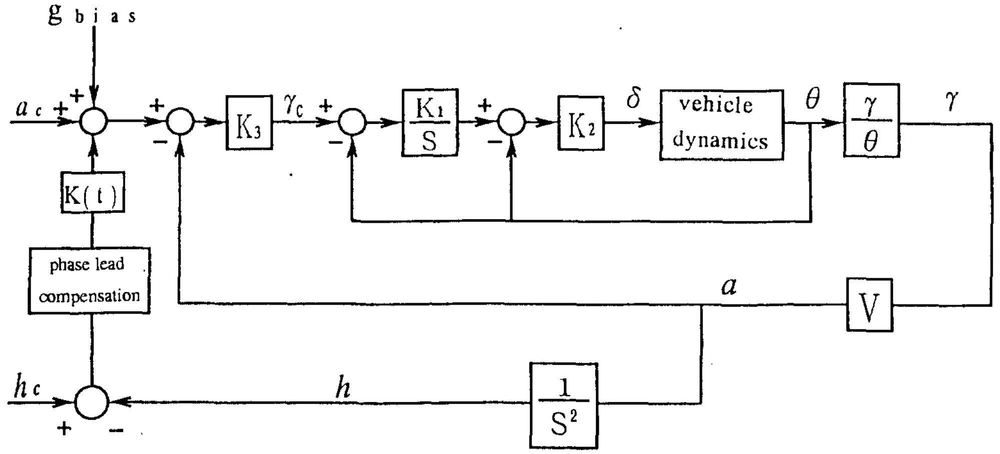

Fig.2 Accelerattiion and altitude feedback type autopilot

By employing this $f_a(s)$, the altitude-loop transfer function; $h_c(s)$ to $h(s)$ is given by

$$\frac{h(s)}{h_c(s)} = \frac{G_c(s)f_a(s)}{G_c(s)f_a(s)+s^2}$$

where $G_c(s)$ is a phase lead compensation. A lead-lag transfer function is employed here.

4. SIMULATION EXAMPLE

Figures 3 and 4 show the example values of C_L and C_m in relation to α, and Fig.5 shows in relation to δ at a nominal condition ($h = 192m, V = 51.8m/s$). The aerodynamic stability is negative, and C_m values drasticaly changes at a large α, therefore the autopilot must be designed by taking these characteristics into consideration. As the value of c_1 defined in section 2 is the function of velocity and dynamic pressure, the open-loop gains in Fig.2 should be changed depending on the condition. In this case, the values of the autopilot gain constants K_1 and K_2 are tuned depending on the vehicle dynamic pressure. The altitude loop are activated at the altitude less than 100m, where h_c is the indicated altitude, and the feedback gain $K(t)$ is gradually increases from 0 to 1.0 so that it does not give a large impact to the system. Figures 6 through 8 show simulation examples where the vehicle parameter are

$$m = 760kg, \quad I = 1366kgm^2$$
$$S = 9.45m^2, \quad c = 3.154m$$

Figures 6 and 7 show inditial responces of the pitch rate $\dot{\theta}$ and the lateral acceleration a, respectively. Figure 8 shows the flight trajectory simulation example at the final approach. Simulation results generally shows the fine performance of the system.

5.CONCLUSION

The flight path and altitude control system designed by the proposed method shows fine performance. The lateral autopilot is currently under design, and by conbining both of them a total flight control system will be completed.

REFERENCES

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2) S. Akishita and F. Imado, "General Purpose Tactical Missile Simulation Program", Proc. of 13 th Annual Simulation Symposium, Society for Computer Simulation, Tampa, Fl., pp.257-270, Mar. 1980.

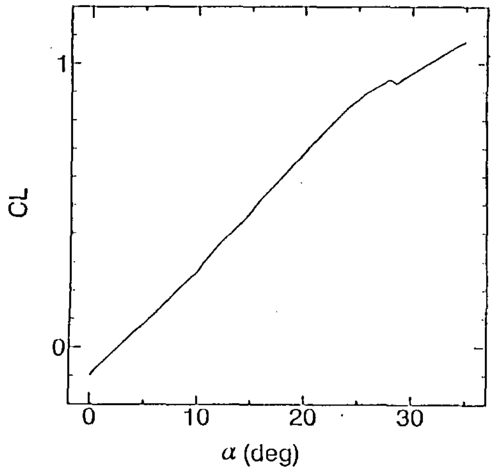

Fig.3 C_L values in relation to α
(At a nominal state)

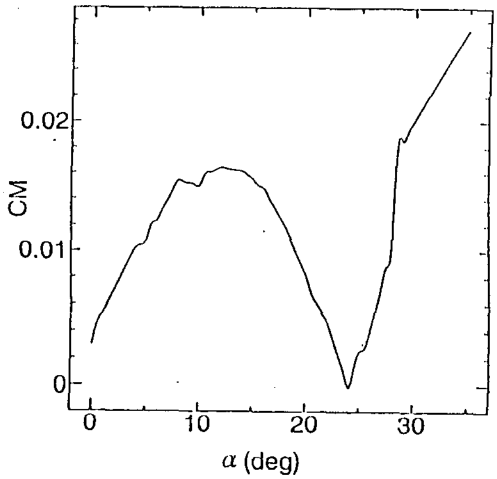

Fig.4 C_m values in relation to α
(At a nominal state)

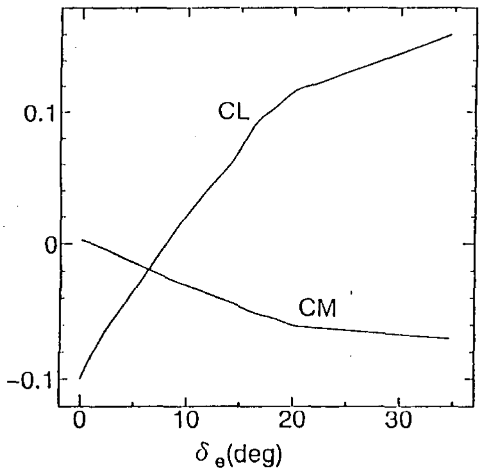

Fig.5 C_L and C_m values in relation to δ
(At a nominal state)

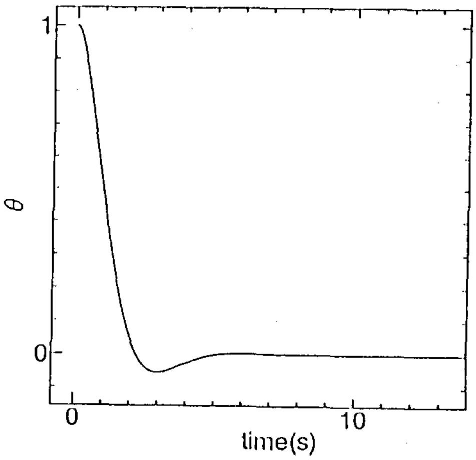

Fig.6 Inditial responce of the pitch rate
(At a nominal state)

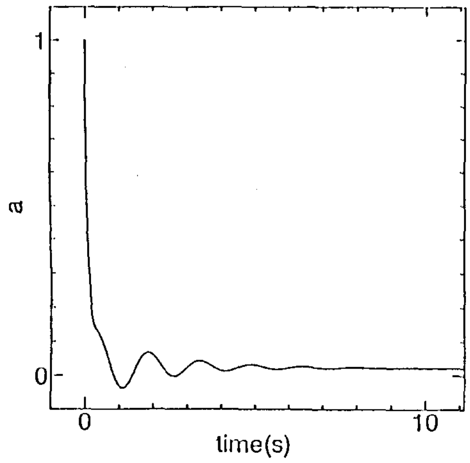

Fig.7 Inditial responce of the lateral acceleration
(At a nominal state)

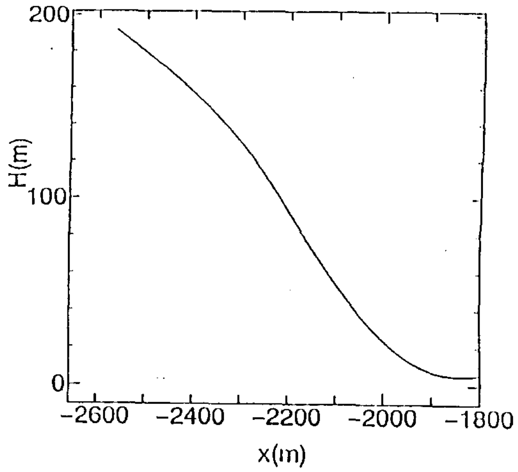

Fig.8 An example of the flight trajectory
simulation