Auto Pilot

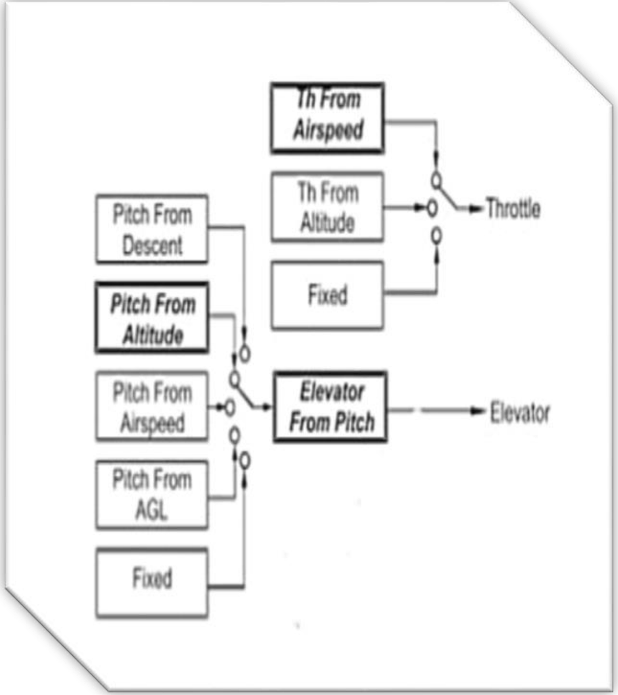
Task 5

Team 4

Name	Sec	B.N.
Mohammed Ahmed Hassan Ahmed	2	37
Ibrahim Thabet Allam	1	1
Mohammed Hatem Mohammed Saeed	2	39
Mohamed Hassan Gad Ali	2	41
Mohammed Abd El MawgoudGhoneam	2	43

Introduction:

- In order to Design a controller first of all we should get the transfer functions of all full longitudinal dynamics model.
- Our methodology is to using inner loops architecture.
- Then using SISO tool to design the controller.
- Finally we use SIMULINK to check the performance of our design.



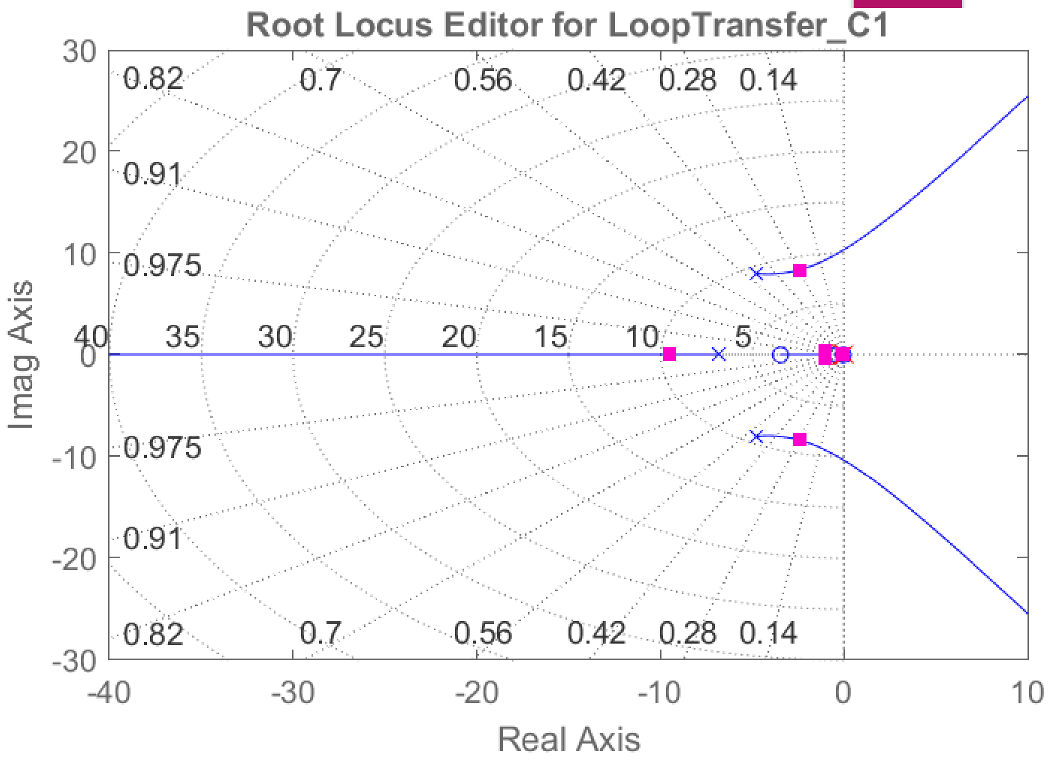
Design Pitch Controller With Pitch Rate Feedback

The open loop transfer function is:

```
OL_theta_thetacom =

                   527 s^2 + 1848 s + 74.13
  ----------------------------------------------------------
  s^5 + 16.43 s^4 + 108.3 s^3 + 441.9 s^2 + 18.57 s + 1.377
```

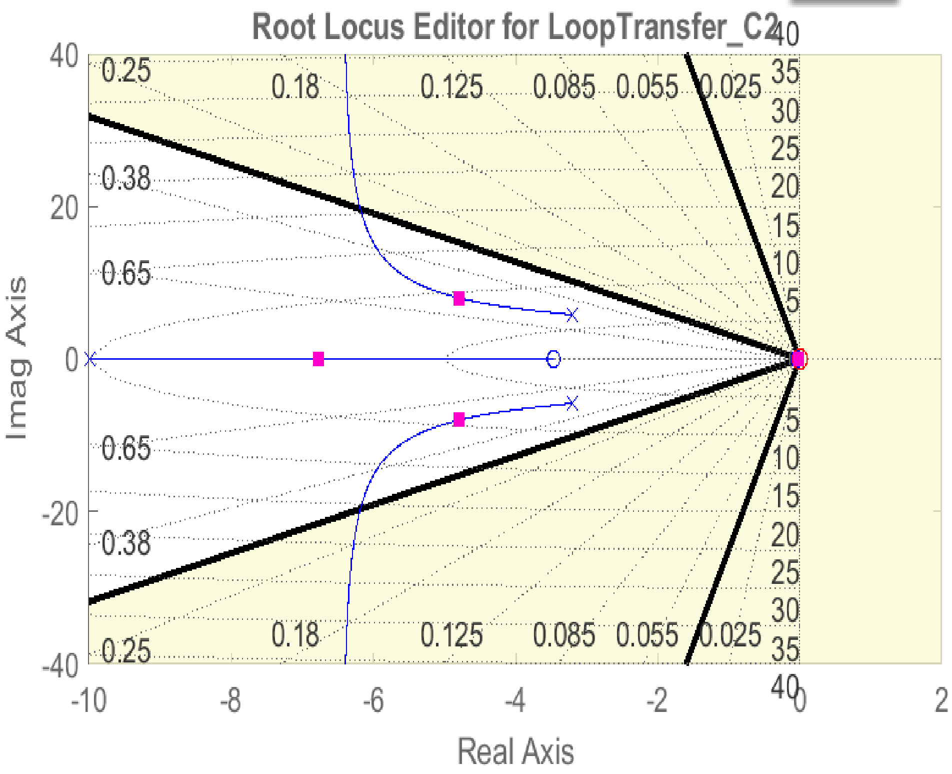
SISO Tool Design

Root locus



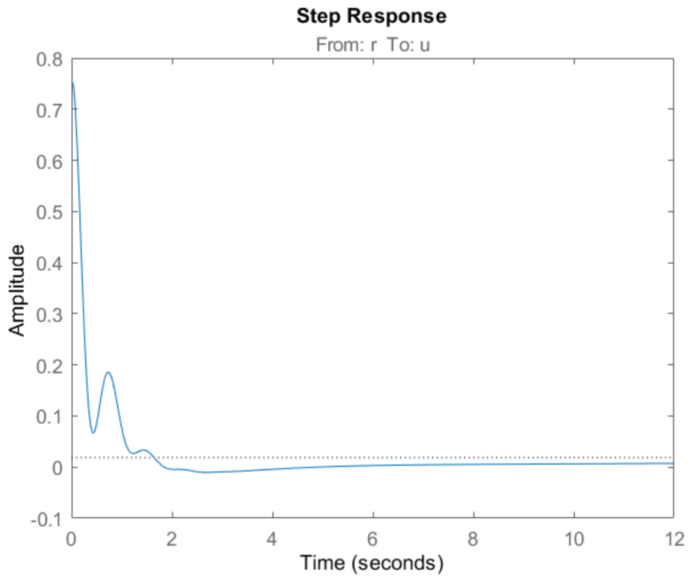
SISO Tool Design

Root locus

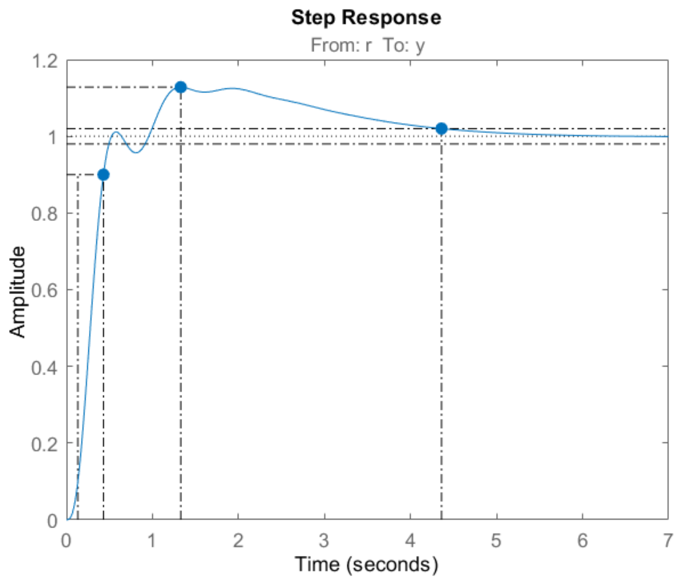


Step response

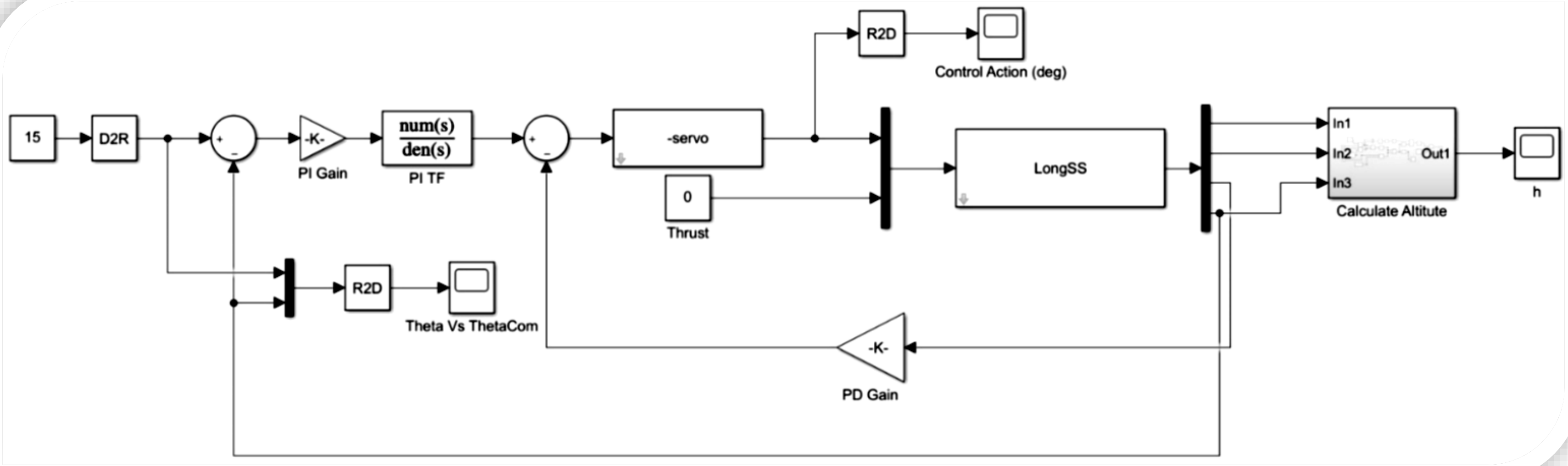
- Control action



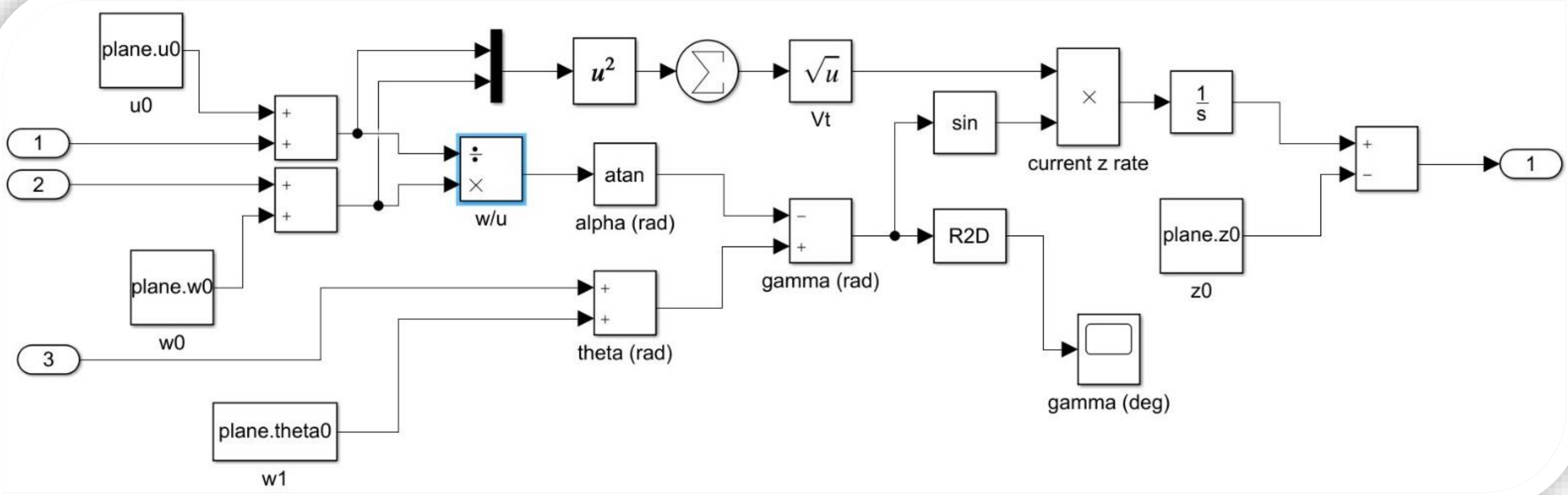
- System Response



Simulink test



Simulink test

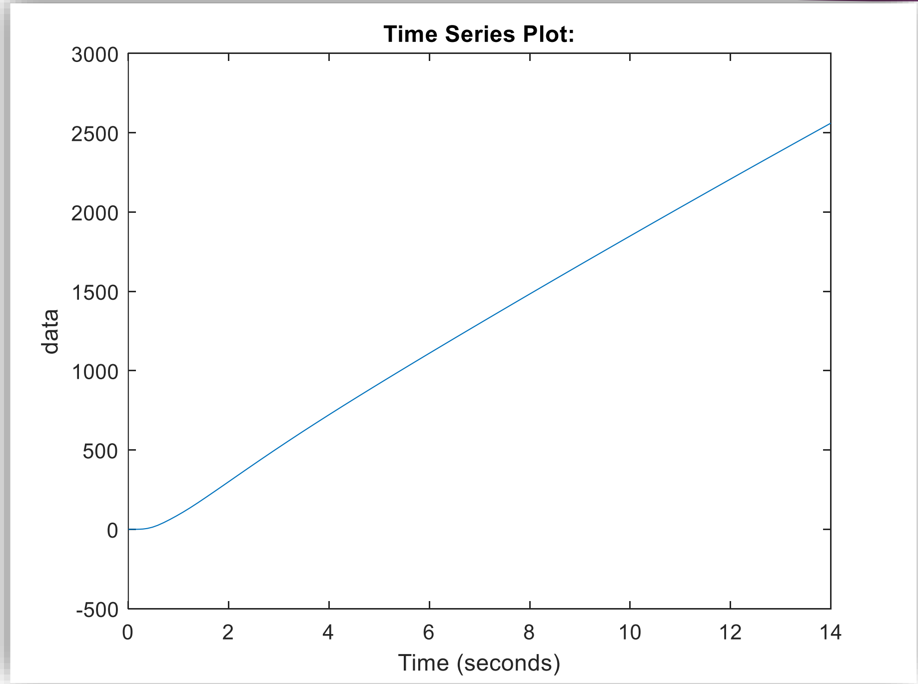


Necessity of velocity control

Necessity of velocity control

- when we input positive pitch angle, the action depends on the thrust if the thrust is big enough to climb upward the airplane will climb upward if the thrust is not enough the airplane would dive downward but logically, when the pilot input a positive pitch the airplane should climb upward

Necessity of velocity control



$$\because \gamma = \theta - \alpha$$

$$\tan(\alpha) = \frac{w}{u}$$

$$\because \dot{h} = V_{to} * Sin(\gamma)$$

Necessity of velocity control

- Our plane climbs upward because it has enough thrust to accomplish this. But this not meaning that we control altitude because the airplane will climb to specific height that its thrust enough to reach, then the airplane would dive downward. And this specific height may be before or after that height we need to reach, so we need to control the velocity to reach to required altitude by change thrust (δ_{th})

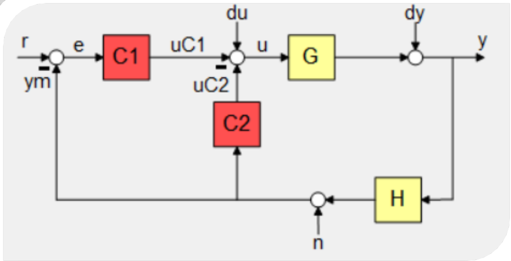
NT-33A engine

- Our aircraft 'NT-33A' was a training aircraft that was developed from the Lockheed martin.
- The Powerplant installed is 1 × Allison J33-A-35 centrifugal flow turbojet engine, with 5,400 lbf (24 kN) thrust for take-off with water injection
- 4,600 lbf (20,461.82 N) maximum continuous thrust.

Velocity Controller

Then the open loop transfer function is

```
Ol_u_ucom =

             0.00235 s^3 + 0.015 s^2 + 0.1027 s - 5.831e-05
  ------------------------------------------------------------------
  s^6 + 16.53 s^5 + 110 s^4 + 452.7 s^3 + 62.76 s^2 + 3.234 s + 0.1377

Continuous-time transfer function.
```



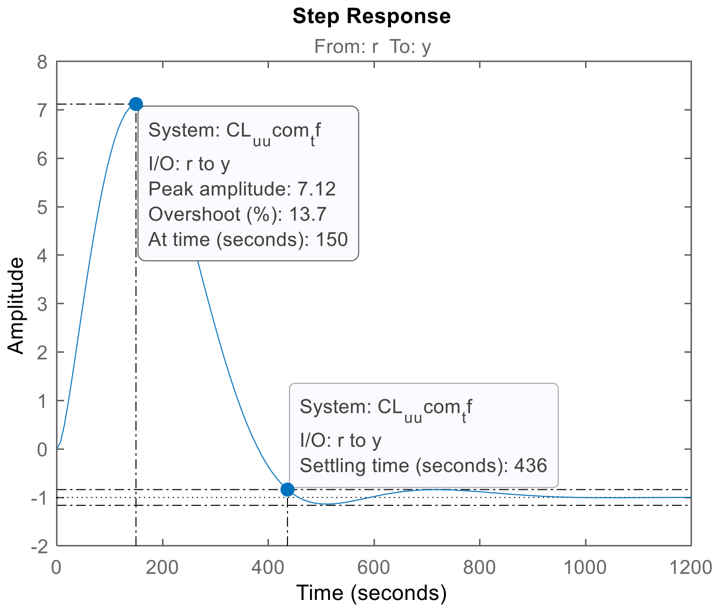
Velocity Controller

```
velocity_C1_tf =

  32.915 (s+0.03648)
  ------------------
          s
```

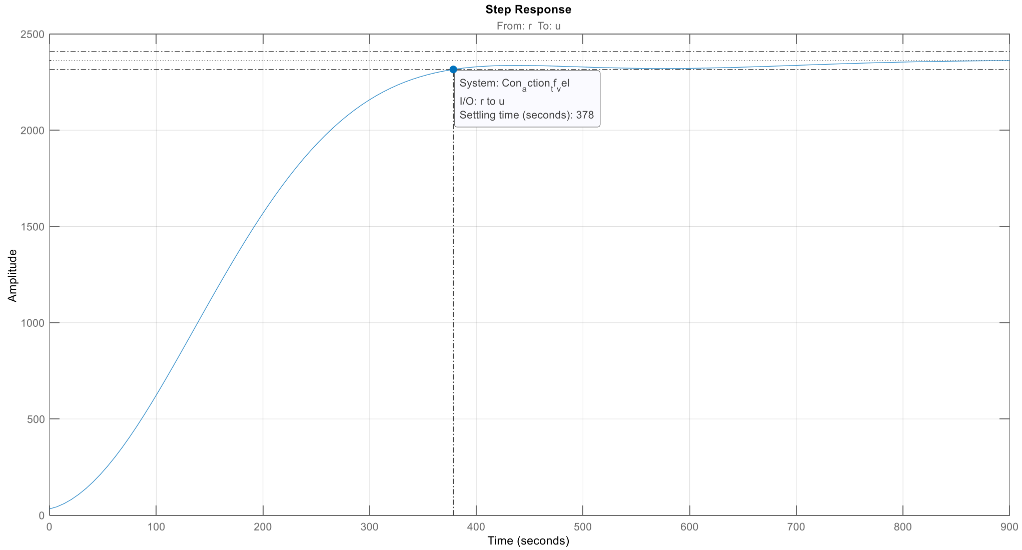
```
velocity_C2_tf =

  15.095 (s+0.1)
  --------------
    (s+0.109)
```

Step response & Control action

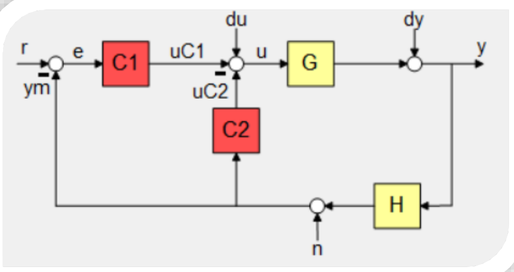
Step response



Control action



Altitude controller




```
OL_h_thetacom =

  From input to output "y":
       -1145 s^4 - 4001 s^3 + 1.073e06 s^2 + 7.461e05 s + 2.728e04
  ---------------------------------------------------------------------
  s^7 + 16.43 s^6 + 153.4 s^5 + 996.9 s^4 + 1678 s^3 + 970 s^2 + 36.61 s
```

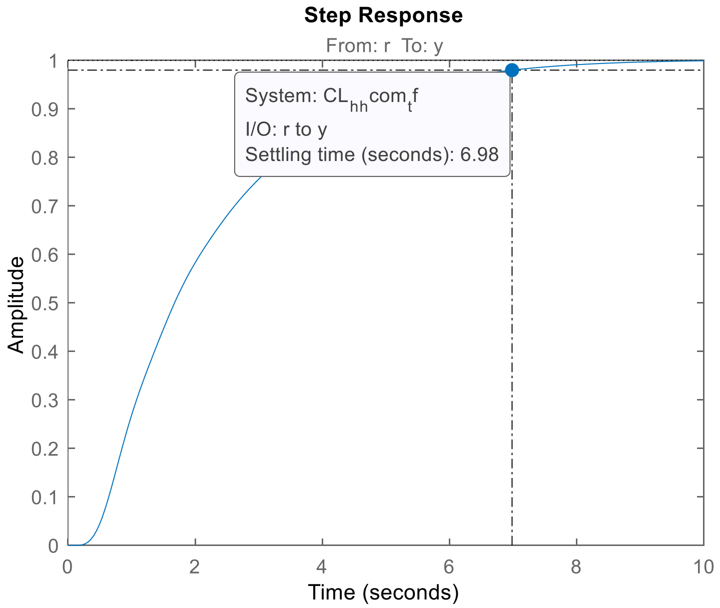
Altitude Controller

```
altitude_C1_tf =

  0.00067403 (s+1.784)
  --------------------
           s
```

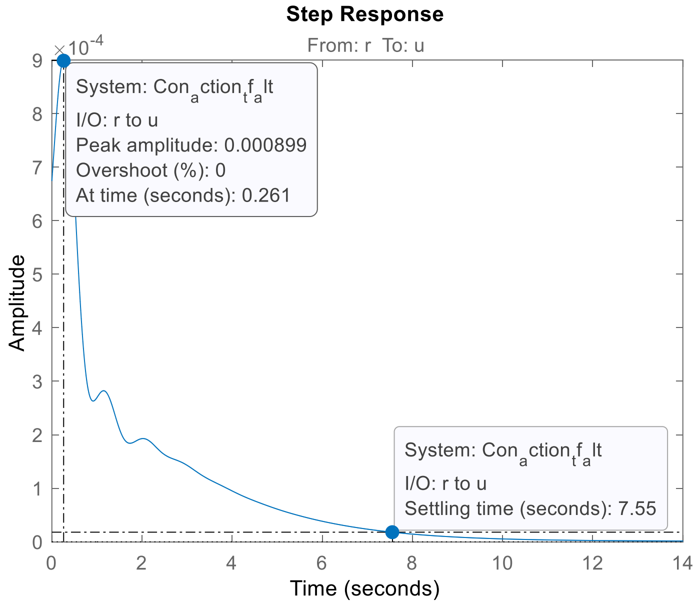
```
altitude_C2_tf =

  0.0014691 (s+1.799)
```

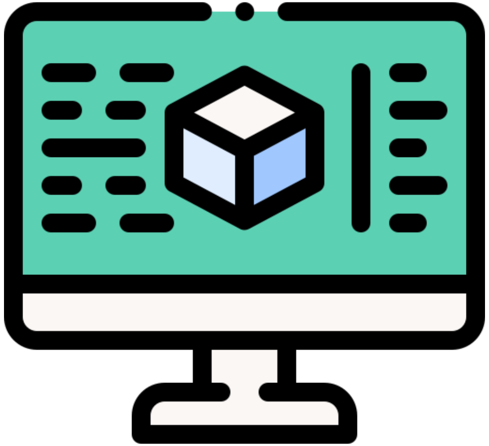
Step response & Control action

Step response



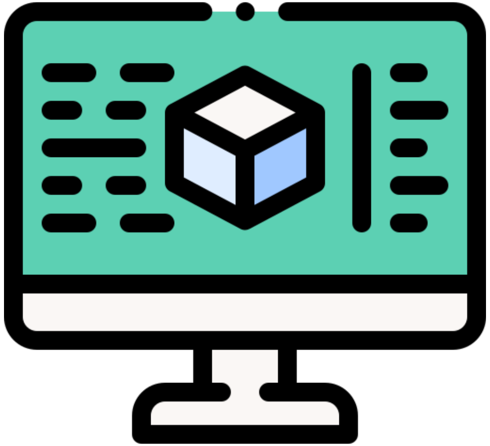
Control action

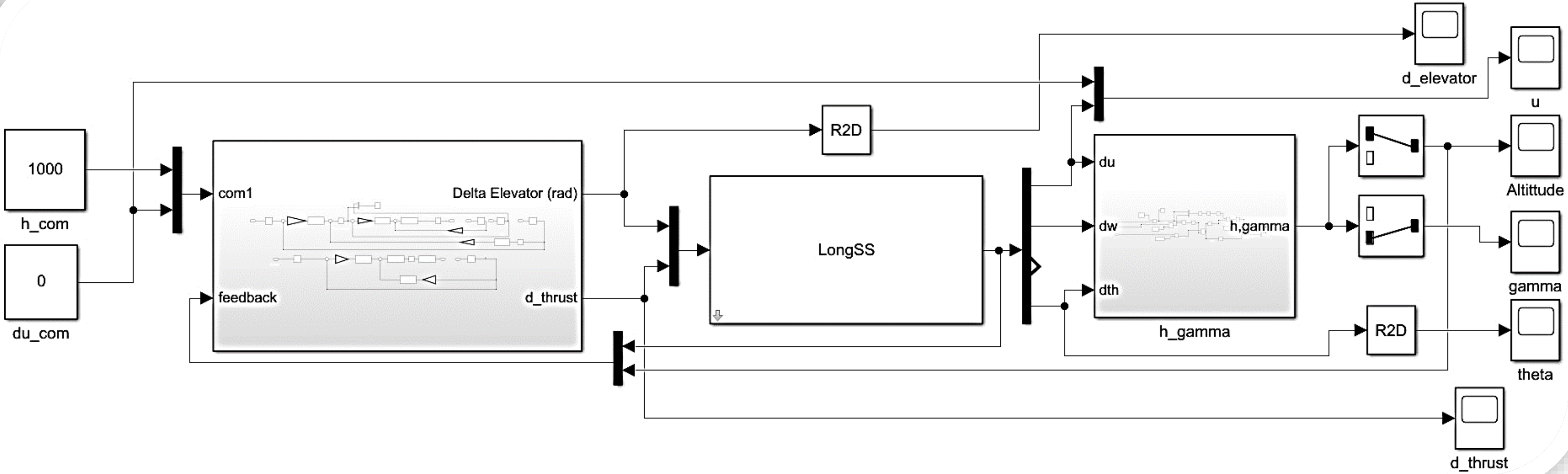




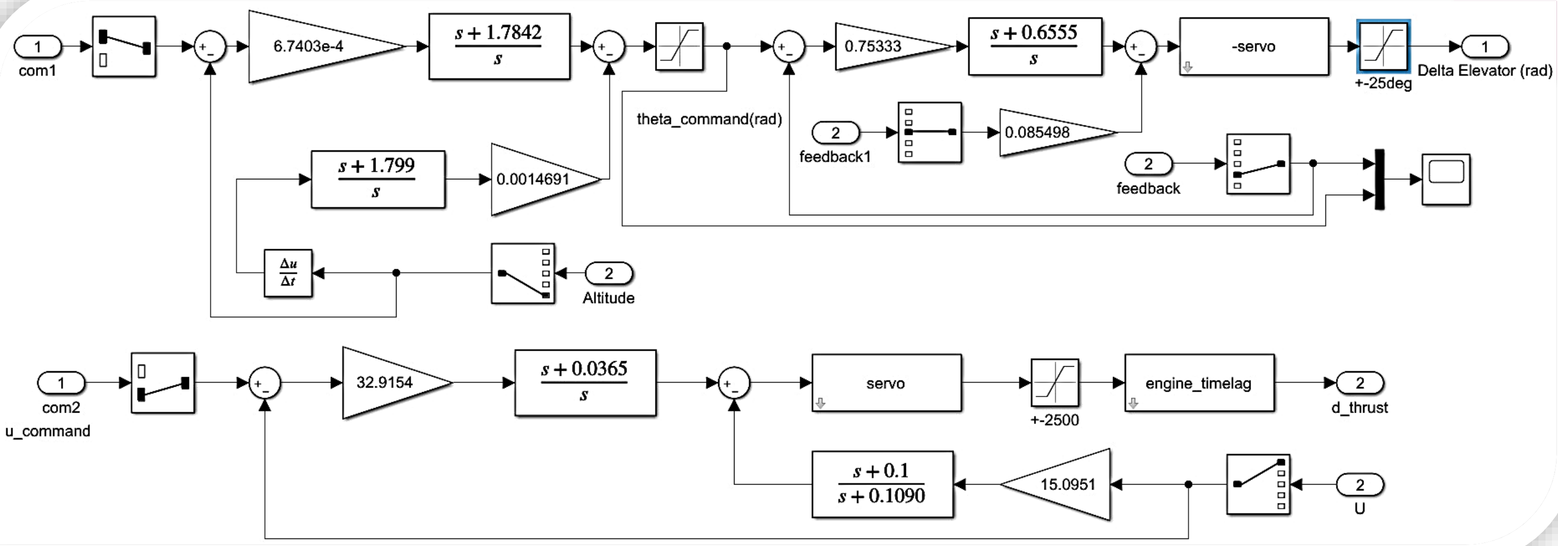
simulation

Results



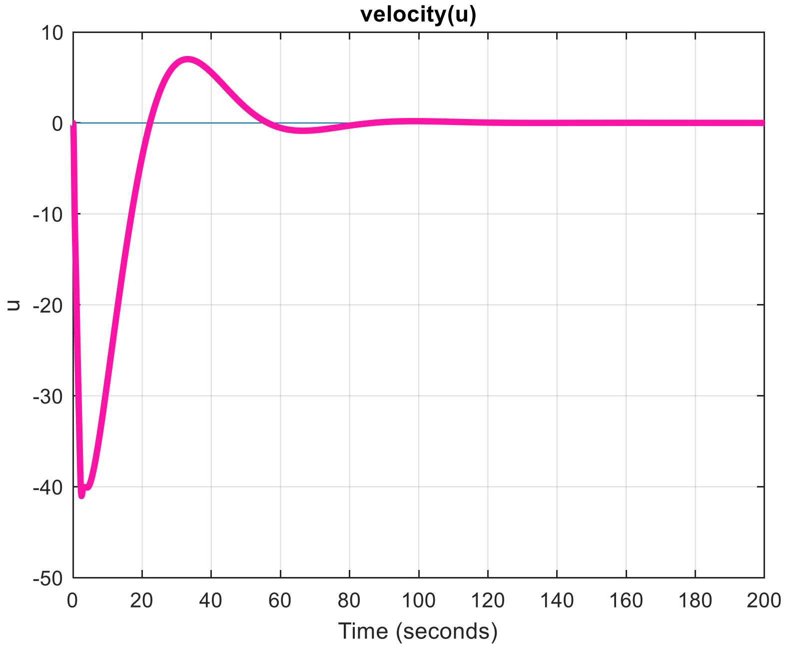


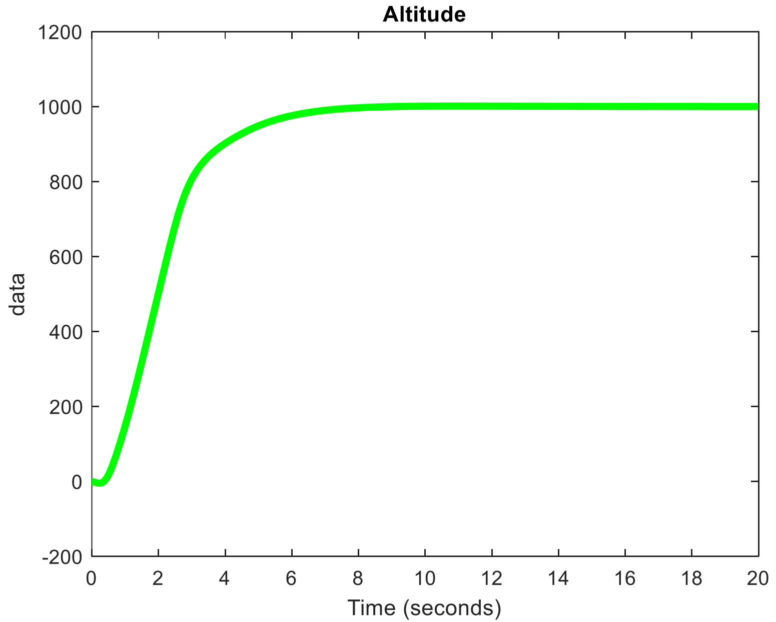
Simulation Blocks



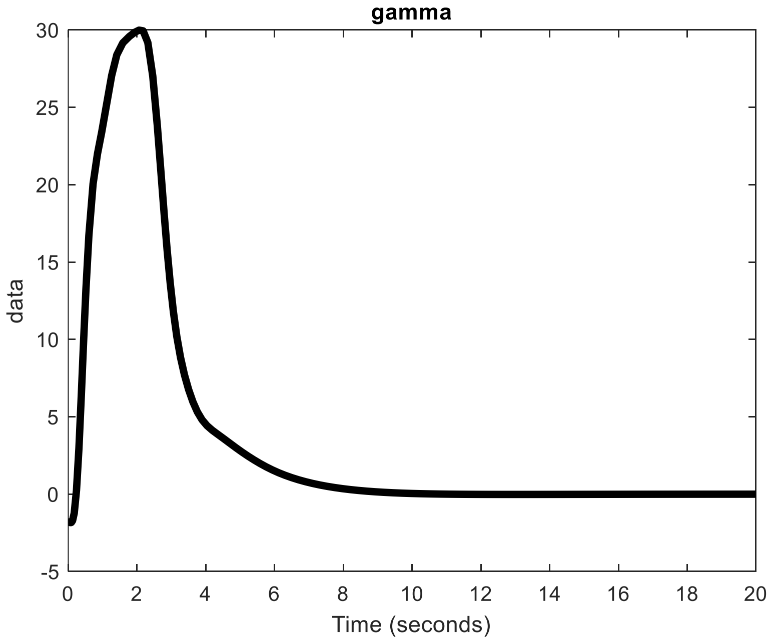
Simulation Blocks

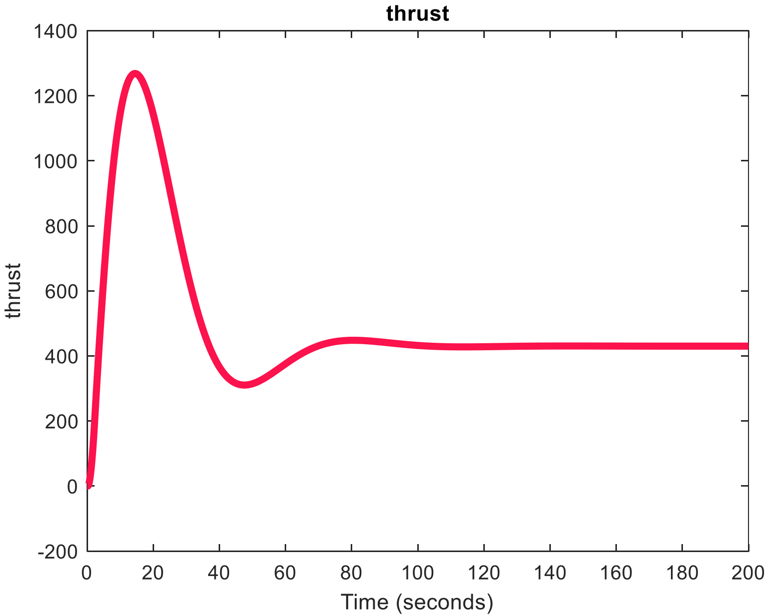
Simulink Results of 1000ft Command



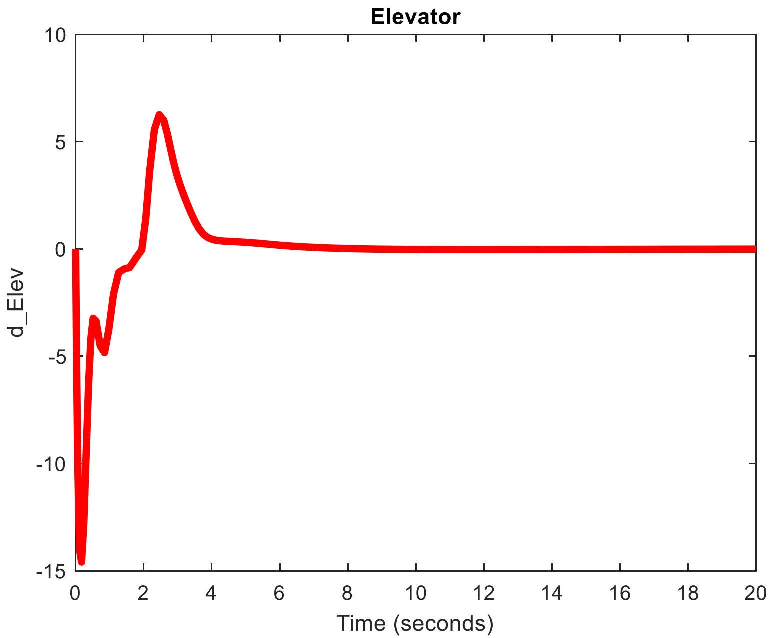


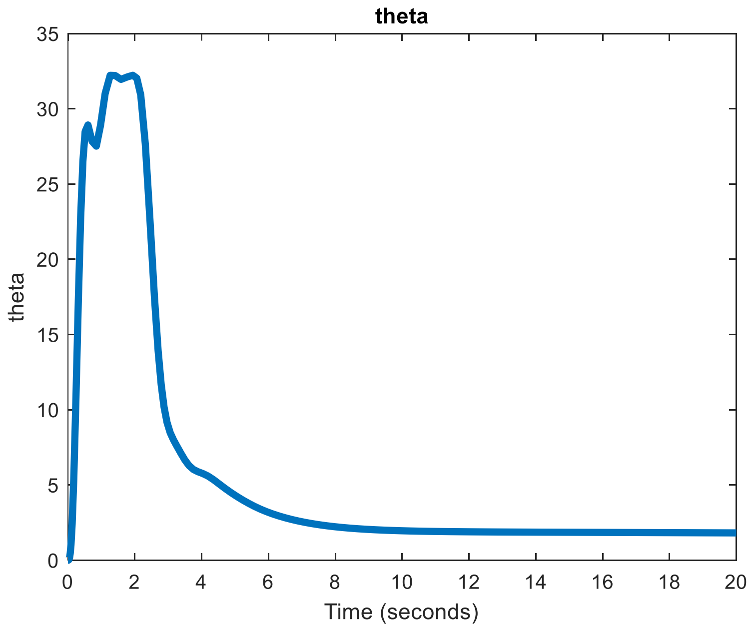
Simulink Results of 1000ft Command





Simulink Results of 1000ft Command





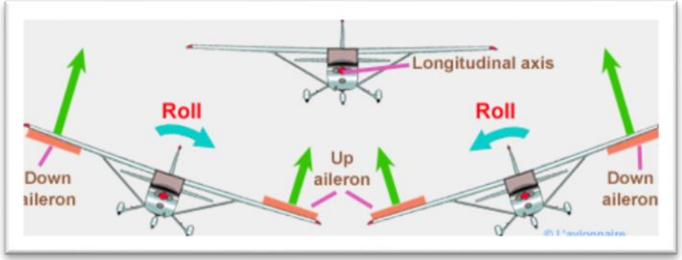
Auto Pilot

Task 6

Lateral Control

The rule of the lateral autopilot is to control the motion of the airplane in the lateral-directional plane, it controls the rudder & aileron to achieve a ***coordinated turn***

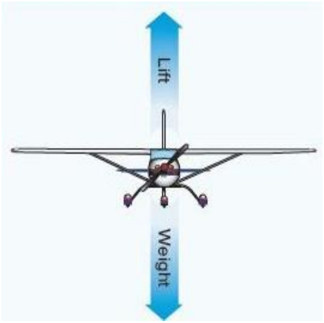
What is coordinated turn ??



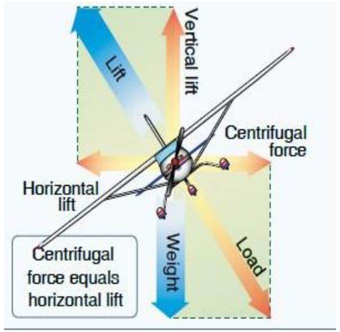
coordinated turn

We may call it "zero-lateral acceleration turn"

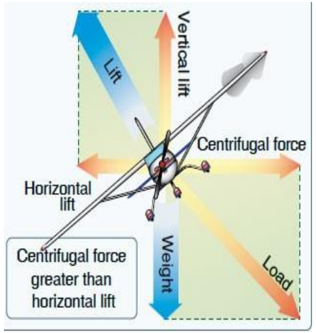
In terms of mechanics



Normal flight



Medium banked turn



Steep banked turn

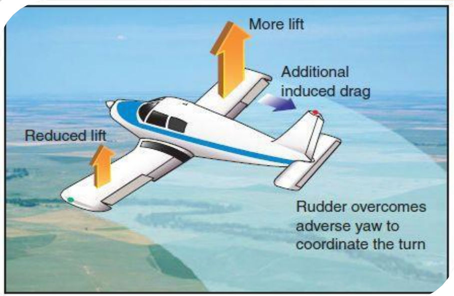
coordinated turn

In terms of aerodynamics

When lift increases in one of the wings the drag also increases

On that wing resulting in “adverse yaw phenomenon”

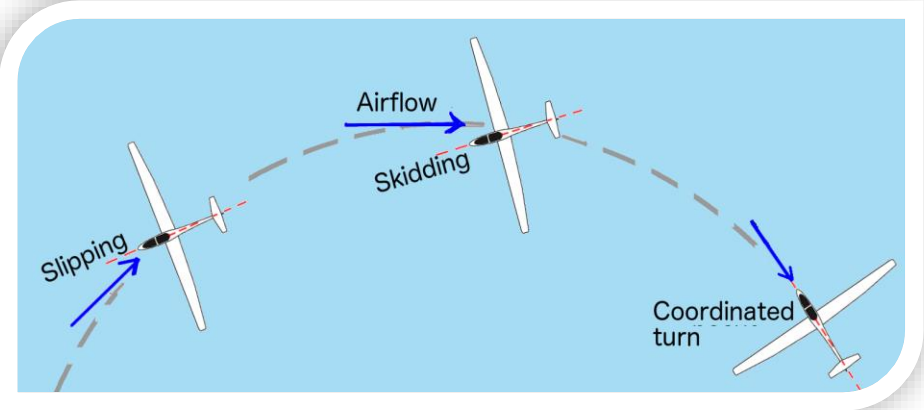
To overcome this phenomenon we need rudder input



coordinated turn

In terms of aerodynamics

The coordinated turn is a maneuver in which the airplane's heading angle is changed (airplane turns) without "slipping or skidding", i.e. the side slip angle ($\beta = 0$). note: skidding is having +ve sideslip angle ($\beta>0$) while slipping is having -ve sideslip angel ($\beta<0$)



“Yaw damper” for the Dutch roll mode

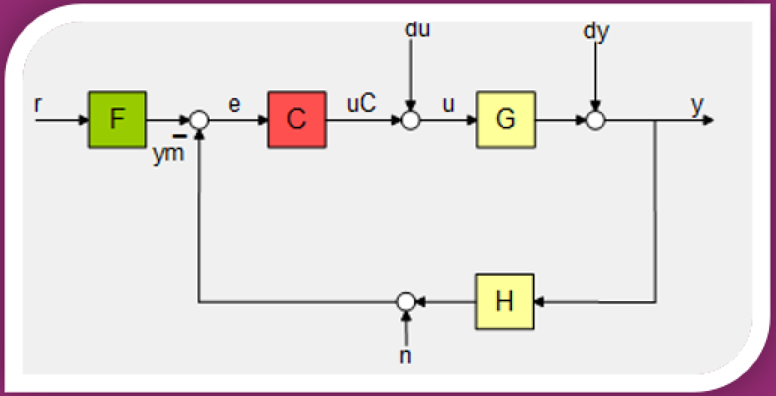
Design

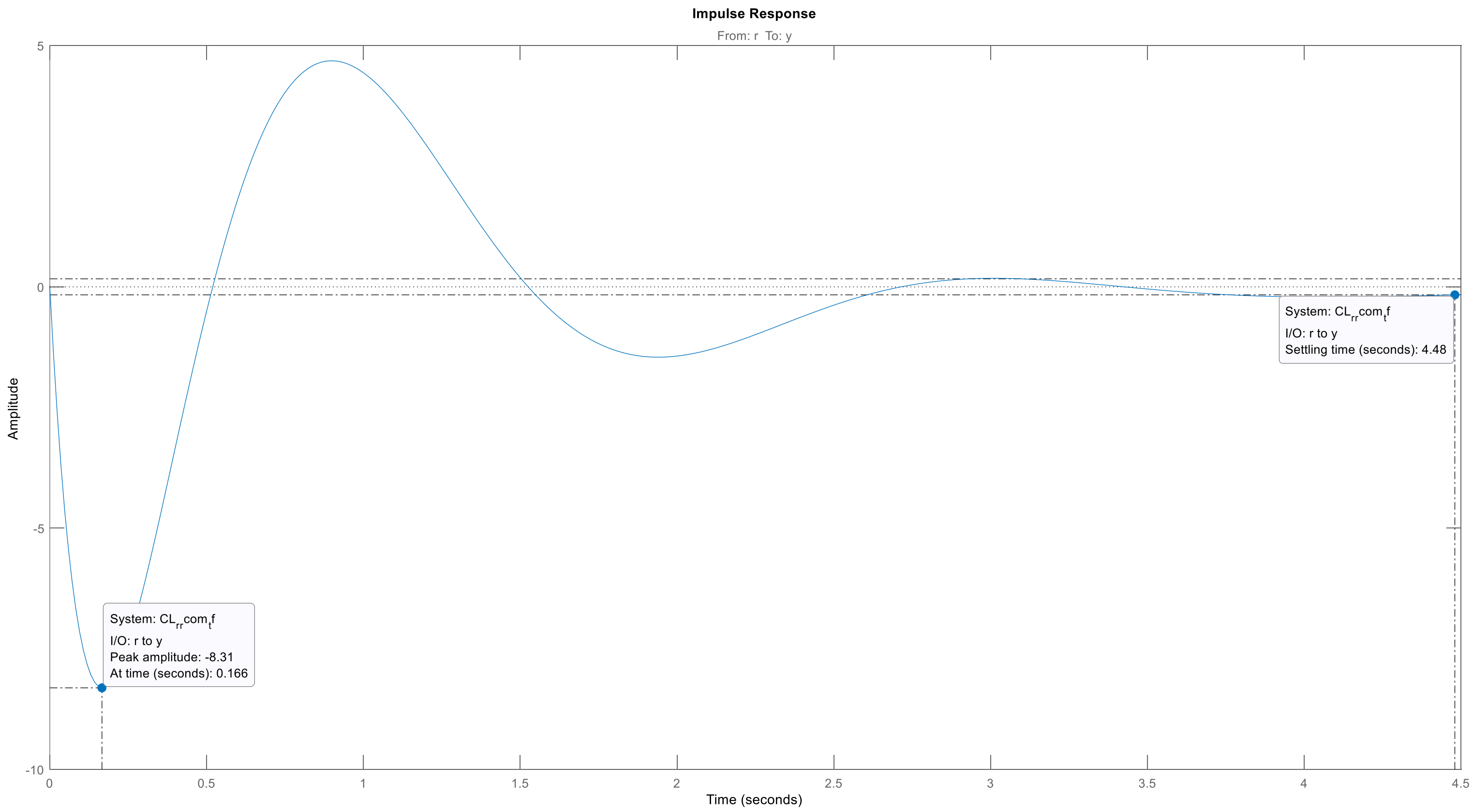
Closed Loop transfer function:

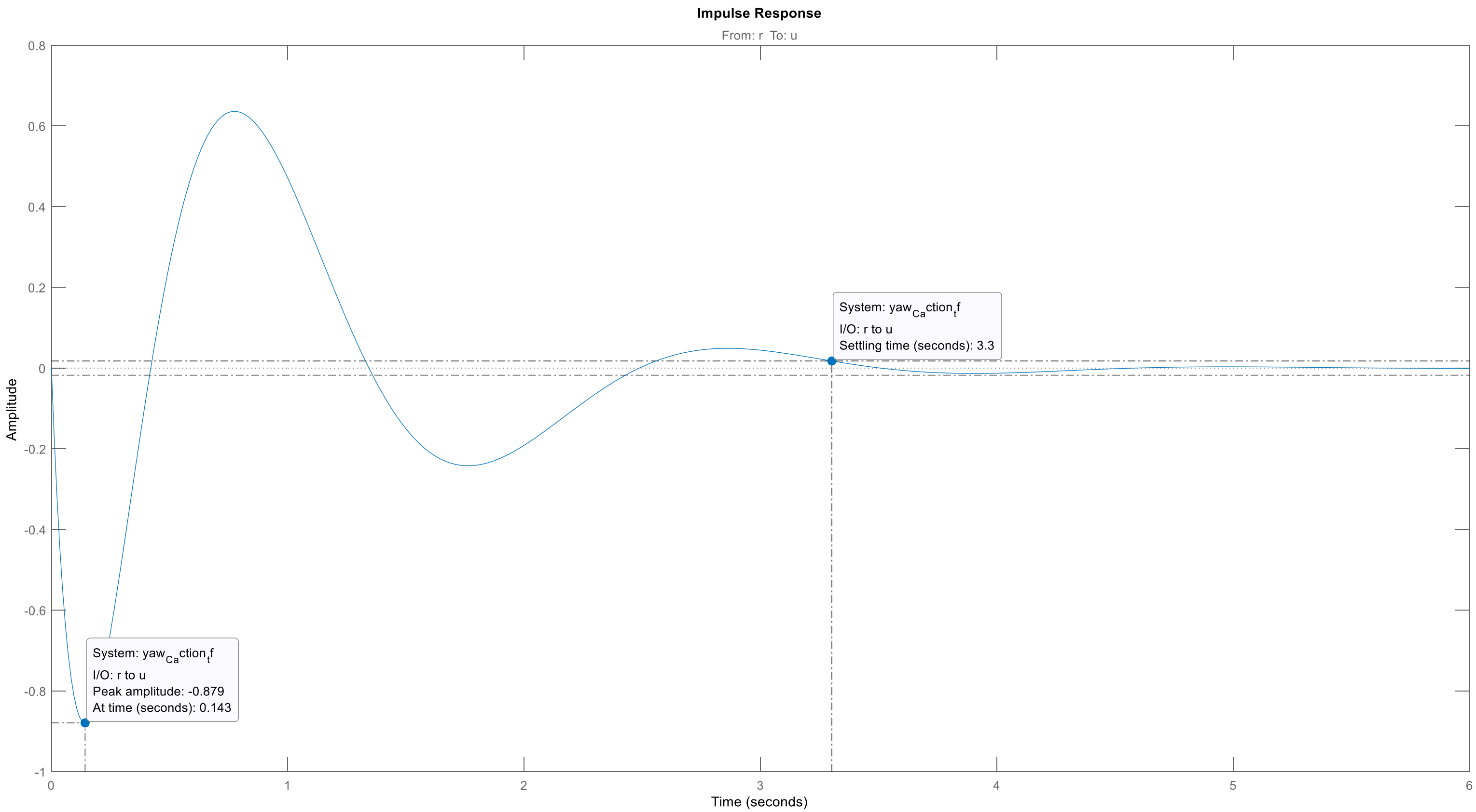
```
CL_r_rcom_tf =

  From input "r" to output "y":

             -126 s^4 - 783.7 s^3 - 1046 s^2 - 314.8 s - 98.98

  ---------------------------------------------------------------------

  s^6 + 16.87 s^5 + 107.3 s^4 + 375.6 s^3 + 807.1 s^2 + 732.1 s + 3.371
```

“Yaw damper” for the Dutch roll mode

Design

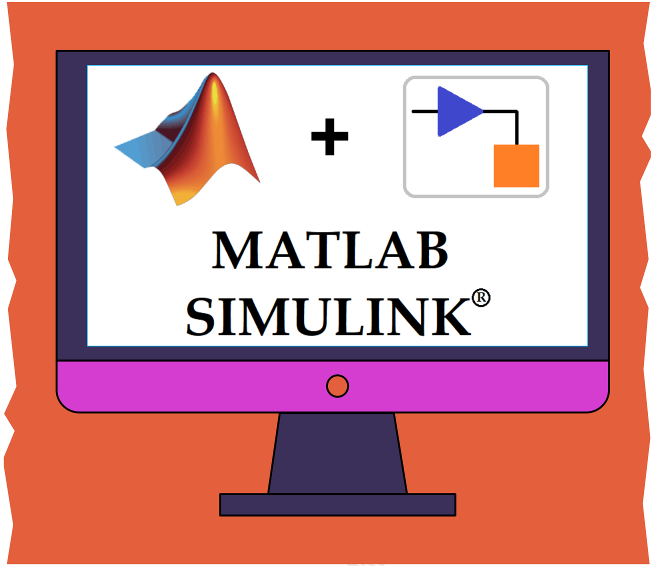
yaw_C_tf	Architecture
$\frac{0.12324\ s}{(s+1.464)}$	


Impulse Response
From: r To: y
Amplitude
Time (seconds)
5
0
-5
-10
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
System: CL_rr com_t f
I/O: r to y
Peak amplitude: -8.31
At time (seconds): 0.166
System: CL_rr com_t f
I/O: r to y
Settling time (seconds): 4.48

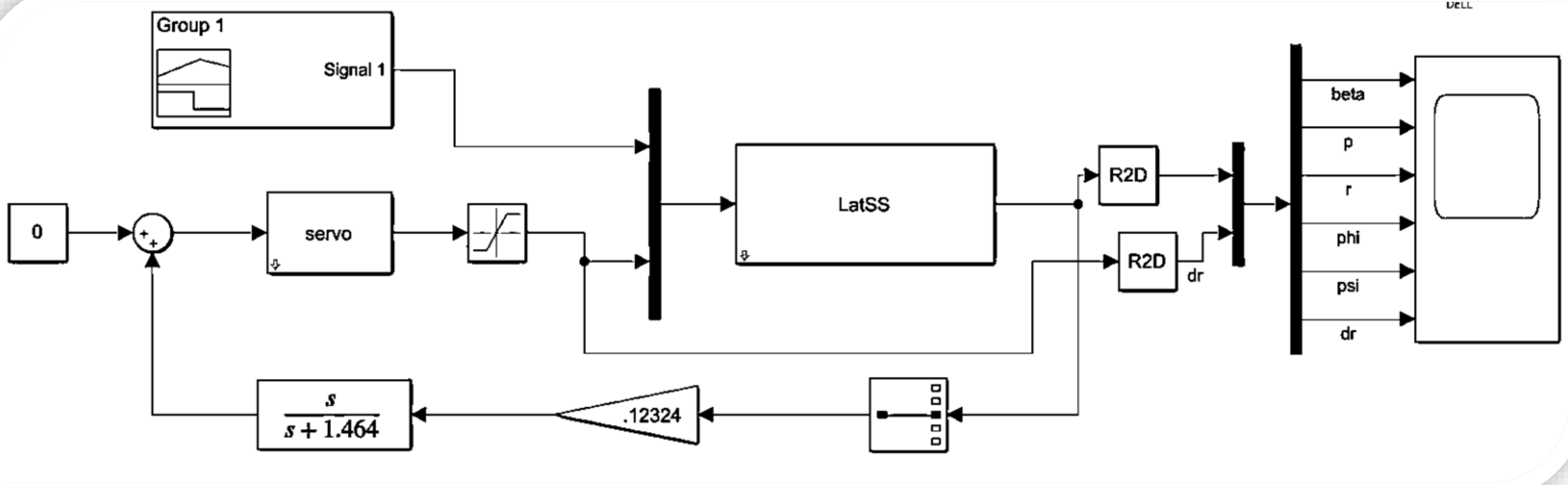


Impulse Response
From: r To: u
Amplitude
Time (seconds)
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
1
2
3
4
5
6
System: yaw_Caction_tf
I/O: r to u
Settling time (seconds): 3.3
System: yaw_Caction_tf
I/O: r to u
Peak amplitude: -0.879
At time (seconds): 0.143

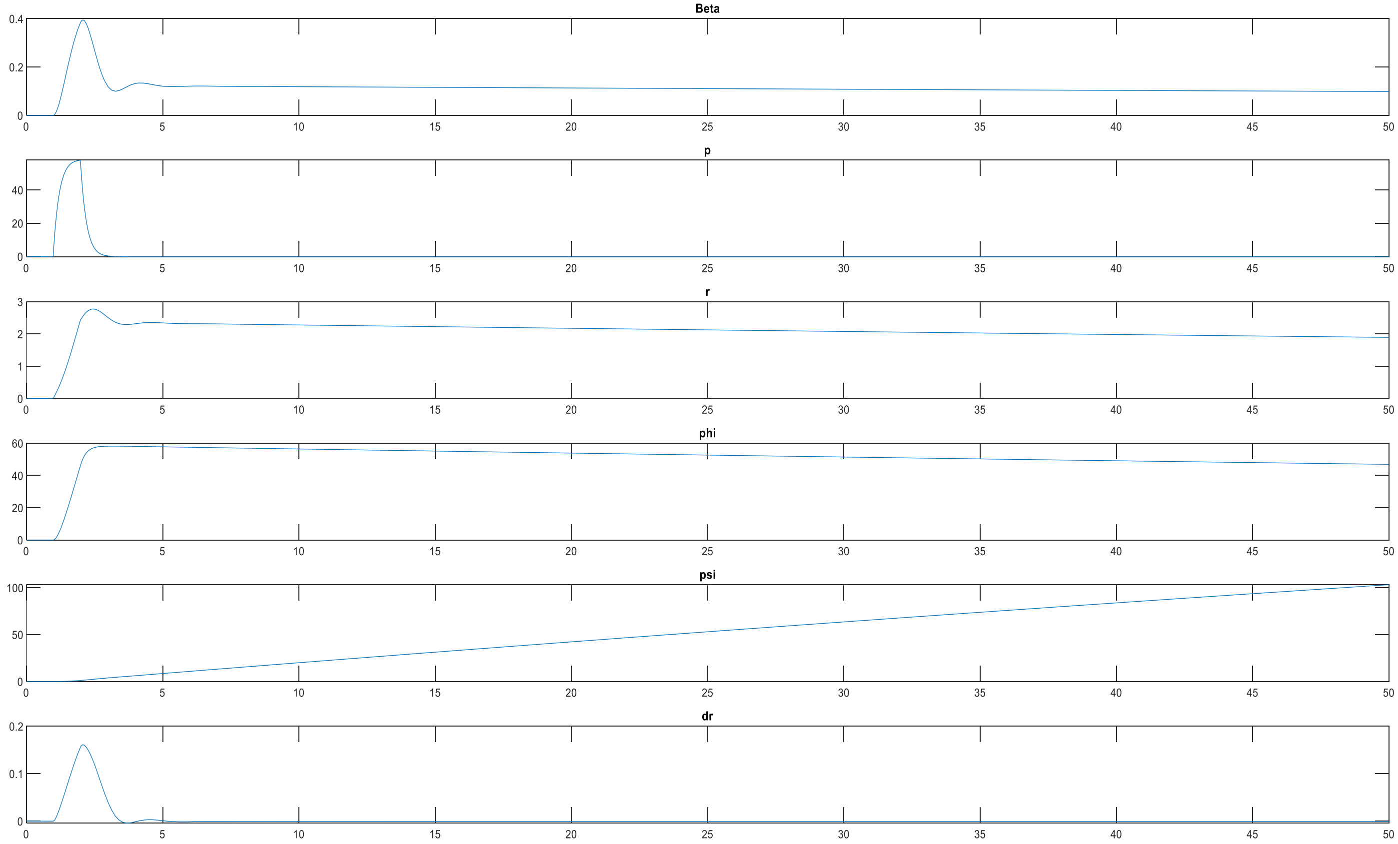
Test The “Yaw damper” controllers on the full state space model



Simulink Test



Test Result



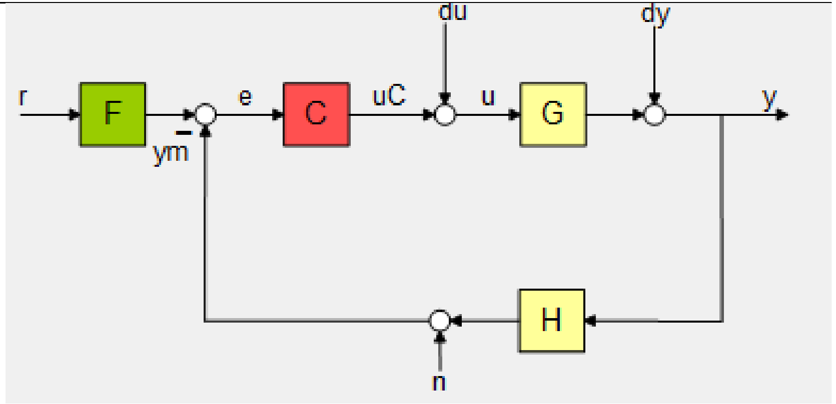
Roll Controller

Closed Loop transfer function:

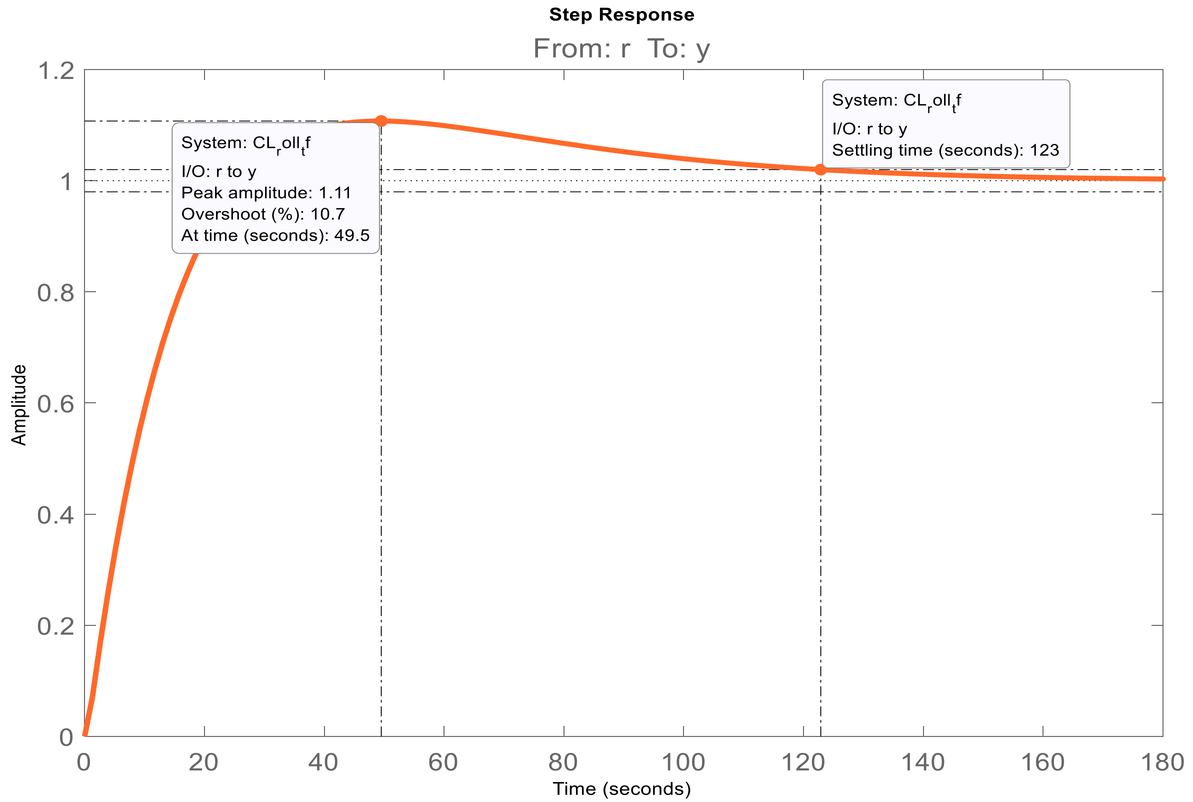
```
CL_roll_tf =

  From input "r" to output "y":


36.72 s^5 + 454.8 s^4 + 1898 s^3 + 5252 s^2 + 5966 s + 128.9

------------------------------------------------------------------------

s^9 + 36.87 s^8 + 544.7 s^7 + 4209 s^6 + 1.908e04 s^5 + 5.489e04 s^4 +
9.725e04 s^3 + 7.853e04 s^2 + 6303 s + 128.9
```

Roll Controller

Design

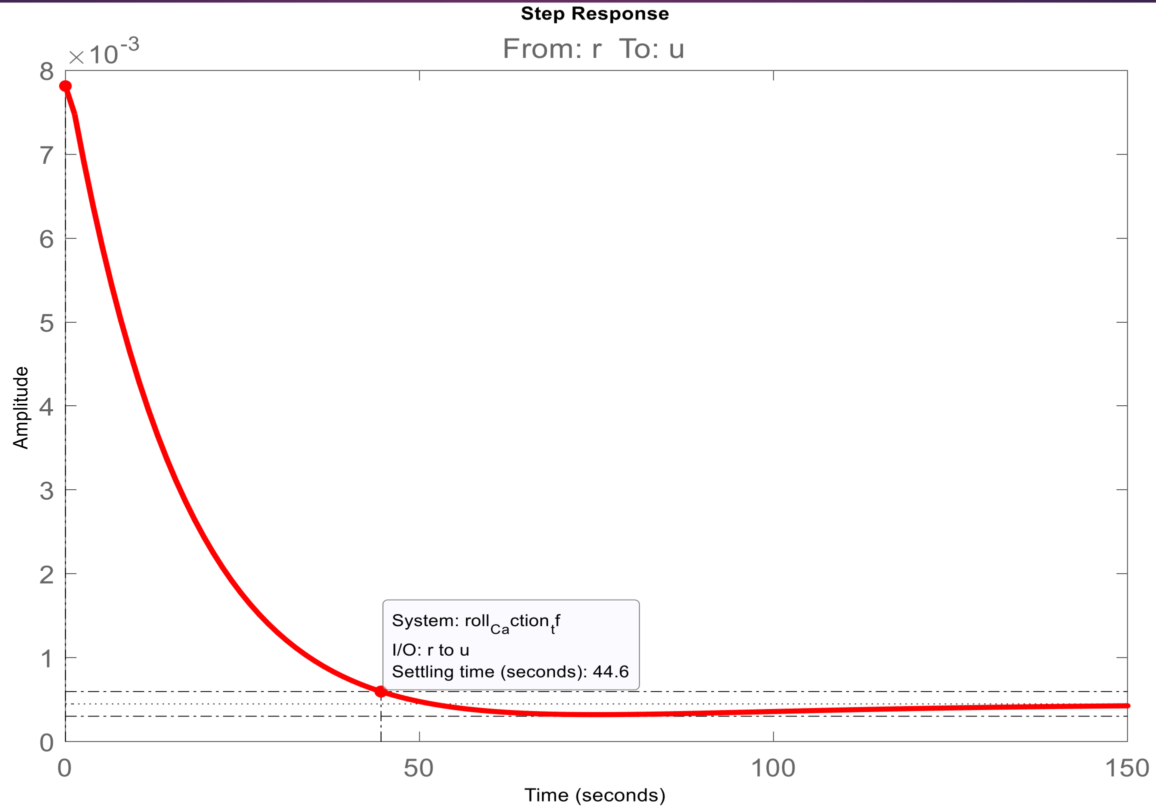
roll_C_tf	Architecture
0.0078128 (s+0.02203) --------------------- s	

Response



Step Response
From: r To: y
1.2
1
0.8
0.6
0.4
0.2
0
Amplitude
0
20
40
60
80
100
120
140
160
180
Time (seconds)
System: CL_roll_tf
I/O: r to y
Peak amplitude: 1.11
Overshoot (%): 10.7
At time (seconds): 49.5
System: CL_roll_tf
I/O: r to y
Settling time (seconds): 123

Control Action

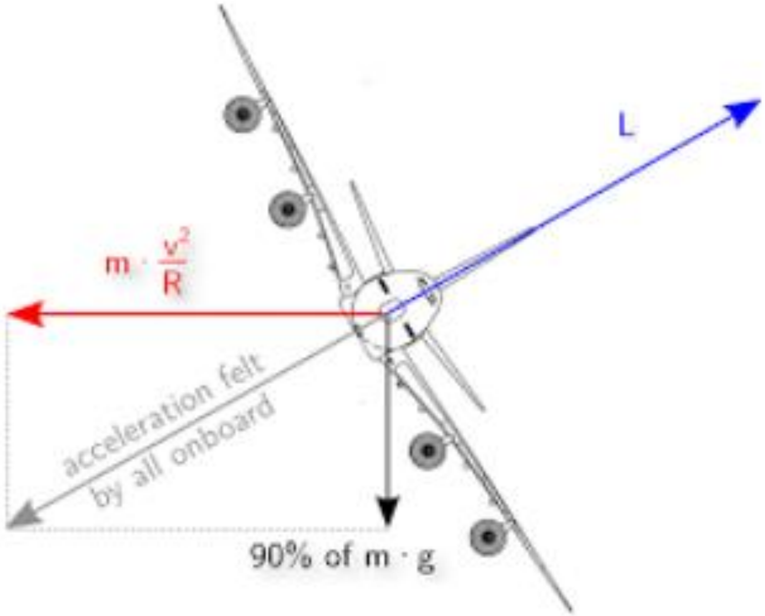


Coordination

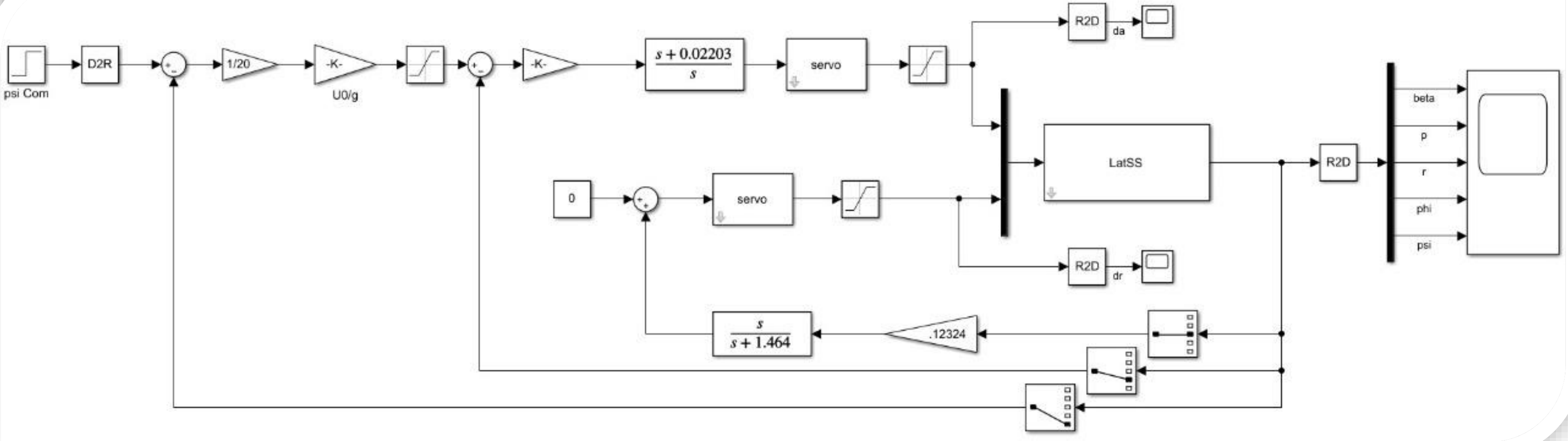
$$\therefore \phi \simeq \frac{U_o\dot{\psi}}{g}$$

$$\psi/_{\psi_d} = \frac{1/_\tau}{s+1/_\tau} \quad , \quad 15 \leq \tau \leq 20$$

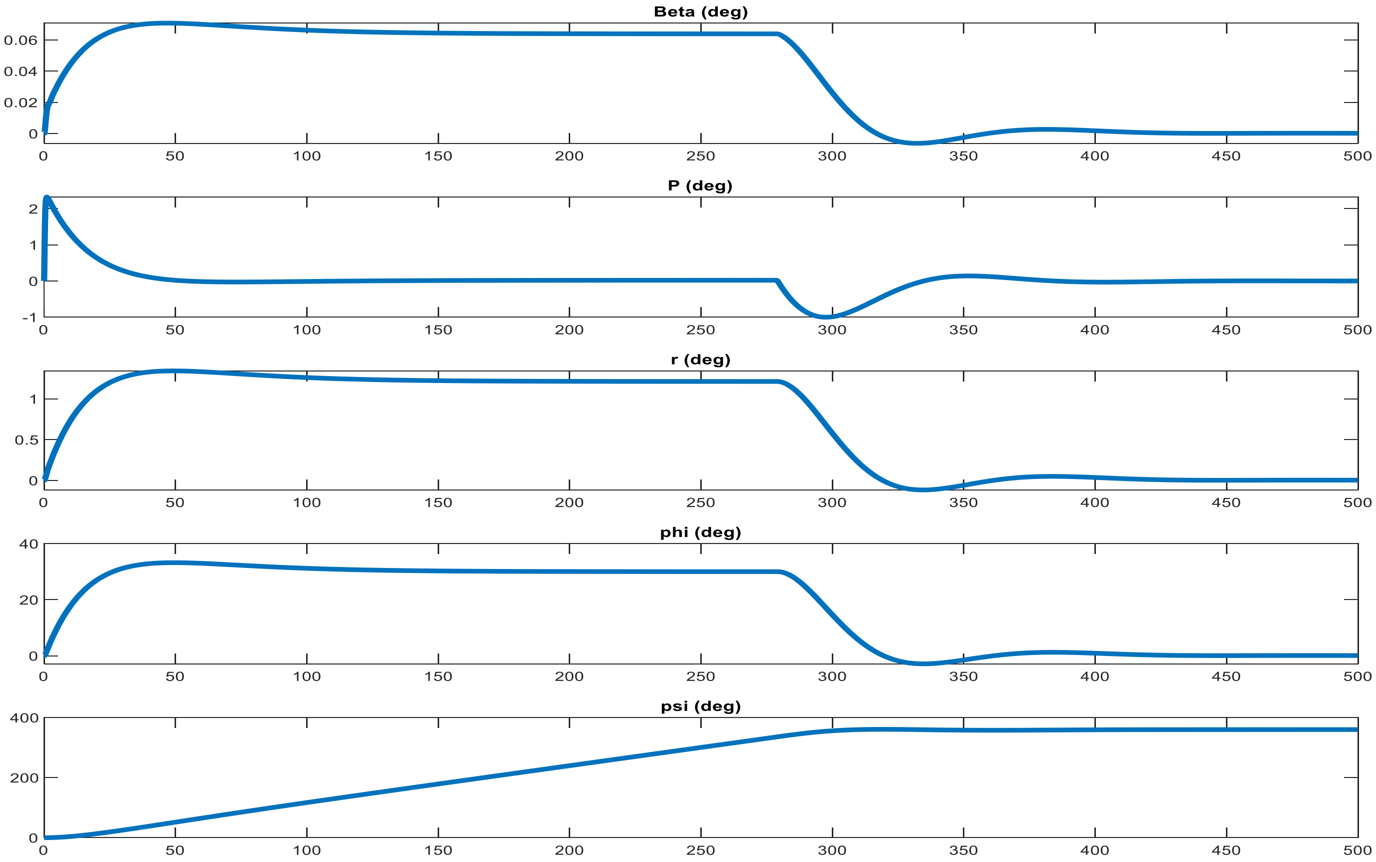
$$\therefore \phi = \frac{U_o}{\tau\, g}\left(\psi_{desired} - \psi\right)$$



Lateral controller Test with Simulink



Result



Thanks