The research of open loop characteristics of lifting wing based on constant speed constant elastic cases

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Abstract. The open loop response of lift wing is researched based on a kind of high speed vehicle model which is released by America air force research center. Since the speed of aircraft is too high, so its open loop response is unstable, which is difficult to do open loop actuator analysis with traditional method. In this paper, a kind of virtual flying conditions is assumed to make the simulation can last longer which can get more data to analysis the actuator effect, so the speed and elastic shape are considered to be constant. With the numerical simulation technology, the unstable open loop characteristics are recorded and analyzed.

Introduction

The research of the open loop characteristic of the lifting airfoil is carried out based on the canard open-loop characteristics in this paper. The aim is to research the instability degree of canard and attack angle. At the same time, the difference of the hypersonic aircraft and conventional aircraft is that engine thrust does not change when hypersonic aircraft does open loop flying, it also can be thought of in the approximate stationary state. And for hypersonic flight vehicle, although setting at constant speed and constant elasticity, the influence of elastic shape change and speed change on aircraft can temporarily not be considered, but due to the rudder deflection caused by the static instability characteristic to thrust changed dramatically caused by the divergence of attack angle.

so the open loop characteristic is difficult to take out the influence of the thrust fluctuation, it is the typical differences of hypersonic flight vehicle, of course, thrust can be set steady, but it is difficult to reflect the rotation characteristics of hypersonic flight vehicle, so the attack angle is also not true, this article would not make the effort. On this basis, this paper also studied the canard compared with the efficiency of the elevator, and the combination effect of synthetic direction is researched in order to further understand the whole steering effect of hypersonic flight vehicle.

Model Description

Considering the elastic shape structure, a kind of pitch channel hypersonic aircraft model built according to Lagrange equation is released by USA air force as followed:

$$\dot{V} = \frac{T\cos\alpha - D}{m} - g\sin\gamma \tag{1}$$

$$\dot{\phi} = -2\varsigma\omega_n\phi - \omega_n^2\phi + \omega_n^2\phi_c \tag{2}$$

$$\dot{\gamma} = \frac{L + T\sin\alpha}{mV} - \frac{g\cos\gamma}{V} \tag{3}$$

$$\dot{\alpha} = q - \dot{\gamma} \tag{4}$$

$$\dot{q} = \frac{M}{I} \tag{5}$$

$$\dot{h} = V \sin \gamma \quad (6)$$

$$\ddot{\eta}_i = -2\varepsilon_m \omega_{mi} \dot{\eta}_i - \omega_{mi}^2 \eta_i + N_i \quad (7)$$

And V is speed, γ is the speed angle, α is attack angle, Q is the attitude angle speed, h is the height. ϕ is the oil supplying factor, δ_c is the duck wing and δ_e is the lift rudder.

Simulation settings of free flying

In order to testify the rightness of the model of hypersonic aircraft, choose a initial height as $h_0 = 85000 * 0.3048$, initial speed as $V_0 = 7846 * 0.3048$, initial attack angle as $\alpha_0 = 0.0174$, and other initial state as: $\gamma_0 = 0$, $q_0 = 0$, $\eta_{10} = 0.4588 * 0.3048 * 14.59$, $\eta_{20} = -0.08726 * 0.3048 * 14.59$, $\eta_{30} = -0.03671 * 0.3048 * 14.59$, Setting the throttle opening of engine for the switching control law of the PID control law with diffusion control law, selection

$$\phi_c = k_{et} e_v + k_{set} e_v + k_{de} \dot{e}_v + k_{etb} \frac{e_v}{|e_v| + \varepsilon_{ev}}, e_v > 0,$$

$$\phi_c = -300, e_v < 0$$

Among them, k_{et}、k_{set}、k_{de}、k_{etb} and ε_{ev} are adjustable positive.

The expectations speed is $V^d = 2391$, the control volume is $\delta_c = 0$, $\delta_e = 1/57.3$, testing open loop dynamic characteristics of the rise and fall wing of superb aircraft, setting $\dot{\eta}_i = 0$, The flight time is 0.5 seconds.

Numerical Simulation and result analysis

With above initial condition ,the simulation can be done and simulation results can be shown as following figure 1.

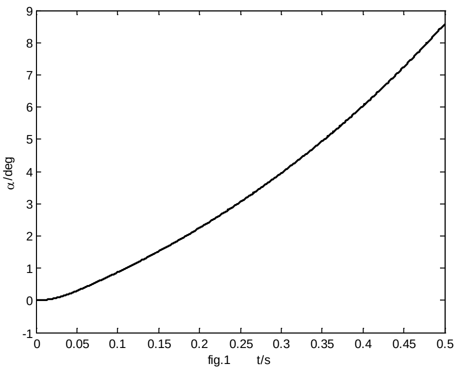

Fig 1 The curve of attack angle

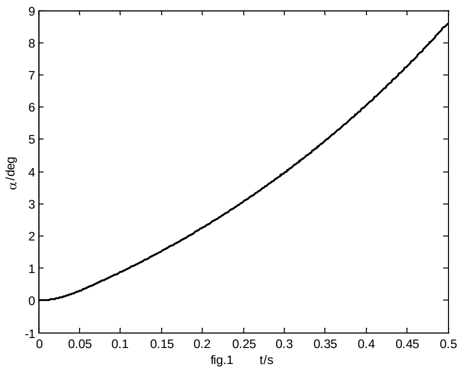

Fig 2 The curve of attack angle

It can be seen from simulation that the elevation angle remains stable in constant speed and elasticity 0.5 seconds lifting wing constant open loop flight, but the divergence of attack angle is also too fast, the divergence of attack angle about 8 degrees can be preliminary judged according to the graph. This is the place that is different from conventional aircraft at low speed, because attack angle of the low speed vehicle open-loop characteristics can remain stable for a short time. It can be seen that attack angle of the hypersonic aircraft has static instability characteristics, the greater difficulty and challenge will be brought for the design of its controller. At the same time, the simulation results graphics of the short time are strikingly similar by canard open-loop simulation results. But this does not mean that the efficiency of canard and lift wing is the same, It is mainly because the simulation of the two curves are divergent, so it is not good to compare. It can only show that the divergence speed is similar, or both open loop simulation results representation are unstable characteristics of hypersonic missiles, It may be given other rudder deflection value, its short-term simulation results also won't have too big change. Therefore the open loop dynamic characteristic is analyzed when the wing and the lifting wing are tried to play role at the same time. Setting $\delta_c = 1/57.3$, $\delta_e = 1/57.3$, and the simulation curve of the divergence of attack angle are as figure 2.

And setting the rudder slants for other value, $\delta_c = -10/57.3$, $\delta_e = -10/57.3$, and the simulation results are as figure 3 and figure 4.

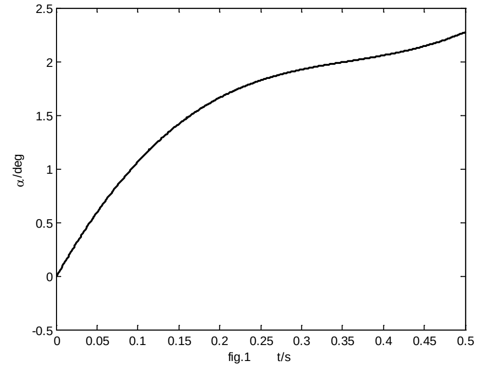

Fig 3 The curve of attack angle

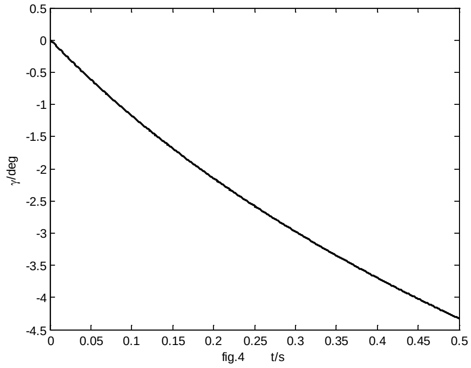

Fig 4 The curve of attack angle

It can be seen that the speed of the aircraft has a great influence on rudder in this case. The constant speed control doesn't work. And in the case of attack angle decreases, flying stalls quickly, speed decreases rapidly in 0.5 seconds, It mainly is the resistance decreases more slow than the thrust reduction. It can be seen that the coupling between the engine and attack angle, the coupling between lift and rudder slant is larger, it will greatly increase the difficulty of the controller design. The lift wing and canard contrast analysis based on constant speed constant elasticity case.

Setting $\delta_c = 0$, $\delta_e = -10/57.3$ in the first case, the simulation result is as figure 5. Setting $\delta_c = -10/57.3$, $\delta_e = 0$, in the second case, the simulation result is as figure 6.Setting $\delta_c = -10/57.3$, $\delta_e = 10/57.3$, in the third case, the simulation result can be shown as figure 7. Setting $\delta_c = 10/57.3$, $\delta_e = -10/57.3$ in the fourth case, the simulation result can be shown as figure 8.

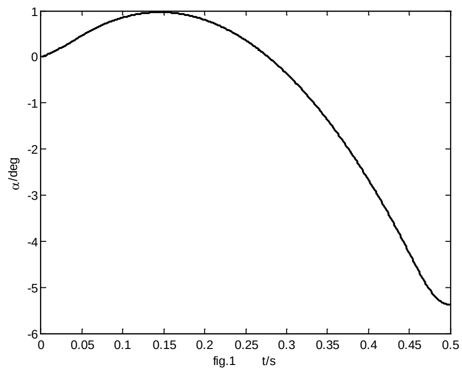

Fig 5 The curve of attack angle

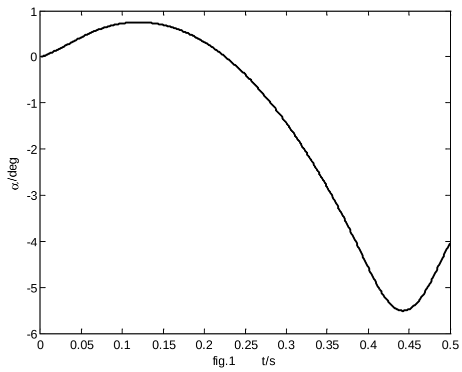

Fig 6 The curve of attack angle

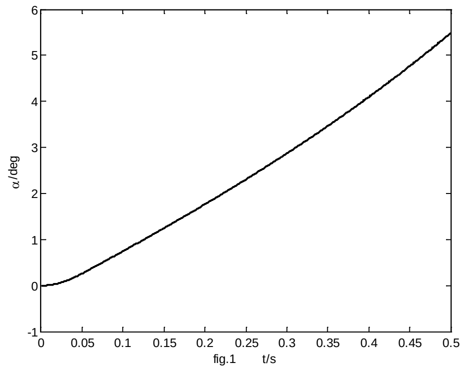

Fig 7 The curve of attack angle

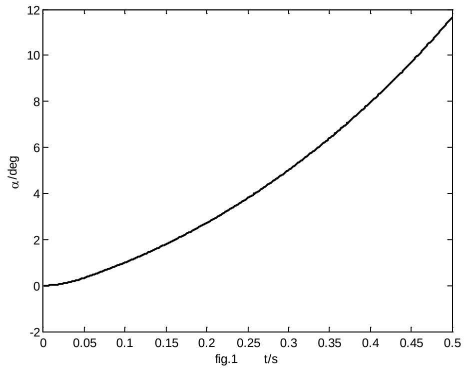

Fig 8 The curve of attack angle

Conclusion

The static unstable features from lifting wing to attack angle is shown by open loop flight simulation analysis of lift wing constant setting the hypersonic aircraft constant speed and constant elasticity assumption in this paper. It shows that control difficulty of control difficulty is very big. By lifting wing and canard contrast at the same time, as well as other constant rudder deflection value test, we found that the change of attack angle will cause the rapid change of the engine thrust, at the same time, the speed of craft will also change quickly, the coupling relationship between engine and attack angle is very serious, it will bring great challenges to the design of the controller.

References

[1]Wang J L，Sundararajan N．A nonlinear flight controller design for aircraft[J].Control Eng.Practice，1995，3(6)：813-825．

[2]A. E. Finzi, M. Lavagna, A. Di Gregorio, Atmospheric re-entry trajectory tracking and control for an unmanned space vehicle with a Lyapunov approach [A], In: AIAA Guidance, Navigation, and Control Conference and Exhibit [C], Austin: AIAA, 2003-5441

[3] Reiman S E，Dillon C H，Lee H P，et a1．Robust adaptive reconfigumble control for ahypersonic cruise vehicle，In：AIA A Guidance,Navigation，and Control Conference，Chicago，USA，AIA A 2009-6185：1．10．

[4]Christopher I．Marrison．synthesis of robust control systems for a hypersonic aircraft decision and contro1．IEEE，1994。4:3324-3329

[5]Gregory I M, Mcminn J D and Shaughnessy J D. Hypersonic vehicle control law development using ∞ H and μ-synthesis [R]. NASA TM-4562, 1994.

[6]Lohsoonthorn P, Jonckheere E and Dalzell S. Eigenstructure vs constrained ∞ H design for hypersonic winged cone [J]. Journal of Guidance, Control, and Dynamics, 2001, 24(4): 648-658.

[7]Appleby B D and Adams N J. Robust estimator design applied to the lateral dynamics of a hypersonic vehicle [A]. In: AIAA Guidance, Navigation, and Control Conference and Exhibit [C]. AIAA-1991-2689.

[8]D.K.Schmidt. Ingegrated Control of Hypersonic Vehicles-A Necessity Not Just a Possibility. AIAA,1993:539-549.

[9]Chavez F R and Schmidt D K.Uncertainy modeling for multivariable-control robustness analysis of elastic high-speed vehicles[J].Journal of Guidance, Control,and Dynamics,1999,22(1):87-95.

[10]Irene M．Gregory．Hypersonic vehicle control law development using H infinity and mu-synthesis．NASA Technical Memprandum．1994-4526：1-32．