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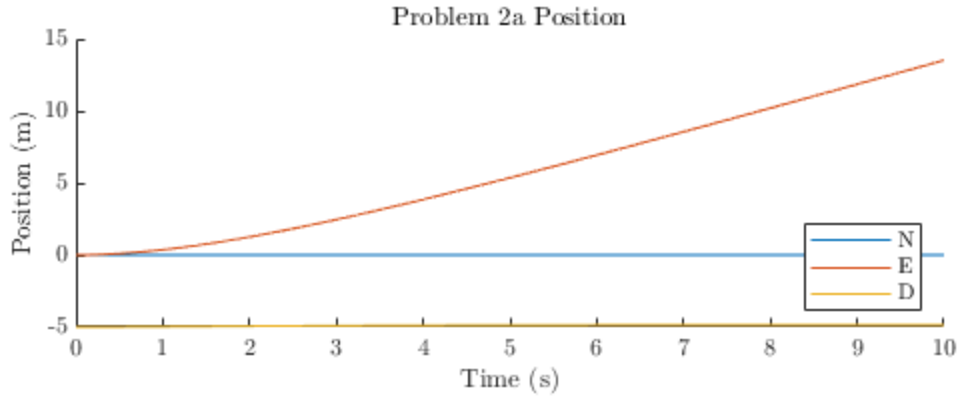
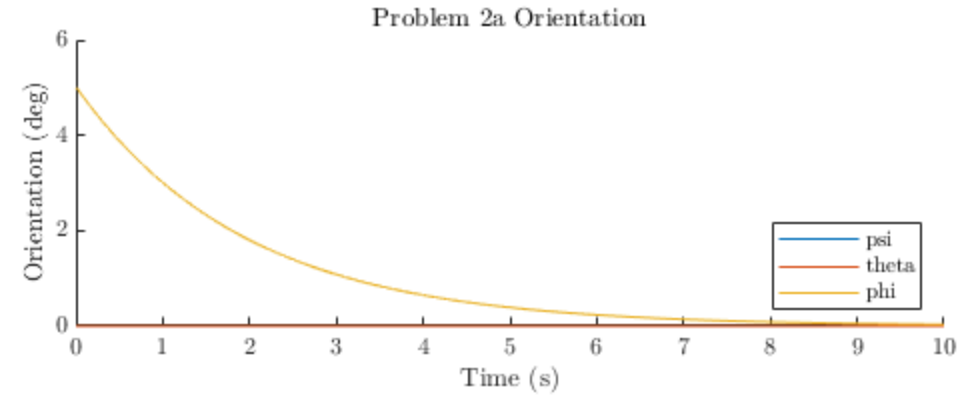
```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Author: Samuel Razumovskiy
% Date written: 9/20/19
% Date modified: 9/26/19
%
% Purpose: Modeling quadcopter flight and comparing three different
 models
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

set(groot, 'defaulttextinterpreter', 'latex');
set(groot, 'defaultAxesTickLabelInterpreter', 'latex');
set(groot, 'defaultLegendInterpreter', 'latex');
```

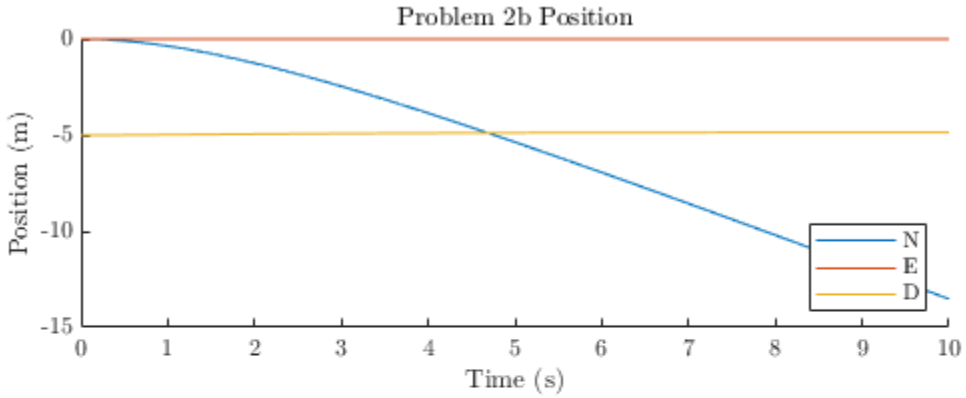
Problem 2

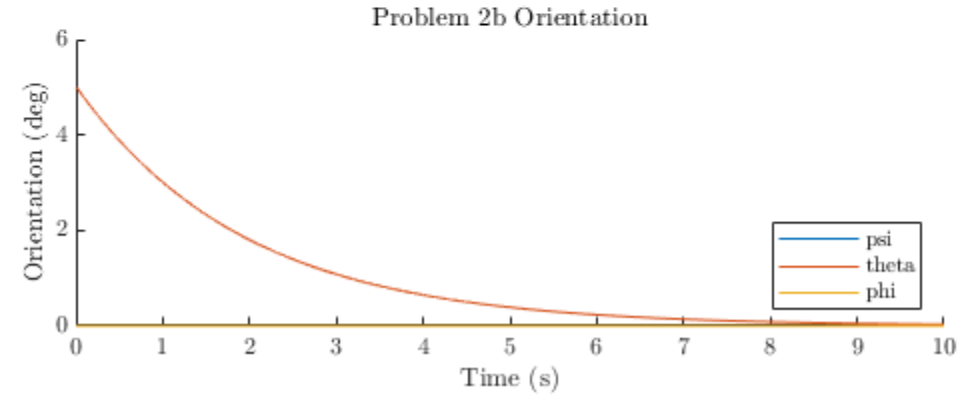
```
clear,clc,close all
dtheta = 5*pi/180;
dphi = 5*pi/180;
dp = 0.1;
dq = 0.1;
k1 = 0.0116;
k2 = 0.005916;
k3 = 0.0144;
k4 = 0.007344;
letter = ['a','b','c','d'];
changes = [dphi,0,0,0,0,0;0,dtheta,0,0,0,0;0,0,0,dp,0,0;...
    0,0,0,0,dq,0];
[row,~] = size(changes);
for i = 1:row
    change = changes(i,:);
    % Non changing values
    mass = 0.068; % kg
    g = 9.81; % m/s^2
    weight = mass*g; % N B frame 3x1
    radius = 0.060; % m
    del_f1 = 0; % N B frame 3x1
    del_f2 = 0; % N B frame 3x1
    del_f3 = 0; % N B frame 3x1
    del_f4 = 0; % N B frame 3x1
    I_B = [6.8e-5,0,0;0,9.2e-5,0;0,0,1.35e-4]; % kg/m^2 B frame 3x3
```

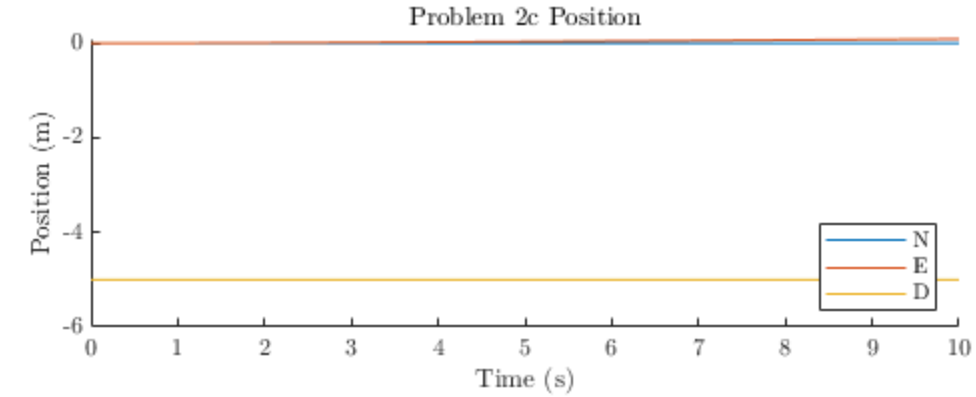
```
    tspan = [0 10];

    % Initial conditions for changing variables
    pos_N = 0; pos_E = 0; pos_D = -5; % m E frame
    velE_xB = 0; velE_yB = 0; velE_zB = 0; % m/s B frame
    y_trans = [pos_N; pos_E; pos_D; velE_xB; velE_yB; velE_zB];

    psi = change(3); theta = change(2); phi = change(1); % rad
    p = change(4); q = change(5); r = change(6); % rad/s B frame
    y_rot   = [psi; theta; phi; p; q; r];

    y = [y_trans;y_rot];

    opt = odeset('maxstep',0.001);
    [t,pos] =
ode45(@(t,y)linearized_FB_quadcopter_ODE(t,y,mass,I_B,g,radius,del_f1,del_f2,del_

    figure(i)
    subplot(2,1,1)
    hold on
    plot(t,pos(:,1))
    plot(t,pos(:,2))
    plot(t,pos(:,3))
    xlabel('Time (s)')
    ylabel('Position (m)')
    title(sprintf("Problem 2%s Position",letter(i)))
    legend('N','E','D','location','southeast')
    subplot(2,1,2)
    hold on
    plot(t,pos(:,7).*180./pi)
    plot(t,pos(:,8).*180./pi)
    plot(t,pos(:,9).*180./pi)
    xlabel('Time (s)')
    ylabel('Orientation (deg)')
    title(sprintf("Problem 2%s Orientation",letter(i)))
    legend('psi','theta','phi','location','southeast')

end
```

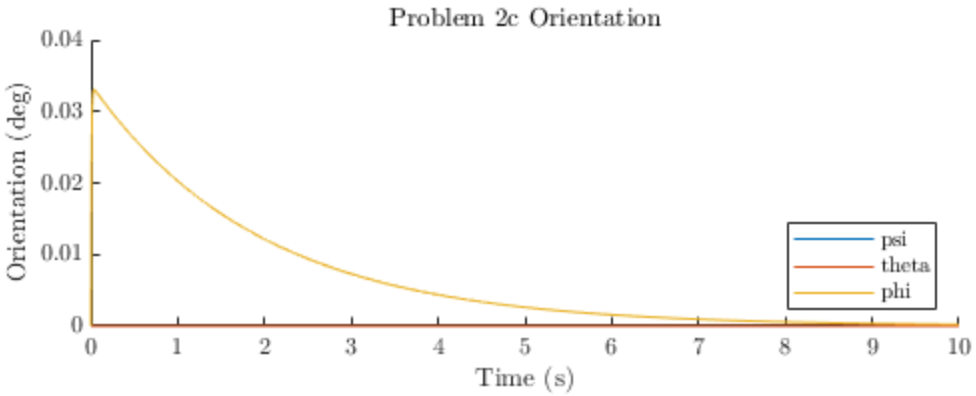

Problem 2a Position
Position (m)
Time (s)
N
E
D

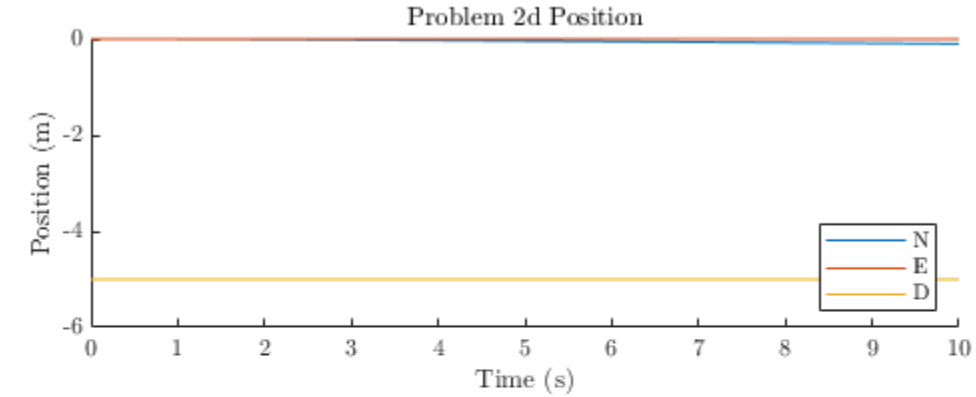

Problem 2a Orientation
Orientation (deg)
Time (s)
psi
theta
phi

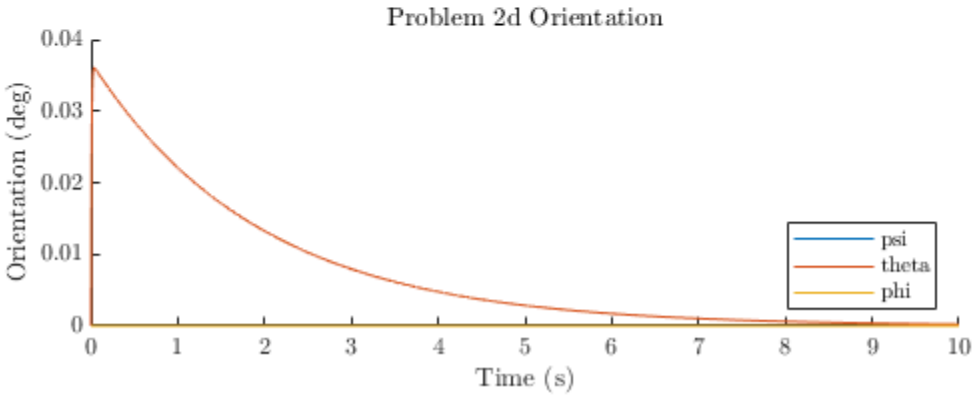

Problem 2b Position
Position (m)
Time (s)
N
E
D


Problem 2b Orientation
Orientation (deg)
Time (s)
psi
theta
phi


Problem 2c Position
Position (m)
Time (s)
N
E
D


Problem 2c Orientation
Orientation (deg)
Time (s)
psi
theta
phi

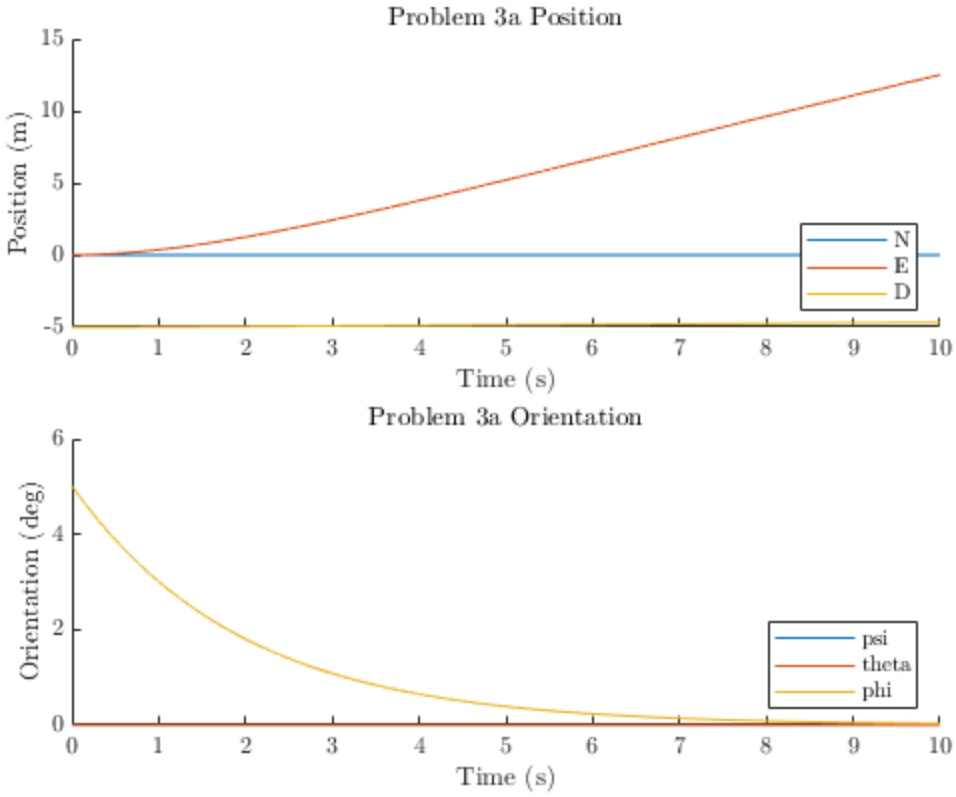

Problem 2d Position
Position (m)
Time (s)
N
E
D

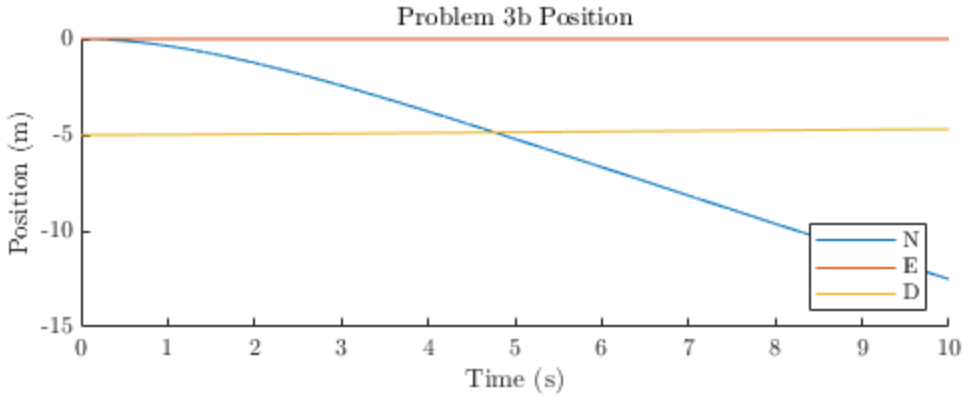

Problem 2d Orientation
Orientation (deg)
Time (s)
psi
theta
phi

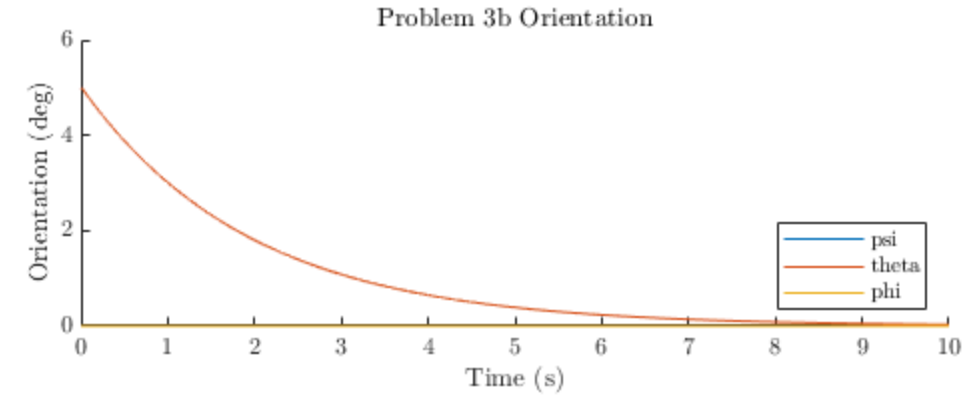
Problem 3

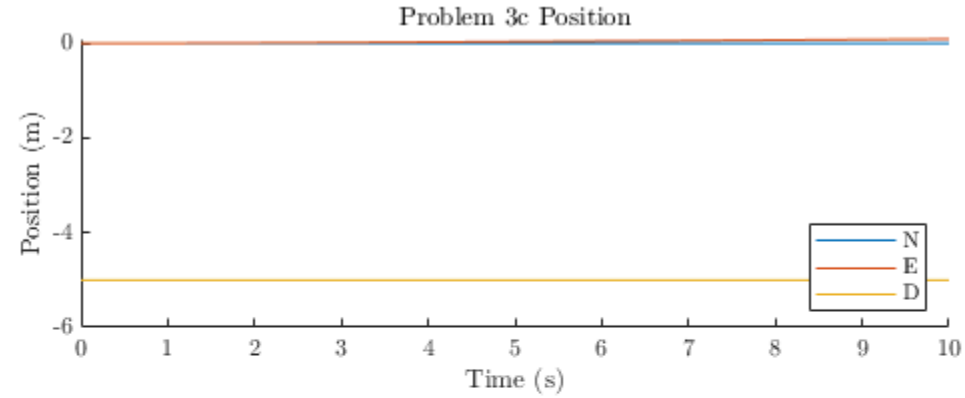
```
clear,clc,close all
dtheta = 5*pi/180;
dphi = 5*pi/180;
dp = 0.1;
dq = 0.1;
k1 = 0.0116;
k2 = 0.005916;
k3 = 0.0144;
k4 = 0.007344;
letter = ['a','b','c','d'];
changes = [dphi,0,0,0,0,0;0,dtheta,0,0,0,0;0,0,0,dp,0,0;...
    0,0,0,0,dq,0];
[row,~] = size(changes);
for i = 1:row
    change = changes(i,:);
    % Non changing values
    mass = 0.068; % kg
    g = 9.81; % m/s^2
    weight = mass*g; % N B frame 3x1
    radius = 0.060; % m
    f1 = -weight/4; % N B frame 3x1
    f2 = -weight/4; % N B frame 3x1
    f3 = -weight/4; % N B frame 3x1
    f4 = -weight/4; % N B frame 3x1
    I_B = [6.8e-5,0,0;0,9.2e-5,0;0,0,1.35e-4]; % kg/m^2 B frame 3x3
    tspan = [0 10];

    % Initial conditions for changing variables
    pos_N = 0; pos_E = 0; pos_D = -5; % m E frame
    velE_xB = 0; velE_yB = 0; velE_zB = 0; % m/s B frame
    y_trans = [pos_N; pos_E; pos_D; velE_xB; velE_yB; velE_zB];

    psi = change(3); theta = change(2); phi = change(1); % rad
    p = change(4); q = change(5); r = change(6); % rad/s B frame
    y_rot   = [psi; theta; phi; p; q; r];

    y = [y_trans;y_rot];

    opt = odeset('maxstep',0.001);
    [t,pos] =
 ode45(@(t,y)FB_quadcopter_ODE(t,y,mass,I_B,g,k1,k2,k3,k4),tspan,y,opt);

    figure(i)
    subplot(2,1,1)
    hold on
    plot(t,pos(:,1))
    plot(t,pos(:,2))
    plot(t,pos(:,3))
    xlabel('Time (s)')
    ylabel('Position (m)')
    title(sprintf("Problem 3%s Position",letter(i)))
```

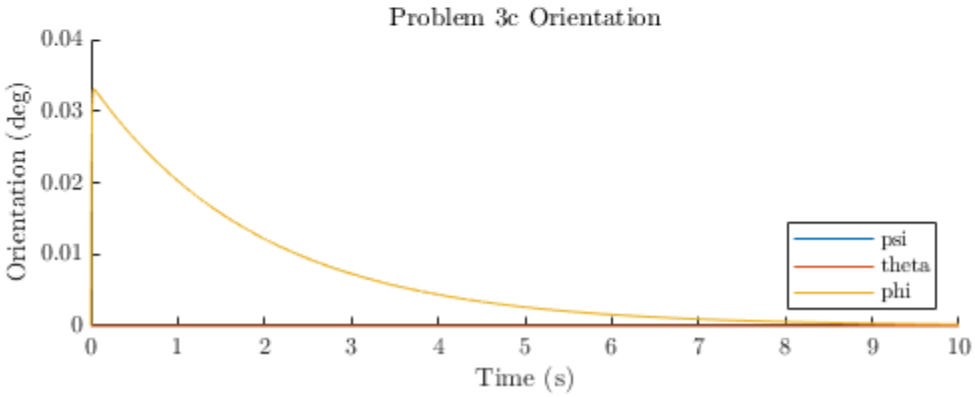
```
        legend('N','E','D','location','southeast')
        subplot(2,1,2)
        hold on
        plot(t,pos(:,7).*180./pi)
        plot(t,pos(:,8).*180./pi)
        plot(t,pos(:,9).*180./pi)
        xlabel('Time (s)')
        ylabel('Orientation (deg)')
        title(sprintf("Problem 3%s Orientation",letter(i)))
        legend('psi','theta','phi','location','southeast')

end
```

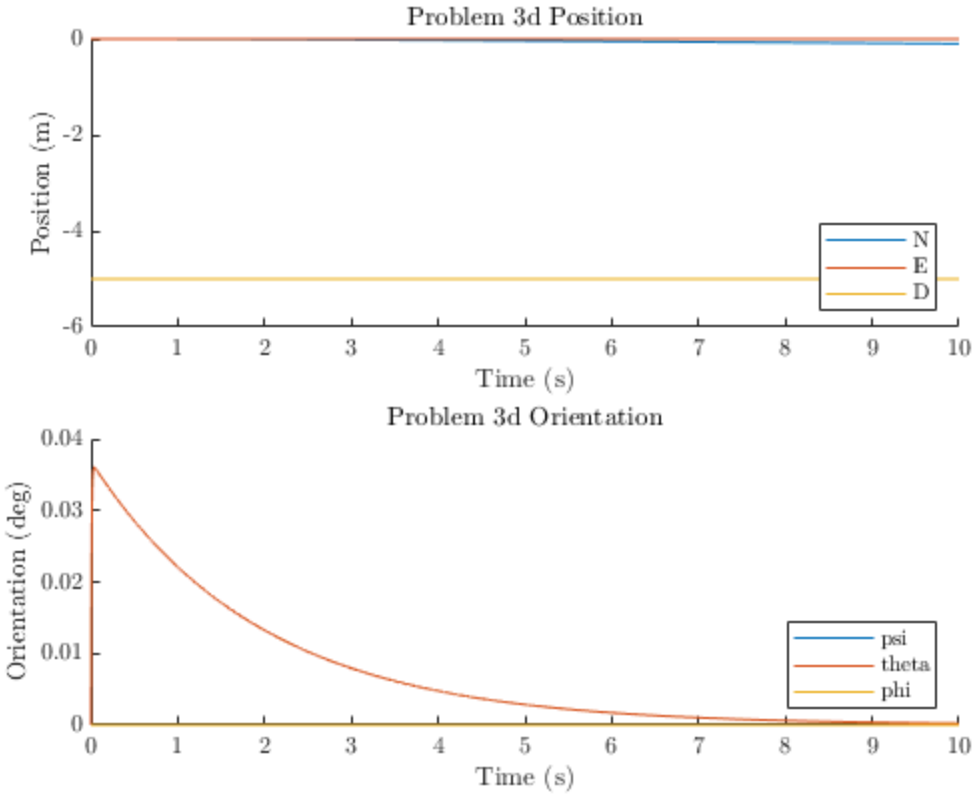



Problem 3b Position
Position (m)
Time (s)
N
E
D


Problem 3b Orientation
Orientation (deg)
Time (s)
psi
theta
phi


Problem 3c Position
Position (m)
Time (s)
N
E
D

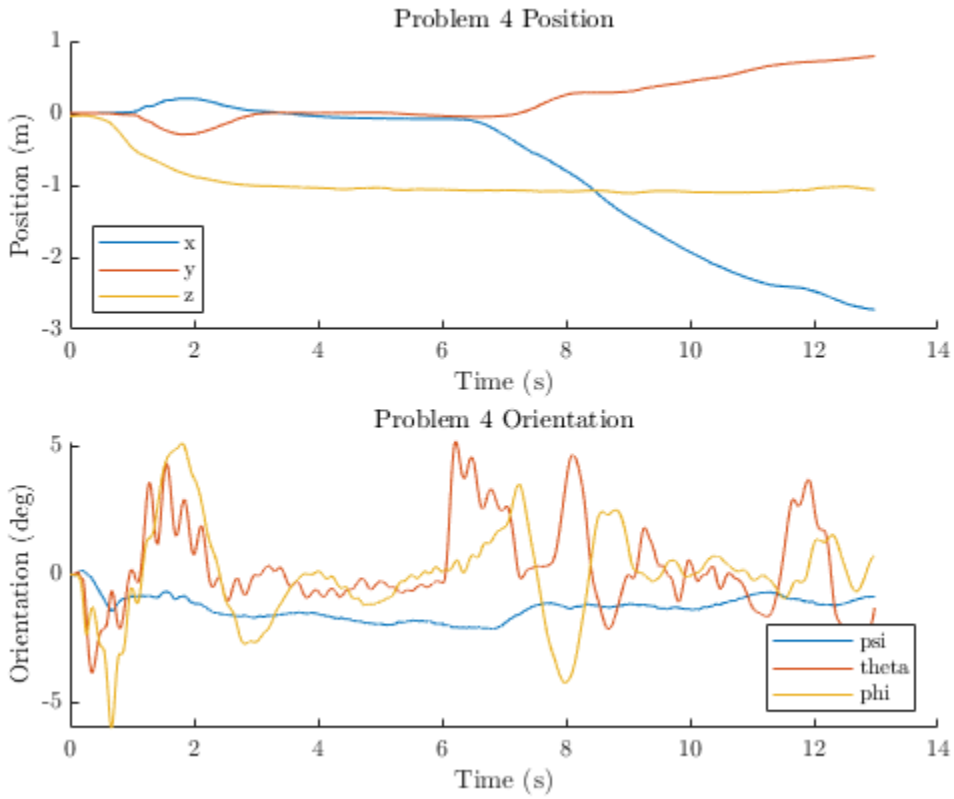

Problem 3c Orientation
Orientation (deg)
Time (s)
psi
theta
phi



Problem 4

```
clear,clc,close all

load RSdata_one_1512.mat
times = rt_estimatedStates.time(:);
xdata = rt_estimatedStates.signals.values(:,1);
ydata = rt_estimatedStates.signals.values(:,2);
zdata = rt_estimatedStates.signals.values(:,3);
psi = rt_estimatedStates.signals.values(:,4);
theta = rt_estimatedStates.signals.values(:,5);
phi = rt_estimatedStates.signals.values(:,6);

figure(18)
subplot(2,1,1)
hold on
plot(times,xdata)
plot(times,ydata)
plot(times,zdata)
xlabel('Time (s)')
ylabel('Position (m)')
title("Problem 4 Position")
legend('x','y','z','location','southwest')

subplot(2,1,2)
```

```
hold on
plot(times,psi.*180./pi)
plot(times,theta.*180./pi)
plot(times,phi.*180./pi)
xlabel('Time (s)')
ylabel('Orientation (deg)')
title("Problem 4 Orientation")
legend('psi','theta','phi','location','southeast')
```



Functions Called

The following functions were built and called as part of this assignment.

```
function [dydt] =
 linearized_FB_quadcopter_ODE(t,y,mass,I_B,g,radius,del_f1,del_f2,del_f3,del_f4,k1
% quadcopter_ODE This function is used to simulate trimmed flight of a
% quadcopter with simplified kinematics and dynamics.

% Position in E frame
del_pos_N = y(1); del_pos_E = y(2); del_pos_D = y(3); % m
% Velocity in B frame
del_vel_xB = y(4); del_vel_yB = y(5); del_vel_zB = y(6); % m/s
del_psi = y(7); del_theta = y(8); del_phi = y(9); % rad
del_p = y(10); del_q = y(11); del_r = y(12); % rad/s
del_VE_B = [del_vel_xB;del_vel_yB;del_vel_zB];
```

```
% Transfer matrix from B to E frame coordinates
L_EB =
 [cos(del_theta)*cos(del_psi),sin(del_phi)*sin(del_theta)*cos(del_psi)-
cos(del_phi)*sin(del_psi),...

 cos(del_phi)*sin(del_theta)*cos(del_psi)+sin(del_phi)*sin(del_psi);cos(del_theta)

 sin(del_phi)*sin(del_theta)*sin(del_psi)+cos(del_phi)*cos(del_psi),...
    cos(del_phi)*sin(del_theta)*sin(del_psi)-
sin(del_phi)*cos(del_psi);...
    -
sin(del_theta),sin(del_phi)*cos(del_theta),cos(del_phi)*cos(del_theta)];

% Forces from rotors and aerodynamic drag
del_Xc = 0;
del_Yc = 0;
del_Zc = del_f1+del_f2+del_f3+del_f4;
del_Ac = [del_Xc;del_Yc;del_Zc];

% Acceleration in B frame coordinates
del_u_d = -g*del_theta;
del_v_d = g*del_phi;
del_w_d = 1/mass*del_Ac(3);

% Velocity in E frame coordinates
VE_E = L_EB*del_VE_B;
vel_NE = VE_E(1);
vel_EE = VE_E(2);
vel_DE = VE_E(3);

% Finding the aerodynamic moments from rotors and drag
del_Lc = -k1*del_p - k2*del_phi;
del_Mc = -k3*del_q - k4*del_theta;
del_Nc = -0.004*del_r;
del_G_c = [del_Lc,del_Mc,del_Nc];

% Finding change in p,q,r
del_p_d = 1/I_B(1,1)*del_G_c(1);
del_q_d = 1/I_B(2,2)*del_G_c(2);
del_r_d = 1/I_B(3,3)*del_G_c(3);

% Finding changes in psi,theta,phi from p,q,r
del_psi_d = del_r;
del_theta_d = del_q;
del_phi_d = del_p;

yd_trans = [vel_NE; vel_EE; vel_DE; del_u_d; del_v_d; del_w_d];
yd_rot  = [del_psi_d; del_theta_d; del_phi_d; del_p_d; del_q_d;
 del_r_d];

dydt = [yd_trans;yd_rot];
end
```

```
function [dydt] = FB_quadcopter_ODE(t,y,mass,I_B,g,k1,k2,k3,k4)
% quadcopter_ODE This function is used to simulate trimmed flight of a
% quadcopter with simplified kinematics and dynamics.

% Position in E frame
pos_N = y(1); pos_E = y(2); pos_D = y(3); % m
% Velocity in B frame
vel_xB = y(4); vel_yB = y(5); vel_zB = y(6); % m/s
psi = y(7); theta = y(8); phi = y(9); % rad
p = y(10); q = y(11); r = y(12); % rad/s
VE_B = [vel_xB;vel_yB;vel_zB];
wEB = [p;q;r];

% Transfer matrix from B to E frame coordinates
L_EB = [cos(theta)*cos(psi),sin(phi)*sin(theta)*cos(psi)-
cos(phi)*sin(psi),...

 cos(phi)*sin(theta)*cos(psi)+sin(phi)*sin(psi);cos(theta)*sin(psi),...
    sin(phi)*sin(theta)*sin(psi)+cos(phi)*cos(psi),...
    cos(phi)*sin(theta)*sin(psi)-sin(phi)*cos(psi);...
    -sin(theta),sin(phi)*cos(theta),cos(phi)*cos(theta)];

% Weight in B frame coordinates
weight = L_EB\[0;0;mass*g];

% Drag in B frame coordinates
VEmag = norm(VE_B);
Aa = -1*10^-3.*VEmag.*VE_B;

% Forces from rotors and aerodynamic drag added together
Xc = 0;
Yc = 0;
Zc = -mass*g;
Ac = [Xc;Yc;Zc];
FB = weight+Aa+Ac;

% Acceleration in B frame coordinates
a_B = FB./mass-cross(wEB,VE_B);
uB_d = a_B(1);
vB_d = a_B(2);
wB_d = a_B(3);

% Velocity in E frame coordinates
VE_E = L_EB*VE_B;
vel_NE = VE_E(1);
vel_EE = VE_E(2);
vel_DE = VE_E(3);

% Finding the aerodynamic moments from rotors and drag
wmag = norm(wEB);
G_a = -2*10^-6*wmag.*[p;q;r];

Lc = -k1*p-k2*phi;
```

```
Mc = -k3*q-k4*theta;
Nc = -0.004*r;
G_c = [Lc;Mc;Nc];
G_B = G_a+G_c;

% Finding changes in psi,theta,phi from p,q,r
Rates = [1, sin(phi)*tan(theta), cos(phi)*tan(theta);...
         0, cos(phi),            -sin(phi);...
         0, sin(phi)*sec(theta), cos(phi)*sec(theta)]*[p;q;r];
phi_d = Rates(1);
theta_d = Rates(2);
psi_d = Rates(3);

% Finding change in p,q,r
w_d = I_B\(cross(-wEB,I_B*wEB)+G_B);

p_d = w_d(1);
q_d = w_d(2);
r_d = w_d(3);

yd_trans = [vel_NE; vel_EE; vel_DE; uB_d; vB_d; wB_d];
yd_rot  = [psi_d; theta_d; phi_d; p_d; q_d; r_d];

dydt = [yd_trans;yd_rot];
end
```

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