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Settling Time Performance Controller Design Of A Typical UAV With Minimum Control Surfaces

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Abstract—
The UAV (Unmanned Aerial Vehicle) is an aircraft with no pilot on board. UAVs can be remote controlled (flown by a pilot at a ground control station) or can fly autonomously based on pre-programmed flight plans. UAVs have three control surfaces namely elevator, aileron and rudder for the control of pitch, roll and yaw movements respectively in general. But the UAV used here has only two independently driven elevon surfaces. Though this type of design provides mechanical simplicity, unmanned aerial vehicles with only two elevon surfaces present interesting challenges in dynamics modelling. The H-infinity controllers are used in controlling their certain flight performance within the required settling time specification.
Index Terms— *Aileron, elevator, elevon, nonminimum phase system, rudder, unmanned aerial vehicles.*

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I. INTRODUCTION

An unmanned aerial vehicle (UAV) is commonly known as a drone. It is also called by several other names. UAV is an aircraft without a human pilot abroad. The flight of UAVs may be controlled either autonomously by onboard computers or by the remote control of a pilot on the ground in another vehicle [1]. Unmanned aircraft is classified into two types: 1) Autonomous aircraft 2) Remotely piloted aircraft. In Fig.1, P15035 UAV is shown having only two independent elevon control surfaces.

Fig.1.P15035 UAV, having only two independent elevon control surfaces.

The term unmanned aerial system (UAS) was adopted for UAV by the United States Department of Defence due to its applications in the field of military works. UAS includes elements such as the unmanned aircraft, ground control stations, data links and other related supporting equipment [2]. In general, UAVs have elevators, aileron and rudders as three control surfaces. The UAV used in this work have no rudder or elevators. Hence its roll, pitch and yaw movements are controlled by two independently driven elevon surfaces. This type of UAV is colloquially called a plank. With the propellor mounted in a tractor configuration but having no rudder or elevators, its attitude control is done by two independently driven elevon surfaces, as shown in Fig. 1. It is very rugged, easy to maintain, of compact construction, and have better flight behaviour and wide airspeed range. It is because of these reasons, a similar configuration was adopted for the Dragon Eye, a small UAV for use by the U.S. Marine Corps [7]. However, its two elevon (combining elevator and aileron) control surfaces result in an underactuated configuration and a significant coupling between roll and yaw, presenting a challenge for controller design[3].

II. MODELLING OF UAV

According to Newton's second law of motion for each of the six degrees of freedom the product of mass and its acceleration produce (disturbing) force. For the rotary motion, the mass, acceleration and disturbing force become moment of inertia, angular acceleration and disturbing moment or torque respectively [4].

The Components of Inertial Acceleration

Consider the motion of a body referred to an orthogonal reference axis set oxyz [6]. Let u, v, w be the components of velocity and X, Y, Z represents the components of force. In similar way, p, q, r represents the components of angular velocity and L, M, N represents the moment components along x, y, z directions respectively [4].

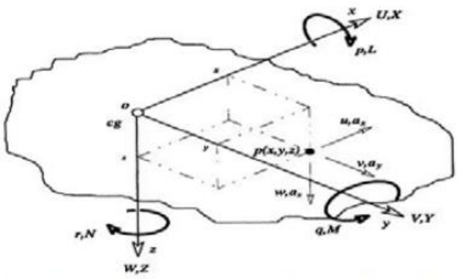

Fig.2.Motion referred to generalised body axis.

The velocity components at p (x, y, z) are given by,

$$\begin{aligned} u &= \dot{x} - \mathrm{ry} + \mathrm{qz} \\ \mathrm{v} &= \dot{y} - \mathrm{pz} + \mathrm{rx} \\ \mathrm{w} &= \dot{z} - \mathrm{qx} + \mathrm{py} \end{aligned} \qquad (1)$$

Since the aircraft is assumed to be rigid, $\dot{x} = \dot{y} = \dot{z} = 0$. Then,

$$\begin{aligned} u &= -\mathrm{ry} + \mathrm{qz} \\ \mathrm{v} &= -\mathrm{pz} + \mathrm{rx} \\ \mathrm{w} &= -\mathrm{qx} + \mathrm{py} \end{aligned} \qquad (2)$$

Corresponding components of acceleration are given by,

$$\begin{aligned} a_x &= \dot{u} - \mathrm{rv} + \mathrm{qw} \\ a_y &= \dot{v} - \mathrm{pw} + \mathrm{ru} \\ a_z &= \dot{w} - \mathrm{qu} + \mathrm{pv} \end{aligned} \qquad (3)$$

The inertial velocity components are given by,

$$\begin{aligned} \dot{u} &= U + u = U - \mathrm{ry} + \mathrm{qz} \\ \dot{v} &= V + v = V - \mathrm{pz} + \mathrm{rx} \\ \dot{w} &= W + w = W - \mathrm{qx} + \mathrm{py} \end{aligned} \qquad (4)$$

Similarly, the inertial acceleration components are

$$\begin{aligned} a'_x &= \dot{U} - \mathrm{rv} + \mathrm{qw} - \mathrm{x}(q^2 + r^2) + y(pq - \dot{r}) + z(pr + \dot{q}) \\ a'_y &= \dot{V} - \mathrm{pw} + \mathrm{ru} - \mathrm{x}(pq + \dot{r}) - y(p^2 + r^2) + z(qr + \dot{p}) \\ a'_z &= \dot{W} - \mathrm{qu} + \mathrm{pv} + \mathrm{x}(pr - \dot{q}) + y(qr + \dot{p}) - z(p^2 + q^2) \end{aligned} \qquad (5)$$

III. ELEVON CONTROLLED UAV

Conventional aircraft controls yaw, pitch and roll movements using rudder, elevator and aileron control surfaces [5]. Our UAV has only two elevon surfaces. The two elevons must control roll, pitch and indirectly yaw as there is no rudder. Let and be the left and right elevon angles, respectively and q, p, r be the rate vector of pitch, roll and yaw [7].

IV. H-INFINITY CONTROLLER

Under perturbed condition the conventional controllers like PID may become a failure in proper control. To maintain stability in real perturbed conditions, the robust H-infinity controller is taken for the given stability analysis. The general block diagram of H-infinity controller is shown in fig.3.

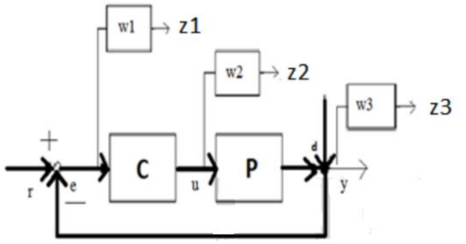

Fig.3: H-infinity controller and its weights along with the plant

Three weights namely W1, W2 and W3 are used to tune for achieving performance and stability. For achieving good disturbance rejection, the weight W1 should be properly selected. For stability margin, W3 should be tuned. W1 should be small inside the desired control bandwidth. The weight labelled W2 is known as control weight and is taken as an empty weight in this application. W1 is known as performance weight and W3 is known as stability weight. W1, W2 and W3 penalize the error, control and output signals respectively. The necessary condition to be satisfied for the application of H-infinity controller is that the infinity norm of the product of weights assigned and the sensitivity(S)/complementary sensitivity (T) should be less than or equal to one. The SV (Singular Value) plots in fig.8 verified the application eligibility of H-infinity controllers in the present problem.

V. RESULTS

Open Loop Response

The open loop responses of pitch angle and yaw angle are shown in fig.6 & fig.7 respectively. On analysing the responses, it is clear that we must go for a suitable controller for obtaining the required performances.

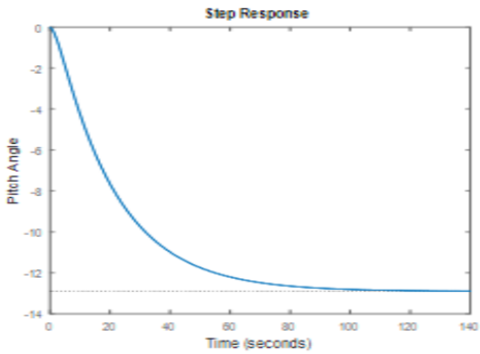

Fig.6: Response of pitch angle to elevon

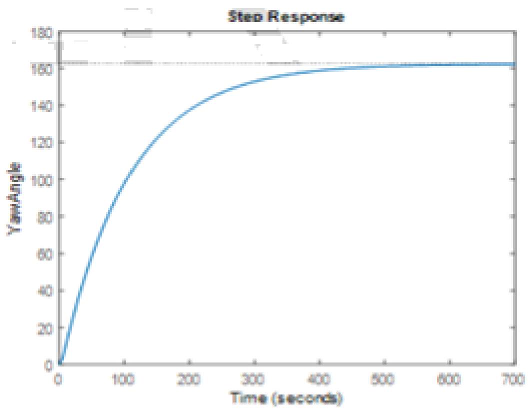

Fig.7: Response of yaw angle to elevon

Response with H-infinity controller

The responses of pitch angle and yaw angle with H-infinity controller are shown in fig.9 & fig.10 respectively. On analysing the response, it is clear that their settling times meet the required specifications (0.5 seconds).

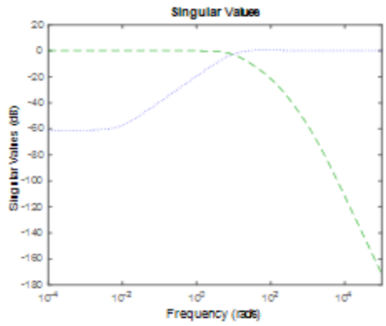

Fig.8: SV Plot

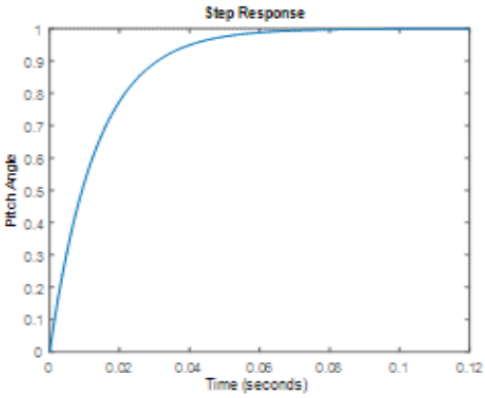

Fig.9: Response of H-inf controlled pitch angle to elevon

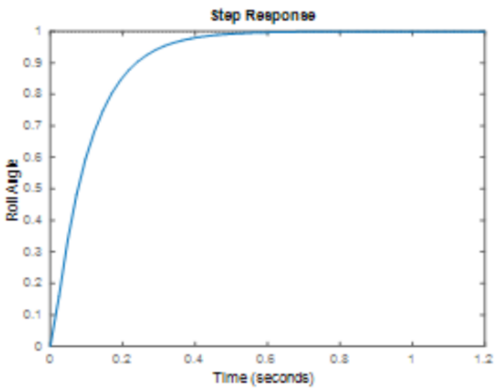

Fig.10: Response of H-inf controlled yaw angle to elevon

VI. CONCLUSION

The present article gives the test results of an unconventional controlled UAV using elevons without rudders or elevators. Through the fine-tuning process, the H-infinity controllers led to satisfactory flight performances within the minimum required settling times (0.5 seconds) in the response of pitch and yaw angles.

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