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Project Team Members

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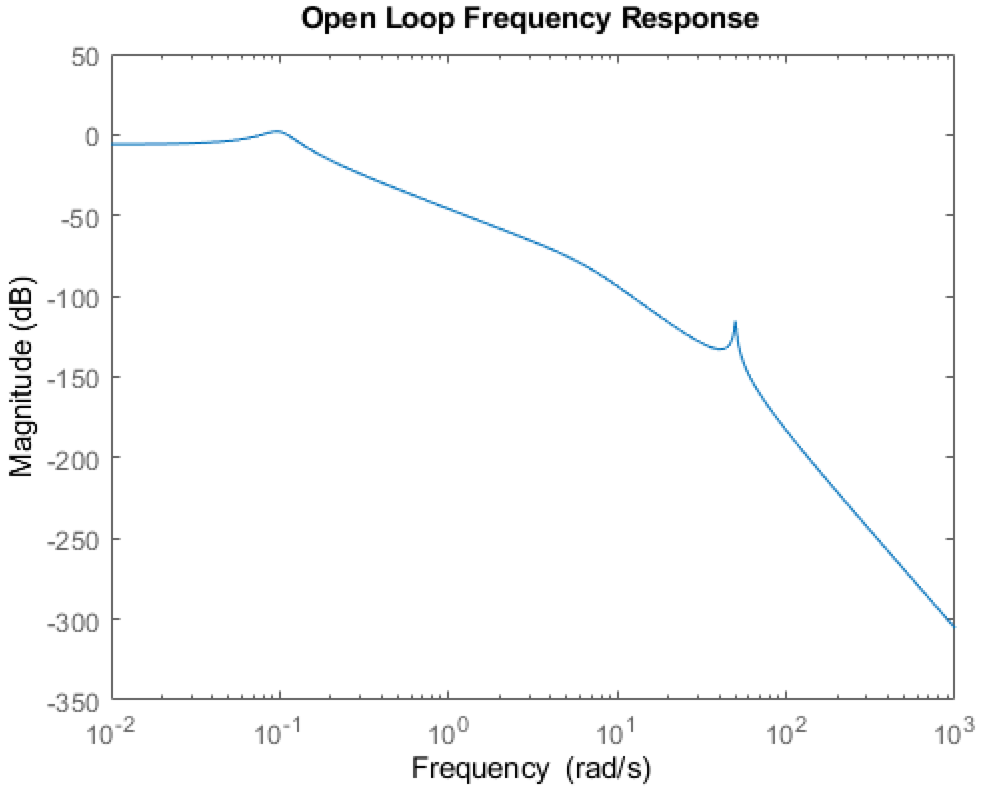
```
clear; clc;
close all
```

Helicopter Model

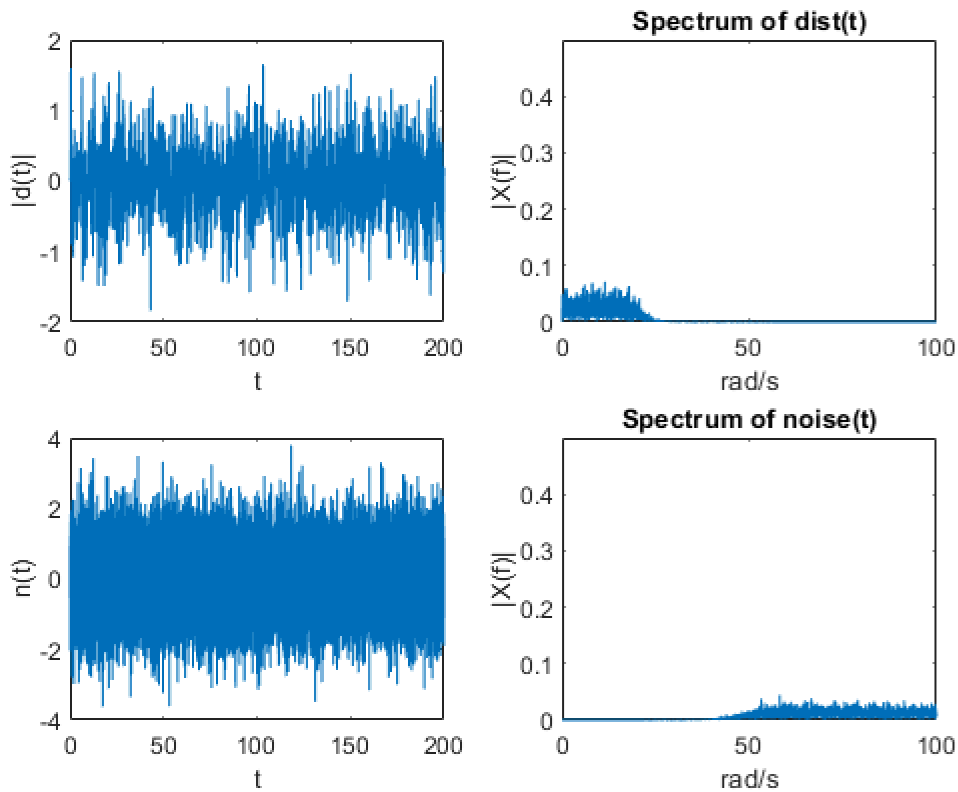
```
s = tf('s');

Om1 = 0.1; z1 = 0.2; % Phugoid
Om2 = 6.5; z2 = 0.7; % Short period
Om3 = 50; z3 = 0.01; % Flex mode

G1 = tf(Om1^2,[1 2*z1*Om1 Om1^2]);
G2 = tf(Om2^2,[1 2*z2*Om2 Om2^2]);
G3 = tf(Om3^2,[1 2*z3*Om3 Om3^2]);
G = 0.5*G1*G2*G3;

figure("Name", "Open Loop Frequency Response")
bodemag(G); title('Open Loop Frequency Response')
% print -depsc plantBode.eps
```



Create disturbance and noise signals.

```
dt = 0.01; Fs = 1/dt;
F = 1/(s/5+1);
T = 0:dt:200;

% Create disturbance
D = 2*randn(length(T),1);
wc = (20/2/pi)/(Fs/2); % Normalized cutoff frequency (10 rqd/s)
[fb,fa] = butter(10,wc,'low'); % butter worth filter.
d = filter(fb,fa,D); % Now filter the disturbance. This generates colored
 noise
L = length(T)+1;

NFFT = 2^nextpow2(L); % Next power of 2 from length of y
Z = 2*fft(d,NFFT)/L;
f = Fs/2*linspace(0,1,NFFT/2+1); % Only interested in signals upto Fs/2 Hz.
absZ = abs(Z(1:NFFT/2+1));
figure(3);
subplot(2,2,1);plot(T,d);
xlabel('t'); ylabel('|d(t)|');

subplot(2,2,2);plot(2*pi*f,absZ); axis([0 100 0 .5]);
title('Spectrum of dist(t)');
xlabel('rad/s');
```

```
ylabel('|X(f)|');

% Create sensor noise
N = randn(length(T),1);
wc = (50/2/pi)/(Fs/2); % Normalized cutoff frequency (10 Hz)
[fb,fa] = butter(10,wc,'high'); % butter worth filter.
n = filter(fb,fa,N); % Now filter the disturbance. This generates colored
 noise
L = length(T)+1;

NFFT = 2^nextpow2(L); % Next power of 2 from length of y
Z = fft(n,NFFT)/L;
f = Fs/2*linspace(0,1,NFFT/2+1); % Only interested in signals upto Fs/2 Hz.
absZ = 2*abs(Z(1:NFFT/2+1));
figure(3);
subplot(2,2,3);plot(T,n);
xlabel('t');
ylabel('n(t)');

subplot(2,2,4);plot(2*pi*f,absZ); axis([0 100 0 .5]);
title('Spectrum of noise(t)');
xlabel('rad/s');
ylabel('|X(f)|');

% Save Data
P = G;
distTime = d;
noiseTime = n;

save heli.mat P distTime noiseTime T
```



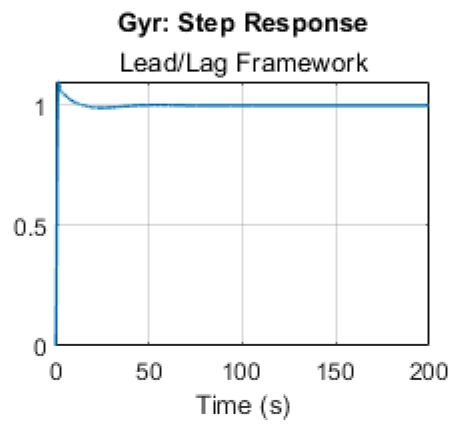
Lead/Lag Controller

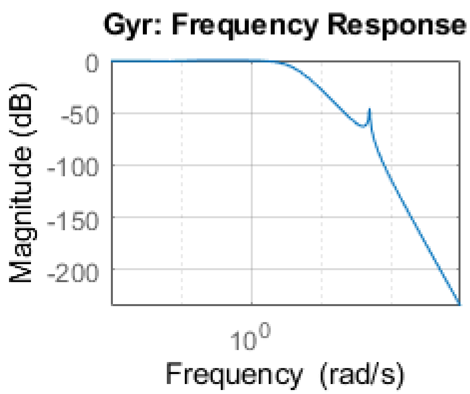
```
K = 30; %With only proportional control the system oscillates. Needs dampening

%Introduce Lead and Lag compensators

z1 = 0.1;
p1 = 11;
z2 = 0.3;
p2 = 0.25;

Lead = ((s/z1)+1)/((s/p1)+1);  %where p>>z>0

Lag = ((s+z2)/(s+p2)); %z>p>0 but z is close to p

%Having lots of issues with steady state error with just
%Lead/Lag

Ki = 5;

C = K*Lead*Lag + Ki/s;

Gyr = C*G/(1+C*G);
```

Time Simulation

```
Y1_leadlag = step(Gyr,T);

stepResults_leadlag = stepinfo(Y1_leadlag, T)
% Lead/Lag framework satisfies the rise time requirement (0.683 sec),
 overshoot requirement (9.921%)
% but does not satisfy the settling time requirement (8.969 sec > 5 sec).
figure("Name", "Lead Lag Controller"); clf;
subplot(2,2,1); plot(T,Y1_leadlag,'Linewidth',1); title('Gyr: Step Response');
 subtitle('Lead/Lag Framework'); xlabel('Time (s)'); grid on;
subplot(2,2,3); bodemag(Gyr); title('Gyr: Frequency Response'); grid on;
```

```
stepResults_leadlag =

  struct with fields:

         RiseTime: 0.6830
    TransientTime: 8.9690
     SettlingTime: 8.9690
      SettlingMin: 0.9024
      SettlingMax: 1.0992
        Overshoot: 9.9208
       Undershoot: 0
             Peak: 1.0992
         PeakTime: 1.6700
```





PID Controller Design: Iteration 0 (given)

For the purposes of experimenting with the PID framework and to achieve the settling time requirement:

```
K = 100;
Ki = 30;
Kd = 200;

C = K + Ki/s + Kd*s/(s/10+1); % PID

Gyr = C*G/(1+C*G);
Gyd = G/(1+C*G);
Gyn = -Gyr;
Gur = C/(1+C*G);
```

Time Simulation: Iteration 0 (given)

```
Y1_0 = step(Gyr,T);
Y2_0 = lsim(Gyd,10*d,T);
Y3_0 = lsim(Gyn,10*n,T);
u = step(Gur,T);
```

Calculate rise time, settling time, and overshoot

```
stepResults_0 = stepinfo(Y1_0,T);
tSettle_0 = stepResults_0.SettlingTime;
tRise_0 = stepResults_0.RiseTime;
maxOvershoot_0 = stepResults_0.Overshoot;
```

Controller Design: Iteration 1 (increased derivative action)

Overshoot was high, increasing derivative action will increase damping and decrease overshoot

```
K = 100;
Ki = 30;
Kd = 300;

C = K + Ki/s + Kd*s/(s/10+1); % PID

Gyr = C*G/(1+C*G);
Gyd = G/(1+C*G);
Gyn = -Gyr;
Gur = C/(1+C*G);
```

Time Simulation: Iteration 1 (increased derivative action)

```
Y1_1 = step(Gyr,T);
Y2_1 = lsim(Gyd,10*d,T);
Y3_1 = lsim(Gyn,10*n,T);
u = step(Gur,T);
```

Calculate rise time, settling time, and overshoot

```
stepResults_1 = stepinfo(Y1_1,T);
tSettle_1 = stepResults_1.SettlingTime;
tRise_1 = stepResults_1.RiseTime;
maxOvershoot_1 = stepResults_1.Overshoot;
```

Controller Design: Iteration 2 (decreased proportional term)

Overshoot is still too high. Decreasing proportional term by factor of 0.5.

```
K = 50;
Ki = 30;
Kd = 300;

C = K + Ki/s + Kd*s/(s/10+1); % PID

Gyr = C*G/(1+C*G);
Gyd = G/(1+C*G);
Gyn = -Gyr;
Gur = C/(1+C*G);
```

Time Simulation: Iteration 2 (decreased proportional term)

```
Y1_2 = step(Gyr,T);
Y2_2 = lsim(Gyd,10*d,T);
Y3_2 = lsim(Gyn,10*n,T);
u = step(Gur,T);
```

Calculate rise time, settling time, and overshoot

```
stepResults_2 = stepinfo(Y1_2,T);
tSettle_2 = stepResults_2.SettlingTime;
tRise_2 = stepResults_2.RiseTime;
maxOvershoot_2 = stepResults_2.Overshoot;
```

Controller Design: Iteration 3 (decreased integral term)

Overshoot is still too high. Decreasing integral term from 30 to 10.

```
K = 50;
Ki = 10;
Kd = 300;

C = K + Ki/s + Kd*s/(s/10+1); % PID

Gyr = C*G/(1+C*G);
Gyd = G/(1+C*G);
Gyn = -Gyr;
Gur = C/(1+C*G);
```

Time Simulation: Iteration 3 (decreased integral term)

```
Y1_3 = step(Gyr,T);
```

```
Y2_3 = lsim(Gyd,10*d,T);
Y3_3 = lsim(Gyn,10*n,T);
u = step(Gur,T);
```

Calculate rise time, settling time, and overshoot

```
stepResults_3 = stepinfo(Y1_3,T);
tSettle_3 = stepResults_3.SettlingTime;
tRise_3 = stepResults_3.RiseTime;
maxOvershoot_3 = stepResults_3.Overshoot;
```

Controller Design: Iteration 4 FINAL CONTROLLER (decreased proportional and integral terms)

Overshoot is still too high. Decreasing proportional and integral terms and performing additional tailoring until design criteria are met.

```
K = 20;
Ki = 3.65;
Kd = 307;

C = K + Ki/s + Kd*s/(s/10+1); % PID

Gyr = C*G/(1+C*G);
Gyd = G/(1+C*G);
Gyn = -Gyr;
Gur = C/(1+C*G);
```

Time Simulation: Iteration 4 (FINAL CONTROLLER)

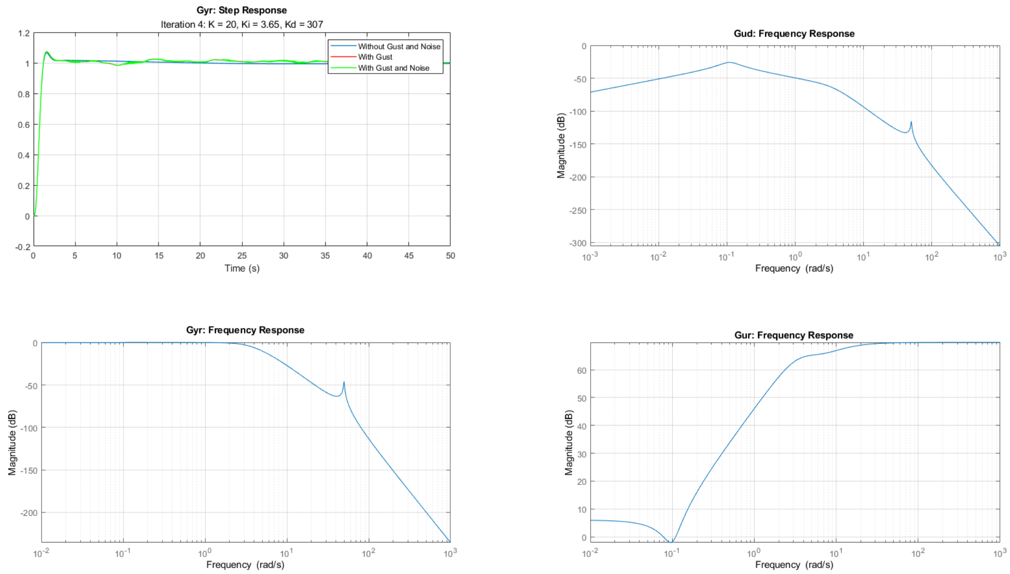
```
Y1_4 = step(Gyr,T);
Y2_4 = lsim(Gyd,10*d,T);
Y3_4 = lsim(Gyn,10*n,T);
u = step(Gur,T);
```

Calculate rise time, settling time, and overshoot

```
stepResults_4 = stepinfo(Y1_4,T)
tSettle_4 = stepResults_4.SettlingTime;
tRise_4 = stepResults_4.RiseTime;
maxOvershoot_4 = stepResults_4.Overshoot;
```

```
f = figure("Name", "Final PID Controller"); clf;
f.WindowState = "Maximized";
subplot(2,2,1); plot(T,Y1_4,'Linewidth',1); title('Gyr: Step Response');
 subtitle('Iteration 4: K = 20, Ki = 3.65, Kd = 307'); xlabel('Time (s)');
 grid on;
hold on; plot(T,Y1_4+Y2_4,'r','Linewidth',1);
 plot(T,Y1_4+Y2_4+Y3_4,'g','Linewidth',1); xlim([0,50]); legend('Without Gust
 and Noise','With Gust', 'With Gust and Noise'); hold off;
subplot(2,2,2); bodemag(Gyd); title('Gud: Frequency Response'); grid on;
subplot(2,2,3); bodemag(Gyr); title('Gyr: Frequency Response'); grid on;
subplot(2,2,4); bodemag(Gur); title('Gur: Frequency Response'); grid on;
hold off;
% By inspection of the Gyr Step Response graph using a PID framework,
% maximum overshoot is 6.5084%, which is less than the 10% design criteria.
% Rise time is 0.6915 seconds, which is less than the 1 second design criteria
% and settling time is 2.36 seconds (within 2% of steady state value),
% which is less than the 5 second design criteria.

% There are no significant oscillations. However, while the settling time
% is less than 5 seconds, the time it takes for the system to maintain the
% steady state value without any low-frequency/low amplitude oscillations
% is roughly ~40 seconds. During this time, the error never exceeds 1.5%,
% so oscillations can be treated as negligible. This was most likely a
% result of the system requiring very low K and Ki values in conjunction
% with large Kd values in order to maintain a low overshoot at the cost of
% higher steady state error.
```

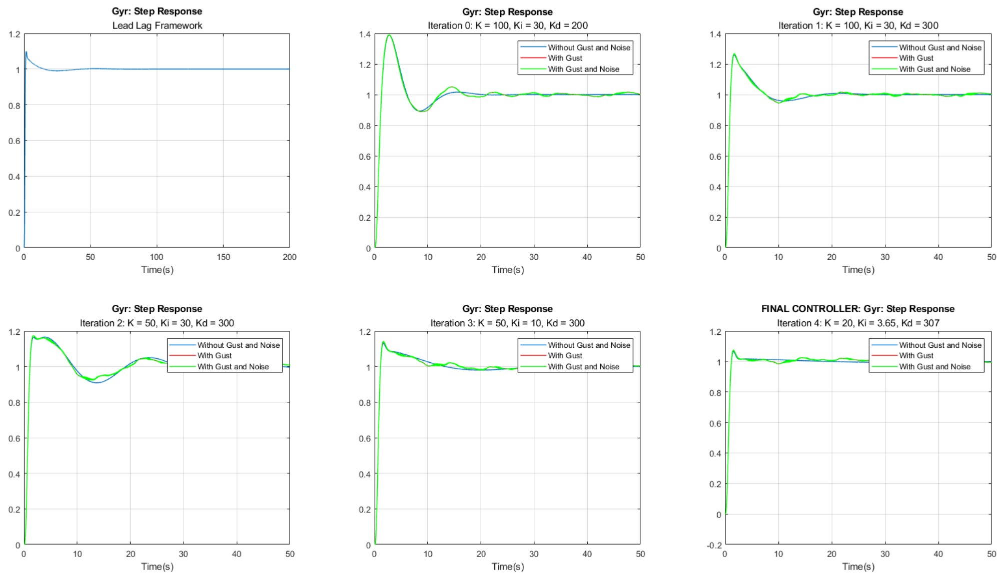
```
stepResults_4 =

  struct with fields:

         RiseTime: 0.6915
    TransientTime: 2.3599
     SettlingTime: 2.3599
      SettlingMin: 0.9010
      SettlingMax: 1.0651
        Overshoot: 6.5084
       Undershoot: 0
             Peak: 1.0651
         PeakTime: 1.5700
```



Final Plots

```
f = figure("Name", "Final Controller Plots"); clf;
f.WindowState = 'maximized';
subplot(2,3,1); plot(T, Y1_leadlag,'Linewidth',1); title('Gyr: Step
 Response'); subtitle("Lead Lag Framework"); xlabel('Time(s)'); grid on;

subplot(2,3,2); plot(T, Y1_0,'Linewidth',1); title('Gyr: Step Response');
 subtitle("Iteration 0: K = 100, Ki = 30, Kd = 200"); xlabel('Time(s)');
 grid on;
hold on; plot(T,Y1_0+Y2_0,'r','Linewidth',1);
 plot(T,Y1_0+Y2_0+Y3_0,'g','Linewidth',1); xlim([0,50]); legend('Without Gust
 and Noise','With Gust', 'With Gust and Noise'); hold off;

subplot(2,3,3); plot(T, Y1_1,'Linewidth',1); title('Gyr: Step Response');
 subtitle("Iteration 1: K = 100, Ki = 30, Kd = 300"); xlabel('Time(s)');
 grid on;
hold on; plot(T,Y1_1+Y2_1,'r','Linewidth',1);
 plot(T,Y1_1+Y2_1+Y3_1,'g','Linewidth',1); xlim([0,50]); legend('Without Gust
 and Noise','With Gust', 'With Gust and Noise'); hold off;

subplot(2,3,4); plot(T, Y1_2,'Linewidth',1); title('Gyr: Step Response');
 subtitle("Iteration 2: K = 50, Ki = 30, Kd = 300"); xlabel('Time(s)');
 grid on;
hold on; plot(T,Y1_2+Y2_2,'r','Linewidth',1);
 plot(T,Y1_2+Y2_2+Y3_2,'g','Linewidth',1); xlim([0,50]); legend('Without Gust
 and Noise','With Gust', 'With Gust and Noise'); hold off;

subplot(2,3,5); plot(T, Y1_3,'Linewidth',1); title('Gyr: Step Response');
 subtitle("Iteration 3: K = 50, Ki = 10, Kd = 300"); xlabel('Time(s)');
 grid on;
```

```
hold on; plot(T,Y1_3+Y2_3,'r','Linewidth',1);
 plot(T,Y1_3+Y2_3+Y3_3,'g','Linewidth',1); xlim([0,50]); legend('Without Gust
 and Noise','With Gust', 'With Gust and Noise'); hold off;

subplot(2,3,6); plot(T, Y1_4,'Linewidth',1); title('FINAL CONTROLLER: Gyr:
 Step Response'); subtitle("Iteration 4: K = 20, Ki = 3.65, Kd = 307");
 xlabel('Time(s)'); grid on;
hold on; plot(T,Y1_4+Y2_4,'r','Linewidth',1);
 plot(T,Y1_4+Y2_4+Y3_4,'g','Linewidth',1); xlim([0,50]); legend('Without Gust
 and Noise','With Gust', 'With Gust and Noise');
```



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