Contents


```
% In the name of Allah the beneficent the merciful
% Code by NVE Team, Sharif University, Tehran, Iran
% Date : 1395/12/24
```

Cleaning

```
clc; clear; close all
```

Optimization

Constraints

```
lb = [1e4;1e4;1e4;1e4;1e4;1e4;1e4;1e4;1e4;0;0;0;0;0;0;0;0;-.2;-.2;-.2;-.2;-.2;-.2;-.2;-.2;-.2;50];
ub = [1e6;1e6;1e6;1e6;1e6;1e6;1e6;1e6;1e6;pi/2;pi/2;pi/2;pi/2;pi/2;pi/2;pi/2;pi/2;pi/2;-.1;-.1;.2;.2;.2;.2;.2;.2;.2;70];
x0 = lb*10.5;
x0(1:9) = 5e4;
x0(19:27) = -.1;
x0(end)=50;
options = optimoptions('fmincon','Display','iter','TolX',1e-200,'MaxFunEvals',100000);
f=fmincon(@myfun2,x0,[],[],[],[],lb,ub,[],options);
```

```
                                          First-order      Norm of
 Iter F-count            f(x)  Feasibility   optimality         step
    0       29    1.143993e+05    0.000e+00    1.402e+05
    1       59    2.753492e+04    0.000e+00    1.628e+05    4.248e-01
    2       90    2.324279e+04    0.000e+00    1.740e+05    1.005e-01
    3      121    1.285920e+04    0.000e+00    1.753e+05    1.555e+00
    4      157    9.809407e+03    0.000e+00    9.095e+04    5.672e-02
    5      189    9.395152e+03    0.000e+00    1.446e+05    1.503e-01
    6      221    8.134252e+03    0.000e+00    1.127e+05    1.486e-01
    7      252    4.717031e+03    0.000e+00    1.935e+05    2.587e+00
    8      281    2.764779e+03    0.000e+00    1.375e+05    4.018e-01
    9      310    2.749791e+03    0.000e+00    1.325e+05    8.869e-03
   10      340    1.310124e+03    0.000e+00    1.577e+05    1.118e+00
   11      372    1.269314e+03    0.000e+00    1.216e+05    8.035e-02
```

12	402	1.015932e+03	0.000e+00	1.371e+05	1.091e+00
13	432	9.377511e+02	0.000e+00	1.365e+05	1.112e+00
14	464	8.975881e+02	0.000e+00	1.435e+05	6.935e-01
15	493	7.995578e+02	0.000e+00	1.296e+05	1.175e+00
16	523	7.960950e+02	0.000e+00	1.413e+05	3.899e-01
17	552	7.455550e+02	0.000e+00	1.374e+05	8.650e-01
18	582	7.452255e+02	0.000e+00	1.374e+05	3.019e-03
19	611	7.443401e+02	0.000e+00	1.379e+05	2.550e-01
20	641	7.328082e+02	0.000e+00	1.455e+05	1.519e+00
21	670	6.978697e+02	0.000e+00	1.444e+05	1.770e+00
22	699	6.950840e+02	0.000e+00	1.342e+05	1.868e-01
23	728	4.825426e+02	0.000e+00	1.465e+05	1.659e+00
24	758	3.674297e+02	0.000e+00	1.472e+05	1.234e+00
25	791	1.917972e+02	0.000e+00	1.076e+05	3.268e-02
26	820	6.246119e+01	0.000e+00	1.784e+05	1.822e+00
27	851	5.478705e+01	0.000e+00	1.875e+05	4.190e-01
28	881	4.446795e+01	0.000e+00	1.844e+05	6.082e-01
29	910	3.687585e+01	0.000e+00	1.761e+05	1.040e+00
30	940	3.198537e+01	0.000e+00	1.175e+05	1.052e+00

Iter	F-count	f(x)	Feasibility	First-order optimality	Norm of step
31	969	2.709227e+01	0.000e+00	1.536e+05	1.602e+00
32	998	2.169816e+01	0.000e+00	1.495e+05	6.343e-01
33	1027	1.167502e+01	0.000e+00	1.512e+05	7.383e-01
34	1057	7.513969e+00	0.000e+00	1.562e+05	6.322e-01
35	1086	6.443723e+00	0.000e+00	1.504e+05	4.558e-01
36	1116	3.555641e+00	0.000e+00	1.353e+05	8.065e-01
37	1148	3.025728e+00	0.000e+00	1.424e+05	1.453e-01
38	1180	2.277253e+00	0.000e+00	1.092e+05	2.774e-01
39	1211	1.821471e+00	0.000e+00	1.476e+05	2.318e-01
40	1252	1.758077e+00	0.000e+00	1.073e+05	4.762e-06
41	1282	1.758039e+00	0.000e+00	1.073e+05	8.368e-06
42	1315	8.087569e-01	0.000e+00	9.265e+04	8.997e-06
43	1345	8.074734e-01	0.000e+00	9.265e+04	1.607e-04
44	1385	7.645169e-01	0.000e+00	9.051e+04	1.095e-06
45	1415	7.644991e-01	0.000e+00	9.051e+04	2.616e-06
46	1449	6.869247e-01	0.000e+00	4.231e+04	1.046e-06
47	1479	6.868877e-01	0.000e+00	4.231e+04	5.408e-06
48	1513	6.829423e-01	0.000e+00	9.558e+04	1.999e-06
49	1543	6.829067e-01	0.000e+00	9.558e+04	5.252e-06
50	1576	6.579661e-01	0.000e+00	9.051e+04	4.014e-06
51	1606	6.578758e-01	0.000e+00	9.051e+04	1.385e-05
52	1639	5.710125e-01	0.000e+00	1.076e+05	8.328e-06
53	1669	5.702668e-01	0.000e+00	1.076e+05	1.229e-04

```
   54     1703    4.912445e-01    0.000e+00    7.459e+04    1.653e-05
   55     1733    4.911271e-01    0.000e+00    7.459e+04    4.602e-05
   56     1767    4.854382e-01    0.000e+00    4.232e+04    1.712e-05
   57     1797    4.852116e-01    0.000e+00    4.232e+04    1.190e-04
   58     1832    4.542045e-01    0.000e+00    8.786e+04    8.062e-06
   59     1862    4.540214e-01    0.000e+00    8.786e+04    5.751e-05
   60     1897    3.951132e-01    0.000e+00    8.627e+04    4.375e-06

                                                First-order      Norm of
 Iter F-count            f(x)  Feasibility   optimality         step
   61     1927    3.948702e-01    0.000e+00    8.627e+04    6.114e-05
   62     1966    3.792641e-01    0.000e+00    5.148e+04    2.629e-07
   63     1996    3.792439e-01    0.000e+00    5.148e+04    3.830e-06
   64     2032    3.727394e-01    0.000e+00    1.128e+04    1.336e-07
   65     2062    3.727344e-01    0.000e+00    1.128e+04    1.984e-06
   66     2095    3.687595e-01    0.000e+00    5.861e+04    5.353e-07
   67     2125    3.687335e-01    0.000e+00    5.861e+04    3.010e-06
   68     2158    3.534428e-01    0.000e+00    1.196e+04    2.216e-06
   69     2188    3.533970e-01    0.000e+00    1.196e+04    3.155e-05
   70     2224    3.435536e-01    0.000e+00    5.398e+04    1.044e-06
   71     2254    3.435326e-01    0.000e+00    5.398e+04    1.586e-05
   72     2294    3.428969e-01    0.000e+00    3.443e+04    3.347e-08
   73     2324    3.428965e-01    0.000e+00    3.443e+04    2.344e-07
   74     2358    3.403954e-01    0.000e+00    3.760e+04    3.295e-08
   75     2388    3.403902e-01    0.000e+00    3.782e+04    1.582e-06
   76     2455    3.403902e-01    0.000e+00    3.778e+04    2.725e-17
   77     2491    3.403902e-01    0.000e+00    3.778e+04    3.407e-18
   78     3008    3.403902e-01    0.000e+00    3.778e+04    0.000e+00

Local minimum possible. Constraints satisfied.

fmincon stopped because the size of the current step is less than
the selected value of the step size tolerance and constraints are
satisfied to within the default value of the constraint tolerance.
```

Mass Matrix

```
global m I T_Amp T_Freq T_phase

m = 150; % mass of the engine or powertrain
I = [5.82 -0.82 0.19 ; -0.82 3.41 -0.21 ; 0.19 -0.21 5.50];     % Inertia matrix
M = [m*eye(3) zeros(3) ; zeros(3) I];
```

```
T_Amp = 100;     % N/m
T_Freq = 50;     % Rad/s
T_phase = 0;     % Radian
```

Stiffness Matrix

Mount Positions

```
r_1 = f(19:21);
r_2 = f(22:24);
r_3 = f(25:27);
B_1 = [0 -r_1(3) r_1(2) ; r_1(3) 0 -r_1(1) ; -r_1(2) r_1(1) 0];
B_2 = [0 -r_2(3) r_2(2) ; r_2(3) 0 -r_2(1) ; -r_2(2) r_2(1) 0];
B_3 = [0 -r_3(3) r_3(2) ; r_3(3) 0 -r_3(1) ; -r_3(2) r_3(1) 0];

% Mount Inclinations
o_1 = f(10:12);
o_2 = f(13:15);
o_3 = f(16:18);

% Mount Rotation Matrices
A_1 = [cos(o_1(3))*cos(o_1(2)) -
sin(o_1(3))*cos(o_1(1))+cos(o_1(3))*sin(o_1(2))*sin(o_1(1))
sin(o_1(3))*sin(o_1(1))+cos(o_1(3))*sin(o_1(2))*cos(o_1(1));
    sin(o_1(3))*cos(o_1(2))
cos(o_1(3))*cos(o_1(1))+sin(o_1(3))*sin(o_1(2))*sin(o_1(1)) -
cos(o_1(3))*sin(o_1(1))+sin(o_1(3))*sin(o_1(2))*cos(o_1(1));
    -sin(o_1(2)) cos(o_1(2))*sin(o_1(1)) cos(o_1(2))*cos(o_1(1))];
A_2 = [cos(o_2(3))*cos(o_2(2)) -
sin(o_2(3))*cos(o_2(1))+cos(o_2(3))*sin(o_2(2))*sin(o_2(1))
sin(o_2(3))*sin(o_2(1))+cos(o_2(3))*sin(o_2(2))*cos(o_2(1));
    sin(o_2(3))*cos(o_2(2))
cos(o_2(3))*cos(o_2(1))+sin(o_2(3))*sin(o_2(2))*sin(o_2(1)) -
cos(o_2(3))*sin(o_2(1))+sin(o_2(3))*sin(o_2(2))*cos(o_2(1));
    -sin(o_2(2)) cos(o_2(2))*sin(o_2(1)) cos(o_2(2))*cos(o_2(1))];
A_3 = [cos(o_3(3))*cos(o_3(2)) -
sin(o_3(3))*cos(o_3(1))+cos(o_3(3))*sin(o_3(2))*sin(o_3(1))
sin(o_3(3))*sin(o_3(1))+cos(o_3(3))*sin(o_3(2))*cos(o_3(1));
    sin(o_3(3))*cos(o_3(2))
cos(o_3(3))*cos(o_3(1))+sin(o_3(3))*sin(o_3(2))*sin(o_3(1)) -
cos(o_3(3))*sin(o_3(1))+sin(o_3(3))*sin(o_3(2))*cos(o_3(1));
    -sin(o_3(2)) cos(o_3(2))*sin(o_3(1)) cos(o_3(2))*cos(o_3(1))];

% Mount Stiffness
k_l_1 = diag([f(1) f(4) f(7)]);
k_l_2 = diag([f(2) f(5) f(8)]);
```

```
k_l_3 = diag([f(3) f(6) f(9)]);
k_1 = A_1*k_l_1*A_1';
k_2 = A_2*k_l_2*A_2';
k_3 = A_3*k_l_3*A_3';

% Finally! The Stiffness Matrix
K = [k_1 k_1*B_1' ; (k_1*B_1')' B_1*k_1*B_1'] + [k_2 k_2*B_2' ; (k_2*B_2')'
B_2*k_2*B_2'] + [k_3 k_3*B_3' ; (k_3*B_3')' B_3*k_3*B_3'];
```

Damping Matrix

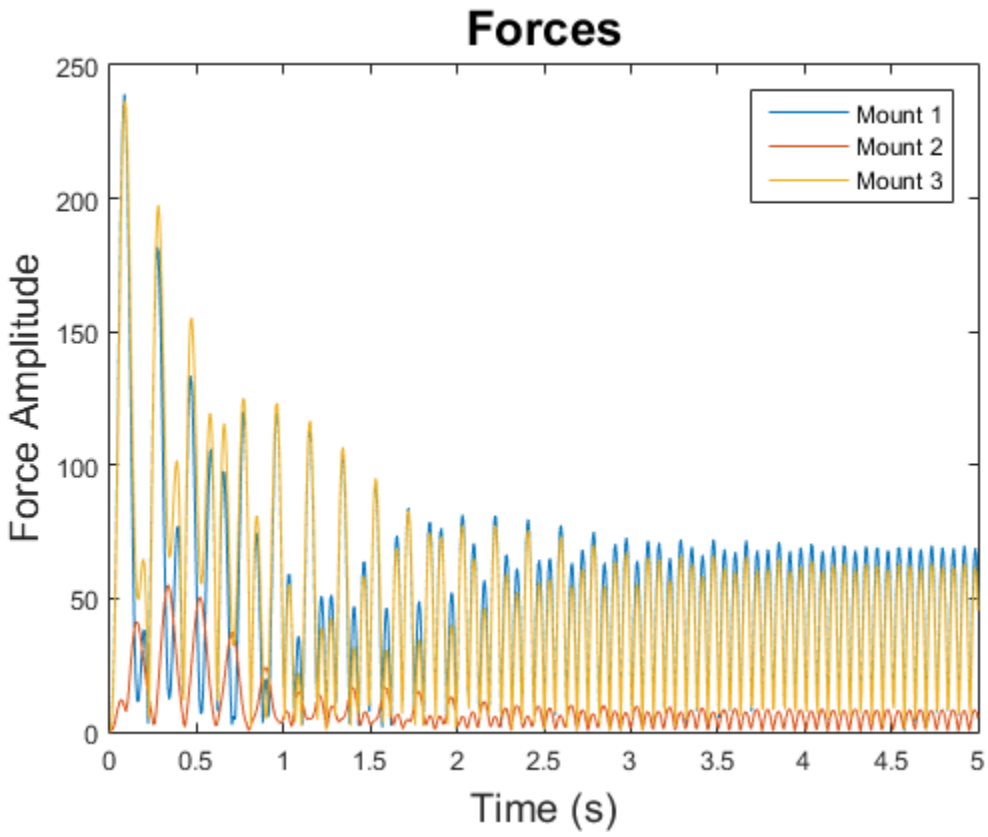
Mount Damping Coefficients

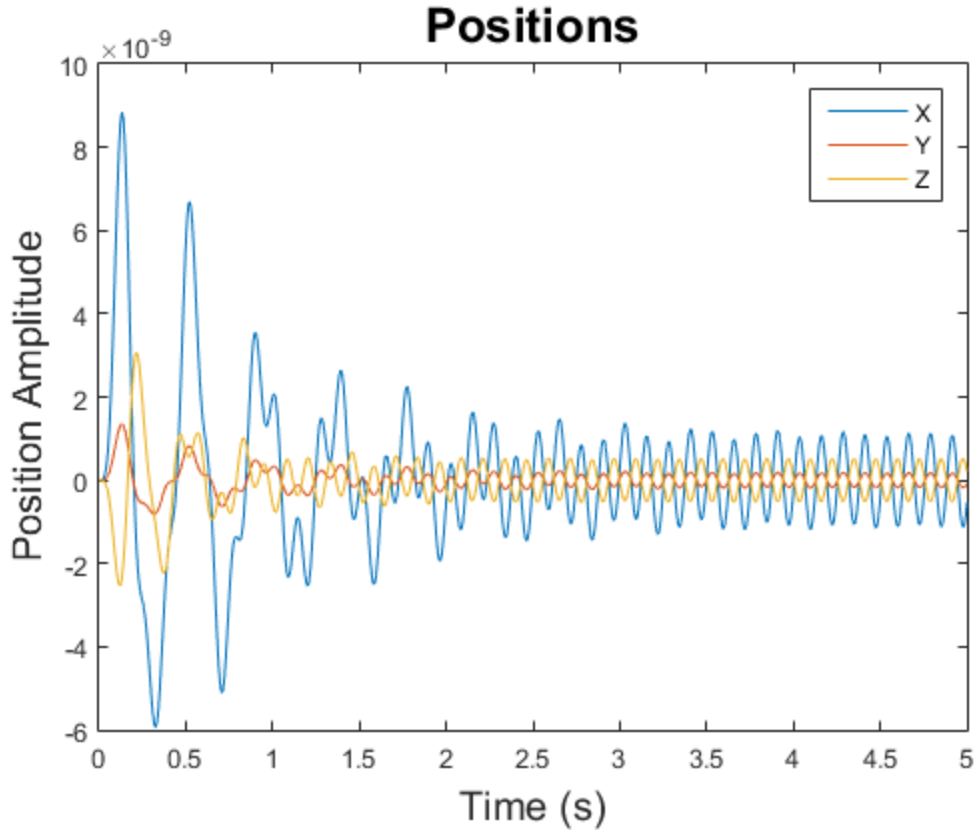
```
c_l_1 = diag([f(1) f(4) f(7)])*0.01;
c_l_2 = diag([f(2) f(5) f(8)])*0.01;
c_l_3 = diag([f(3) f(6) f(9)])*0.01;
c_1 = A_1*c_l_1*A_1';
c_2 = A_2*c_l_2*A_2';
c_3 = A_3*c_l_3*A_3';

% Damping Matrix
% C = [c_1 c_1*B_1' ; (c_1*B_1')' B_1*c_1*B_1'] + [c_2 c_2*B_2' ; (c_2*B_2')'
B_2*c_2*B_2'] + [c_3 c_3*B_3' ; (c_3*B_3')' B_3*c_3*B_3'];
C = 0.01*K;
```

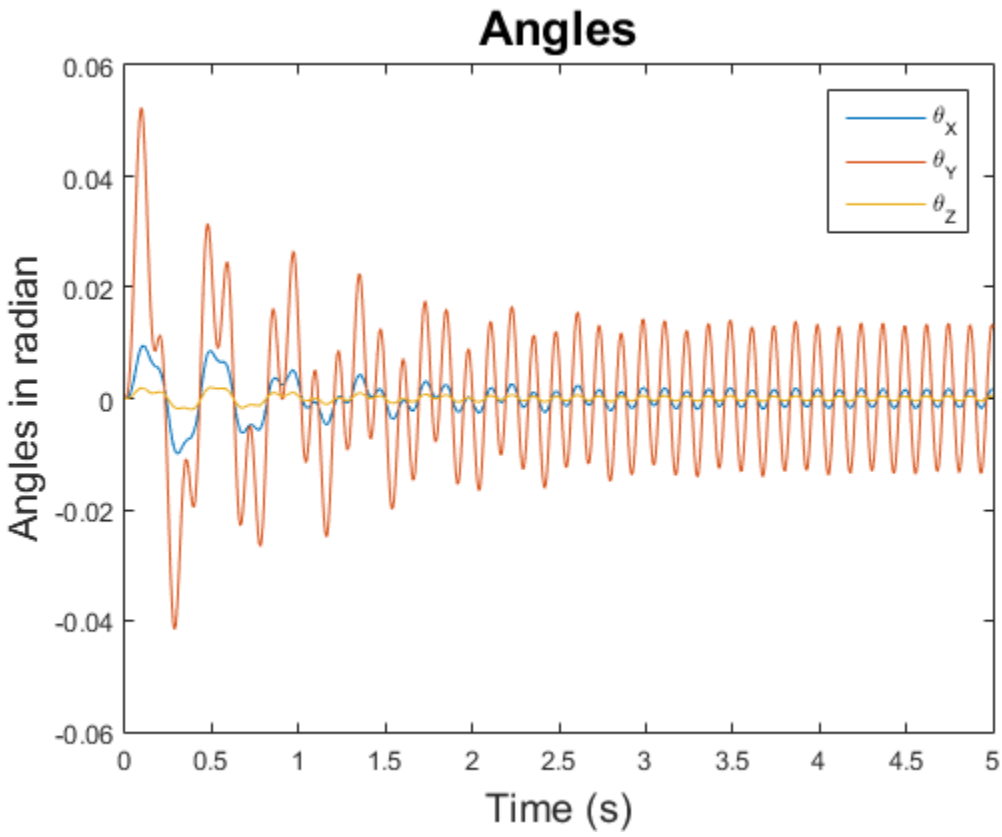
Execution

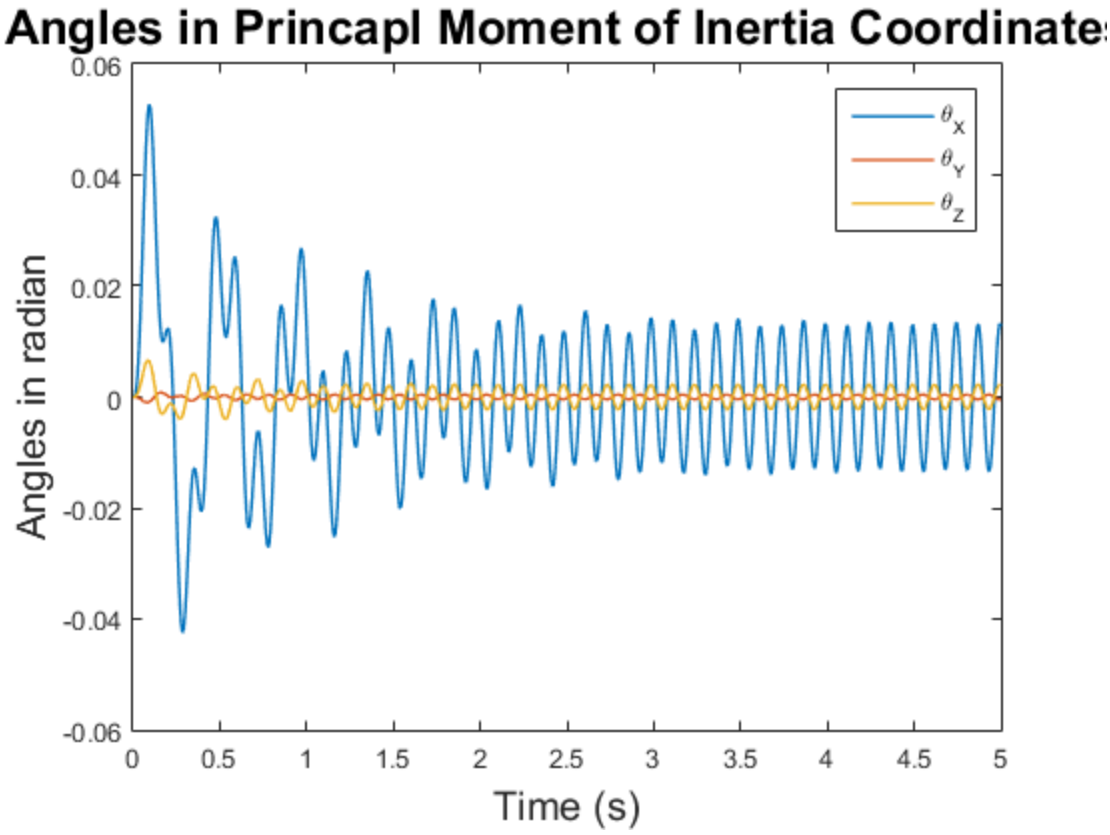
```
x0 = [0;0;0;0;0;0;0;0;0;0;0;0];     % The initial condition
[t,x] = ode45(@eng_mount, [0 5], x0, [], M, C, K);      % solving the ODE with the
duration of 5 seconds
P1 = cube([0 0 0],[0 0 0]);     % plotting the engine in its equilibrium position

F_1 = zeros(length(t),3);   F_2 = F_1;  F_3 = F_1;
F_1_n = t';  F_2_n = F_1_n;   F_3_n = F_1_n;

for i = 1:length(t)
    F_1(i,:) = (-k_1*[eye(3) B_1']*x(i,1:6)' - c_1*[eye(3) B_1']*x(i,7:12)')';
    F_1_n(i) = norm(F_1(i,:));
    F_2(i,:) = (-k_2*[eye(3) B_2']*x(i,1:6)' - c_2*[eye(3) B_2']*x(i,7:12)')';
    F_2_n(i) = norm(F_2(i,:));
    F_3(i,:) = (-k_3*[eye(3) B_3']*x(i,1:6)' - c_3*[eye(3) B_3']*x(i,7:12)')';
    F_3_n(i) = norm(F_3(i,:));
end


figure;plot(t,F_1_n)
hold on
```

```
plot(t,F_2_n)
plot(t,F_3_n)
title('Forces','fontsize',18);
xlabel('Time (s)','fontsize',15);
ylabel('Force Amplitude','fontsize',15);
legend('Mount 1','Mount 2','Mount 3');

figure;plot(t,x(:,1:3))
title('Positions','fontsize',18);
xlabel('Time (s)','fontsize',15);
ylabel('Position Amplitude','fontsize',15);
legend('X','Y','Z');

figure;plot(t,x(:,4:6))
title('Angles','fontsize',18);
xlabel('Time (s)','fontsize',15);
ylabel('Angles in radian','fontsize',15);
legend('\theta_X','\theta_Y','\theta_Z');

[u,~] = eig(I);
R_EAD = [eye(3) zeros(3);zeros(3) u'];

EE = zeros(length(x),6);
for i = 1:length(x)
EE(i,:) = (R_EAD*x(i,1:6)')';
end

figure;plot(t,EE(:,4:6),'linewidth',1)
title('Angles in Princapl Moment of Inertia Coordinates','fontsize',18);
xlabel('Time (s)','fontsize',15);
ylabel('Angles in radian','fontsize',15);
legend('\theta_X','\theta_Y','\theta_Z');

% End of code
```


Forces
Mount 1
Mount 2
Mount 3
Force Amplitude
Time (s)
250
200
150
100
50
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


Positions
×10-9
X
Y
Z
Position Amplitude
Time (s)
10
8
6
4
2
0
-2
-4
-6
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


Angles
Angles in radian
Time (s)
θX
θY
θZ
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


Angles in Princapl Moment of Inertia Coordinate
Angles in radian
Time (s)
θX
θY
θZ
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5