24-774: Lab 1

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Team: 4

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Notes on Plant Model and Reference:

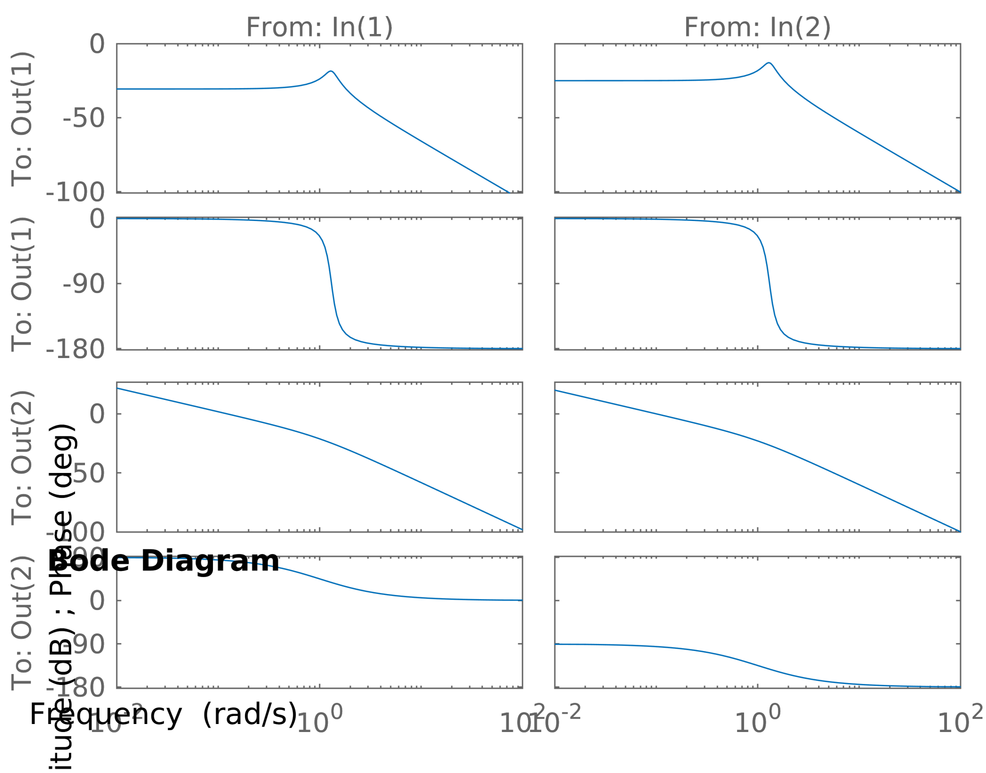
Yaw should have amplitude π/4 rad (0.7854) and freq 0.5 rad/s (0.08 Hz, T = 12.5s)

Pitch should have amplitude π/6 rad (0.5236)and freq 0.4 rad/s (0.06 Hz, T = 16.7s)

Preliminaries

```
quanser_aero_parameters
quanser_aero_state_space

% nominal plant model
Gnom = ss(A, B, C, D) ;
bode(Gnom) ;
```




```
% bodemag(Gnom) ;
```

The outputs to channel 1 both show typical second order behavior with a resonant peak at about 1.3 rad/s. The output to channel 2 seems to be a proper system with a pole and zero, with first order characteristics. I cannot see anything that I would call "unusual". But I thought that the Bode plots on the diagonals (1,1) and (2,2) would be more similar and the off-diagonal plots would be more chaotic? Why are all the bodes for a particular output (regardless of the input) very similar? --> Maybe its related to coupling somehow?

--> control dominant - one input is stronger than the other

WHAT ARE CHANNELS 1 AND 2 ON INPUT AND OUTPUT REPRESENTING?

```
% saturation nonlinearity to limit control voltages to +/- 25V
Wu = eye(2)*1/25 ;
```

PID Control

See the Lab1_NomPlantModel.slx and Lab1_PIDControllers.slx files for PID controller implementation.

Dynamic Decoupling

$G_s = G_D G_M^{-1} G$ where G_M is the plant model (Gnom above). G_D is the diagonal portion of the plant model. G_M^{-1} is a proper, stable approximation of the inverse of the nominal plant model. (I think the last G in the expression is G_M --> this is correct for the simulation. On the hardware we replace G with the actual plant.)

```
s = tf('s') ;
Gm = Gnom ; % plant model
Gd = [Gnom(1,1), 0 ; 0 , Gnom(2,2)]; % diagonal portion of plant model

K = 1E2 ; % position of high frequency poles for making inverse a proper tf
Gm_inv = tf(inv(Gnom))*(1/((s/K)+1))^2 ; % writing the extra poles this way ensures the
% Gm_inv = inv(Gnom)*((K/(s+K))^2) ; % proper, stable inverse of plant model

%bodemag(inv(Gnom),Gm_inv) ; legend('original inverse', 'proper stable inverse') ;
Gd = minreal(Gd) ;
```

```
4 states removed.
```

```
Gm_inv = minreal(Gm_inv) ;
Gs = tf(Gm_inv)*tf(Gd) ;
Gs = minreal(Gs,1e-3) ;

%% converting decoupling controller to discrete time

% PID for yaw
Kp_y = 700;
Ki_y = 20;
Kd_y = 600;
% Kp_y = 150;
% Ki_y = 0;
% Kd_y = 80;
N_y = 1000;
Kyaw = Kp_y + Ki_y*(1/s) + Kd_y*(N_y / (1 + N_y*(1/s))) ;
```

```
% PID for pitch
Kp_p = 700;
Ki_p = 10;
Kd_p = 400;
% Kp_p = 200;
% Ki_p = 60;
% Kd_p = 80;
N_p = 1000;
Kpitch = Kp_p + Ki_p*(1/s) + Kd_p*(N_y / (1 + N_y*(1/s))) ;
Kpid = [Kpitch, 0 ; 0, Kyaw] ;
Kdecoupling = Gs*Kpid ;
Kdecoupling = minreal(Kdecoupling);

% put into controllable canonical form
% Kdecoupling_canon = canon(Kdecoupling,'modal') ; % is companion a good mode to use?

% sampling time
Ts = 1/500 ; % assuming 500Hz sampling rate
%step(feedback(Kdecoupling*Gnom,eye(2)))
kDT2 = c2d(Kdecoupling,Ts,'zoh')
```

```
kDT2 =

  From input 1 to output...
            1171 z^3 - 1804 z^2 + 100.5 z + 532.3
   1:  ------------------------------------------------
       z^4 - 2.773 z^3 + 2.665 z^2 - 0.9826 z + 0.09072

            1437 z^3 - 2214 z^2 + 123.4 z + 653.3
   2:  ------------------------------------------------
       z^4 - 2.773 z^3 + 2.665 z^2 - 0.9826 z + 0.09072

  From input 2 to output...
            -3350 z^3 + 5165 z^2 - 290.9 z - 1524
   1:  ------------------------------------------------
       z^4 - 2.773 z^3 + 2.665 z^2 - 0.9826 z + 0.09072

            1755 z^3 - 2706 z^2 + 152.4 z + 798.3
   2:  ------------------------------------------------
       z^4 - 2.773 z^3 + 2.665 z^2 - 0.9826 z + 0.09072

Sample time: 0.002 seconds
Discrete-time transfer function.
```

```
%step(feedback(kDT2(1,1)*c2d(Gnom(1,1),Ts),1))

 K_lqr = [(1711*s + 4910)/(s+50), (-1557*s - 5153)/(s+50) ;
         (2432*s + 7817)/(s+50), (921.5*s + 3308)/(s+50) ] ;
 kDT = c2d(K_lqr,Ts,'zoh')
```

```
kDT =

  From input 1 to output...
       1711 z - 1702
   1:  -------------
        z - 0.9048

       2432 z - 2417
```

```
    2:  -------------
         z - 0.9048

   From input 2 to output...
        -1557 z + 1547
    1:  --------------
          z - 0.9048

        921.5 z - 915.2
    2:  ---------------
          z - 0.9048

 Sample time: 0.002 seconds
 Discrete-time transfer function.
```

```
 %step(kDT(1,1))
% step(kDT(1,1)*c2d(Gnom(1,1),Ts))

% B0 = 0 FIX THIS
%tf(minreal(kDT))
%kDT_min = balred(kDT,6)
%bode(kDT,kDT_min)
%ss(ans);


%kDT = canon(minreal(kDT),'companion') % companion results in singular controllability
%kDT_tf = ss2tf(kDT.A,kDT.B,kDT.C,kDT.D,1) % what is the numerator, denominator?
```

The controller output is now very small compared to the reference signals. Why is that happening? Does it have to do with the location of the poles I added to make the inverse plant proper?

See Lab1_DynamicDecoupledPlantModel.slx and Lab1_DynamicDecoupledControllers.slx for this implementation.

State Space Control

```
% KF
Q_kf = 1*eye(4) ;
R_kf = 1*eye(2) ;

% LQR
Q = 1 * eye(4) ;
R = 1 * eye(2) ;
[Klqr,~,~] = lqr(Gnom,Q,R) ;
```