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ANALYSIS OF BOEING 747-200 LONGITUDINAL STABILITY USING PID CONTROLLER

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Abstract:

In aircraft autopilot designing, it is crucial to evaluate its stability and control of the system. In order to derive transfer function of a control system the behaviour of the system should be derived into mathematical form. In this paper the model of Boeing 747-200 is considered with the transfer functions of longitudinal modes and how elevator deflection affects system stability. Initially we figure out system stability with the help of poles location, root locus and bode plot. In order to find step response, we used unity feedback system in the Simulink. The step response of not as per the aircraft requirement as it is not settling at 1. Therefore, we designed PID controller in order to make our system stable.

I. Introduction

Throttle and braking systems are generally controlled by actuators in the cruise control system. An Actuator is a part of machine that releases force, torque and displacement [7]. If the controller parameter is not adjusted, then it will lead to unpredictable changes that cause poor control performance. Missiles as well as Aircraft are generally managed with control systems to offer stability, disturbance rejection, and reference signal tracking. The movement of aircraft in free flight is very complex. Transverse, vertical and horizontal are the translational motions, and pitch, yaw and roll are the rotational motions mostly used in aircraft. The aircraft is generally supposed to have a rigid body and aircraft movements typically include a small variation from equilibrium flight state to decrease the problem of inspection [8].

It is difficult to know and examine the behavior, security, performance and remaining portions of models in aircraft development, before its field testing. Therefore, it is crucial to keep fine numerical design of the framework to completely grasp, forecast and control the response of an aircraft to initialize robust control system. PCS (Pitch Control System) is an autonomous that stabilizes the pitch angle on the framework [1]. The construction and testing of an aircraft pitch plane control system has been a widely understood subject in the field of engineering. several scholars determined precisely the regions of stability of a F-14 in term of pitch attitude, motor thrust, and displayed a global consistency outcome for non-linear patterned pitch axis of a F-14 regulated by a non-linear dynamic inversion control rule [5]. Modern Aircraft structures highly depend on automation system to monitor and regulate several aircraft's subsystem. The growth of automation system has performed a paramount role in advancement of social and defense aerial [6].

II. Mathematical Model

We consider Boeing 747-200 as our testing model. The specification of the aircraft is given below:

Table1.1: Geometric Data for the Boeing B747-200 Aircraft

Wing Surface (ft^2)	s	5,500
Mean Aerodynamic Chord (MAC)	c	27.3
Wing Span	b	196

Table 1.2: Flight Conditions Data for the Boeing B747-200 Aircraft

Altitude (ft)	40,000
Mach Number	0.90
True Airspeed (ft\sec)	871
Dynamic pressure ($1bs/ft^2$)	222.8
Location of CG - % MAC	0.25
Steady state angle of attack (deg)	2.4

Table1.3: Longitudinal Dimensional Stability Derivatives for the Boeing B747-200 Aircraft

Cruise(high)
X_u=-0.0218, X_{Tu}=-0.0604, X_α=1.2227, $X_{\delta E}$=0 Z_u=-0.0569, Z_α = -339.0, Z^*_α=-7.666, $Z_{\alpha q}$=-7.474, $Z_{\delta E}$ =-18.341 M_u=-0.0001, M_{Tu}=0.0, M_α=-1.616, $M_{T\alpha}$=0 $M_{*\alpha}$=-0.1425, M_u=-0.4038, $M_{\delta E}$ =-1.2124

Table1.4: Longitudinal Transfer Functions for the Boeing B747-200 Aircraft

Cruise (high)
$\frac{\alpha(s)}{\delta_E(s)} = \frac{Num_\alpha(s)}{\bar{D}_1(s)} = \frac{A_\alpha s^3+B_\alpha s^2+C_\alpha s+D_\alpha}{A_1 s^4+B_1 s^3+C_1 s^2+D_1 s+E_1}$
$= \frac{-18.341s^3-1{,}055.696\, s^2-84.97s - 1.955}{878.568\, s^4+888.97\, s^3 + 1{,}599.56s^2+ 121.194\, s + 1.617}$
$\frac{u(s)}{\delta_E(s)} = \frac{Num_u(s)}{\bar{D}_1(s)} = \frac{A_u s^2+B_u s+C_u}{A_1 s^4+B_1 s^3+C_1 s^2+D_1 s+E_1}$
$= \frac{-22.426s^2-32{,}442.603s - 12{,}108.424}{878.568\, s^4+888.97\, s^3 + 1{,}599.56s^2+ 121.194\, s + 1.617}$
$\frac{\theta(s)}{\delta_E(s)} = \frac{Num_\theta(s)}{\bar{D}_1(s)} = \frac{A_\theta s^2+B_\theta s+C_\theta}{A_1 s^4+B_1 s^3+C_1 s^2+D_1 s+E_1}$
$= \frac{-1{,}062.524s^2-468.614s - 31.403}{878.568\, s^4+888.97\, s^3 + 1{,}599.56s^2+ 121.194\, s + 1.617}$
roots ($\bar{D}_1$(s)) =-0.4667±11.2364, -0.0612, -0.0172

III. Result and Discussion

Cruise control is self-operating system for maintaining the aircraft in a definite aerial path and plane. In a Rocket, autonomous is a closed loop structure as well as it is a small loop within the leading instruction loop [4]. Creating flight command system is a very complex responsibility due to their nonlinear behavior and ambiguous movement of the aircraft. Because of nonlinear and ambiguous movement of the aircraft, planned stability and execution cannot achieved by traditional classic controller [2]. The root-locus technique of Evans is highly successful and effective weapon for both examination and creation of SISO (single input single output) LTI (linear time invariant) methods [3].

Creators of real-time systems for response process settlement or choosing frequency recurrently create a use of Bode plot depiction of system transfer function [9].

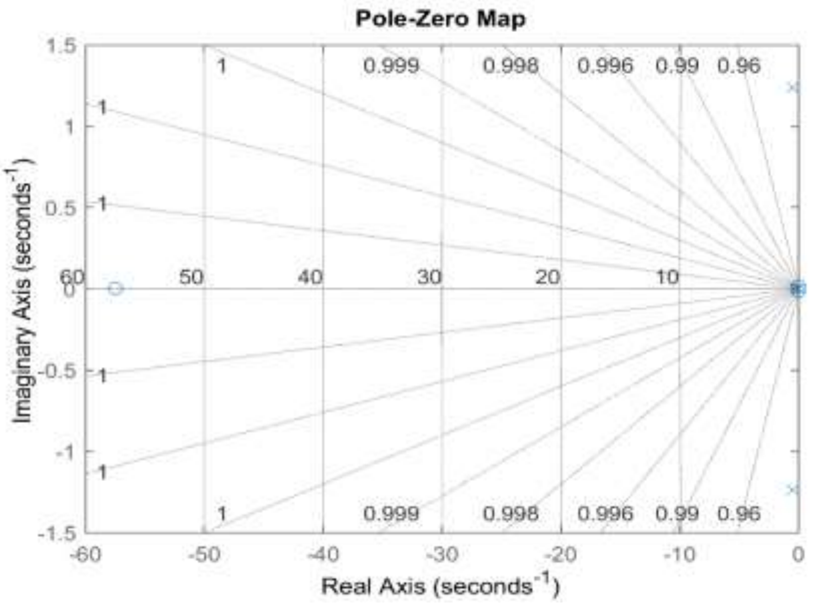

Figure 1: poles zero map of alpha by elevator deflection

Poles zeros map shows the location of poles and zeros in the s plane. All the poles should be lies on Right half plane in order to check the further stability of the system. In the above figure all poles lie on the right half plane.

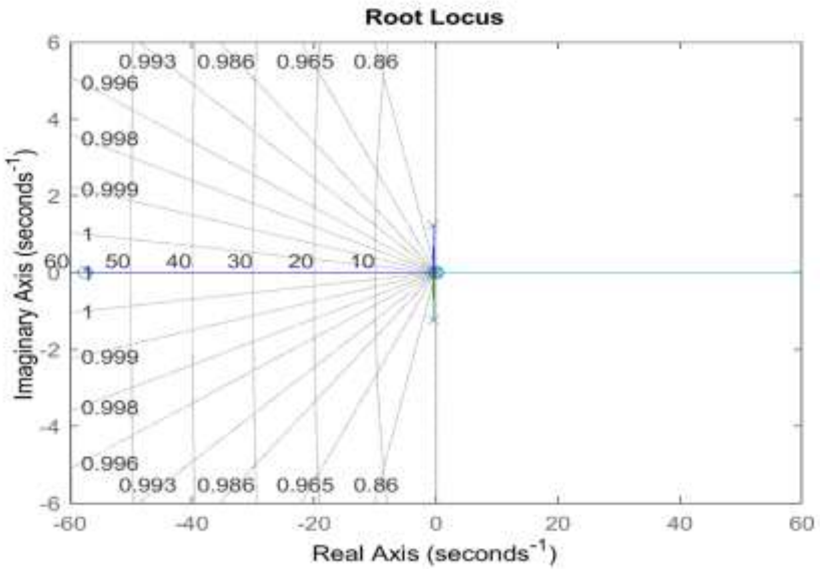

Figure 2: Root locus of alpha by elevator deflection

Root locus plot is used to check the stability of the system by changing gain values. If the root locus branch moves to right hand side, then the system is going to be unstable at that range of gain. If on the imaginary axis the system will be oscillatory.

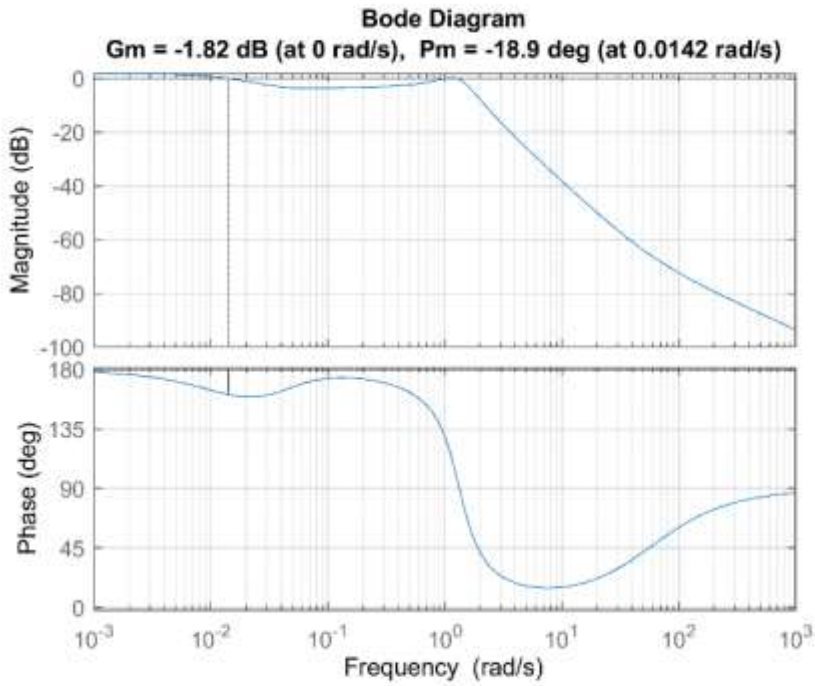

Figure 3: bode plot of alpha by elevator deflection

The bode plot diagram shows the change in system stability with change in frequency. Both Gain margin (Gm) and Phase margin (Pm) should be positive in order to have system stability. In this case it is negative so system will be unstable.

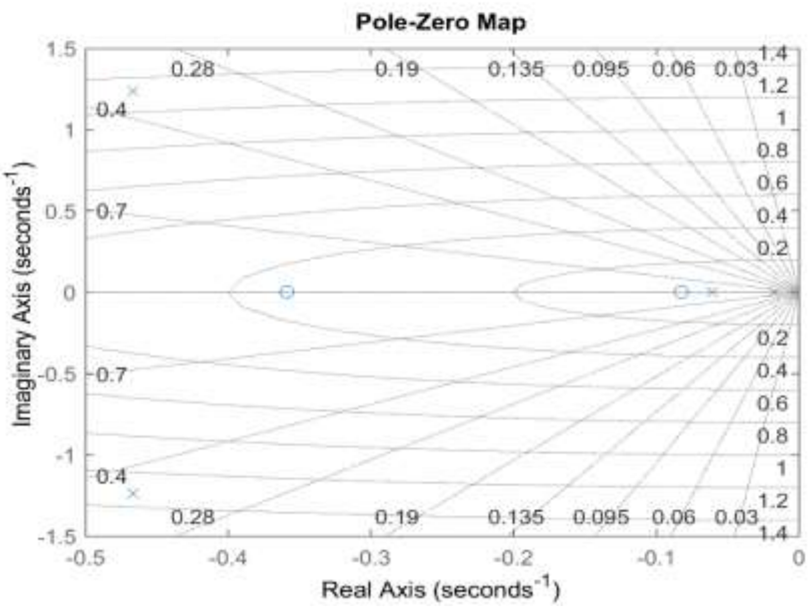

Figure 2: poles zero map of pitch by elevator deflection

The above diagram shows poles zero plot of transfer function of pitch by elevator deflection. As all the poles lies in the left half plane. We can move to check the further stability.

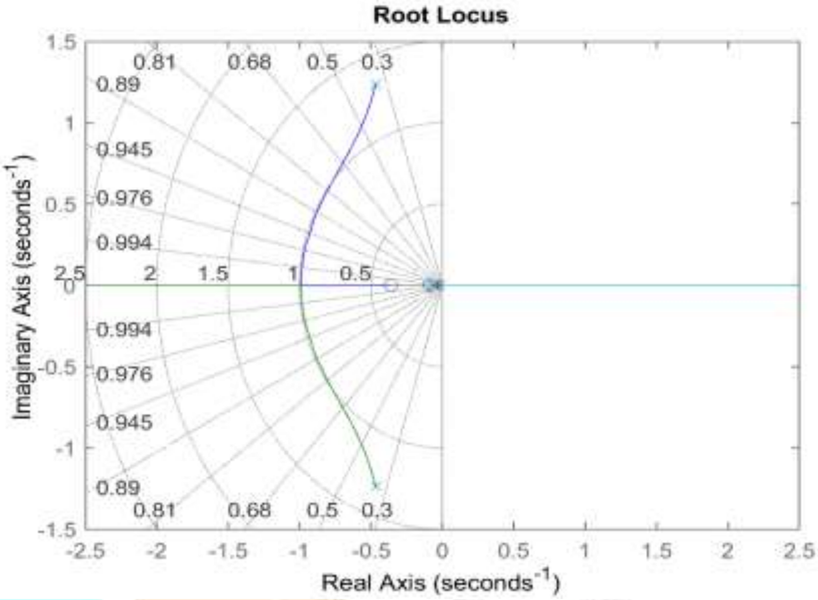

Figure 3: Root locus of pitch by elevator deflection

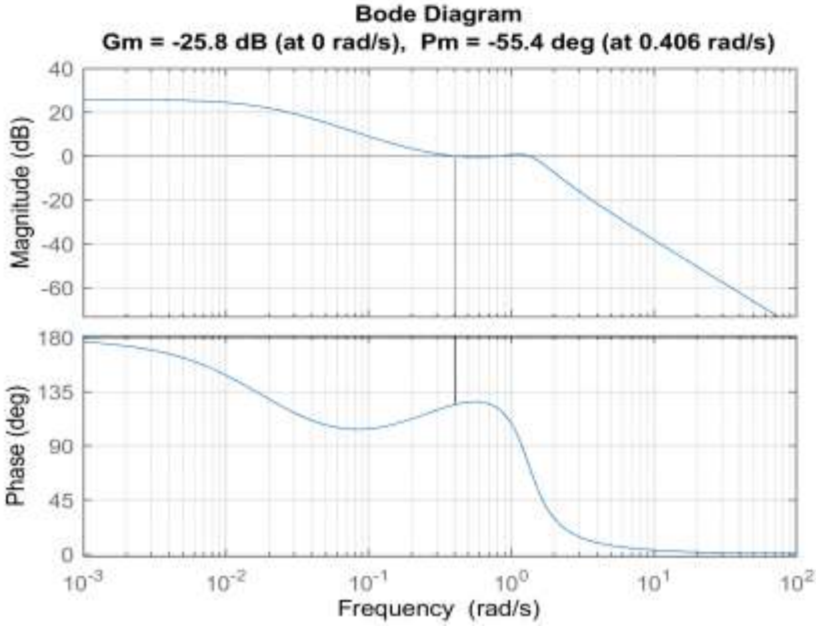

Figure 4: Bode plot of pitch by elevator deflection

As gain margin and phase margins values are negative therefore the system is unstable.

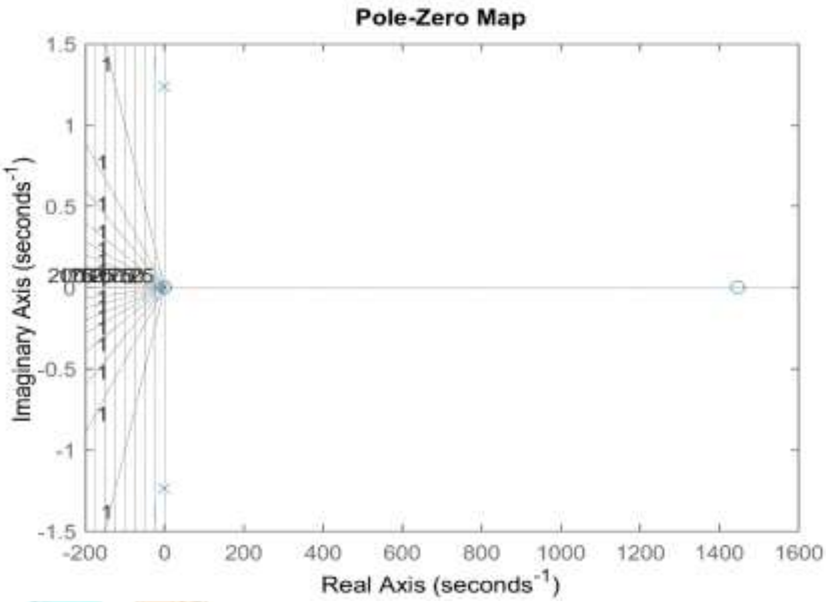

Figure 5 pole zero plot of velocity by elevator deflection

As all the poles lies on the left half plane, we proceed to check root locus plot

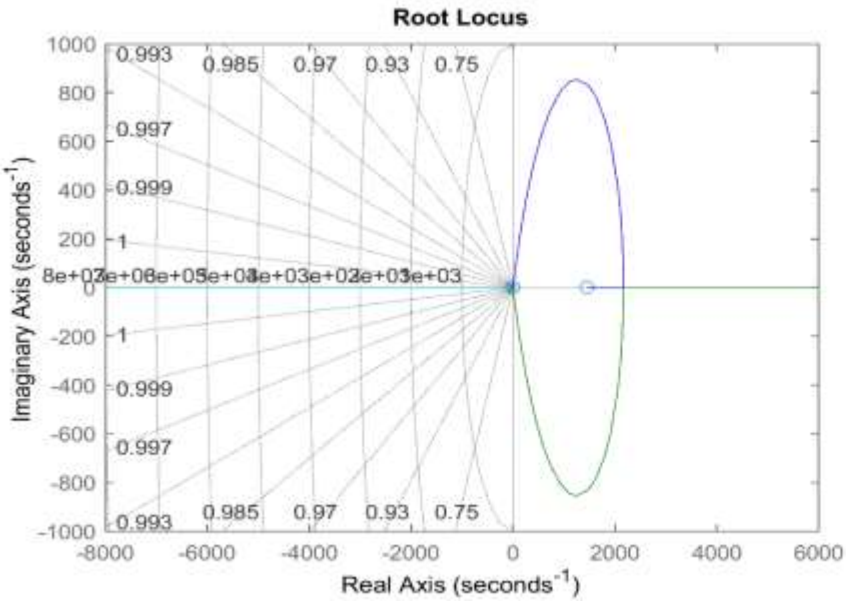

Figure 6 Root locus of velocity by elevator deflection

As one of the root locus branches moves to left hand side. Therefore, the system will become unstable after certain gain.

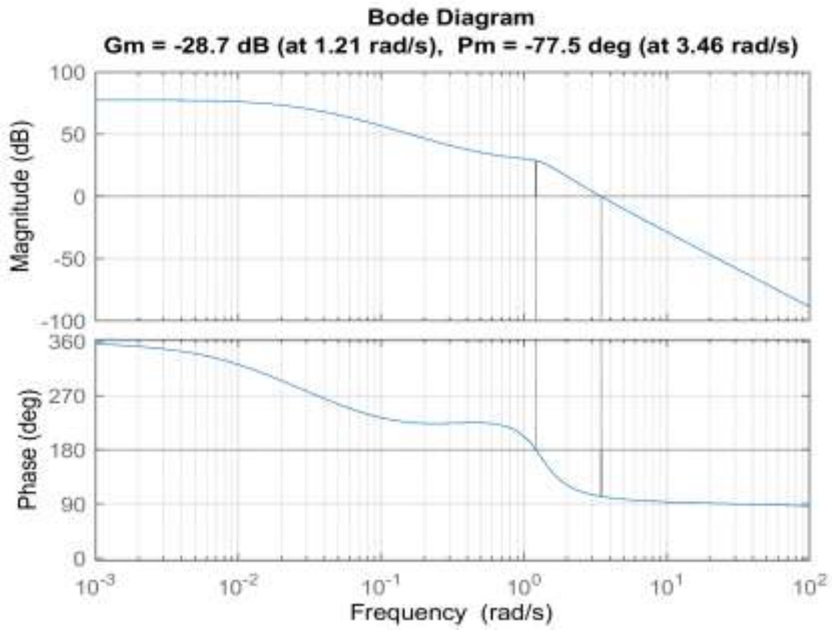

Figure 7 Bode plot of velocity by elevator deflection

Table 1.5: PID Values

PID	Alpha by elevator	Pitch by elevator	Velocity by elevator
P	-4	-4	0.002
I	-2.5	-2.5	2.18e-05
D	-1.5	-1.5	0.0045

As the gain margin and phase margin is negative system will be unstable.

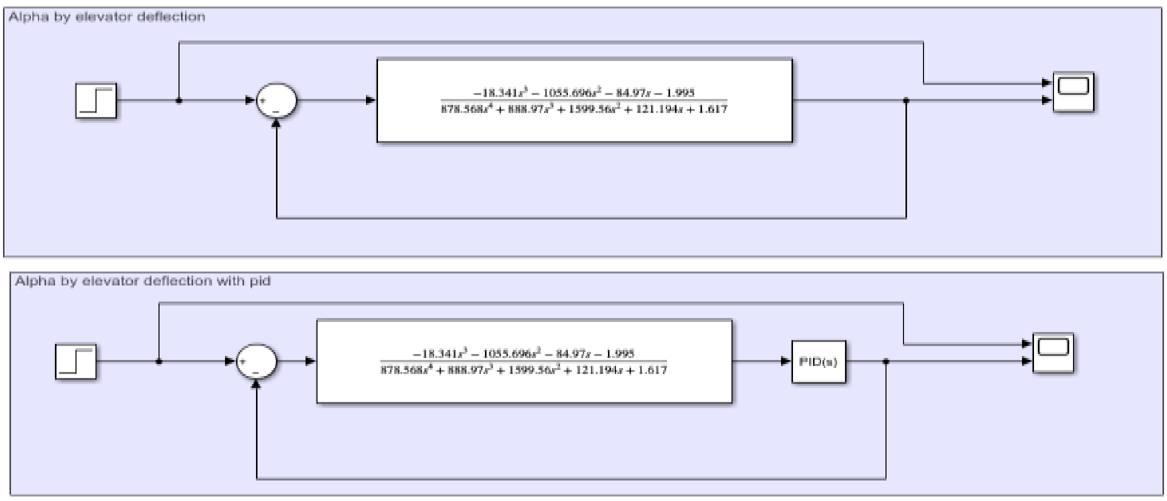

Figure 8 Feedback system of alpha by elevator deflection

The above figure is Simulink diagram made using MATLAB. First block is closed loop diagram of alpha by elevator and the second block uses PID controller with closed loop system.

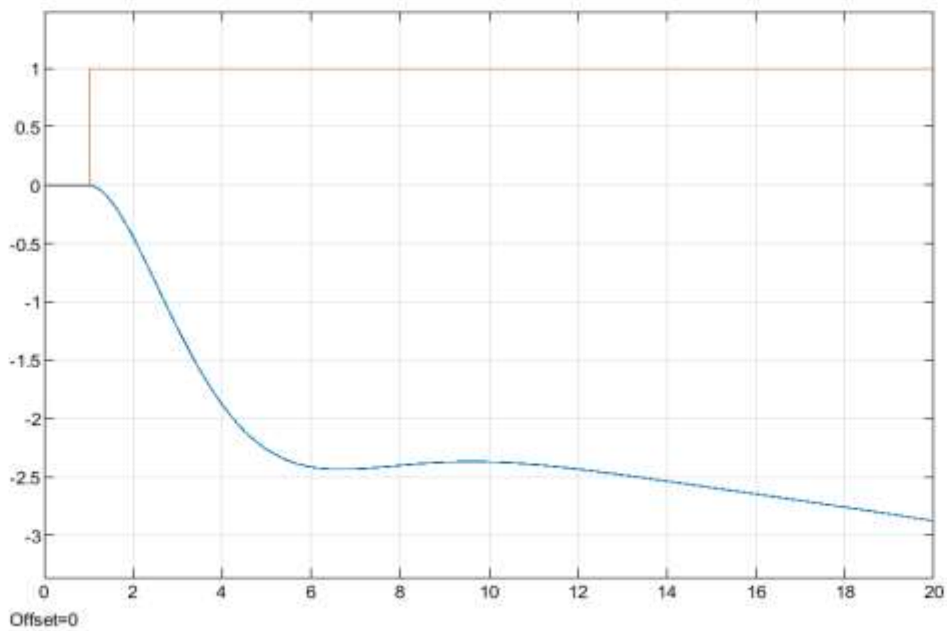

Figure 9 step response of alpha by elevator deflection

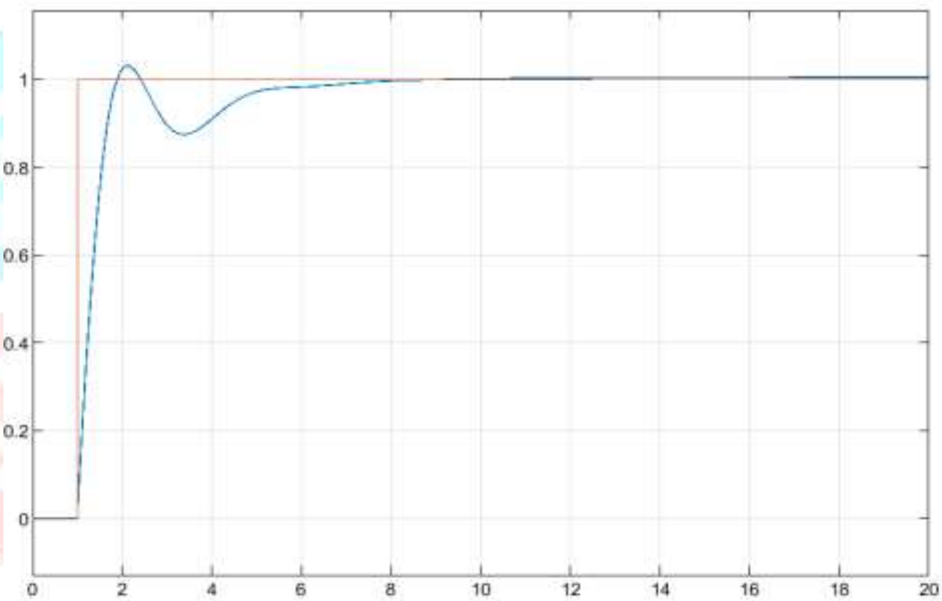

Figure 10: step response of alpha by elevator deflection with PID

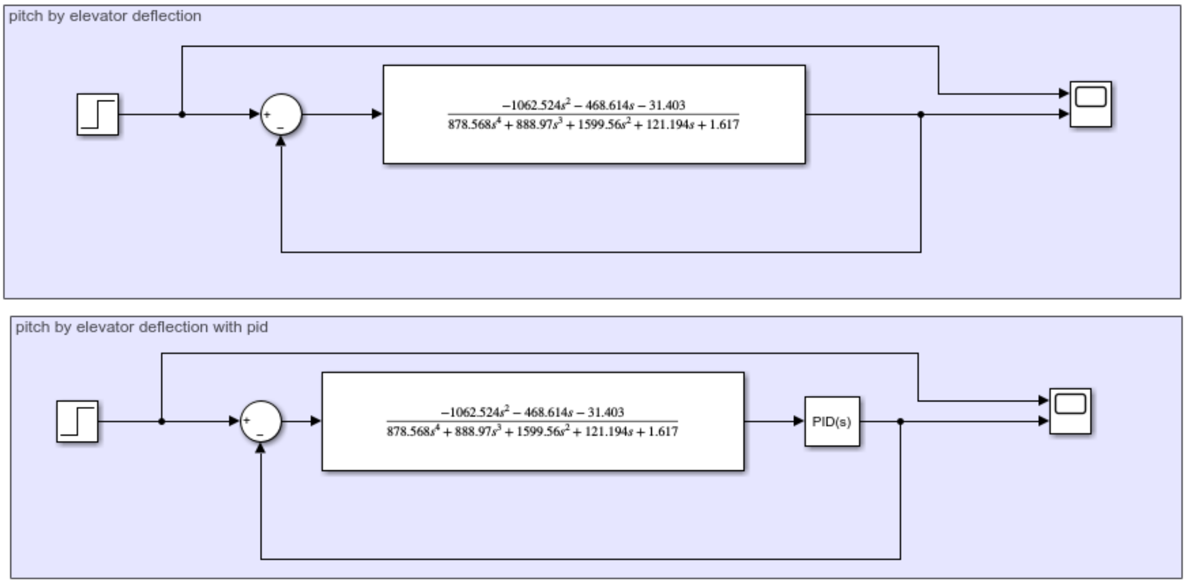

Figure 11:Feedback of pitch by elevator deflection

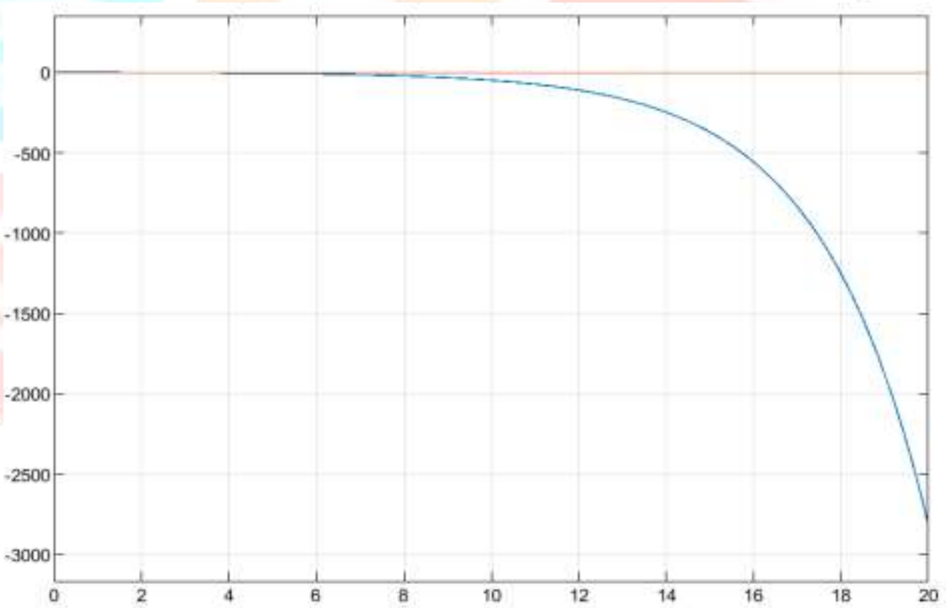

Figure 12: step response of pitch by elevator deflection

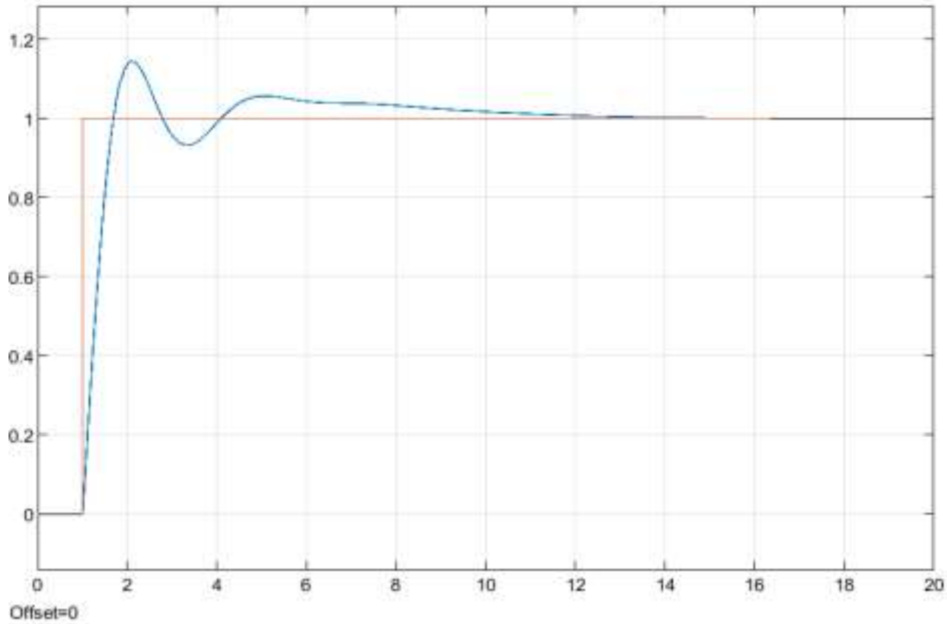

Figure 13: step response of pitch by elevator deflection with PID

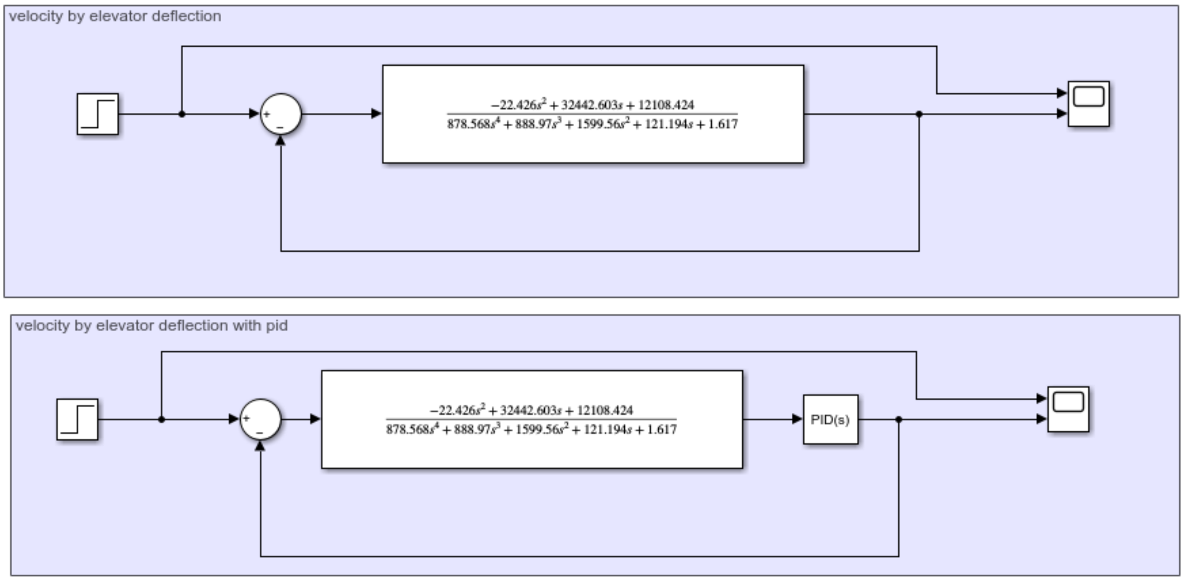

Figure16: Feedback of velocity by elevator deflection

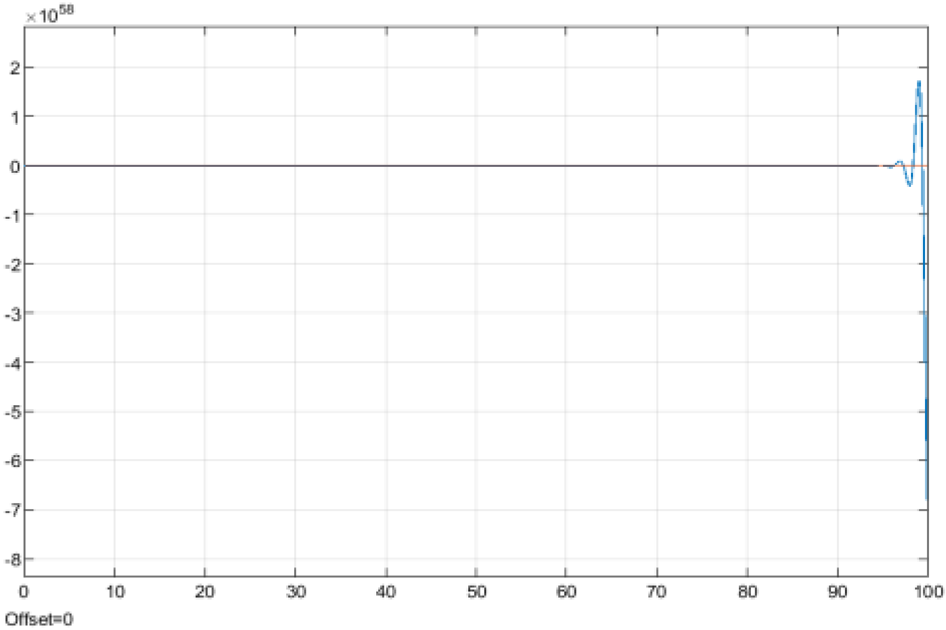

Figure 14: step response of velocity by elevator deflection

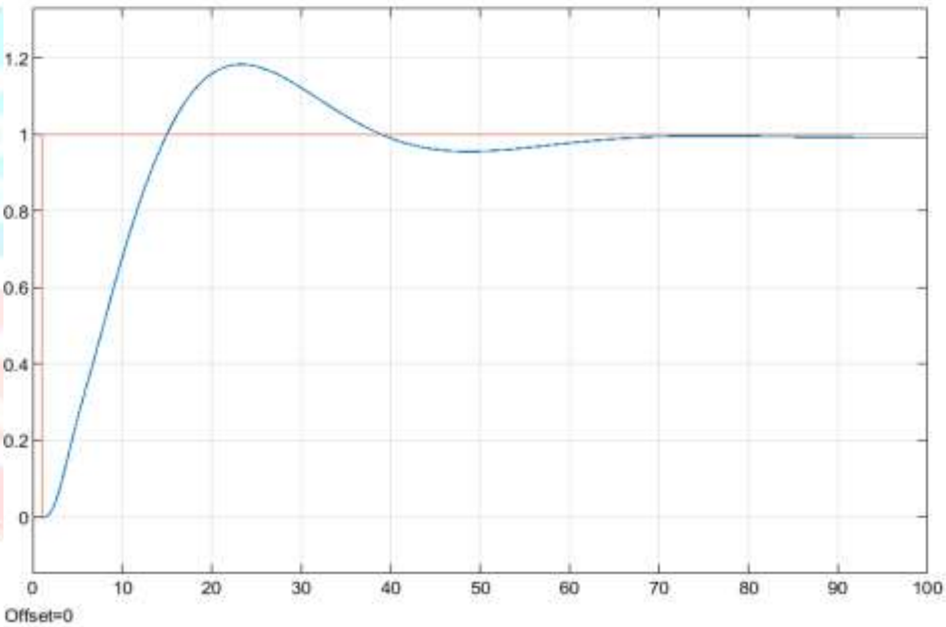

Figure 15: step response of velocity by elevator deflection with PID

The above figure 10, 13 and 16 is Simulink diagram made using MATLAB. First block is closed loop diagram of alpha, pitch and velocity by elevator and the second block uses PID controller with closed loop system.

In figure 11, 14 and 17, The blue line shows the result of closed loop system without PID by giving step input value as 1. As the result is not reaching at 1. Therefore, system will not achieve the desired output.

Figure 12,15 and 18 The blue line shows the result of closed loop system with PID by giving step input value as 1. As the result is settling at 1. Therefore, system will achieve the desired output and will be stable.

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