Acad. Year

2021-22

Project No.

A123

Assignment 2
Autopilots for various Dynamics of Aircraft

G.N.V.A SAI CHAITANYA

Aerodynamics and Flight Mechanics department&

Aerospace Engineering

Indian Institute of Space Science and Technology, India

Year 2021/22

AE606/AE457 : Flight Dynamics and Control

Assignment - 2

The aircraft parameters that can be used for the simulation are as follows.

Table 1: *Geometry, Mass and Inertia Characteristics*

Mean Aerodynamic Chord, $\bar{c}$	$1.211\ m$
Wing Span, b	$15.47\ m$
Aspect Ration, AR	19.9
Wing Area, S	$12.47\ m^2$
Mass, m	$700\ kg$
Moment of Inertia, I_{xx}	$1073\ kg-m^2$
Moment of Inertia, I_{yy}	$907\ kg-m^2$
Moment of Inertia, I_{zz}	$1680\ kg-m^2$
Moment of Inertia, I_{xz}	$1144\ kg-m^2$
Engine Thrust, T	$800\ N$

The aerodynamic model for the aircraft is given in the equations as follows.

Longitudinal Aerodynamic Model

$$C_L = C_{L_0} + C_{L_\alpha}\alpha + C_{L_q}\frac{q\bar{c}}{2V} + C_{L_{\delta_e}}\delta_e$$
$$C_{D_1} = C_{D_0} + C_{D_\alpha}abs(\alpha) + C_{D_{\delta_e}}abs(\delta_e)$$
$$C_m = C_{m_0} + C_{m_\alpha}\alpha + C_{m_q}\frac{q\bar{c}}{2V} + C_{m_{\delta_e}}\delta_e$$
$$C_{D_2} = C_{D_0} + KC_L^2$$

Lateral-Directional Aerodynamic Model

$$C_Y = C_{Y_0} + C_{Y_\beta}\beta + C_{Y_p}\frac{pb}{2V} + C_{Y_r}\frac{rb}{2V} + C_{L_{\delta_r}}\delta_r$$
$$C_l = C_{l_0} + C_{l_\beta}\beta + C_{l_p}\frac{pb}{2V} + C_{l_r}\frac{rb}{2V} + C_{l_{\delta_a}}\delta_a + C_{l_{\delta_r}}\delta_r$$
$$C_n = C_{n_0} + C_{n_\beta}\beta + C_{n_p}\frac{pb}{2V} + C_{n_r}\frac{rb}{2V} + C_{n_{\delta_r}}\delta_r$$

Trim condition for the design problem are:

- Free stream velocity, $V_\infty = 55\ m/s$
- Altitude, $H = 1500\ m$

Aerodynamic Derivatives

(a) *Longitudinal*

C_{D_0} = 0.036	C_{L_0} = 0.365	C_{m_0} = 0.05
C_{D_α}= 0.061	C_{L_α} = 5.2	C_{m_α} = -0.529
e = 0.9	C_{L_q} = 17.3	C_{m_q} = -5.8
$C_{D_{\delta_e}}$ = 0.026	$C_{L_{\delta_e}}$ = 0.5	$C_{m_{\delta_e}}$ = -1.28

(b) *Lateral-Directional*

C_{Y_0} = 0	C_{l_0} = 0	C_{n_0} = 0
C_{Y_β}= -0.531	C_{l_β} = -0.031	C_{n_α} = 0.061
C_{Y_p} = 0.2	C_{l_p} = -0.3251	C_{n_p} = -0.015
C_{Y_r} = 0.633	C_{l_r} = 0.1836	C_{n_r} = -0.091
$C_{Y_{\delta_r}}$ = 0.15	$C_{l_{\delta_r}}$ = 0.005	$C_{n_{\delta_r}}$ = -0.049
$C_{Y_{\delta_a}}$ = 0	$C_{l_{\delta_a}}$ = -0.153	$C_{n_{\delta_a}}$ = 0

Design the Autopilot control system for the following cases

1. Pitch Angle
2. Bank Angle

The Desired Angles the aircraft should follow after the implementation of the auto-pilot system are as follows:

- θ_d should go from trim angle to 5° and then after it got settled it should return to the trim value.
- ϕ_d should go from zero to 30° and then after it got settled it should return to the zero.

You're free to choose your compensator. Derive the transfer function from the perturbed equations we discussed in the class for the altitude. Use the same aircraft as the non-linear simulation assignment. For the Pitch Auto-pilot, you can use the longitudinal non-linear equations to implement. For the Bank Auto-pilot, you are free to use the pure-roll equation to implement the controls. However, you will ge bonus marks for implementing in the Lateral-Directional non-linear equations.

The report should include relevant plots that justifies your design. Explain and justify the design parameters you obtain with proper plots and theory.

Any malpractices in the assignment will bring Negative Marks for both the parties.

1 Introduction:

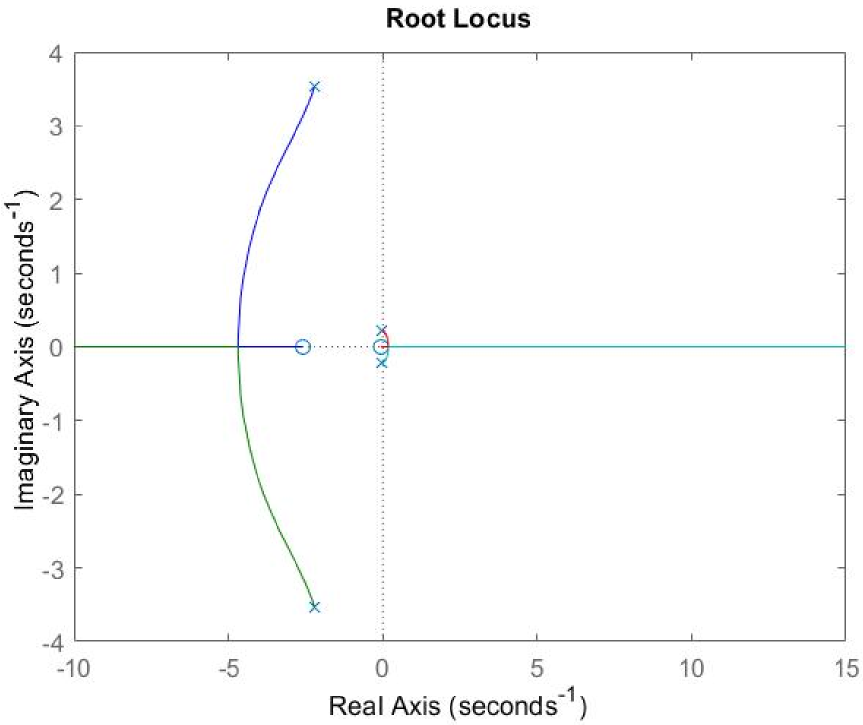
We have known that the aircraft is a dynamic system and there are different modes in which the aircraft can dynamically oscillate when a small disturbance is occured. For the above given dynamic system we are trying to match a best fit controller such that aircraft doesnt go to the stall & unstable region.

2 Dynamics of the Aircraft:

For the given configuration we are first finding the actual dynamics of the aircraft with small disturbance initiated without the controller. Then compare with the result of adding an autopilot. In this execercise we are controlling the fourth order system of the aircraft in the longitudinal mode as well as the lateral mode. The Gains of the controller are taken based on the Characteristics of the system, such as
1.Peak Overshoort ¡10 percent
2.Settling time(2-10 seconds)
3. Rise time and Steady state
For the longitudinal modal using the control system toolbox and based on the above criteria I have deviced 3 types of gains
The values are as follows:
1. PID: Kp=-3.829; Kd=-.6701; Ki=-5.47
2.PD: Kp=-0.060; Kd=-0.518; Ki=0;
3.PI: Ki=-0.02862983; Kp=Ki*15; Kd=0;

2.1 Pitch Autopilot:

First we find out the transfer function for the fourth order longitudinal modal from the given configuration and find out the rootlocus for the given system. We can observe that the system goes to unstable region as the gain varies.



The controller can be chosen based on our requirement and there are 3 things to be considered when we chose a compensator they are:

Proportional controller amplifies the system based on our requirement. Integral Controller makes sure the system reaches to the initial condition. Derivative controller makes the steady state error to the minimum.

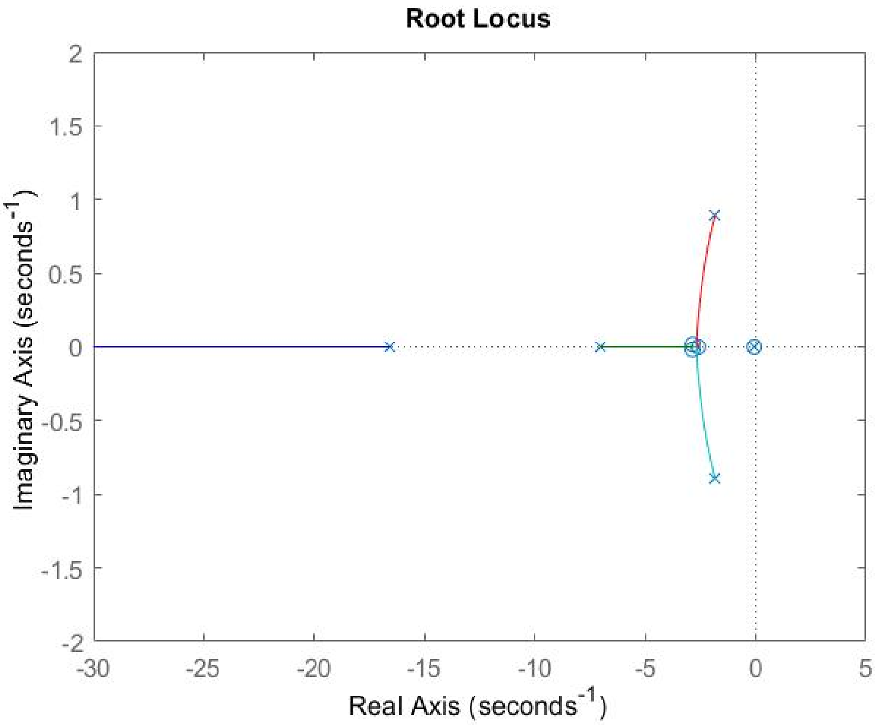
In the below section I am going to compare all the 3 types of compensators used PID,PD, PI. Out of which its seen PID is the best obtained.

Input data:

1. Time of disturbance is 15 seconds for long period mode on $\theta = 0.08726$ and controller is implemented after the distrubance is completed i.e at 15 seconds.

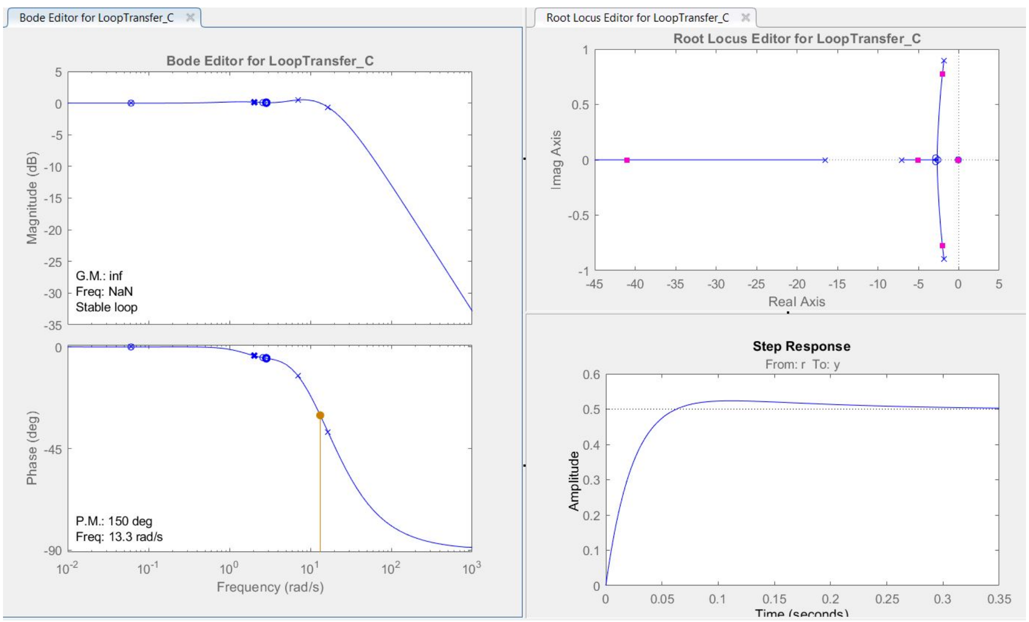
Using a PID Controller

PID is the combination of all the above and hence is the ideal Compensator that can be implemented for a dynamic system.

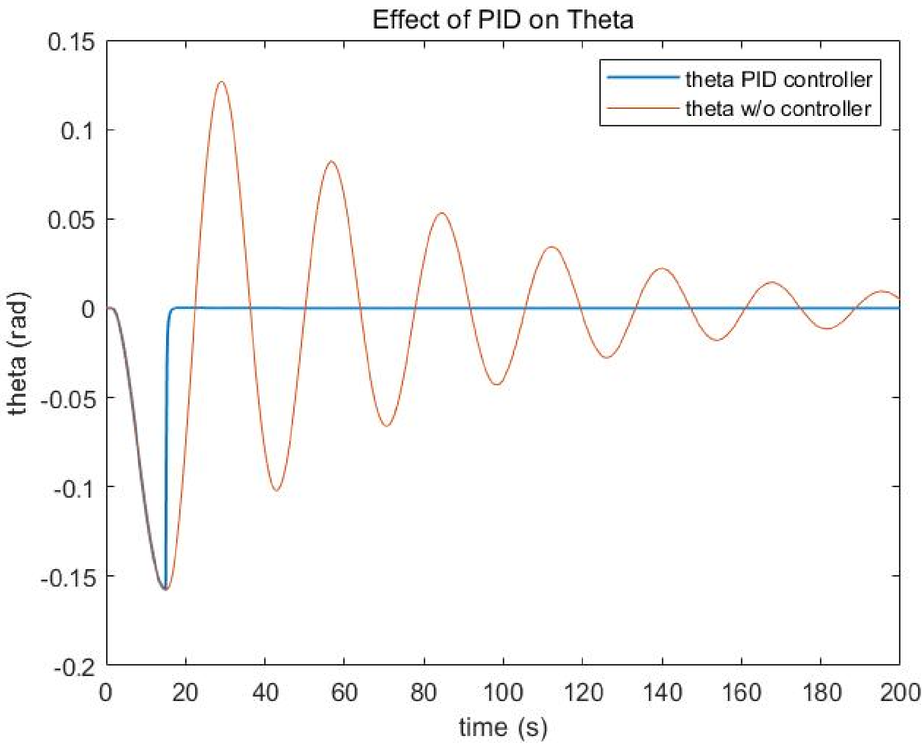


After finding the gains we use them in finding the Aileron deflection as follows:

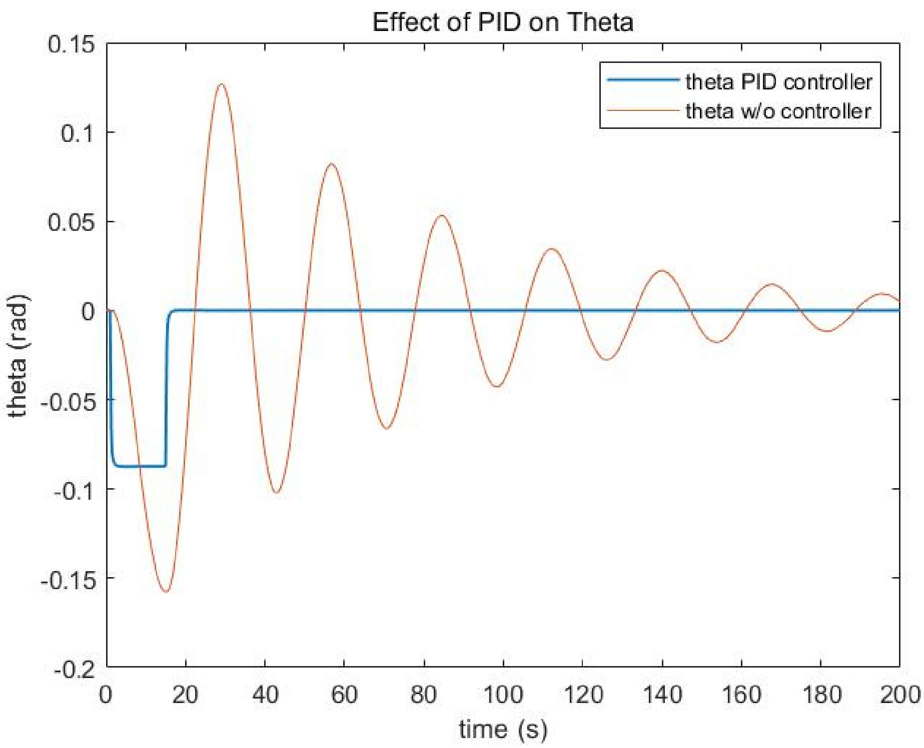
$\delta_e = Kp * (\theta_d - \theta) + Kd * (qd - q) + Ki * (\theta_{old} - \theta)$



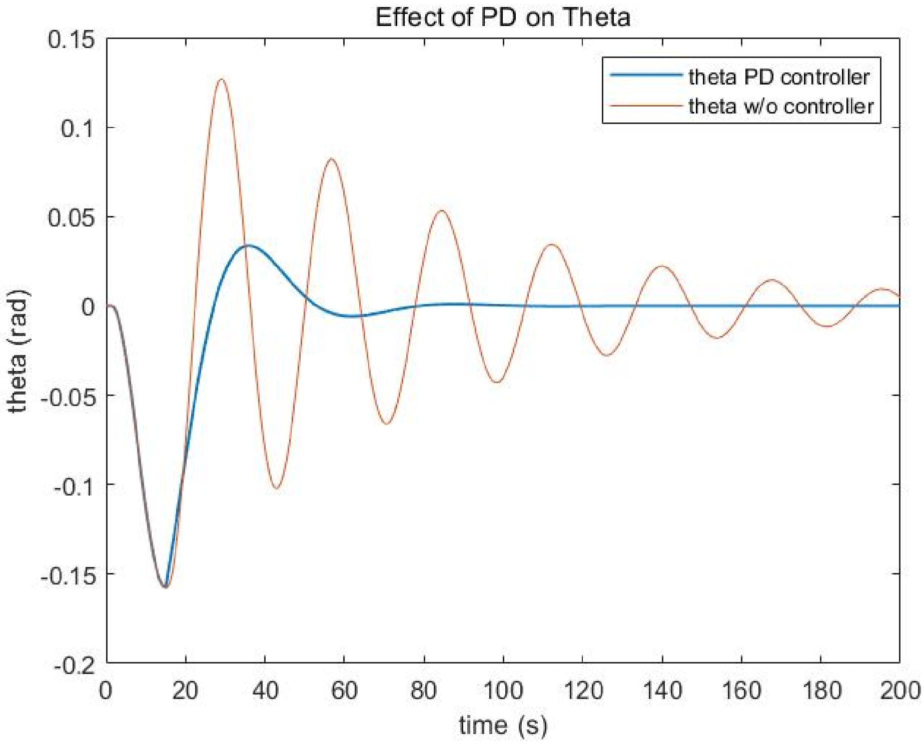
1. Time of disturbance is 15 seconds for long period mode on $\theta = 0.08726$ and controller is implemented after the distrubance is completed i.e at 15 seconds.



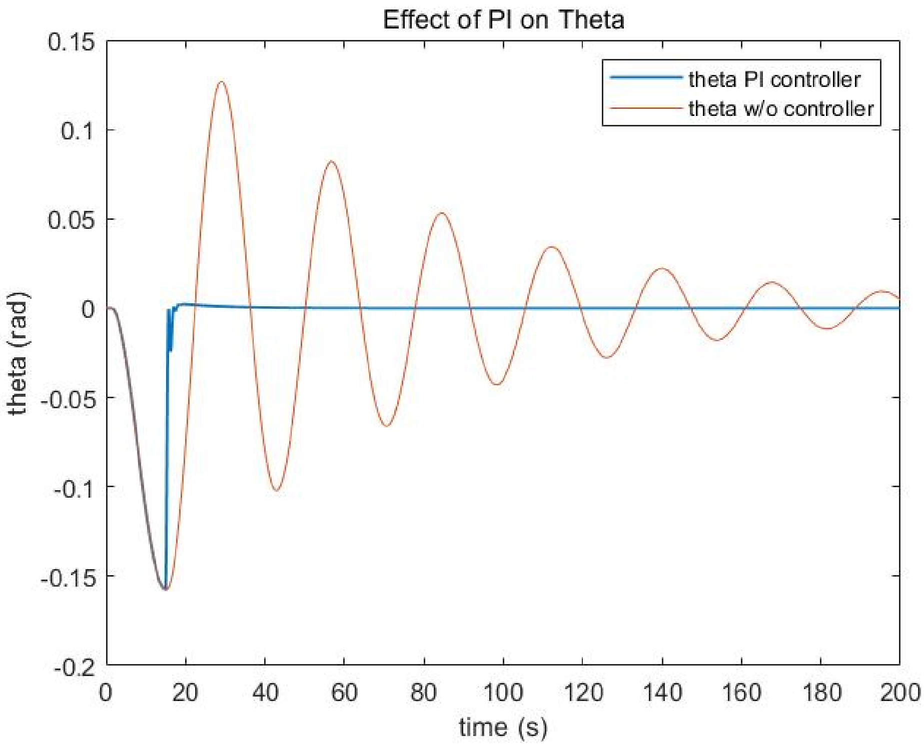
2. Time of disturbance is 15 seconds for long period mode on $\theta = 0.08726$ and controller is implemented at t=0 i.e the controller is initialized at that instant when there is a disturbance.



Using PD Controller: PD controller is inherently improper, however the dynamic system we are considering is stable so adding the controller makes the overall system proper and hence can be implemented. Since we are not including the integrator the system takes more time to reach the steady state.

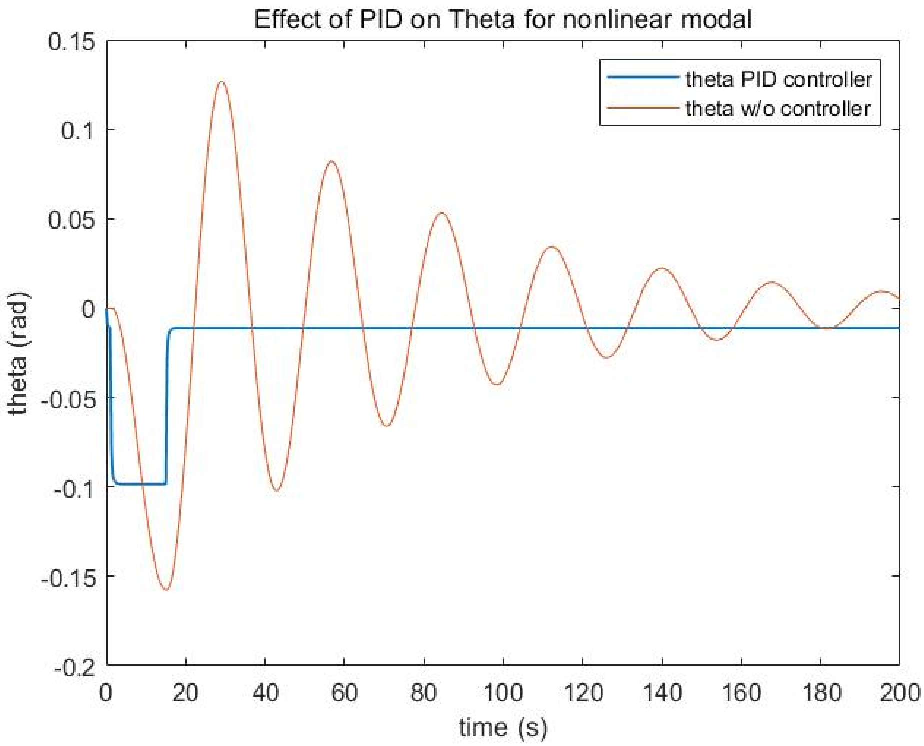


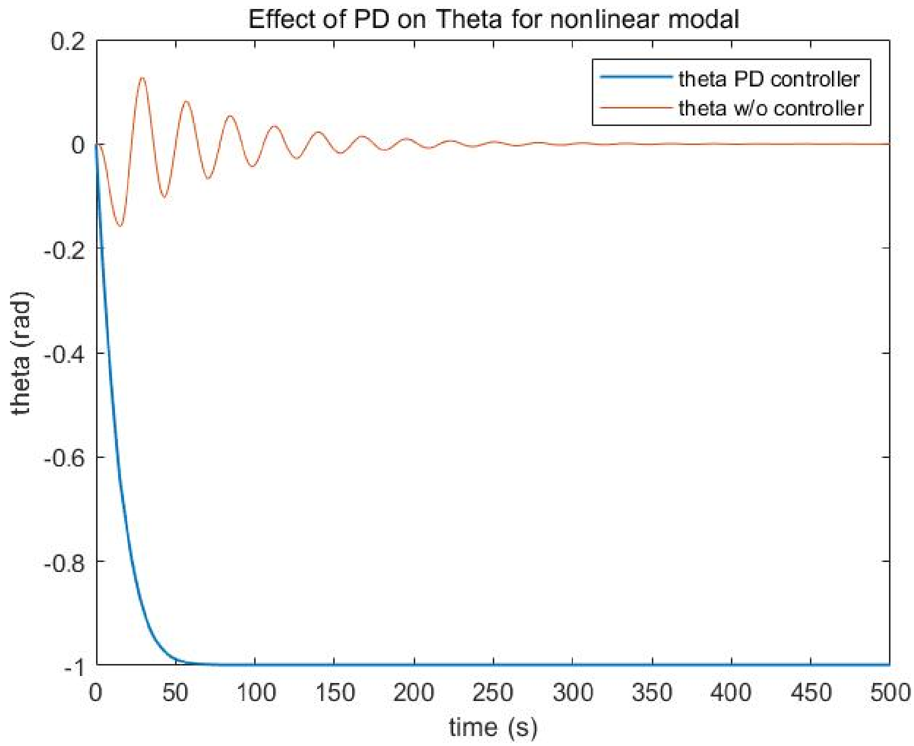
Using PI controller: Since we did not include the Kd we have oscillations in the system.

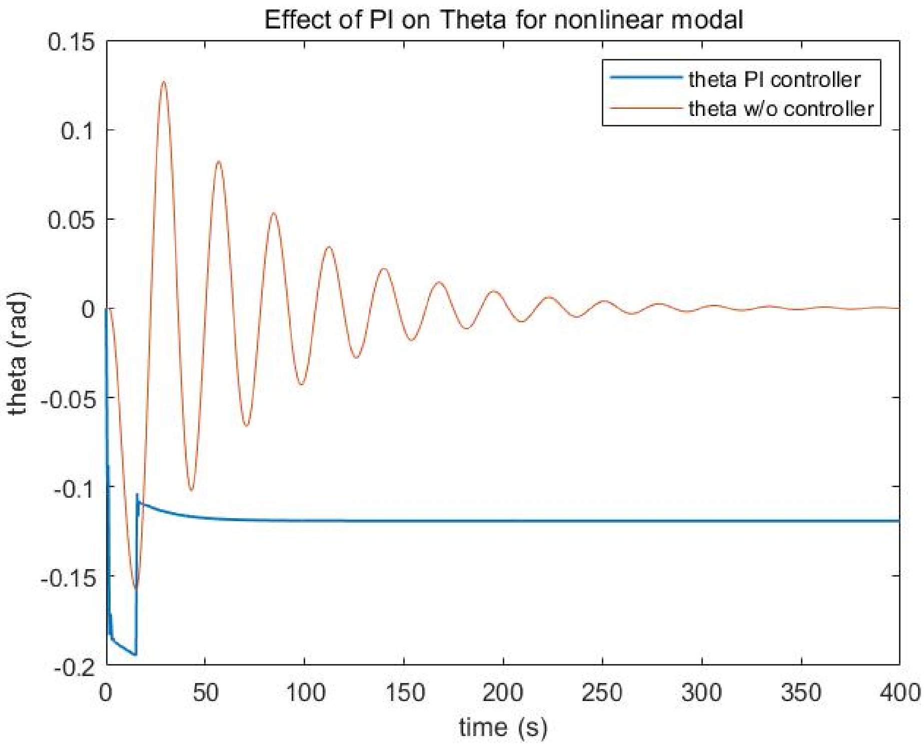


3 Performance of Chosen controller on the non linear Longitudinal system:

Initially we calculate the trim values of α and δ_e and then from the obtained values we find out the CL,CD values which are used in the simulation. Since we are giving the disturbance initially the all the values keep updating dynamically. So in this area from the above chosen controllers PID has only given best control. We are simulating the nonlinear modal for PID,PI,PD controllers.


Effect of PID on Theta for nonlinear modal
theta PID controller
theta w/o controller
theta (rad)
time (s)
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
0
20
40
60
80
100
120
140
160
180
200

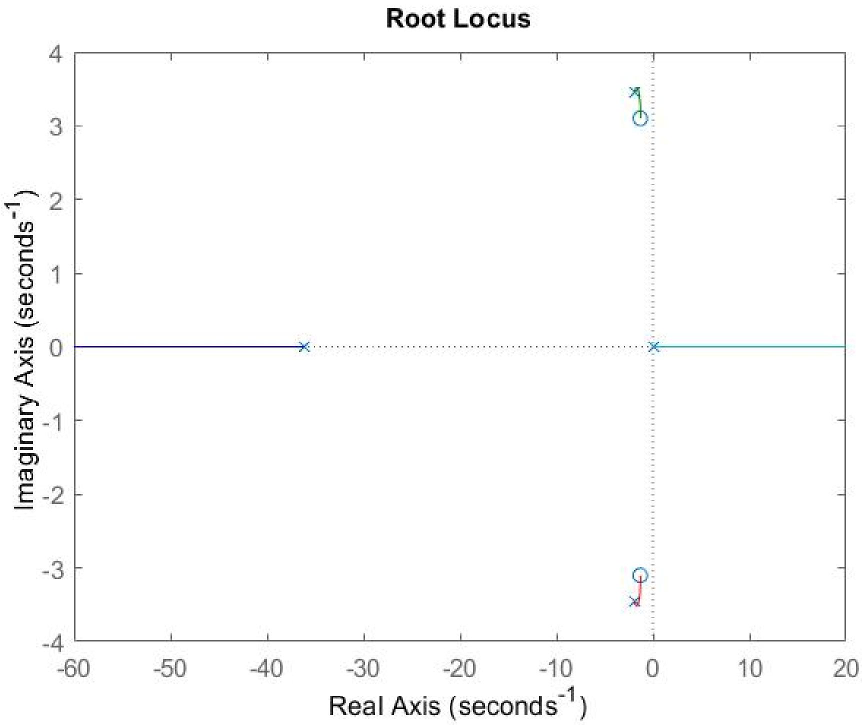

Effect of PD on Theta for nonlinear modal
theta PD controller
theta w/o controller
theta (rad)
time (s)
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
50
100
150
200
250
300
350
400
450
500



From this we can see that the PID controller works better in the nonlinear model. The other controllers which are chosen PD and PI settle at another trim value rather than going back to the actual trim condition. Therefore we conclude PID is better to use for Pitch autopilot.

3.1 Roll Autopilot:

For the given system its been observed that one of the poles lie in the right half of the S- plane. So the system is dynamically unstable in the lateral direction, we can see it from the root locus below.



For this system we have implemented two designs one using PI and another PID controller PI controller gains are as follows:

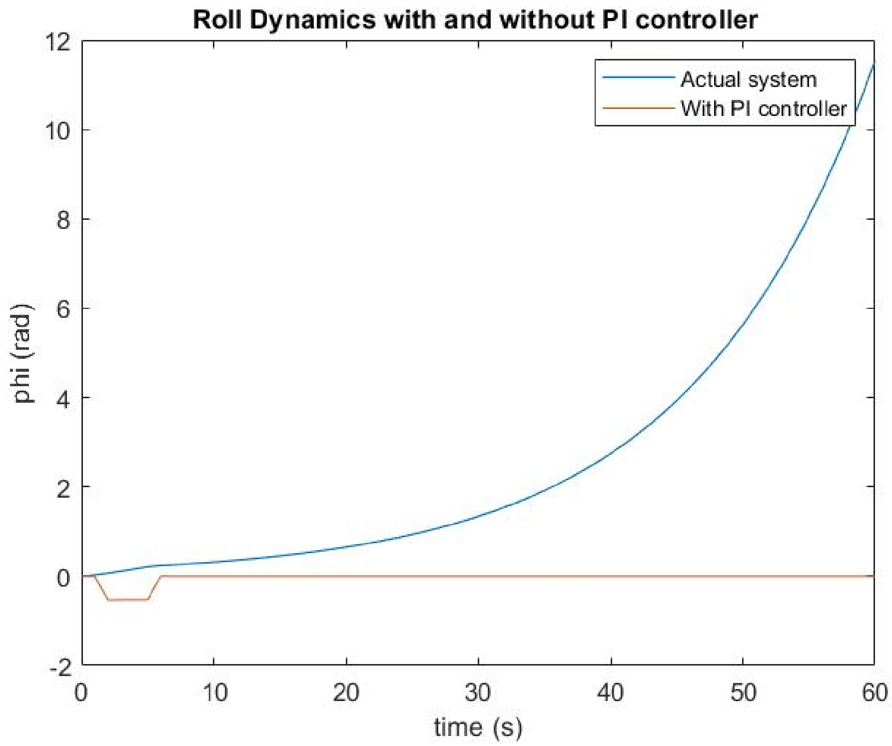
Kp=-0.57832; Ki=-0.34019; Kd=0;

After finding the gains we use them in finding the Aileron deflection as follows:

$\delta_a = Kp * (\phi_d - \phi_{new}) + Kd * (p_d - p) + Ki * (\phi_{old} - \phi_{new})$

Where d=desired state; a= actual state

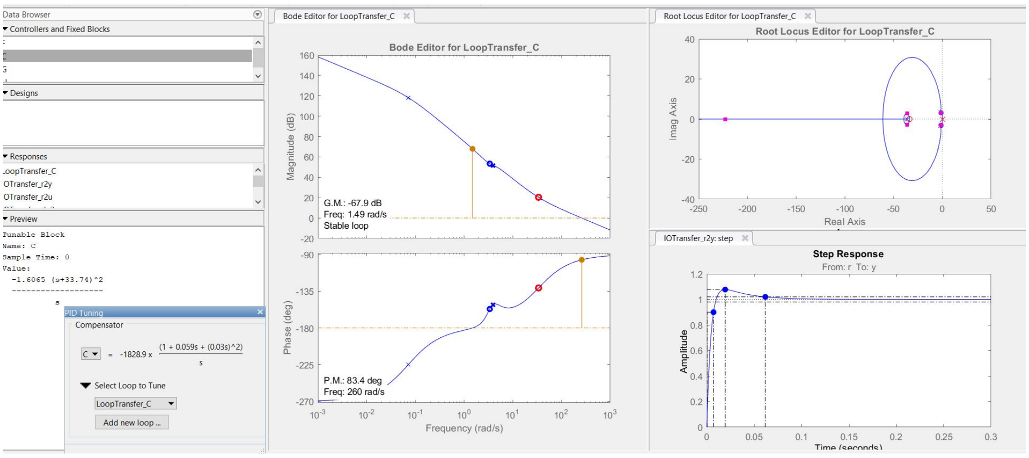
We can see the dynamics of the system from the figure below.

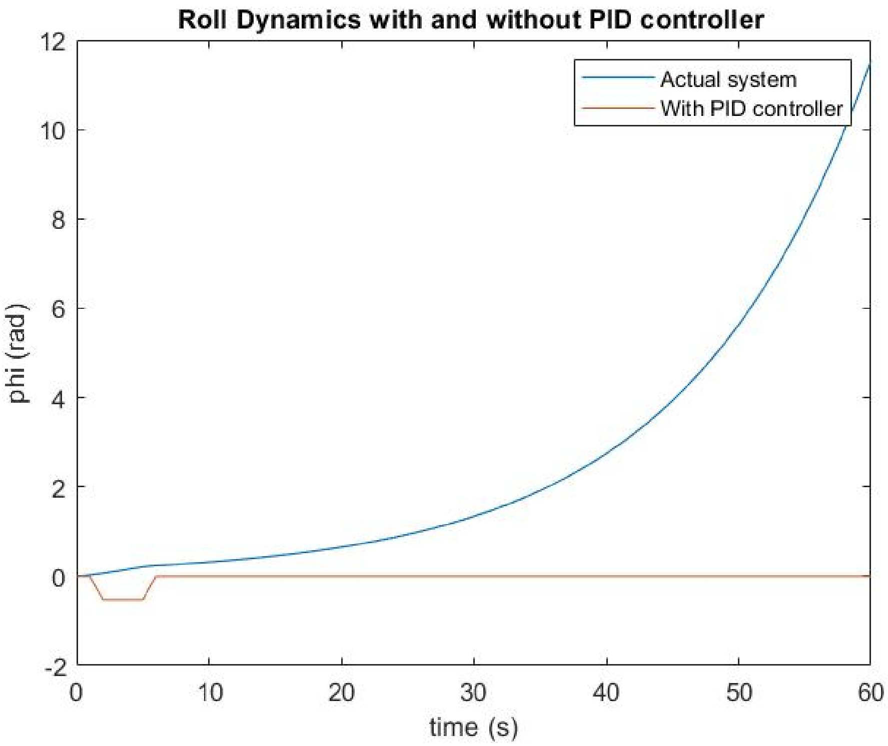


we can see that the actual system is unstable and when we used the controller we make the system stable and controllable.

Implementing the PID controller for roll controller. Gains of PID are:

Kd=-0.38784; Ki=-0.6666 Kp=-1.017;





We can see both PI and PID controller works better for Lateral stability of aircraft in the linear zone.

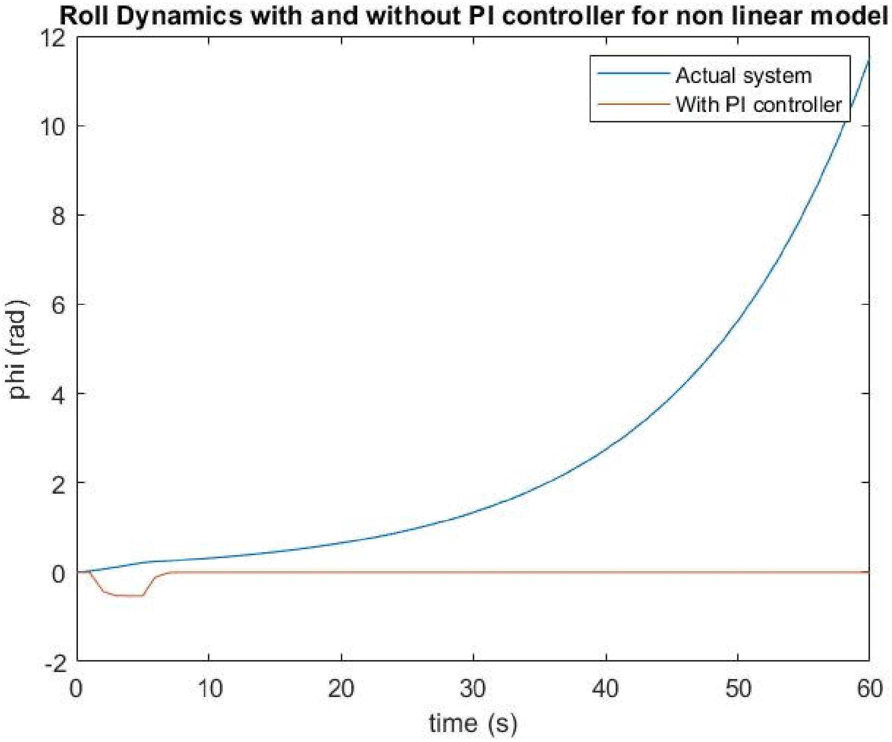
4 Performance on Non-linear Lateral Motion:

Here I have taken the trim values of $\beta_t = 0 and \delta_{at} = 0$. Furthermore, the rudder movement is neglected i.e there is no influence of rudder or yaw rate on the system.

I have considered the fourth order model for the lateral dynamics, It has been observed that for linear system both PI and PID controllers worked good. For the nonlinear model we have the continuous change in variables at different time steps so its observed the PI controller is better choice for this case. The gains for the PI controller are as follows:

Kp=-0.57832; Ki=-0.34019; Kd=0.

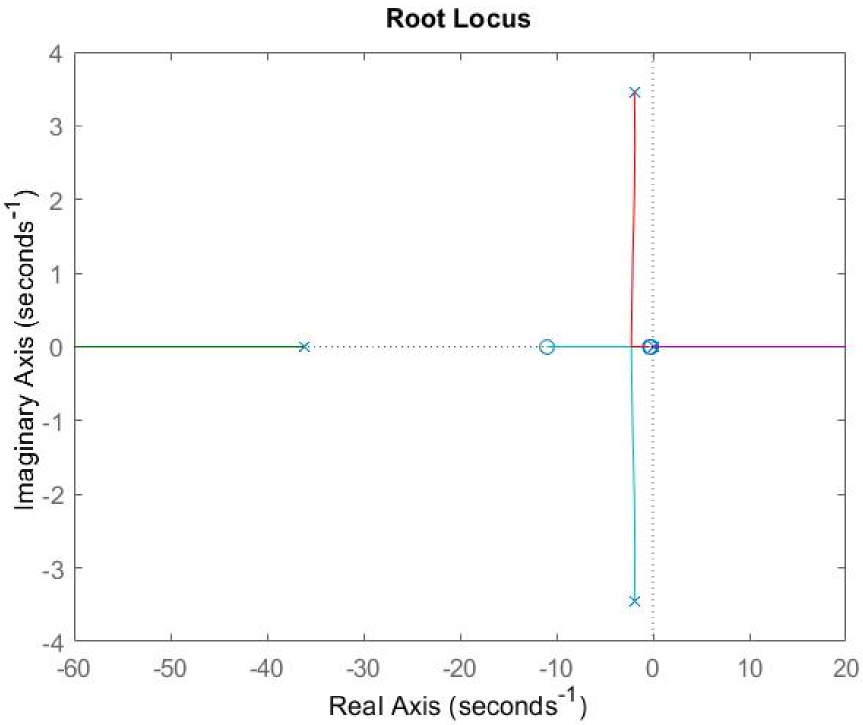
Here is the picture of comparison between PI and actual dynamics. I have observed that the PID controller chosen didn't come out to be useful for nonlinear zone.



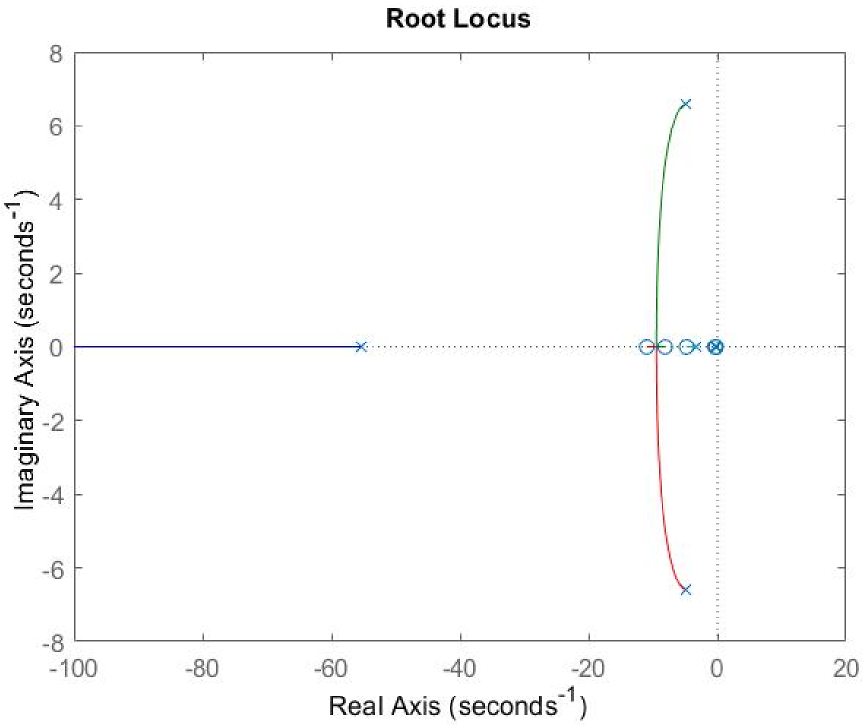
5 Performance of PI and PID on the non-linear Lateral - Directional Motion:

Previously, for the lateral motion we have neglected the effect of rudder and yaw rate on the motion. However, now we will see the influence of adding both rudder deflection and yawing motion.

For this section, I have considered the 5th order model.



After adding the PID controller with gains Kp=-6.386; Kd=-0.494; Ki=-19.28. We can see the variation in root locus such that all the poles are in the left half of S-plane, i.e the dynamic system is stabilized.



The deflection of Aileron and Rudder are derived as to be:

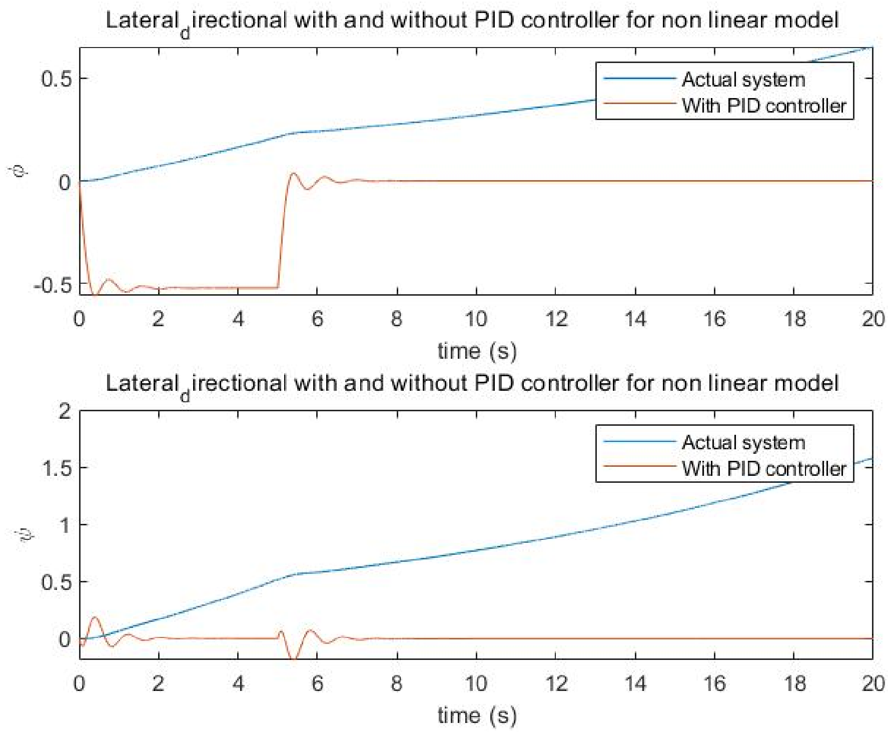
$\delta_a = Kp*(\phi_d - \phi_{new}) + Kd*(p_d + r_d - p - r) + Ki*(\phi_{old} - \phi_{new})$

$\delta_r = Kp*(\psi_d - \psi_{new}) + Kd*(p_d + r_d - p - r) + Ki*(\psi_{old} - \psi_{new})$

We are going to add the disturbance for 3 cases

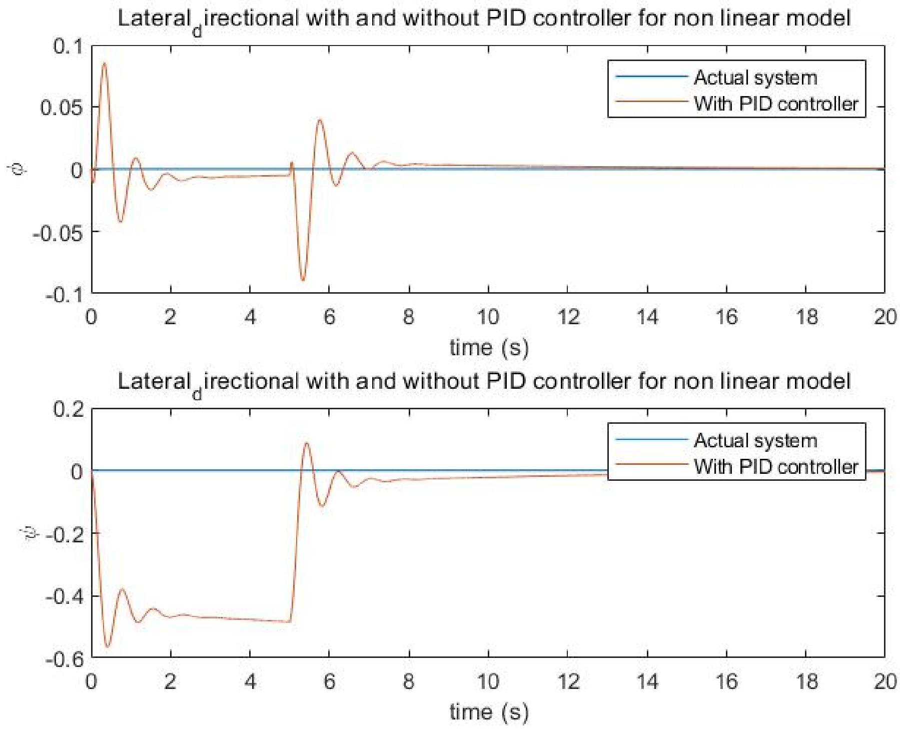
5.1 Disturbance in ϕ:

Giving the initial disturbance of 30 degrees for 5 seconds we compare the results with and without the controller for both the bank and yaw angle.



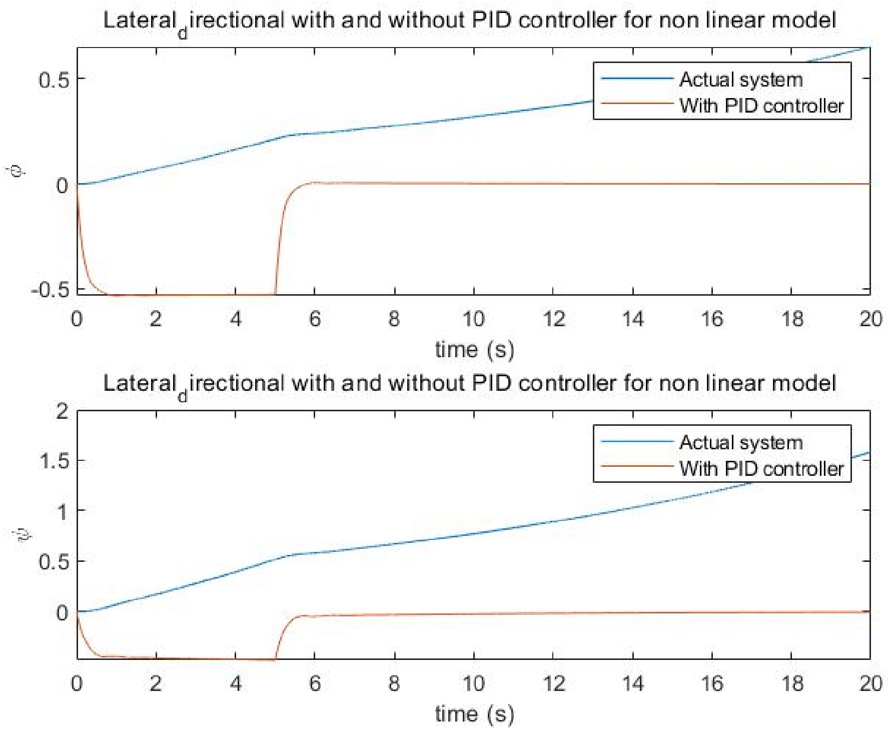
5.2 Disturbance in ψ:

Giving the initial disturbance of 30 degrees for 5 seconds we compare the results with and without the controller for both the bank and yaw angle.



5.3 Disturbance in both $\phi and \psi$:

Giving the initial disturbance of 30 degrees for 5 seconds we compare the results with and without the controller for both the bank and yaw angle.



In all the above plant, I have not included the rate gyro’s and washout, with including many of these aspects we can make the system as realistic as possible.