A New Perspective to Altitude Acquire-and-Hold for Fixed Wing UAVs

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***Abstract*-UAVs are becoming increasingly interesting for many applications, also in the civil field. In a UAV, the onboard autopilot autonomously controls the aircraft flight and navigation. The altitude acquire-and-hold is an important function of autopilot, implemented using a control design algorithm that flies the UAV to commanded altitude and maintains it. While UAVs are usually expected to be in constant contact with base stations, a critical aspect of their usability is related to the autonomy in case of an interruption of communications. In this paper, we present a comparison between two altitude control techniques. Firstly, altitude control through elevator using PID controller. Secondly, altitude control through throttle and elevator using simple Proportional and PID controller. The nonlinear model is linearized around a stable trim condition and decoupled for linear controller design. The results for the compensated linear and nonlinear models are presented. It is observed that controlling altitude via elevator and throttle is better in terms of transient response**.

Keywords-UAV; PID; autopilot

I. INTRODUCTION

Originally Aerosonde was developed for very long endurance as well as low cost UAV for meteorological issues in several areas. By 1995-1998, this UAV was developed by two Australian companies, named as 'Australian Bureau of Meteorology' and 'Insitu group of USA'. This project was co-sponsored by U.S Navy's ONR (Office of Naval Research). In August 1998, Aerosonde became the first UAV to cross Atlantic and covered about 3200 km in 26 hours and 45 minutes. Aerosonde can fly autonomous flights including takeoff and landing. It has a GPS waypoint system, which is used for its navigation and has UHF and SATCOM datalinks for remote control.

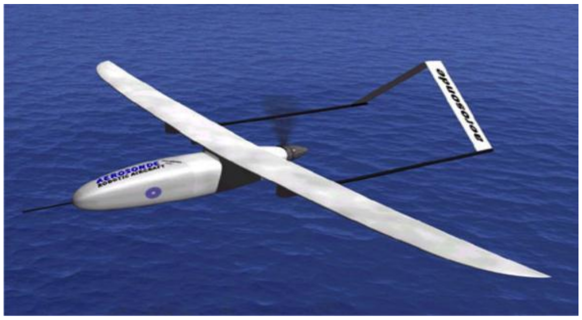

Figure 1: Aerosonde UAV

A. *Data For Aerosonde*

Length: 1.74 m
Wingspan: 2.87 m
Weight: 15 kg
Speed: 150 km/h (80 knots)
Ceiling: 6100 m
Range: 1850 km
Endurance: 30 hours
Propulsion: Piston Engine

Table 1

In modern era, world is unmanned. Today the bots are helping humans not only in their social lives but also are participating in military aspects. UAVs participate as surveillance on borders of any territory, agricultural researchers uses them, they can be sent in an environment which is unaccessed by aerobiological issues like gaseous disasters. Due to these potentiated capabilities, UAV has proved itself to be challenged for any purpose. An Autopilot system installed in a UAV makes it independent of a human pilot, enhancing the accuracies in all types of flight related operations. The efficiencies in aerospace as well as in avionics of a UAV make the UAV more reliable. Development of UAVs involves expertise in different fields like aerodynamics, airframe structure, propulsion system and automatic flight control systems. Automatic flight control system autonomously controls the UAV by generating various control signals for actuating control surfaces of the UAV. Altitude-gain-and-hold is an important function which is required to acquire an altitude and maintain it till further instructions are executed. In recent period a number of methods were used for navigation and control of UAV including invertebrate neuronal models [1], nonlinear feedback linearization [2], neuronal networks [5], multi agent system, PID control (proportional integral derivative)[3],sliding mode variable structure control, multiple model adaptive control [2], based on fuzzy logic [4].

Nowadays, number of autopilot systems are easily available that can be installed with little modifications on a variety of modern aircraft. Generally, commercially available UAV autopilot system uses PID controller for many operations to control. The autopilots by Micro pilot uses definable PID feedback loops. The Picollo series autopilots (Cloud Cap) Technologies enhances the strength of PID control to perform automatic flights [6]. The Kestrel autopilot (Procerus Technologies) use real time PID graphers for onboard tuning of control gains [7] .Guidestar autopilot series (Athena Technologies) use PID controller techniques for trajectory/inclination control (altitude and heading controls). Due to the good performance, wide availability and simplicity of a PID controller it is been appreciated for its use in control systems. PID controllers are generally used on UAVs owing to easy implementation, but these offer limitations in stability and robustness. Phase Lead controllers in the feedback path are mostly used in missile control systems [8] to gain more stability and minimum overshoot, though these compensators can equally be well applied in the forward path after the error signal. This control technique has also been tested for aircraft control systems. A longitudinal motion autopilot using Phase Lead compensator has been designed for the F-16 aircraft nonlinear model [9].

Here, we have compared the performance of the controller using Elevator only and Elevator+Throttle as input to Aerosonde. Both these techniques have been well documented in the control systems literature.

II. NONLINEAR MODELLING AND LINEARIZATION

In order to simulate the Aerosonde dynamic model for 6 Degree-of-Freedom (6-DoF), aeronautical simulation blockset “AeroSim” was used. The basic nonlinear Aerosonde model is further composed of aerodynamics, inertia and propulsion models. It also includes a magnetic field and gravity model for earth, and a standard atmosphere model as shown in figure 2.

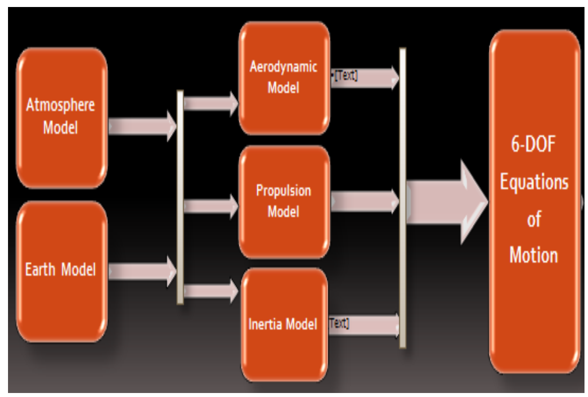

Figure 2: Non-linear UAV Model

Force equations

where m is the mass of aircraft, V_T is the true air velocity, β is the side slip angle, α is the angle of attack of wing, D is drag force, L is lift force, C is the cross wind force, Q is the pitch rate, α_T is the angle of attack of tail and R is yaw rate.

Moment equations

where P is the roll rate, J_x is the moment around x-axis, J_y is the moment around y-axis, J_{xz} is the moment in xz plane, m is the rolling moment and n is the yawing moment.

Velocity equations

where $\dot{P}_N$ is the velocity compnent in north direction, $\dot{P}_E$ is the velocity component in east direction, $\dot{h}$ is the velocity component in vertical direction, U is the velocity in body x-axis, V is the velocity in body y-axis, W is the velocity in body z-axis,s is the short form for 'sine', c is the short form for 'cosine', θ is the pitch angle and φ is the roll angle.

Kinematics equations

where $\dot{\phi}$ is the angular velocity in x-axis, $\dot{\theta}$ is the angular velocity in y-direction, $\dot{\varphi}$ is the angular velocity in z-direction.

After the nonlinear model has been acquired, the linear model is designed so that the implementation of equations already mentioned are easy to implement on an Aircraft. Numerical linearization technique was employed to linearize the nonlinear model around a level flight trim condition. The linear model thus obtained was used to design controllers to cater for aircraft natural longitudinal and lateral modes.

Since the model is linearized around a stable trim condition, UAV will not experience any sideslip or roll motions. Hence longitudinal and lateral sub-models are easily decoupled from within the linear model. The longitudinal model is then used with inputs of elevator and throttle, in designing of altitude controller. Decoupled longitudinal sub-model equation is given in (1).

$$\dot{x} = Ax + Bu \tag{1}$$

where $\dot{x}$ is decoupled longitudinal state vector [u q Θ h] and its time derivative on the left hand side of the equation. *u* is the control input. *A* denotes system matrix and *B* is input matrix for decoupled longitudinal sub-model. State variables matrix for lateral mode is presented in (2).

$$\begin{bmatrix} \dot{u} \\ \dot{q} \\ \dot{\theta} \\ \dot{h} \end{bmatrix} = \begin{bmatrix} Xu & Xw & -W_0 & -g_0\cos\theta_0 \\ Zu & Zw & U_0 & -g_0\sin\theta_0 \\ Mu & Mw & Mq & 0 \\ 0 & 0 & M_\theta & 1 \end{bmatrix} \begin{bmatrix} u \\ q \\ \theta \\ h \end{bmatrix} + \begin{bmatrix} X_{\delta e} & X_{\delta t} \\ Z_{\delta e} & Z_{\delta t} \\ M_{\delta e} & M_{\delta t} \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \delta e \\ \delta t \end{bmatrix} \tag{2}$$

δt represents throttle input and δe denotes elevator deflection. Pitch rate is q, pitch angle is Θ, velocity along body axis is u and altitude is represented by h. This linear model helps us to observe and control the aircraft's response as per desired specifications.

III. CONTROLLER DESIGN

In the controllers design process, settling time and overshoot as the time-response specifications are to be improved and controlled. The flight parameters of altitude and pitch rate are controlled using a Proportional controller. To control oscillations, a Proportional controller is used with aircraft actual pitch rate fed back. Pitch rate closed loop formed an inner closed loop and the outer closed loop is for altitude control. Altitude control uses a PID Controller with aircraft actual altitude fed back. Reference altitude is commanded to the closed loop system. In this way, a closed loop Simulink model is completed. By changing the inputs i.e. first elevator and throttle and then only elevator, different time response specifications are observed and compared.

These time response specifications make it easy to understand how altitude can be controlled with varying the inputs. For throttle to be used as an input with elevator, a conditional loop is formed which comes into play when

I. Throttle remains the same for error to be within +/- 10 m.
II. Throttle is increased to 90% if error becomes greater than 10 m.
III. Throttle is decreased to 40% if error becomes less than -10 m.

For this condition to be fulfilled, we use a for-loop blockset as shown in figure 7.

A. *Elevator and Throttle as Inputs*

When elevator and throttle are applied simultaneously then conditional loop controls the throttle with respect to velocity 'v' which in turn plays an important role in controlling the altitude of aircraft. Similarly altitude is controlled by the elevator and hence velocity and altitude can be controlled at the same time as depicted in figure 3.

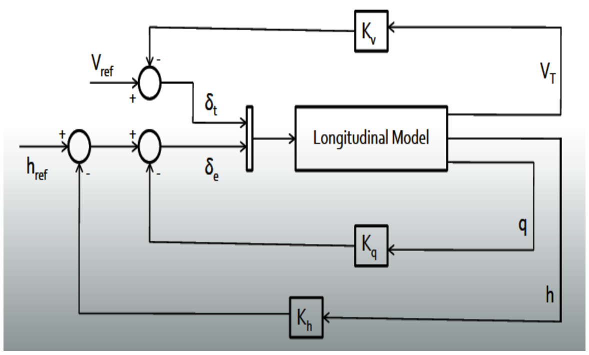

Figure 3: Elevator and Throttle as Inputs

B. *Elevator only as Input*

In this case where elevator alone is taking part as input, altitude is controlled by the process of pitch rate feedback and altitude at the outer closed loop as previously mentioned. But in this process, conditional loop for velocity (throttle as input) doesn't exist at all.

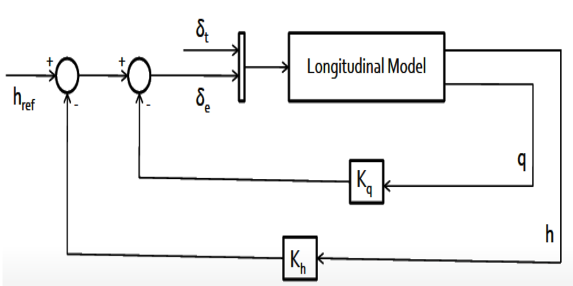

Figure 4: Elevator only as Input

IV. SIMULATION RESULTS

Simulation of Aerosonde linear and nonlinear models are accomplished via Simulink.

A. *PID Altitude Controller via Elevator*

The altitude response to elevator step input is shown in figure 5 for linear model. Settling time for step response is 14 sec, Overshoot is 13.1 percent and rise time is 1.85 sec.

After analyzing the linear model of Aerosonde, the elevator based PID controller is tested for the nonlinear model. Figure 6 shows the result for non-linear model. X-axis is the time axis (in milliseconds) and y-axis is the altitude axis (in meters).

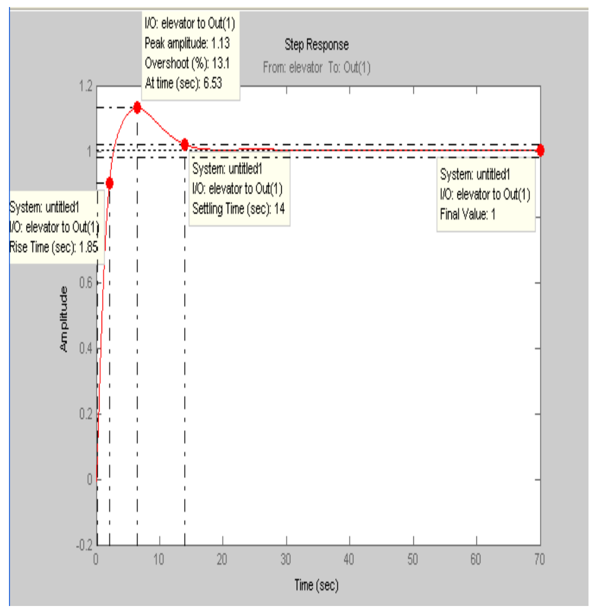

Figure 5: Linear Model Step Response from Elevator

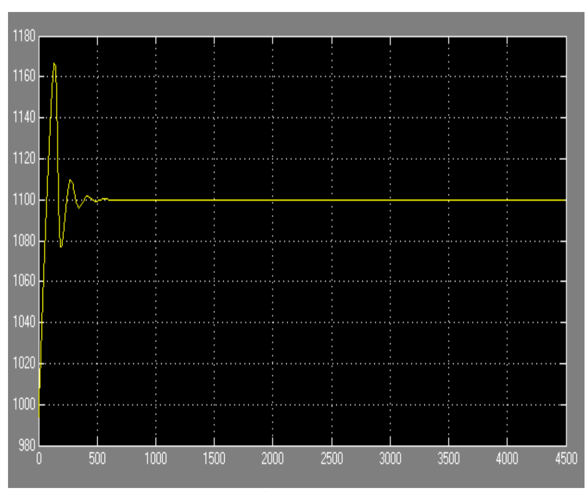

Figure 6: Altitude Control for Non-Linear Model via Elevator

B. PID Altitude Controller via Elevator+Throttle

The part of SIMULINK block diagram built for this purpose is shown in figure 6.

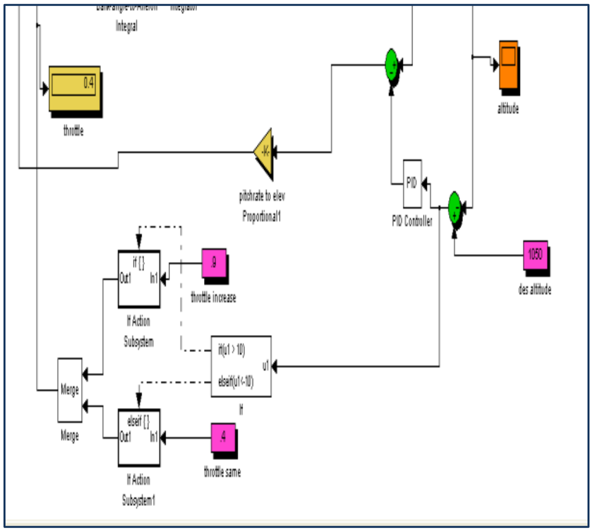

Figure 7: Simulink Model

The elevator based PID controller is tested for the nonlinear model. By carefully adjusting the controller gains, the overshoot has been minimized. Figure 8 shows the result for non-linear model. X-axis is the time axis (in milliseconds) and y-axis is the altitude axis (in meters).

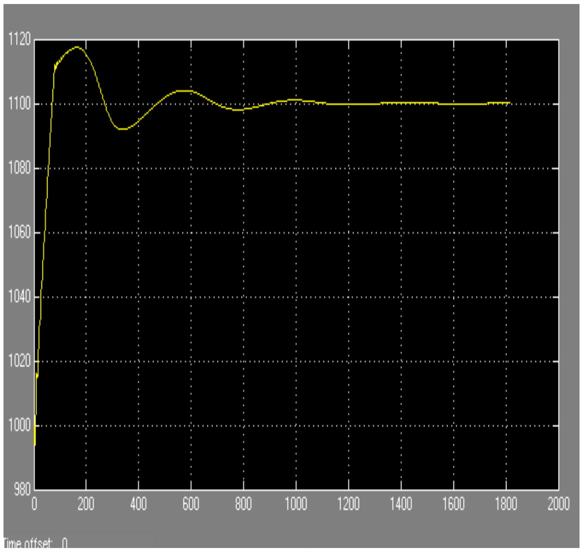

Figure 8: Altitude Control for Non-Linear Model via Elevator+Throttle

IV. CONCLUSION

Almost all of the existing autopilots use PID Controller for altitude control. In this paper , we have compared the performance of two methods of controlling altitude of a fixed Wing UAV-Aerosonde.

Our investigation shows that controlling altitude using elevator and throttle gives better transient response as compared to altitude control through elevator only. Inputs as elevator and throttle give a higher rise and settling time but less overshoot.

The response by PID controller, controlling elevator only offers less rise time and settling time but gives a higher overshoot. Due to specifications of UAV's, less overshoot is more desirable feature to optimize payload performance. Hence PID controller, controlling elevator and throttle, is a better choice for altitude control and stabilizing of UAV.

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