Cairo University Faculty of
Engineering Aerospace
Department

AEROSPACE ENGINEERING

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Task 6

Autopilot -AER 408

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A. Design a “Yaw damper” for the Dutch Roll Mode

Design No. One

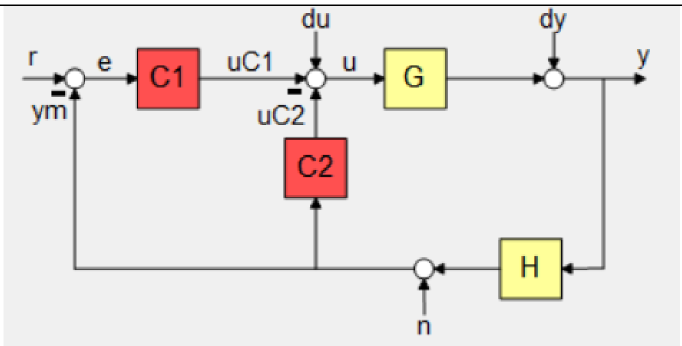
Then the open loop transfer function is

```
OL_r_rcom =

           -126 s^3 - 599.3 s^2 - 168.9 s - 67.62
  --------------------------------------------------------
  s^5 + 15.41 s^4 + 69.2 s^3 + 200.4 s^2 + 492.9 s + 2.303

Continuous-time transfer function.
```

Design control loop:

yaw_C1_tf	yaw_C2_tf	Architecture
0.065926	0.21623 s --------- (s+3.281)	

Closed Loop transfer function:

```
CL_r_rcom_tf =

  From input "r" to output "y":

         -8.307 s^4 - 66.76 s^3 - 140.7 s^2 - 40.98 s - 14.62

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

  s^6 + 18.69 s^5 + 155.3 s^4 + 623.8 s^3 + 1328 s^2 + 1675 s + 22.18
```

Control action transfer function:

```
yaw_C_action_tf =

  From input "r" to output "u":

0.06593 s^6 + 1.232 s^5 + 7.895 s^4 + 28.18 s^3 + 75.84 s^2 + 106.7 s + 0.4981

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

s^6 + 18.69 s^5 + 155.3 s^4 + 623.8 s^3 + 1328 s^2 + 1675 s + 22.18
```

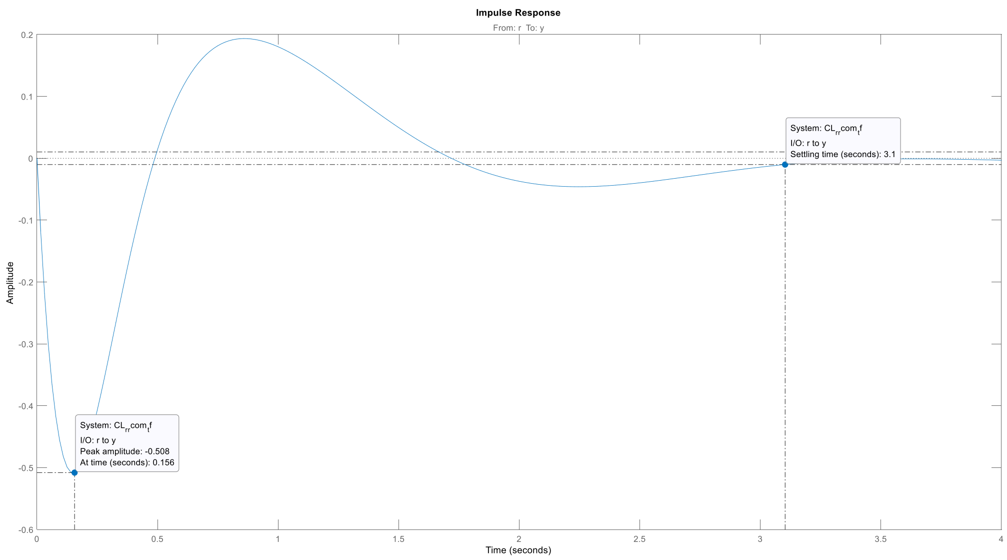


Figure 1. Design 1 - Response

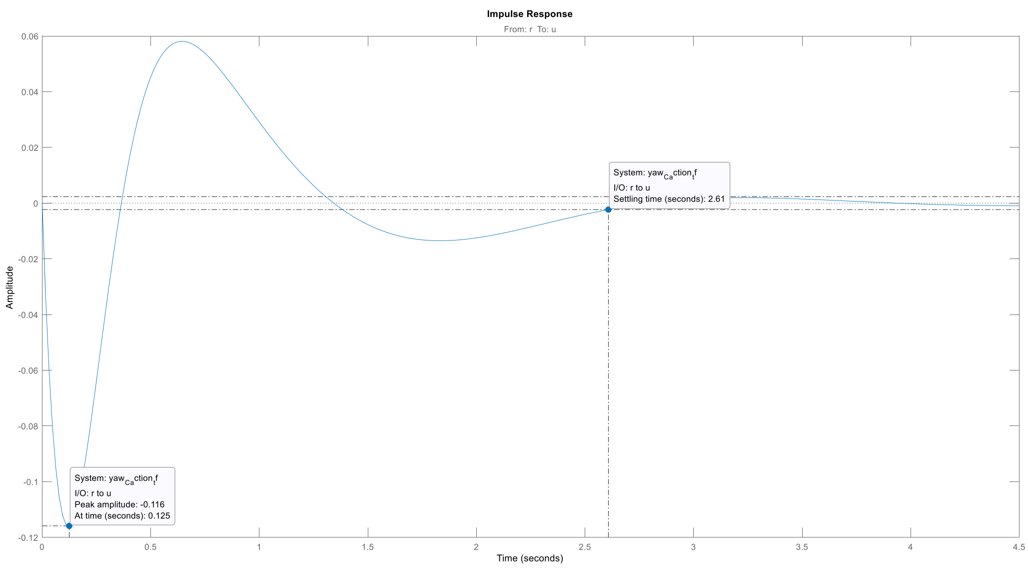


Figure 2. Design 1 - Control Action

Design No. Two

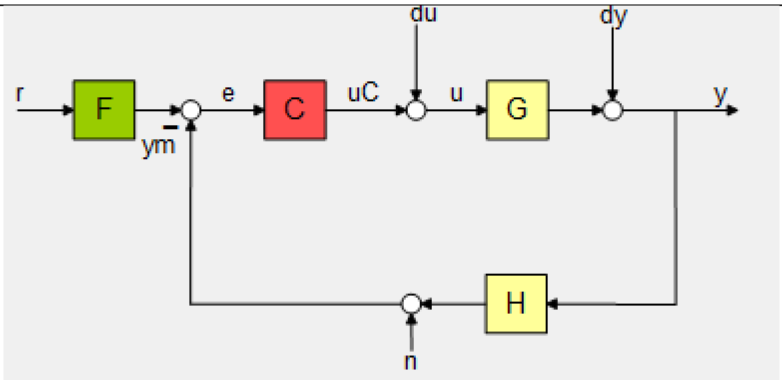
Then the open loop transfer function is

```
OL_r_rcom =

          -126 s^3 - 599.3 s^2 - 168.9 s - 67.62
  --------------------------------------------------------
  s^5 + 15.41 s^4 + 69.2 s^3 + 200.4 s^2 + 492.9 s + 2.303

Continuous-time transfer function.
```

Design control loop:

yaw_C_tf	Architecture
0.12324 s --------- (s+1.464)	

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
```

Control action transfer function:

```
yaw_C_action_tf =

  From input "r" to output "u":

  s^6 + 16.87 s^5 + 91.76 s^4 + 301.7 s^3 + 786.3 s^2 + 723.7 s + 3.371
  ---------------------------------------------------------------------
  s^6 + 16.87 s^5 + 107.3 s^4 + 375.6 s^3 + 807.1 s^2 + 732.1 s + 3.371
```

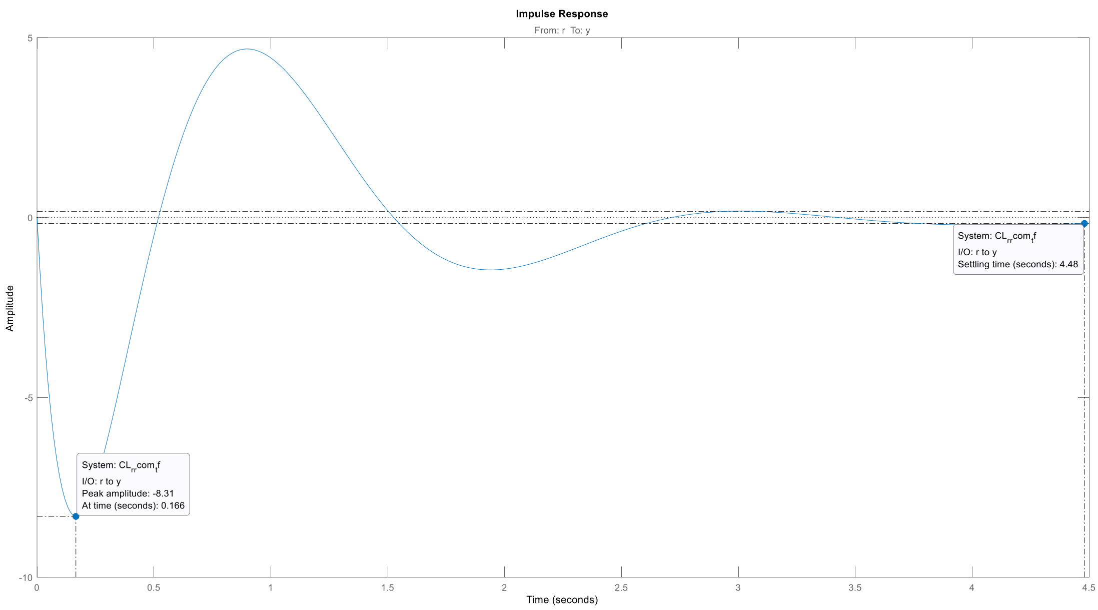


Figure 3. Design 2 - Response

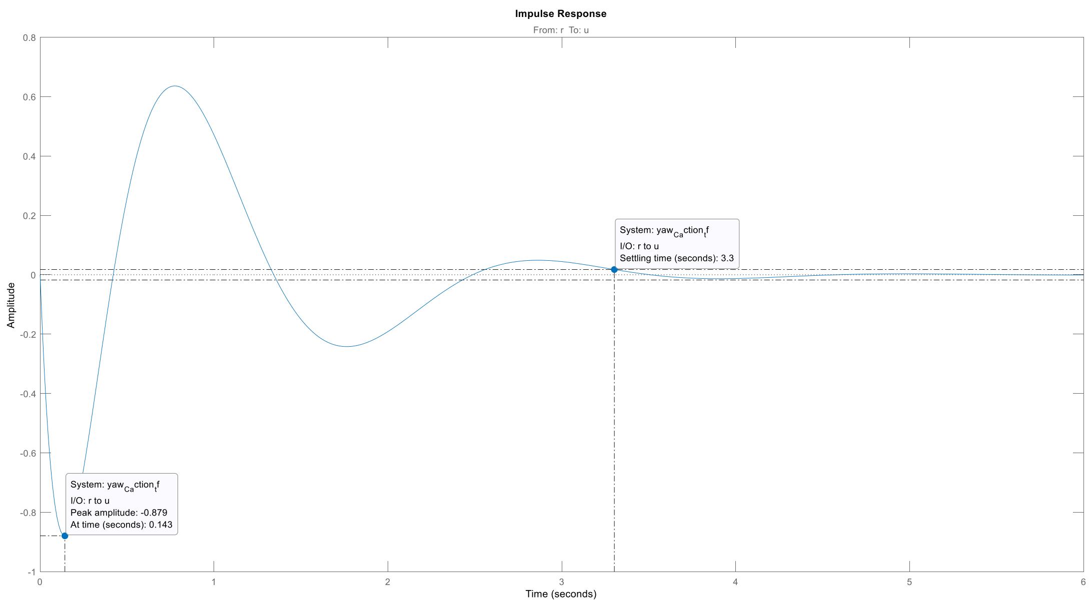
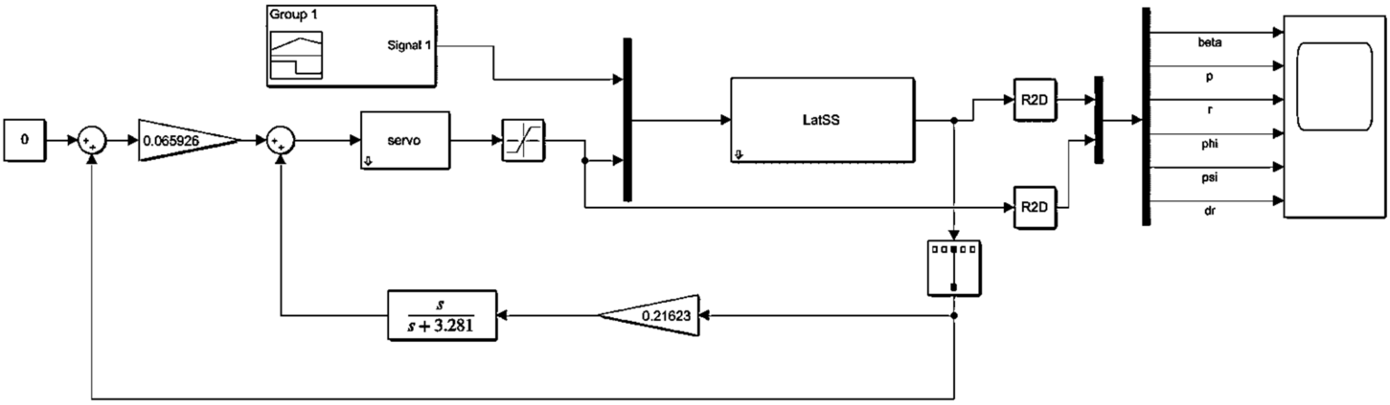


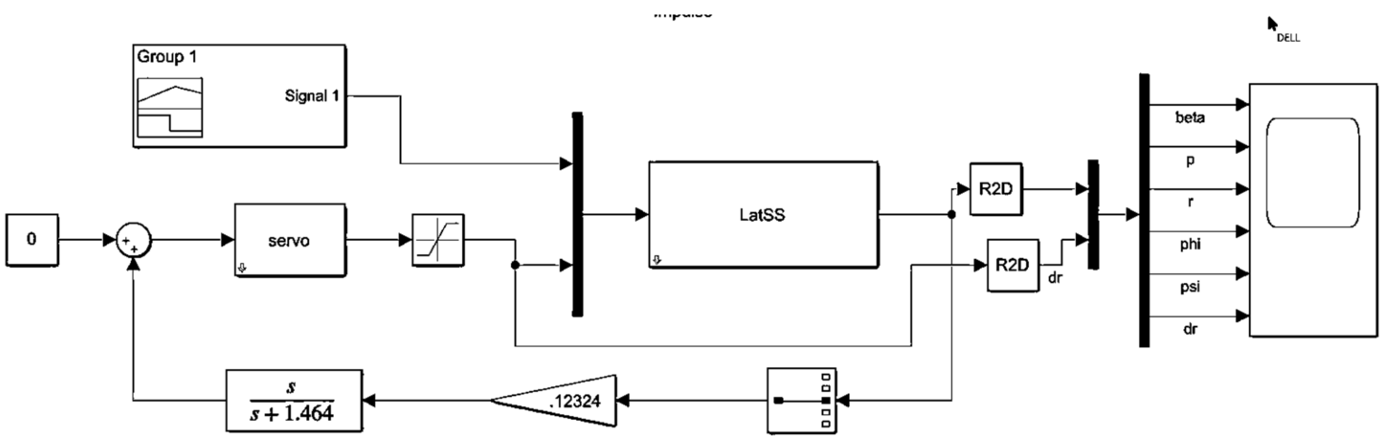
Figure 4. Design 2 - Control Action

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

Design No. One

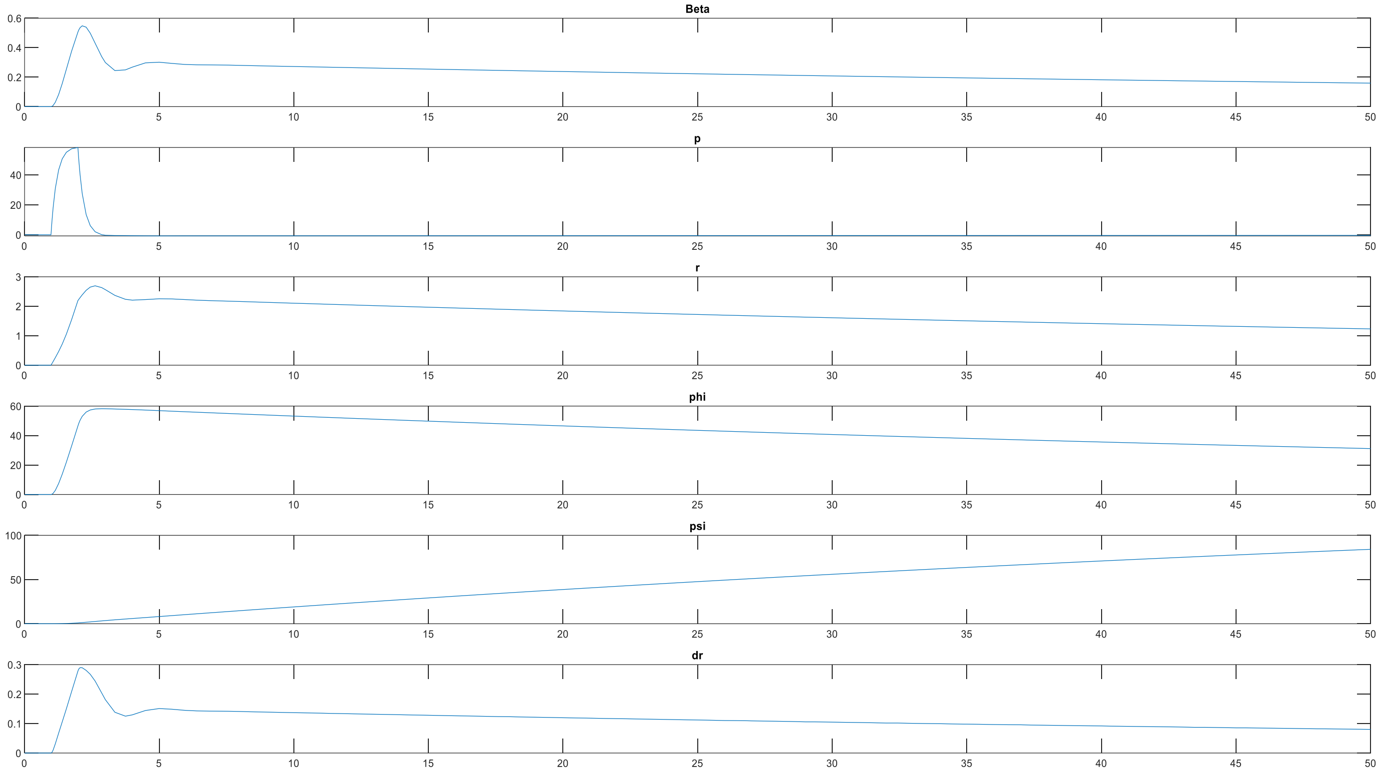


Design No. Two

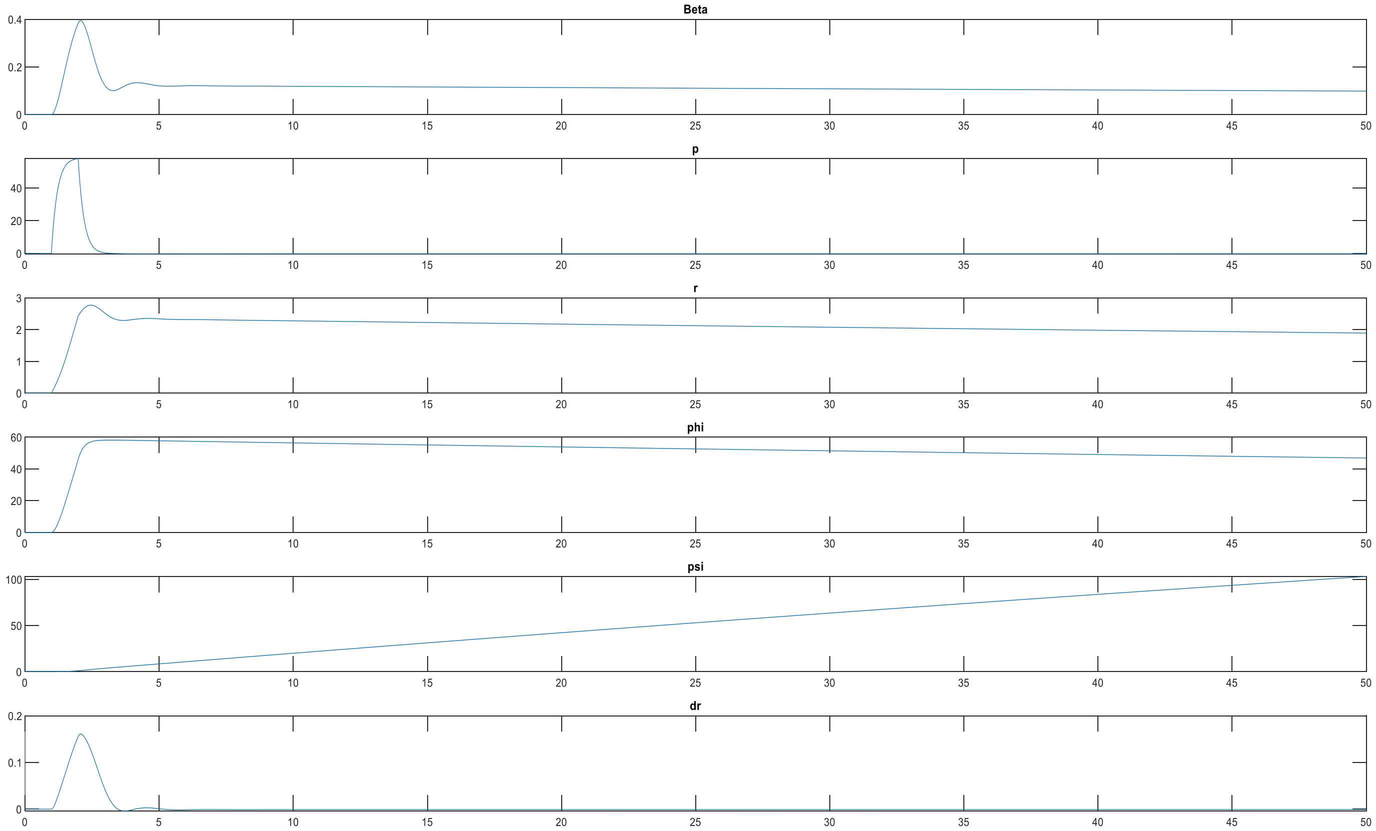


Results:

Design No. One



Design No. Two



c) Design “Roll Controller”

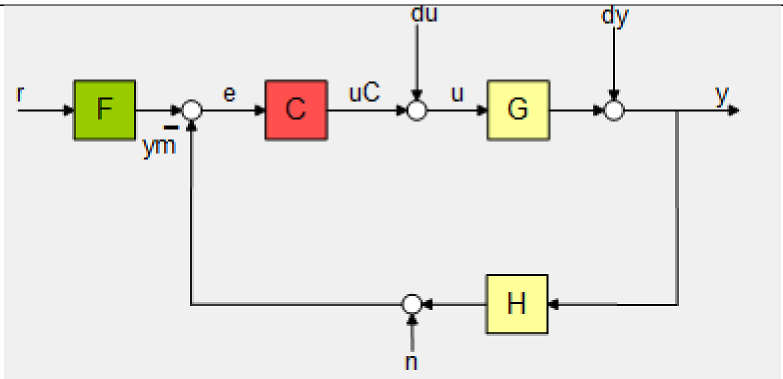
Then the open loop transfer function is

```
OL_phi_phicom =


4700 s^4 + 5.811e04 s^3 + 2.417e05 s^2 + 6.669e05 s + 7.489e05
-------------------------------------------------------------------------
s^8 + 36.87 s^7 + 544.7 s^6 + 4209 s^5 + 1.905e04 s^4 + 5.443e04 s^3
+ 9.535e04 s^2 + 7.327e04 s + 337.1


Continuous-time transfer function.
```

Design control loop:

roll_C_tf	Architecture
0.0078128 (s+0.02203) / s	

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
```

Control action transfer function:

```
roll_C_action_tf =

  From input "r" to output "u":

0.007813 s^9 + 0.2882 s^8 + 4.262 s^7 + 32.97 s^6 + 149.5 s^5 + 428.5 s^4 +
754.3 s^3 + 588.9 s^2 + 15.24 s + 0.05802

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

  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
```

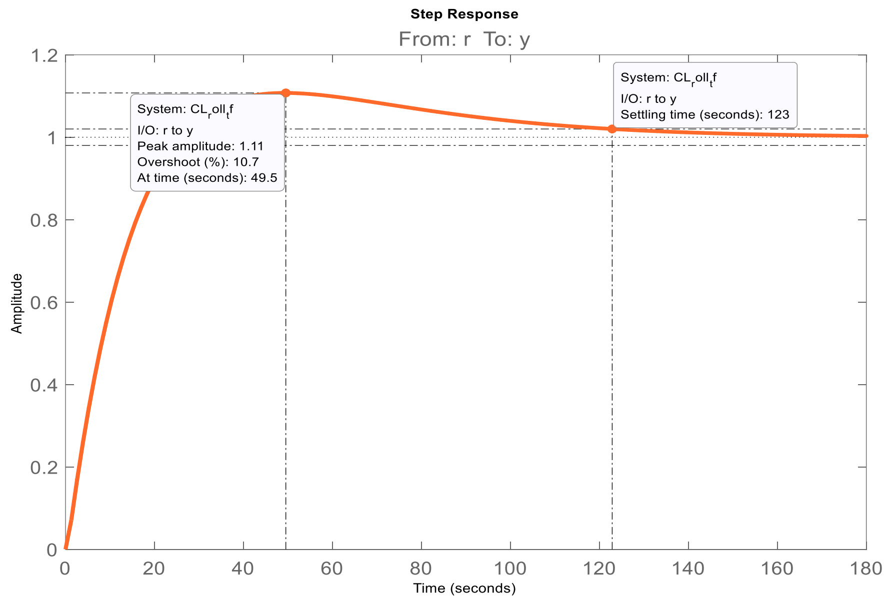


Figure 5. Response

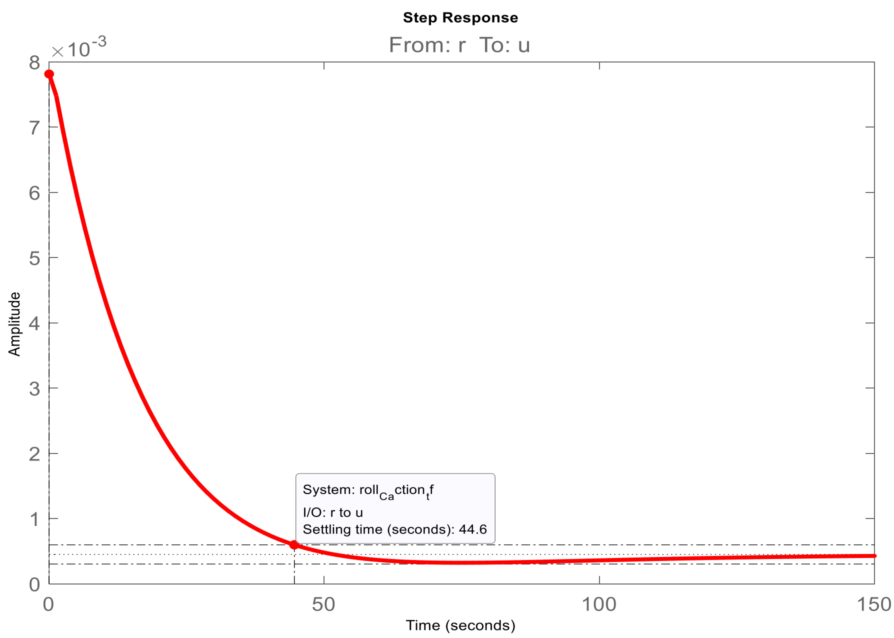
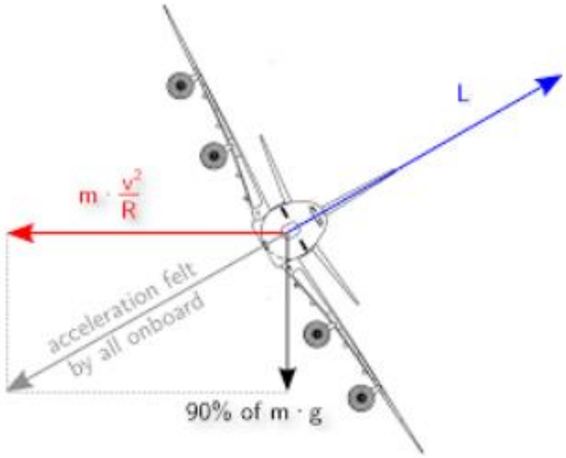


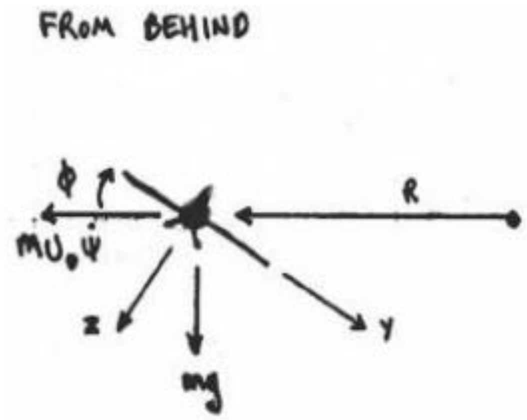
Figure 6. Control Action

d) Coordination

As we can see from previous results that the sideslip angle (β) didn't settle at zero, therefore coordination is not achieved by default.

This can be achieved at a certain bank angle (φ) for a given Speed ($\boldsymbol{U_o}$) and turning rate $\dot{\boldsymbol{\psi}}$.This value of φ can be found from the free body diagram of the airplane during a turn.





Noting that the tangential Velocity is $\boldsymbol{U_o}$, **R** is the radius of the turn.

$$\therefore \boldsymbol{U_o = R\dot{\psi}}$$

From the free body diagram for a coordinated turn, we get the following:

$$L\cos(\phi) = mg$$

$$L\sin(\phi) = m\,U_o\dot{\psi}$$

By dividing the 2nd equation by the 1st one we get:

$$\boldsymbol{\tan(\phi) = \frac{U_o\dot{\psi}}{g}}$$

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

Therefore, in order to fly coordinated flight; for each velocity there is only one corresponding value of bank angle that satisfies the condition.

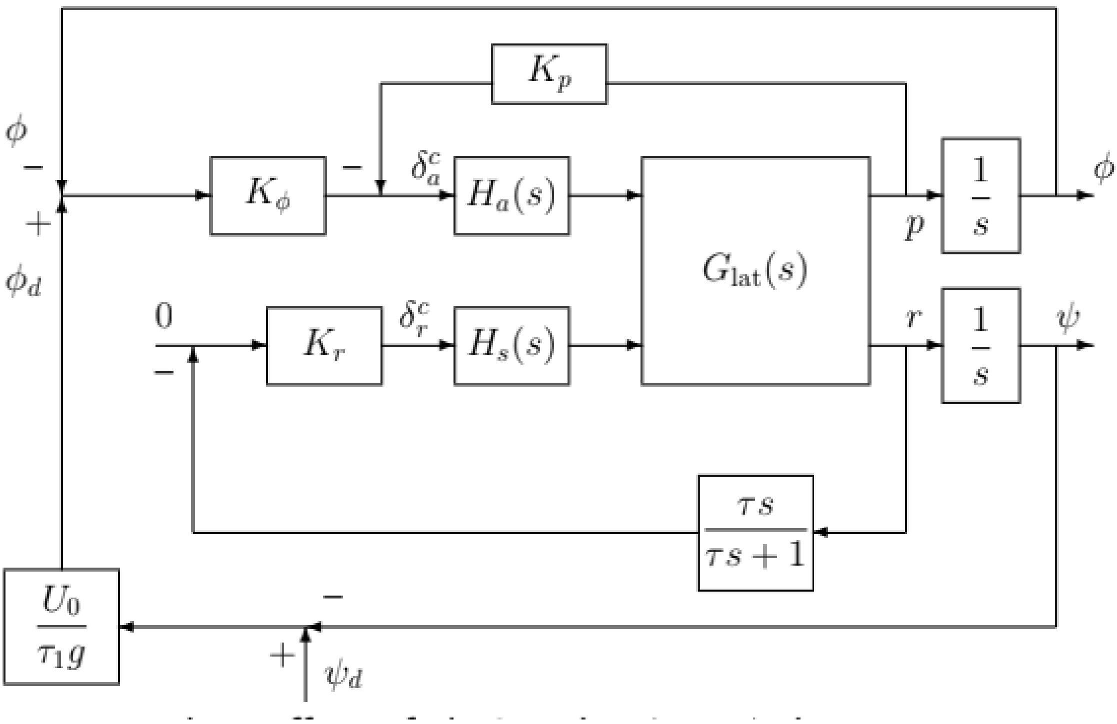
With:

$$\boldsymbol{{}^{\psi}/_{\psi_d} = \frac{{}^{1}/_{\tau}}{s+{}^{1}/_{\tau}}} \;\;,\;\; \boldsymbol{15 \le \tau \le 20}$$

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

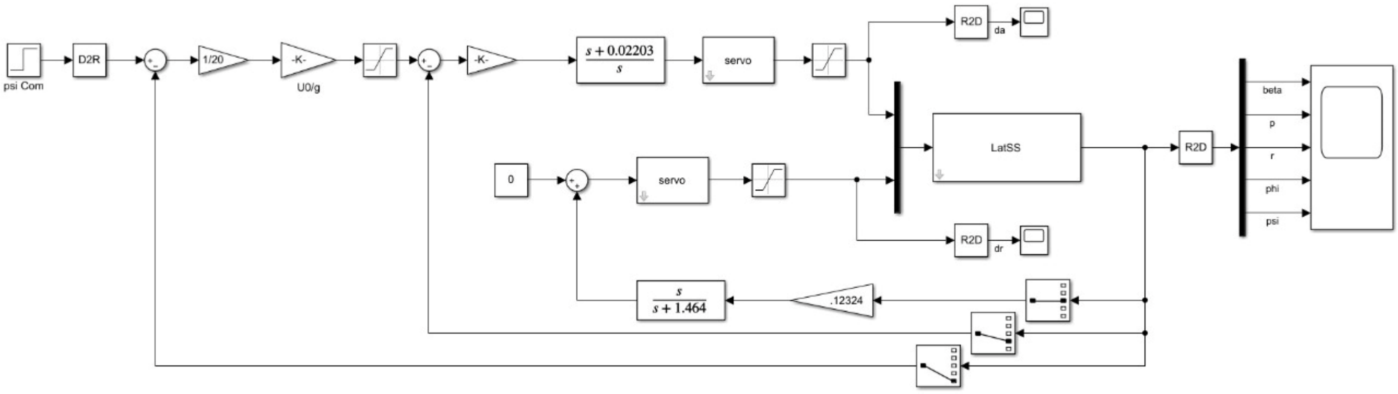
We choose $\boldsymbol{\tau} = \mathbf{15}$ & $\boldsymbol{\psi_d} = \mathbf{360}\ \boldsymbol{degree}$ $(\boldsymbol{Complete\ turn})$

Final Controller after putting pieces together

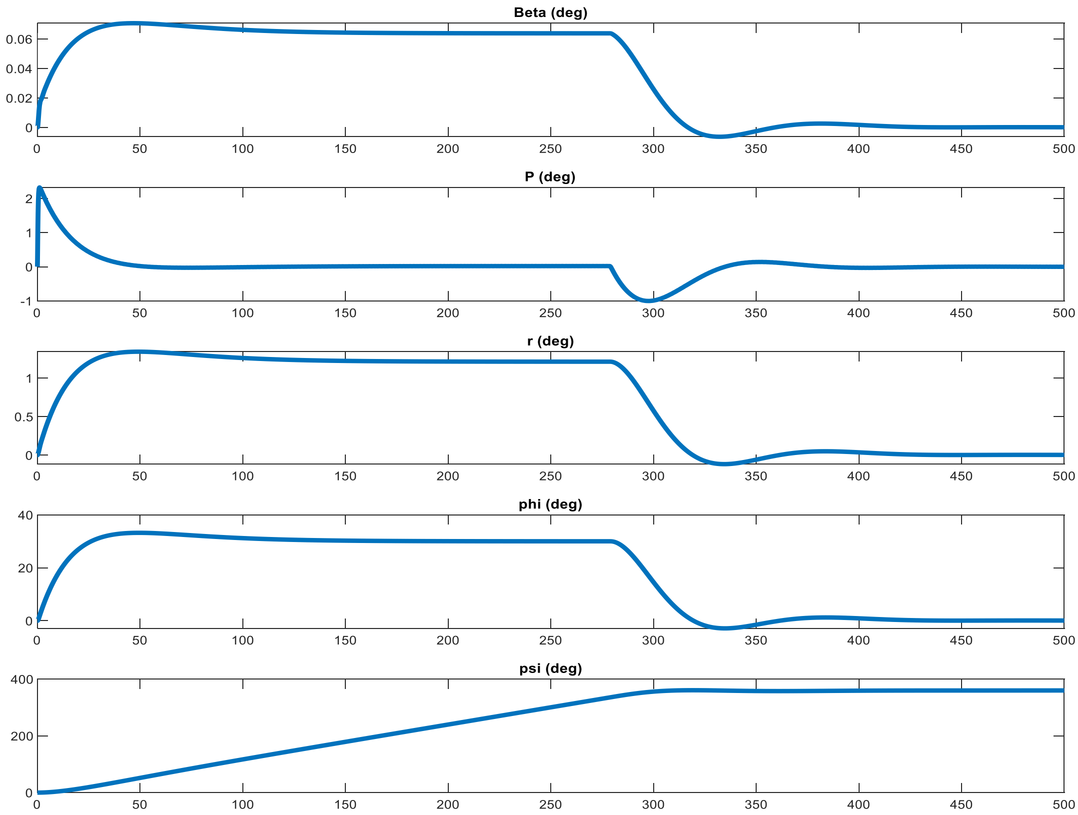


e) Test the designed controllers on the full state space model

Simulink



Results:



Appendix: 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_long, B_long, C_long, D_long] =
lateralFullLinearModel(obj)
            [A_long, B_long, C_long, D_long] =
obj.airPlaneDerivatives.lateralFullLinearModel(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] = lateralFullLinearModel(obj, ICs, g)

            u0 = ICs(1);
            v0 = ICs(2);
            w0 = ICs(3);
            theta0 = ICs(8);

            Vto = sqrt(u0^2 + v0^2 + w0^2);
            YDA_star = obj.YDA/Vto;
            YDR_star = obj.YDR/Vto;
            Yp = 0;
            Yr = 0;

            A = [obj.YB/Vto (Yp+w0)/Vto (Yr-u0)/Vto g*cos(theta0)/Vto
0;...
                   obj.LBd obj.LPd obj.LRd 0 0;...
                   obj.NBd obj.NPd obj.NRd 0 0;...
                   0 1 tan(theta0) 0 0;...
                   0 0 1/cos(theta0) 0 0];
```

```
            B = [YDA_star YDR_star;...
               obj.LDAd obj.LDRd;...
               obj.NDAd obj.NDRd;...
               0 0;0 0];
            C = eye(5); D = zeros(5,2);

        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);


%% 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]);

%%
%%%%%%%%%%%%%%%%%%% Lateral Full Linear Model %%%%%%%%%%%%%%%%%%%
[A_lat, B_lat, C_lat, D_lat] = plane.lateralFullLinearModel();
LatSS = ss(A_lat, B_lat, C_lat, D_lat);
LatTF = tf(LatSS);

%% Design a "Yaw damper" for the Dutch roll mode
R_DR_L = LatTF(3, 2);
OL_r_rcom=servo*R_DR_L;

yawDamperControldesignValues =
matfile("DesignValues/yawDamperControlDesignValues-Design2.mat");

yaw_C_tf = yawDamperControldesignValues.C;
CL_r_rcom_tf = tf(yawDamperControldesignValues.IOTransfer_r2y);
yaw_C_action_tf = tf(yawDamperControldesignValues.IOTransfer_r2u);
```

```
figure;
impulse(yaw_C_action_tf);
title('r/r_{com} Control Action');
figure;
impulse(CL_r_rcom_tf);

%% Design a "Roll Controller"

LatSSYawDamped = feedback(servo * LatSS, yaw_C_tf, 2, 3, 1);
LatTFYawDamped = tf(LatSSYawDamped);
checking_r_rcom_tf = LatTFYawDamped(3, 2);
hold on
impulse(checking_r_rcom_tf, 'r--');
title('r/r_{com} - With Controller Vs. New Lat SS');
hold off

OL_phi_phicom = minreal(servo * LatTFYawDamped(4, 1));

rollControldesignValues =
matfile("DesignValues/rollControllerValues.mat");

roll_C_tf = rollControldesignValues.C;
CL_roll_tf = tf(rollControldesignValues.IOTransfer_r2y);
roll_C_action_tf = tf(rollControldesignValues.IOTransfer_r2u);


%%
%%%%%%%%%%%%%%%%%%% 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);

%% 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_C2_tf = velocityControldesignValues.C2;
velocity_C1_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(velocity_C_action_tf)

%% Altitude Controller h/thetacom
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_C2_tf = altitudeControldesignValues.C2;
altitude_C1_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)
```