Cairo University Faculty of Engineering Aerospace Department

Team 4

4/18/2022

Task 5 part 2

Autopilot -AER 408

Dr.Osama Saaid

Name	sec	BN
Mohammed Ahmed Hassan Ahmed	2	37
Ibrahim Thabet Allam	1	1
Mohammed Hatem Mohammed Saeed	2	39
Mohammed Abd El-Mawgoud Ghoneam	2	43
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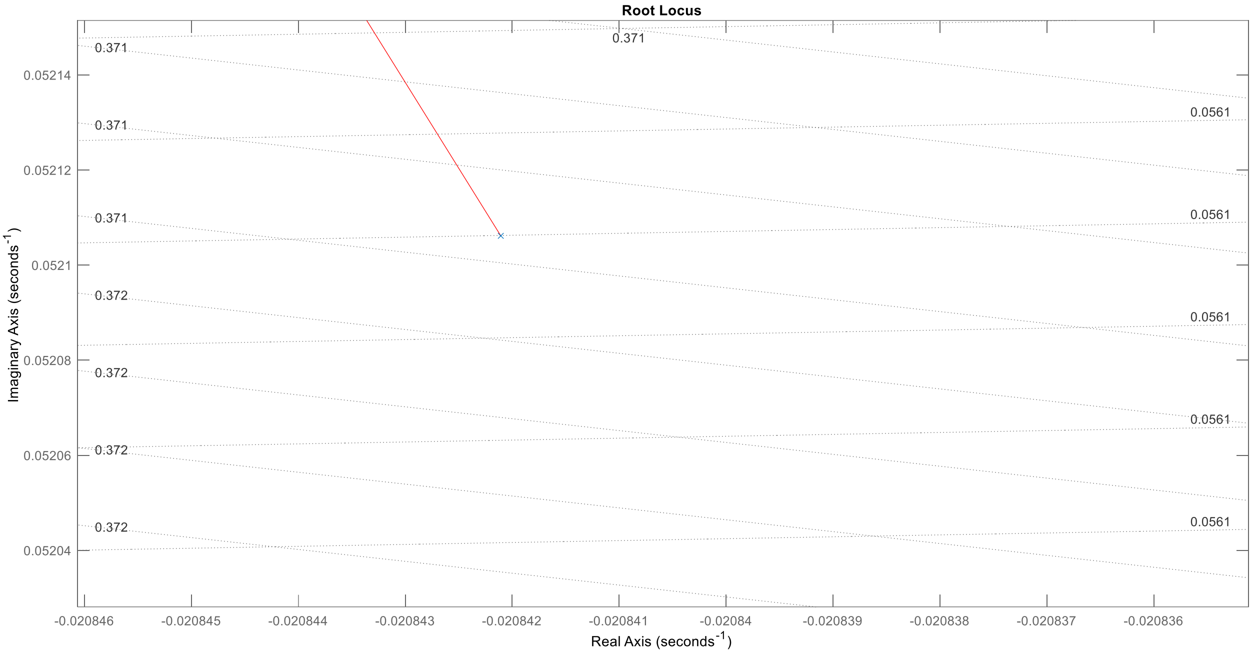
Contents

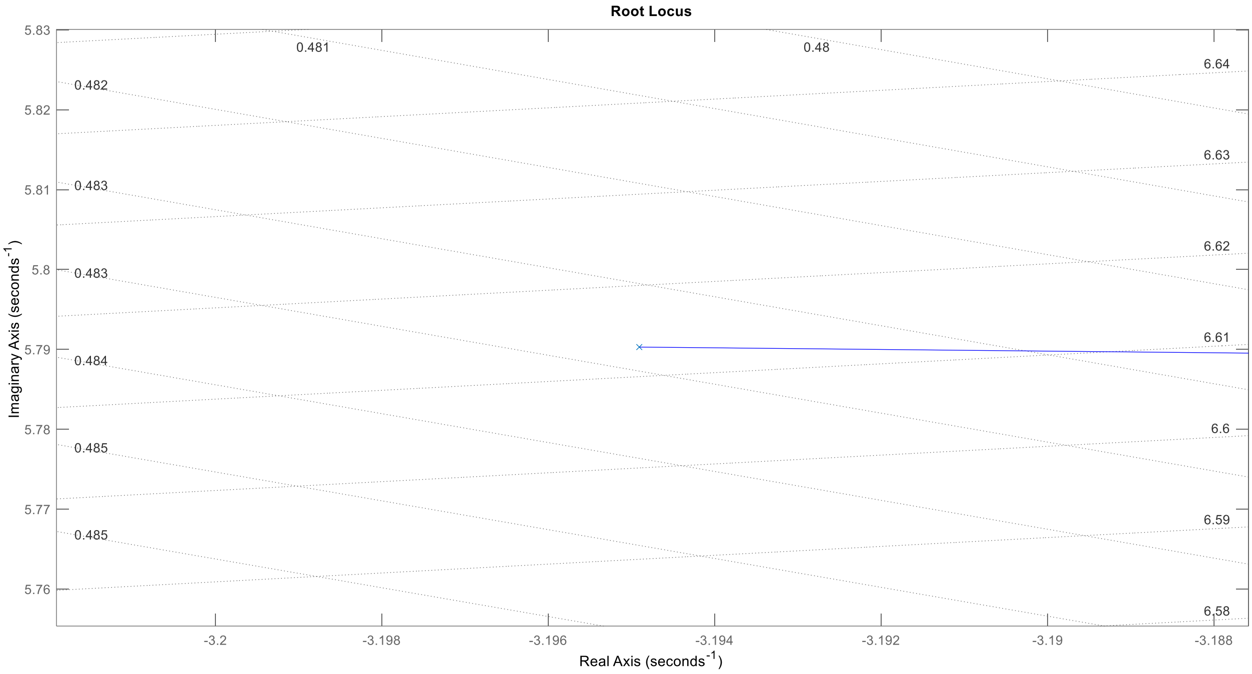
A. Design Pitch Controller with pitch rate feedback

Long period:



$$\xi = 0.3714 > 0.04$$

Short period



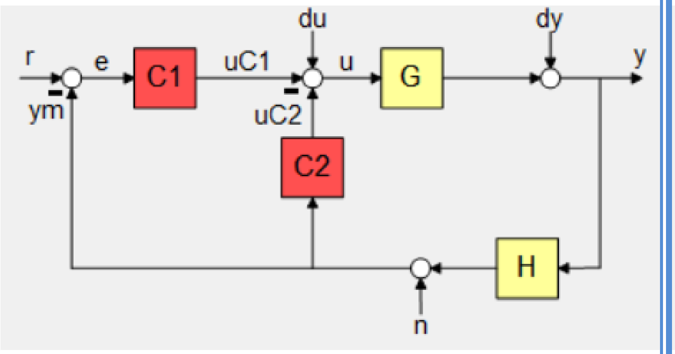
$$0.3 < \xi = 0.4831 < 2.0$$

Then 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

Continuous-time transfer function.
```

Design control loop with PD and PID:

```
PD_tf =

  0.085498 s

Name: C2

Continuous-time zero/pole/gain model.


PI_tf =

  0.75333 (s+0.6555)

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

          s

Name: C1

Continuous-time zero/pole/gain model.
```



Closed Loop transfer function:

```
CL_theta_thetacom_tf =


  From input "r" to output "y":

                 397 s^3 + 1653 s^2 + 968.6 s + 36.61

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

  s^6 + 16.43 s^5 + 153.4 s^4 + 996.9 s^3 + 1678 s^2 + 970 s + 36.61


Continuous-time transfer function.
```

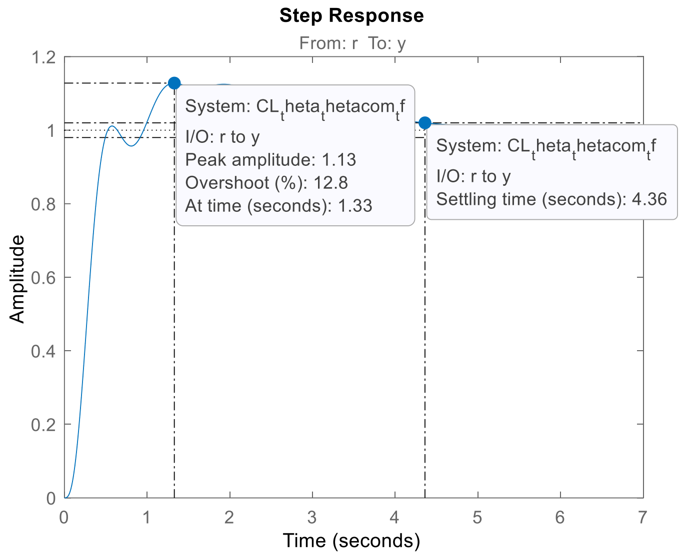


Figure 1. Response

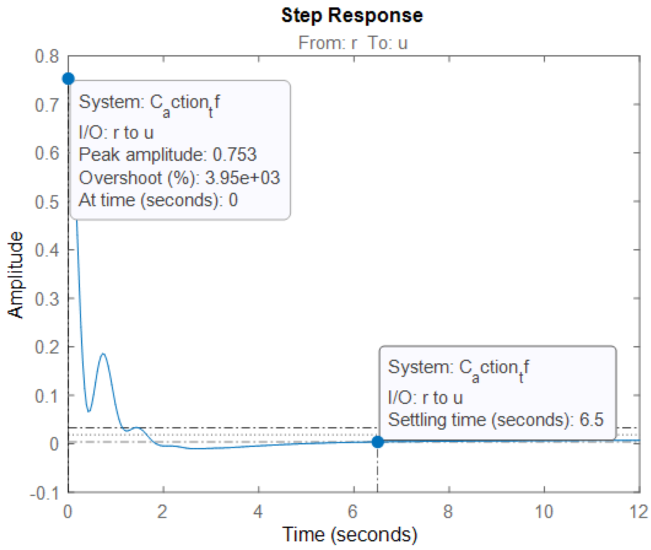


Figure 2. Control Action

Control action transfer function:

```
C_action_tf =
 
 
  From input "r" to output "u":

0.7533 s^6 + 12.87 s^5 + 89.72 s^4 + 386.4 s^3 + 232.2 s^2 + 10.21 s +
0.6802

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

       s^6 + 16.43 s^5 + 153.4 s^4 + 996.9 s^3 + 1678 s^2 + 970 s + 36.61


Continuous-time transfer function.
```

B. Testing Pitch Controller on the Full State Space Model

Simulink Simulation

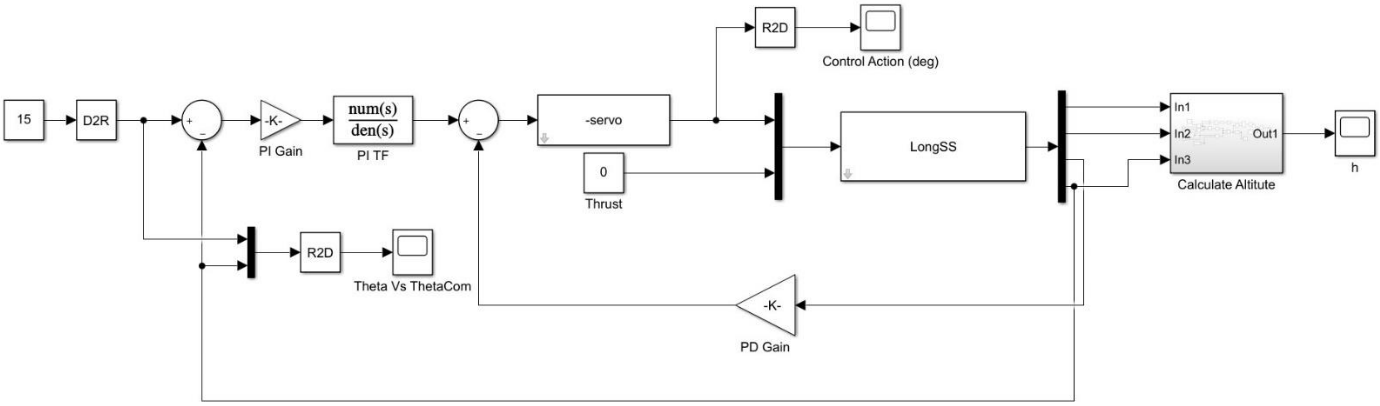


Figure 3. Simulink - Pitch Controller check

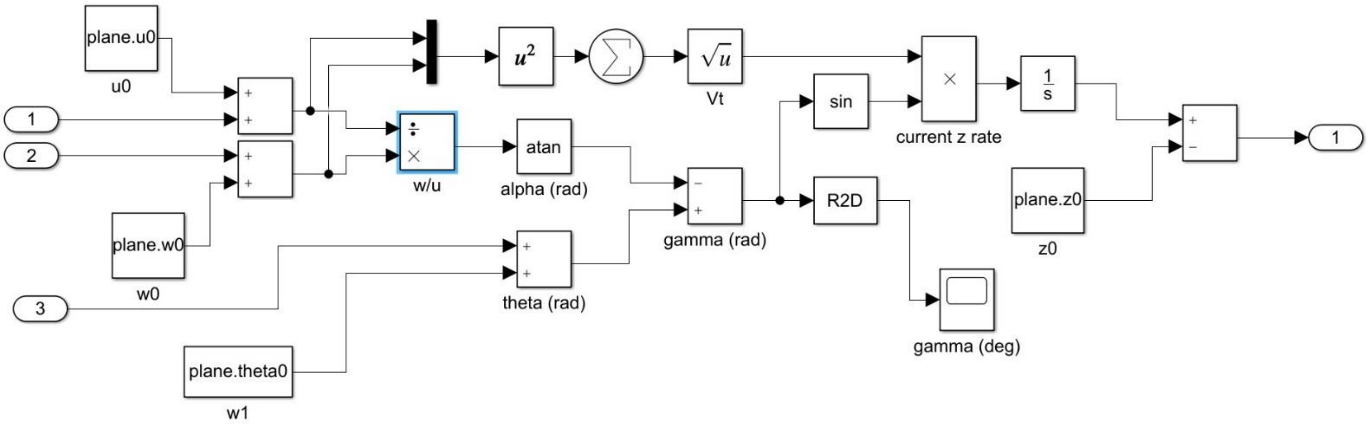


Figure 4. Simulink - Gamma & Altitude

Results

Command of 15-degree pitch angle

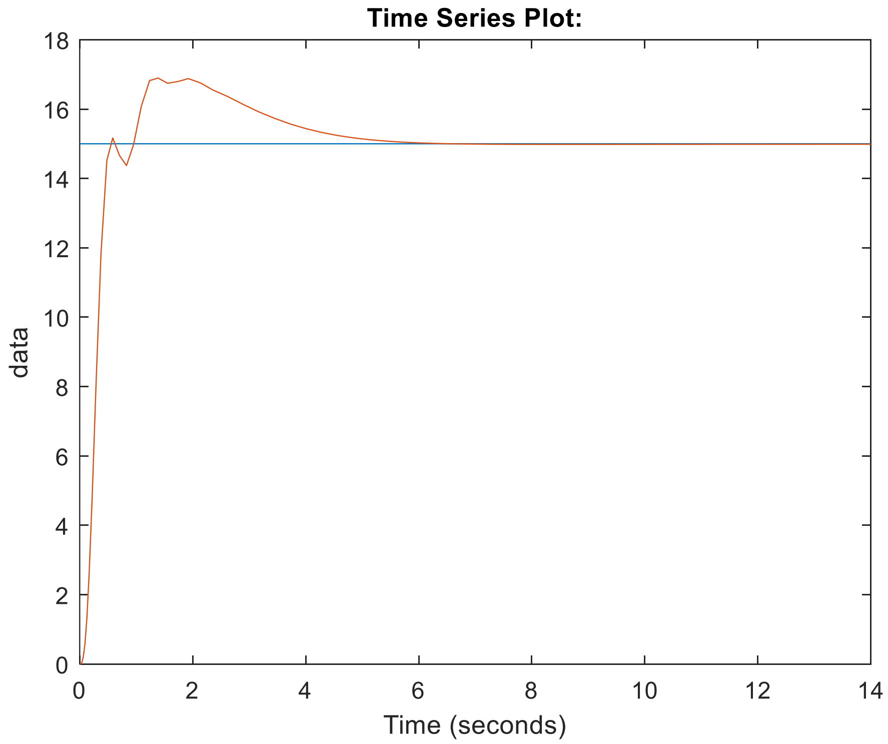


Figure 5. Theta response with Theta Command

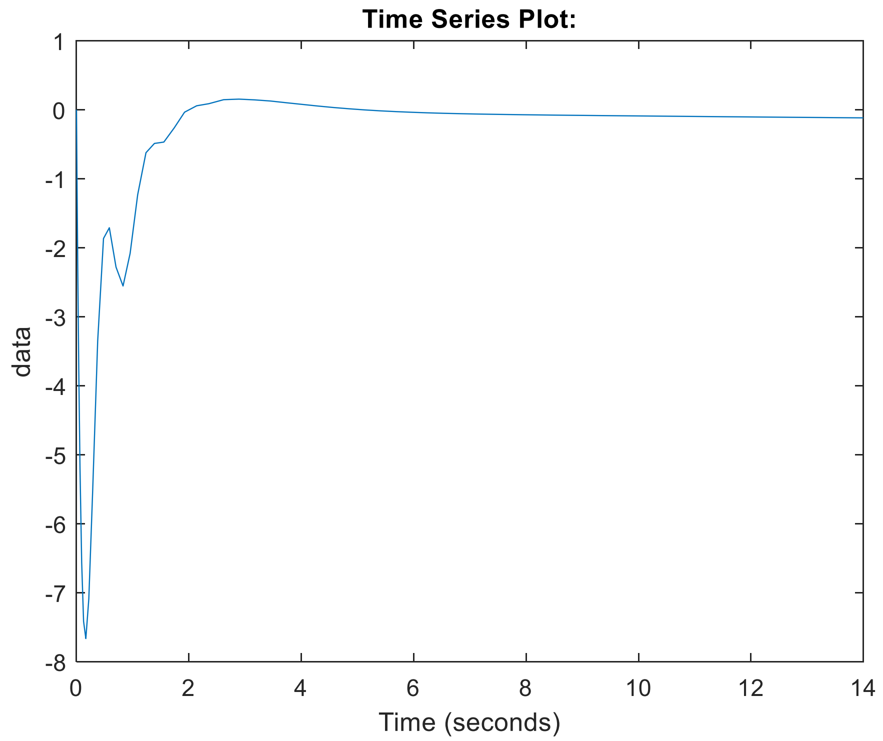


Figure 6. Control Action

C. 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.

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

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

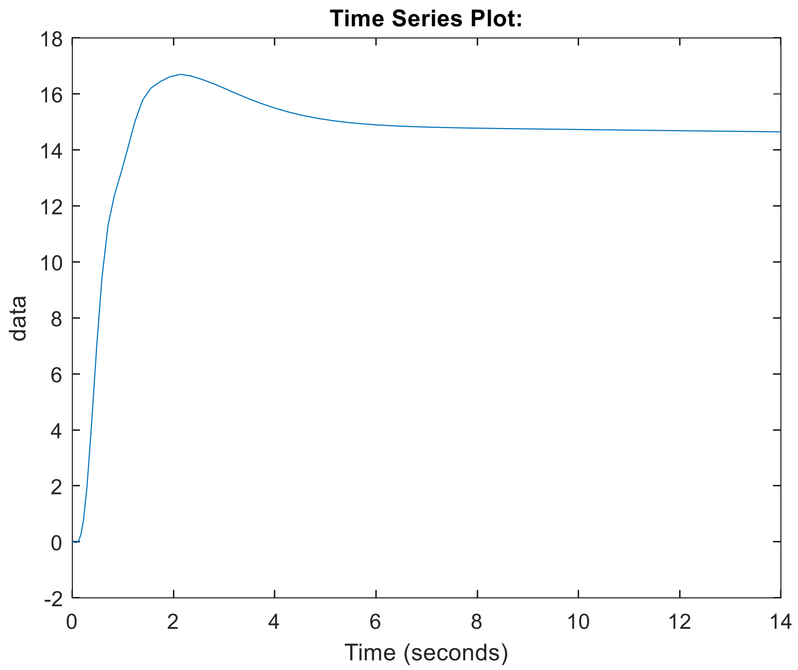


Figure 7. Gamma

We did use this relation to calculate the altitude rate of change and by integration we could obtain the current altitude value.

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

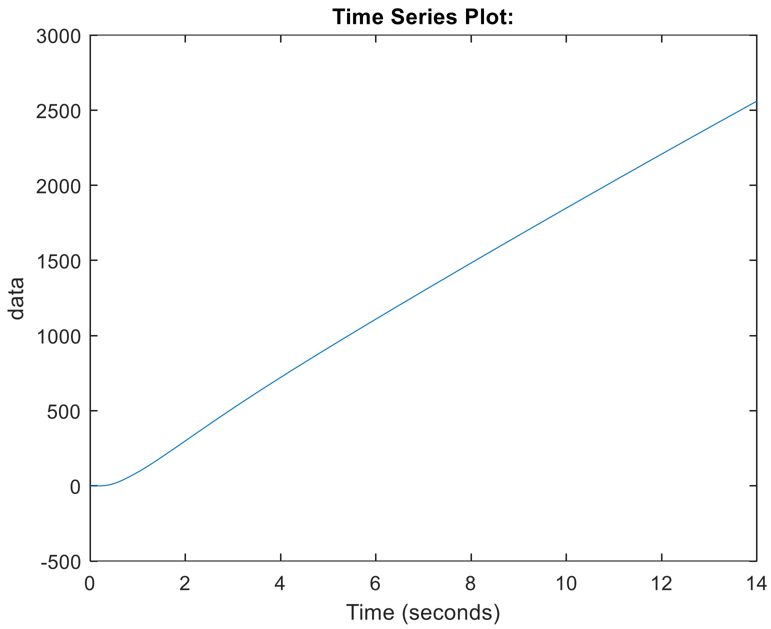


Figure 8. Altitude

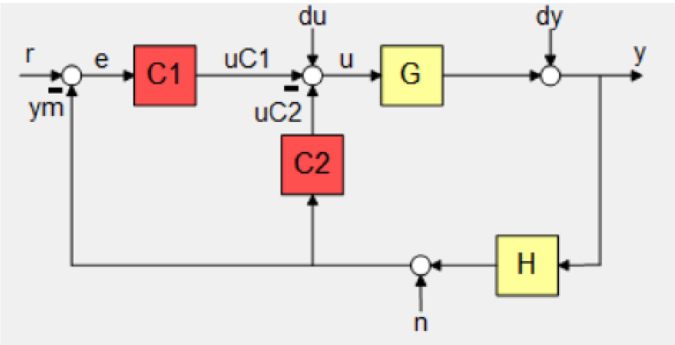
Our plane climbs upward because it has enough thrust to accomplish this. But this not meaning that we control altitude because the airplane will climb to specific height that its thrust enough to reach, then the airplane would dive downward. And this specific height may be before or after that height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

D. Design a “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.
```

Design control loop with PD and PID:




```
PD_tf_vel =


  15.095 (s+0.1)

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

    (s+0.109)


Name: C2

Continuous-time zero/pole/gain model.


PI_tf_vel =


  32.915 (s+0.03648)

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

          s

Name: C1

Continuous-time zero/pole/gain model.
```

Closed Loop transfer function:

```
CL_u_ucom_tf =


  From input "r" to output "y":


 0.07735 s^5 + 0.5051 s^4 + 3.454 s^3 + 0.4919 s^2 + 0.01316 s- 7.629e-06

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

s^8 + 16.64 s^7 + 111.8 s^6 + 464.7 s^5 + 111.8 s^4 + 8.193 s^3 + 0.1525
s^2 + 0.001761 s + 7.629e-06


Continuous-time transfer function.
```

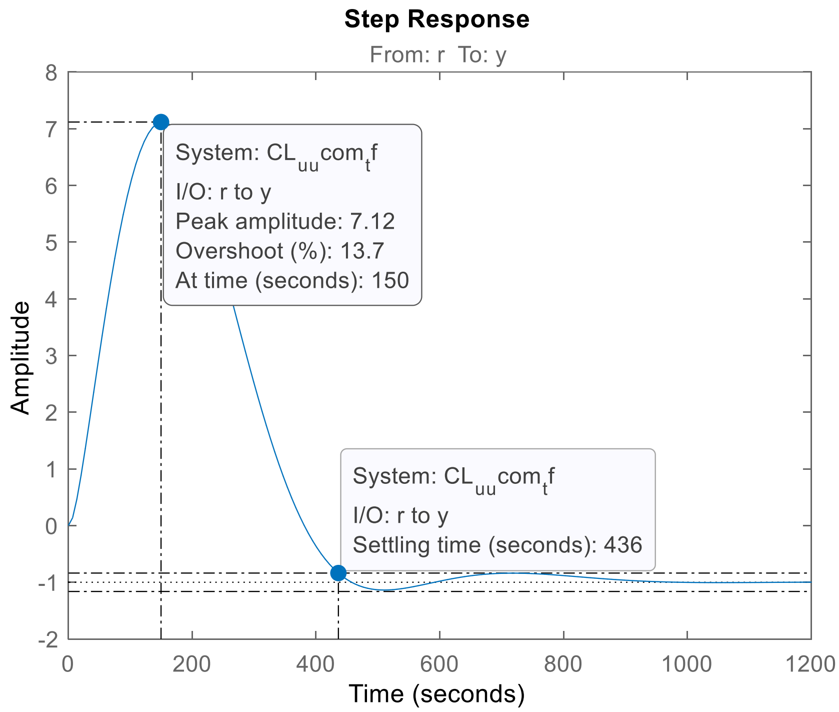


Figure 9 Response

Control action transfer function:

```
Con_action_tf_vel =


  From input "r" to output "u":

32.92 s^8 + 548.9 s^7 + 3699 s^6 + 1.543e04 s^5 + 4247 s^4 + 466.1 s^3 +
28.23 s^2 + 1.083 s + 0.01802

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

s^8 + 16.64 s^7 + 111.8 s^6 + 464.7 s^5 + 111.8 s^4 + 8.193 s^3 + 0.1525
s^2 + 0.001761 s + 7.629e-06


Continuous-time transfer function.
```

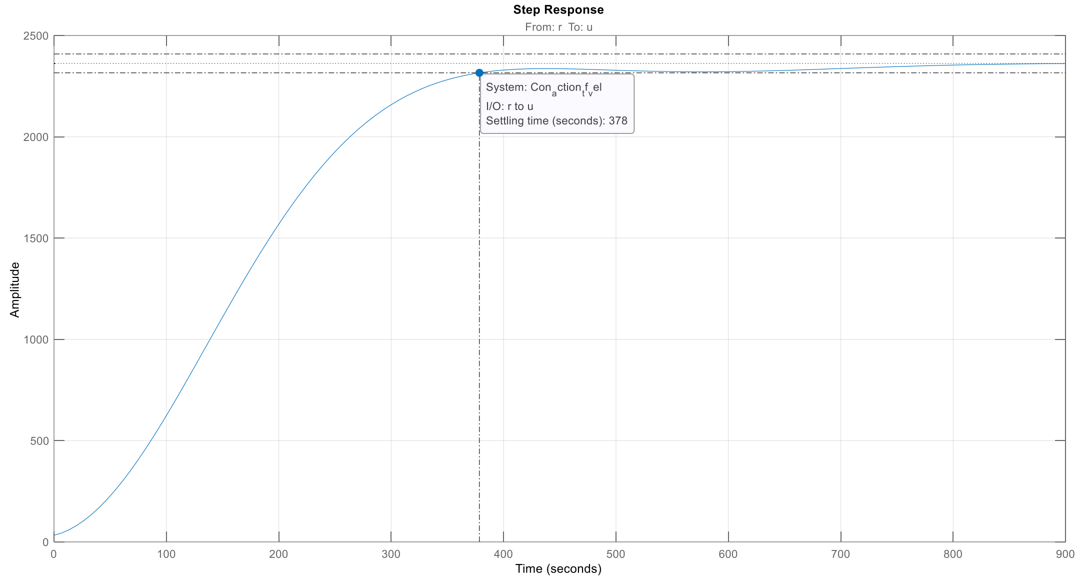


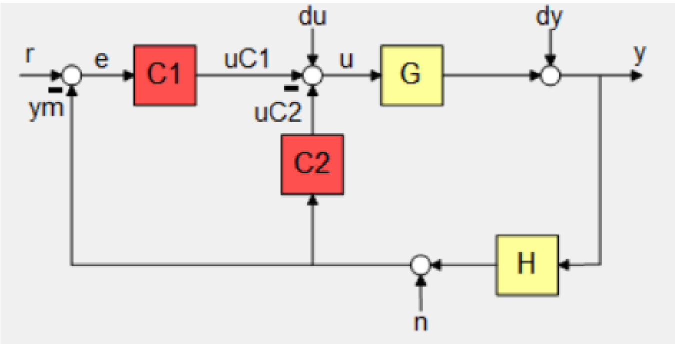
Figure 10 Control Action

F. Design "Altitude controller"

Then the open loop transfer function is

```
Ol_h_hcom =

  From input "r" to output:

 -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
Continuous-time transfer function.
```

Design control loop with PD and PID:




```
PD_tf_alt =


  0.0014691 (s+1.799)


Name: C2

Continuous-time zero/pole/gain model.


PI_tf_alt =


  0.00067403 (s+1.784)

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

           s

 Name: C1

Continuous-time zero/pole/gain model.
```

Closed Loop transfer function:

```
CL_h_hcom_tf =


  From input "r" to output "y":

  -0.7718 s^5 - 4.074 s^4 + 718.1 s^3 + 1793 s^2 + 915.7 s + 32.81
```

```
----------------------------------------------------------------------
 s^8 + 16.43 s^7 + 151.7 s^6 + 987.2 s^5 + 3239 s^4 + 5620 s^3 + 3842 s^2 +
987.8 s + 32.81


Continuous-time transfer function.
```

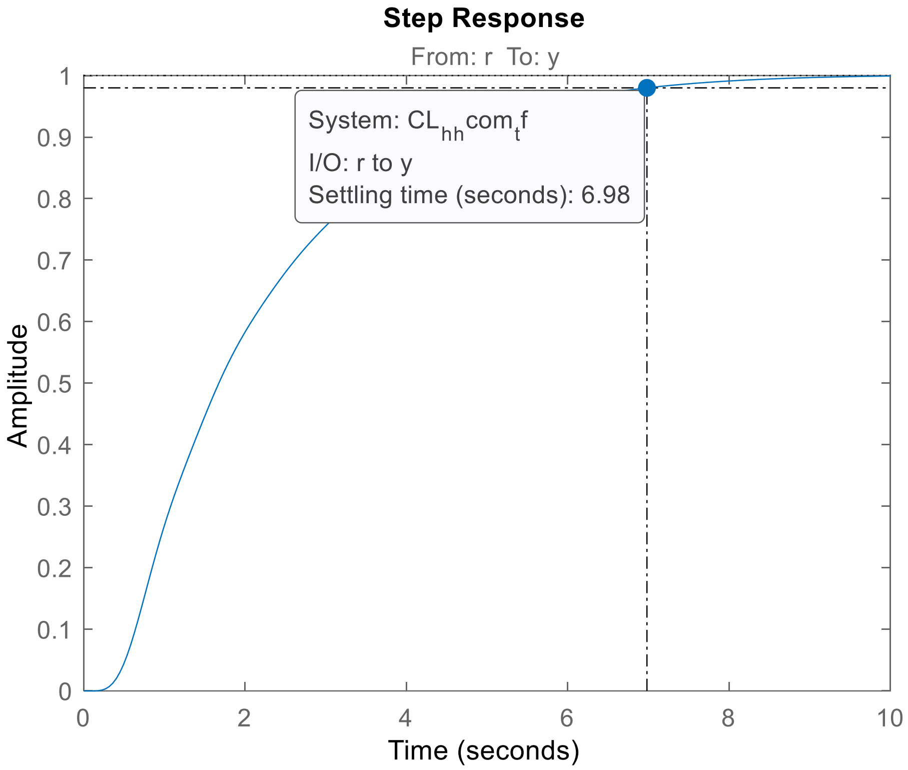


Figure 11 Response

Control action transfer function:

```
Con_action_tf_alt =


  From input "r" to output "u":

0.000674 s^8 + 0.01228 s^7 + 0.1231 s^6 + 0.8564 s^5 + 2.33 s^4 + 2.671 s^3
+ 1.191 s^2 + 0.04403 s + 5.584e-17

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

s^8 + 16.43 s^7 + 151.7 s^6 + 987.2 s^5 + 3239 s^4 + 5620 s^3 + 3842 s^2 +
987.8 s + 32.81

Continuous-time transfer function.
```

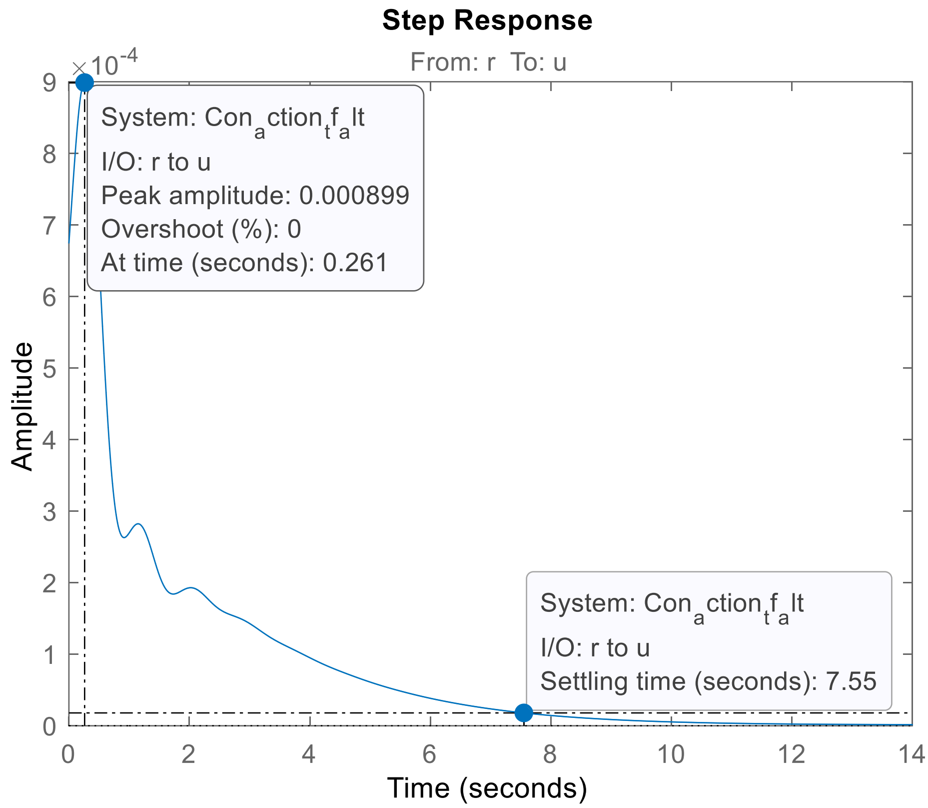
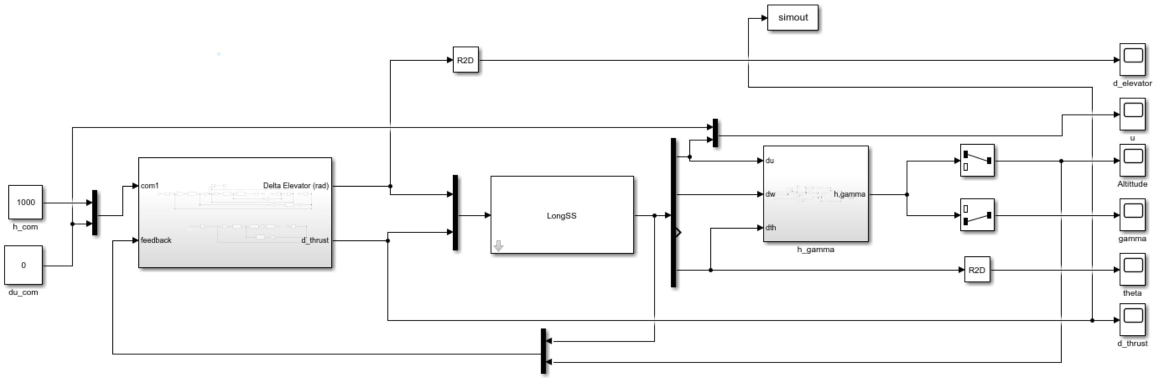


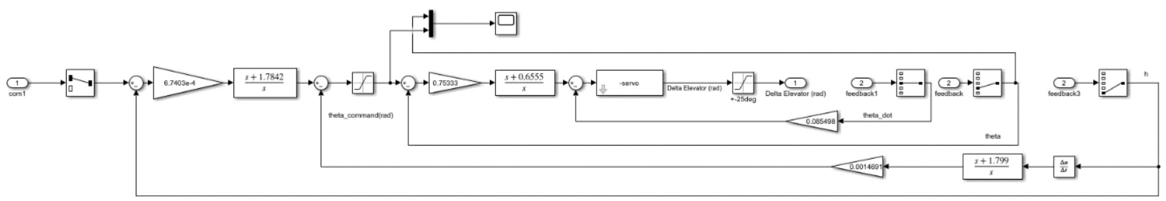
Figure 12 Control Action

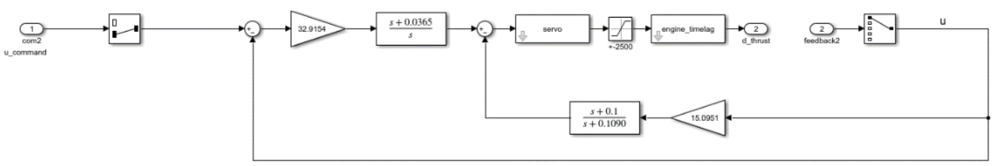
E. Test the (Pitch & Velocity) controllers on the full state space model and (g) Test the "Altitude & Velocity Controllers" together on the full state space model

Simulink Simulation

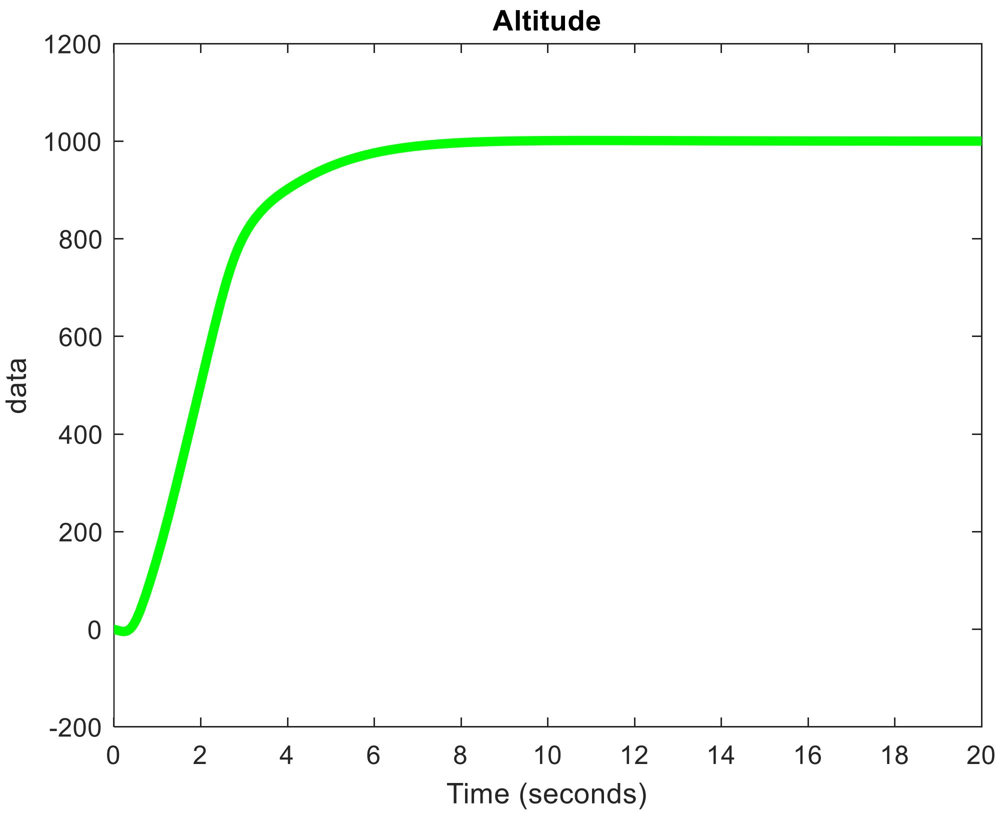


Subsystems:

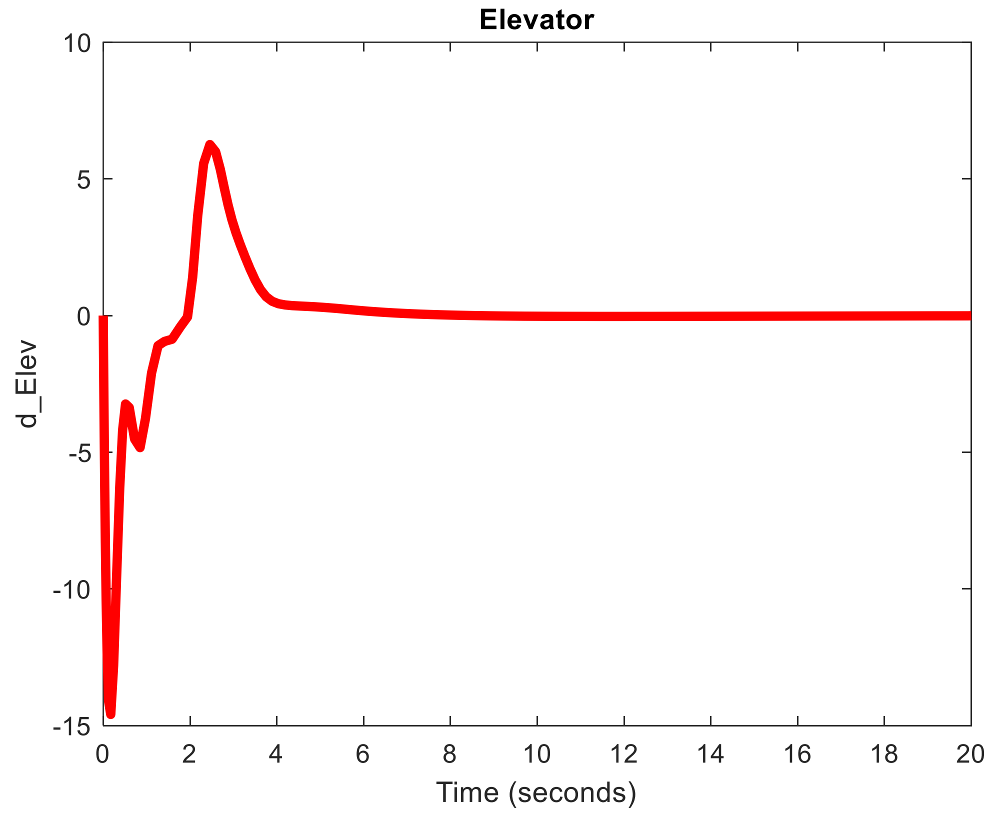




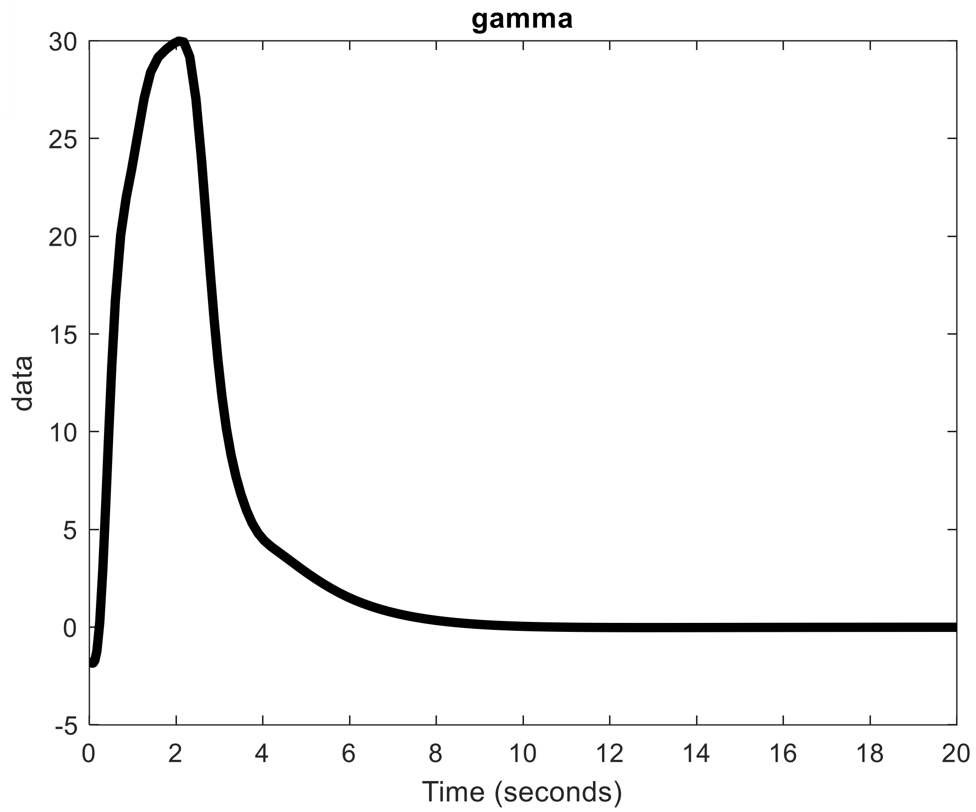
Results:

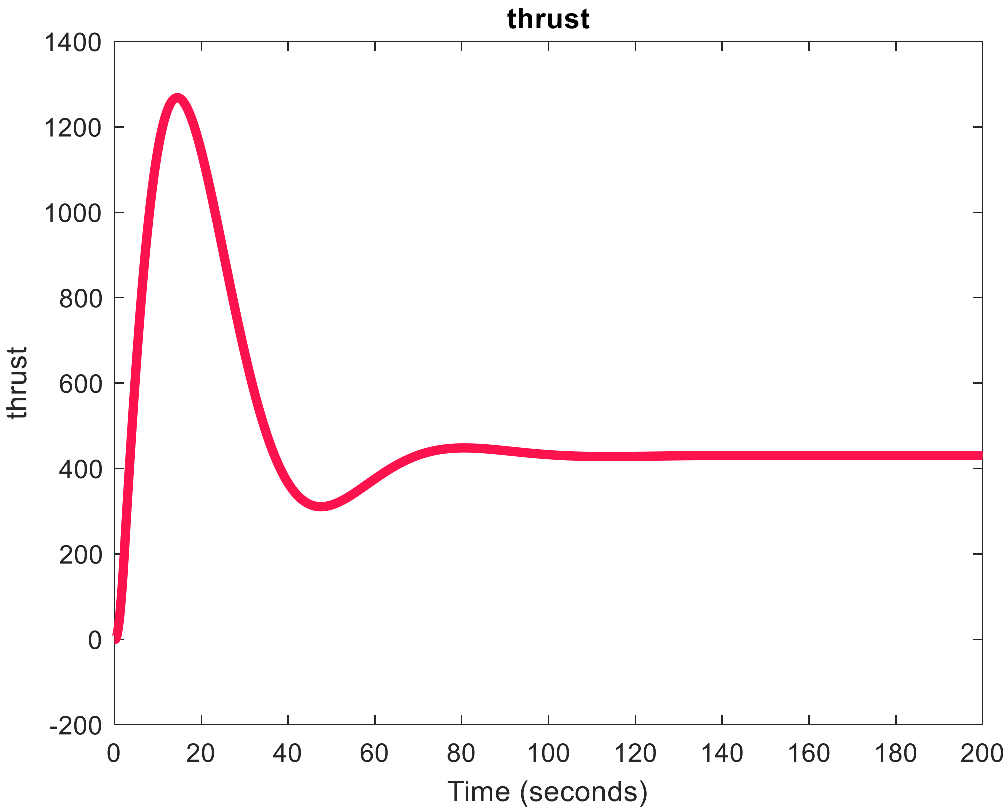


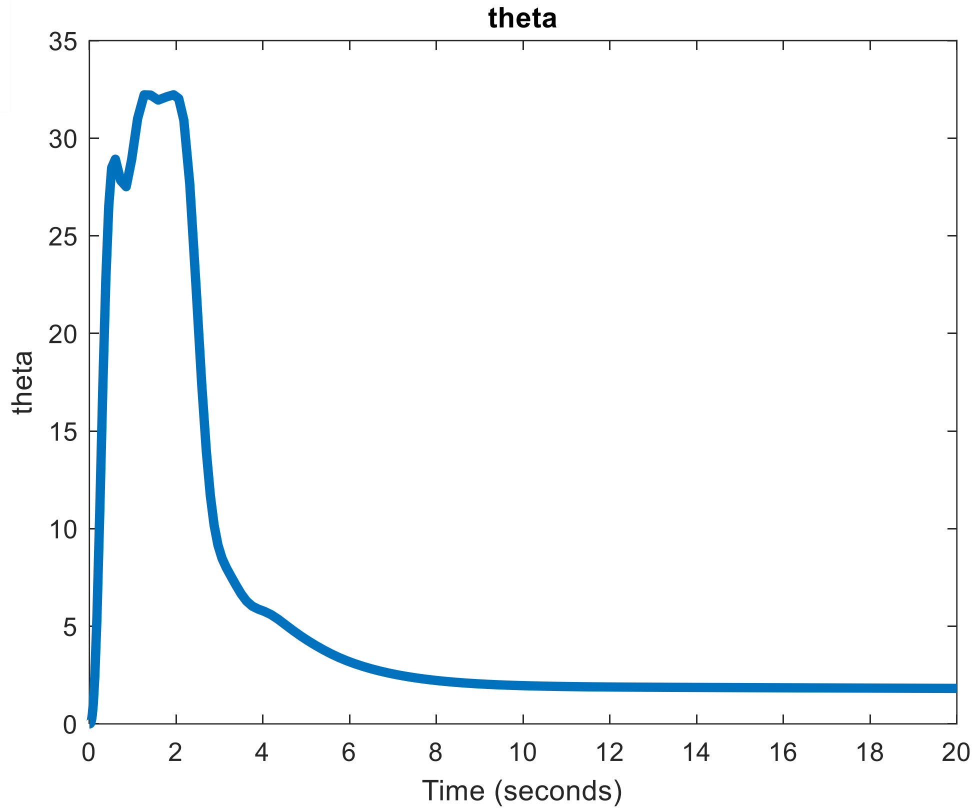
Altitude
1200
1000
800
600
400
200
0
-200
data
0
2
4
6
8
10
12
14
16
18
20
Time (seconds)

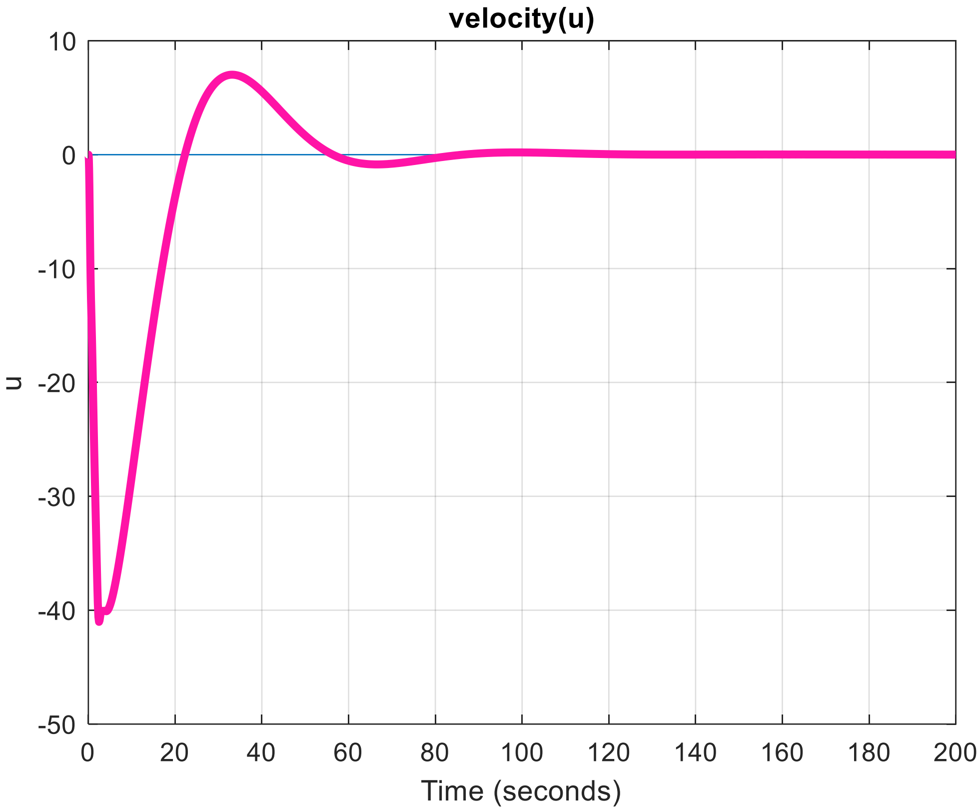


Elevator
10
5
0
-5
-10
-15
d_Elev
0
2
4
6
8
10
12
14
16
18
20
Time (seconds)


gamma
data
30
25
20
15
10
5
0
-5
0
2
4
6
8
10
12
14
16
18
20
Time (seconds)


thrust
thrust
1400
1200
1000
800
600
400
200
0
-200
0
20
40
60
80
100
120
140
160
180
200
Time (seconds)


theta
35
30
25
20
15
10
5
0
theta
0 2 4 6 8 10 12 14 16 18 20
Time (seconds)


velocity(u)
10
0
-10
-20
-30
-40
-50
u
0 20 40 60 80 100 120 140 160 180 200
Time (seconds)

ppendix: Code

AirPlane.m

```
classdef AirPlane < handle
    %UNTITLED Summary of this class goes here
    %   Detailed explanation goes here

    properties
       Mass
       g
       I             % Inirtia
       invI          % Inverse of Inirtia
       timeSpan
       dt
       ICs
       ICs_dot0
       Vt0
       dControl
       SD_Long
       SD_Lat
       SD_Lat_dash
       initialGravity
       airPlaneDerivatives      % Class
       rigidBodySolver          % Class

       u0, v0, w0, theta0, z0

    end

    methods
        function airPlane = AirPlane(inputsFilePath)
            % Inputs
            % here B2:B61 means read the excel sheet from cell B2 to cell
B61
            aircraft_data = xlsread(inputsFilePath,'B2:B61');
            % Integration time span & Step
            airPlane.dt = aircraft_data(1);
            tfinal = aircraft_data(2);
            airPlane.timeSpan = [0 tfinal];

            % Initial Conditions
            % [u; v; w; p; q; r; phi; theta; epsi; xe0; ye0; ze0]
            % ICs = [10; 2; 0; 2*pi/180; pi/180; 0; 20*pi/180; 15*pi/180;
30*pi/180; 2; 4; 7];
            airPlane.ICs = aircraft_data(4:15);
            airPlane.ICs_dot0 = zeros(12,1);
            airPlane.Vt0 = sqrt(airPlane.ICs(1)^2 + airPlane.ICs(2)^2 +
airPlane.ICs(3)^2);    % Vto


            % D_a, D_r, D_e, D_th
            airPlane.dControl = [ aircraft_data(57:59) * pi/180 ;
aircraft_data(60)];

            % gravity, mass % inertia
            airPlane.Mass = aircraft_data(51);
```

```
            airPlane.g = aircraft_data(52);
            Ixx = aircraft_data(53);
            Iyy = aircraft_data(54);
            Izz = aircraft_data(55);
            Ixz = aircraft_data(56);
            Ixy=0;  Iyz=0;
            airPlane.I = [Ixx , -Ixy , -Ixz ;...
                -Ixy , Iyy , -Iyz ;...
                -Ixz , -Iyz , Izz];
            airPlane.invI = inv(airPlane.I);

            % Stability Derivatives Longitudinal motion
            airPlane.SD_Long = aircraft_data(21:36);

            % Stability Derivatives Lateral motion
            airPlane.SD_Lat_dash = aircraft_data(37:50);
            airPlane.SD_Lat_dash(9) =
airPlane.SD_Lat_dash(9)*airPlane.Vt0;    % From dimension-less to
dimensional
            airPlane.SD_Lat_dash(10) =
airPlane.SD_Lat_dash(10)*airPlane.Vt0;  % Form dimension-less to
dimensional



            airPlane.airPlaneDerivatives = AirPlaneDerivatives(...
                airPlane.SD_Lat_dash , airPlane.SD_Long, airPlane.I);

            airPlane.rigidBodySolver = RigidBodySolver(airPlane.Mass,
airPlane.I, airPlane.invI, airPlane.dt, airPlane.g);

            [S, C, ~] = SCT(airPlane.ICs(7:9));
            airPlane.initialGravity = airPlane.Mass*airPlane.g*[
                S.theta;
                -S.phi*C.theta;
                -C.phi*C.theta;
            ];

            airPlane.u0 = airPlane.ICs(1);
            airPlane.v0 = airPlane.ICs(2);
            airPlane.w0 = airPlane.ICs(3);
            airPlane.theta0 = airPlane.ICs(8);
            airPlane.z0 = airPlane.ICs(12);

        end
        function [dForce, dMoment] = airFrame1(obj, state, forces,
moments, dControl)

            [Da, Dr, De, Dth] = feval(@(x) x{:}, num2cell(dControl));

            Ixx = obj.I(1,1);
            Iyy = obj.I(2,2);
            Izz = obj.I(3,3);

            state_dot = obj.rigidBodySolver.DOF6(state, forces, moments);

            ds = state - obj.ICs;
```

```
            ds_dot = state_dot - obj.ICs_dot0;
            beta0 = asin(obj.ICs(2)/obj.Vt0);
            beta = asin(state(2)/obj.Vt0);
            dbeta = beta-beta0;

            dX = obj.Mass*(obj.airPlaneDerivatives.XU*ds(1)+ ...
                    obj.airPlaneDerivatives.XW*ds(3)+ ...
                    obj.airPlaneDerivatives.XDE*De+ ...
                    obj.airPlaneDerivatives.XD_TH*Dth);

            dY = obj.Mass*(obj.airPlaneDerivatives.YV*ds(2)+ ...
                obj.airPlaneDerivatives.YB*dbeta + ...
                obj.airPlaneDerivatives.YDA*Da + ...
                obj.airPlaneDerivatives.YDR*Dr);

            dZ = obj.Mass*(obj.airPlaneDerivatives.ZU*ds(1) + ...
                obj.airPlaneDerivatives.ZW*ds(3) + ...
                obj.airPlaneDerivatives.ZWD*ds_dot(3) + ...
                obj.airPlaneDerivatives.ZQ*ds(5) + ...
                obj.airPlaneDerivatives.ZDE*De + ...
                obj.airPlaneDerivatives.ZD_TH*Dth);

            dL = Ixx*(obj.airPlaneDerivatives.LB*dbeta + ...
                obj.airPlaneDerivatives.LP*ds(4) + ...
                obj.airPlaneDerivatives.LR*ds(6) + ...
                obj.airPlaneDerivatives.LDR*Dr + ...
                obj.airPlaneDerivatives.LDA*Da);

            dM = Iyy*(obj.airPlaneDerivatives.MU*ds(1) + ...
                obj.airPlaneDerivatives.MW*ds(3) + ...
                obj.airPlaneDerivatives.MWD*ds_dot(3) + ...
                obj.airPlaneDerivatives.MQ*ds(5) + ...
                obj.airPlaneDerivatives.MDE*De+ ...
                obj.airPlaneDerivatives.MD_TH*Dth);

            dN = Izz*(obj.airPlaneDerivatives.NB*dbeta + ...
                obj.airPlaneDerivatives.NP*ds(4) + ...
                obj.airPlaneDerivatives.NR*ds(6) + ...
                obj.airPlaneDerivatives.NDR*Dr + ...
                obj.airPlaneDerivatives.NDA*Da);

            dForce = [dX dY dZ];
            dMoment = [dL dM dN];
        end

        function [A_long, B_long, C_long, D_long] = fullLinearModel(obj)
            [A_long, B_long, C_long, D_long] =
obj.airPlaneDerivatives.fullLinearModel(obj.ICs, obj.g);
        end

        function [A_phug, B_phug, C_phug, D_phug] = longPeriodModel(obj)
            [A_phug, B_phug, C_phug, D_phug] =
obj.airPlaneDerivatives.longPeriodModel(obj.ICs, obj.g);
        end
    end
end
```

AirPlaneDerivatives.m

```
classdef AirPlaneDerivatives < handle
    %UNTITLED2 Summary of this class goes here
    %   Detailed explanation goes here

    properties
        % Longtudinal
        XU, ZU, MU, XW, ZW, MW, ZWD, ZQ, MWD, MQ, XDE, ZDE, MDE, XD_TH,
ZD_TH, MD_TH
        % Lateral
        YV
        YB
        LBd, NBd, LPd, NPd, LRd, NRd, LDAd, LDRd,NDAd, NDRd
        LB, NB, LP, NP, LR, NR, YDA, YDR, LDA, NDA, LDR, NDR
    end

    methods
        function obj = AirPlaneDerivatives(SD_Lat_dash , SD_Long,
Inertia, ICs, g)

            [obj.YV, obj.YB, obj.LBd, obj.NBd, obj.LPd, obj.NPd, ...
                obj.LRd, obj.NRd, obj.YDA, obj.YDR, obj.LDAd, ...
                obj.NDAd, obj.LDRd, obj.NDRd] = feval(@(x) x{:},
num2cell(SD_Lat_dash));

            [obj.XU, obj.ZU, obj.MU, obj.XW, obj.ZW, obj.MW, obj.ZWD,...
                obj.ZQ, obj.MWD, obj.MQ, obj.XDE, obj.ZDE, obj.MDE,
obj.XD_TH,...
                obj.ZD_TH, obj.MD_TH] = feval(@(x) x{:},
num2cell(SD_Long));

            LateralSD2BodyAxes(obj, Inertia);
        end

        function [obj] = LateralSD2BodyAxes(obj, Inertia)
            Ixx = Inertia(1);
            Izz = Inertia(9);
            Ixz = -Inertia(3);
            G = 1/(1 - Ixz^2 / Ixx / Izz);
            syms LB_ LP_ LR_ LDR_ LDA_ NB_ NP_ NR_ NDR_ NDA_
            eq1 = (LB_+Ixz*NB_/Ixx)*G == obj.LBd;
            eq2 = (NB_+Ixz*LB_/Izz)*G == obj.NBd;
            eq3 = (LP_+Ixz*NP_/Ixx)*G == obj.LPd;
            eq4 = (NP_+Ixz*LP_/Izz)*G == obj.NPd;
            eq5 = (LR_+Ixz*NR_/Ixx)*G == obj.LRd;
            eq6 = (NR_+Ixz*LR_/Izz)*G == obj.NRd;
            eq7 = (LDR_+Ixz*NDR_/Ixx)*G == obj.LDRd;
            eq8 = (NDR_+Ixz*LDR_/Izz)*G == obj.NDRd;
            eq9 = (LDA_+Ixz*NDA_/Ixx)*G == obj.LDAd;
            eq10 = (NDA_+Ixz*LDA_/Izz)*G == obj.NDAd;

            [A,B] = equationsToMatrix(...
            [eq1, eq2, eq3, eq4, eq5, eq6, eq7, eq8, eq9, eq10],...
            [LB_ LP_ LR_ LDR_ LDA_ NB_ NP_ NR_ NDR_ NDA_]);

            X = A\B;
            X = vpa(X);

            obj.LB = X(1);
```

```
            obj.LP = X(2) ;
            obj.LR = X(3) ;
            obj.LDR = X(4);
            obj.LDA = X(5);
            obj.NB = X(6);
            obj.NP = X(7);
            obj.NR = X(8);
            obj.NDR = X(9);
            obj.NDA = X(10);
        end

        function [A, B, C, D] = fullLinearModel(obj, ICs, g)

            u0 = ICs(1);
            w0 = ICs(3);
            theta0 = ICs(8);

            A =[obj.XU obj.XW -w0 -g*cos(theta0)
                obj.ZU/(1-obj.ZWD) obj.ZW/(1-obj.ZWD) (obj.ZQ+u0)/(1-
obj.ZWD) -g*sin(theta0)/(1-obj.ZWD)
                obj.MU+obj.MWD*obj.ZU/(1-obj.ZWD)
obj.MW+obj.MWD*obj.ZW/(1-obj.ZWD) obj.MQ+obj.MWD*(obj.ZQ+u0)/(1-obj.ZWD)
-obj.MWD*g*sin(theta0)/(1-obj.ZWD)
                0 0 1 0];
            B = [obj.XDE obj.XD_TH;
                obj.ZDE/(1-obj.ZWD) obj.ZD_TH/(1-obj.ZWD);
                obj.MDE+obj.MWD*obj.ZDE/(1-obj.ZWD)
obj.MD_TH+obj.MWD*obj.ZD_TH/(1-obj.ZWD);
                0 0];
            C = eye(4);
            D = zeros(4,2);

        end

        function [A, B, C, D] = longPeriodModel(obj,ICs, g)
            u0 = ICs(1);

            A =[obj.XU -g
                -obj.ZU/(u0+obj.ZQ) 0];
            B =[obj.XDE obj.XD_TH
                -obj.ZDE/(obj.ZQ+u0) -obj.ZD_TH/(obj.ZQ+u0)];
            C = eye(2);
            D = zeros(2,2);

        end

    end
end
```

RigidBodySolver.m

```
classdef RigidBodySolver < handle
    %UNTITLED3 Summary of this class goes here
    %   Detailed explanation goes here

    properties
       Mass, Inertia, invInertia, dt, g
    end

    methods
        function obj = RigidBodySolver(Mass, Inertia, invInertia, dt,g)
            obj.Mass = Mass;
            obj.Inertia = Inertia;
            obj.invInertia = invInertia;
            obj.dt = dt;
            obj.g = g;
        end

        function state = nextStep(RBS, currentState, Force, Moments)
            K = zeros(12, 4);

            K(:, 1) = RBS.dt*DOF6(RBS, currentState ,Force, Moments);
            K(:, 2) = RBS.dt*DOF6(RBS, currentState+0.5*K(:, 1) ,Force,
Moments);
            K(:, 3) = RBS.dt*DOF6(RBS, currentState+0.5*K(:, 2) ,Force,
Moments);
            K(:, 4) = RBS.dt*DOF6(RBS, currentState+K(:, 3) ,Force,
Moments);

            state = currentState + (...
                K(:, 1)+...
                2*K(:, 2)+...
                2*K(:, 3)+...
                K(:, 4))/6;
        end

        function F = DOF6(RBS, currentState, forces, Moments)

            % (Sin, Cos, Tan) of (phi, theta, epsi)
            [S, C, T] = SCT(currentState(7:9));
            s_theta = S.theta;
            c_theta = C.theta;
            t_theta = T.theta;
            s_epsi = S.epsi;
            c_epsi = C.epsi;
            s_phi = S.phi;
            c_phi = C.phi;

            Forces = forces + RBS.Mass*RBS.g*[
                -s_theta;
                s_phi*c_theta;
                c_phi*c_theta;
            ];

            % (u, v, w) dot
            u_v_w_dot = (1/RBS.Mass)*Forces - cross(...
                currentState(4:6, 1), currentState(1:3, 1)...
            );
```

```
            % (p, q, r) dot
            p_q_r_dot = RBS.invInertia *(Moments - cross(...
                currentState(4:6, 1), RBS.Inertia * currentState(4:6,
1)...
            ));

            % (phi, theta, epsi) dot
            phi_theta_epsi_dot = [
                1, s_phi*t_theta, c_phi*t_theta;
                0, c_phi, -s_phi;
                0, s_phi/c_theta, c_phi/c_theta;
            ] * currentState(4:6, 1);

            % (x, y, z) dot
            x_y_z_dot = [
                c_theta*c_epsi, (s_phi*s_theta*c_epsi - c_phi*s_epsi),
(c_phi*s_theta*c_epsi + s_phi*s_epsi);
                c_theta*s_epsi, (s_phi*s_theta*s_epsi + c_phi*c_epsi),
(c_phi*s_theta*s_epsi - s_phi*c_epsi);
                -s_theta, s_phi*c_theta, c_phi*c_theta
            ] * currentState(1:3, 1);

            F = [u_v_w_dot; p_q_r_dot; phi_theta_epsi_dot; x_y_z_dot];

        end


    end
end
```

SCT.m

```
% Calculate Sin, Cos ,Tan for any set of three angles
% and return results in struct form for easy access in code.
function [S, C, T] = SCT(ICs)
    S = struct(...
        'phi', sin(ICs(1)),...
        'theta', sin(ICs(2)),...
        'epsi', sin(ICs(3))...
    );
    C = struct(...
        'phi', cos(ICs(1)),...
        'theta', cos(ICs(2)),...
        'epsi', cos(ICs(3))...
    );
    T = struct(...
        'phi', tan(ICs(1)),...
        'theta', tan(ICs(2)),...
        'epsi', tan(ICs(3))...
    );
end
```

Main.m

```
clc; clear; close all;

%% Inputs
% Forces, Moments and Inertia
plane = AirPlane("NT-33A_4.xlsx");

steps = (plane.timeSpan(2) - plane.timeSpan(1))/plane.dt;
Result = NaN(12, steps);
Result(:,1) = plane.ICs;
time_V = linspace(0, plane.timeSpan(2), steps+1);

%% Longitudenal Full Linear Model

% Two Inputs - Four Output Each
[A_long, B_long, C_long, D_long] = plane.fullLinearModel();
LongSS = ss(A_long, B_long, C_long, D_long);
LongTF = tf(LongSS);

%% Servo Transfer Function
servo = tf(10,[1 10]);
integrator = tf(1,[1 0]);
differentiator = tf([1 0],1);
engine_timelag = tf(0.1 , [1 0.1]);

%% pitch control theta/theta_com
theta_dE = LongTF(4,1);
OL_theta_thetacom = -servo * theta_dE;
pitchControldesignValues =
matfile("DesignValues/pitchControldesignValues.mat");

pitch_PD_tf = pitchControldesignValues.C2;
pitch_PI_tf = pitchControldesignValues.C1;
CL_theta_thetacom_tf = tf(pitchControldesignValues.IOTransfer_r2y);
pitch_C_action_tf = tf(pitchControldesignValues.IOTransfer_r2u);
```

```
figure;
step(CL_theta_thetacom_tf)
figure;
step(pitch_C_action_tf)

%% Velocity Controller u/u_com
u_dTh = LongTF(1, 2);
OL_u_ucom = u_dTh * servo * engine_timelag;
velocityControldesignValues =
matfile("DesignValues/velocityControldesignValues.mat");

velocity_PD_tf = velocityControldesignValues.C2;
velocity_PI_tf = velocityControldesignValues.C1;
CL_u_ucom_tf = tf(velocityControldesignValues.IOTransfer_r2y);
velocity_C_action_tf = tf(velocityControldesignValues.IOTransfer_r2u);

figure;
step(CL_u_ucom_tf)
figure;
step(altitude_C_action_tf)

%% Altitude Controller h/h_com
w_de = LongTF(2,1);
theta_de = LongTF(4, 1);
w_theta = minreal(w_de/theta_de);
h_theta = -1 * integrator * (w_theta - plane.u0);
OL_h_thetacom = minreal(CL_theta_thetacom_tf * h_theta);

altitudeControldesignValues =
matfile("DesignValues/altitudeControldesignValues.mat");

altitude_PD_tf = altitudeControldesignValues.C2;
altitude_PI_tf = altitudeControldesignValues.C1;
CL_h_thetacom_tf = tf(altitudeControldesignValues.IOTransfer_r2y);
altitude_C_action_tf = tf(altitudeControldesignValues.IOTransfer_r2u);

figure;
step(CL_h_thetacom_tf)
figure;
step(altitude_C_action_tf)
```