ASEN 5010 - HW 3

Spring 2025

Jash Bhalavat

## Problem 1

ASEN 5010

Spring 2025

Jash Bhalavat

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$\boxed{\text{HW \#3}}$

Problem 1 → 3.29

$$\sigma_i = \frac{\beta_i}{1+\beta_0}, \quad i=1,2,3.$$

$$\beta_0 = \frac{1-\sigma^2}{1+\sigma^2}, \quad \sigma^2 = \sigma_1^2+\sigma_2^2+\sigma_3^2 = \frac{\beta_1^2+\beta_2^2+\beta_3^2}{(1+\beta_0)^2} = \frac{1-\beta_0^2}{(1+\beta_0)^2} = \frac{(1-\beta_0)\cancel{(1+\beta_0)}}{(1+\beta_0)^{\cancel{2}}} = \frac{1-\beta_0}{1+\beta_0}$$

$$\beta_0 = \frac{1-\frac{(1-\beta_0)}{1+\beta_0}}{1+\frac{(1-\beta_0)}{1+\beta_0}} = \frac{\frac{\cancel{1}+\beta_0-\cancel{1}+\beta_0}{\cancel{1+\beta_0}}}{\frac{1+\cancel{\beta_0}+1-\cancel{\beta_0}}{\cancel{1+\beta_0}}} = \frac{\cancel{2}\beta_0}{\cancel{2}} = \boxed{\beta_0 = \beta_0}$$

$$\beta_i = \frac{2\sigma_i}{1+\sigma^2} = \frac{2\left(\frac{\beta_i}{1+\beta_0}\right)}{1+\frac{(1-\beta_0)}{1+\beta_0}} = \frac{\frac{2\beta_i}{\cancel{1+\beta_0}}}{\frac{1+\cancel{\beta_0}+1-\cancel{\beta_0}}{\cancel{1+\beta_0}}} = \frac{\cancel{2}\beta_i}{\cancel{2}} = \boxed{\beta_i = \beta_i}$$

# Problem 2

Problem 2 → 3.34

Eqn 3.161 → $\dot{\sigma}^S = -\dfrac{\dot{\sigma}}{\sigma^2} + \dfrac{1}{2}\left(\dfrac{1+\sigma^2}{\sigma^4}\right)\sigma\sigma^{T\,B}\underline{\omega}$

Eqn. 3.160 → $\dot{\sigma} = \dfrac{1}{4}\left[(1-\sigma^2)I_{3\times3} + 2[\tilde{\sigma}] + 2\sigma\sigma^T\right]^B\underline{\omega}$

Eqn. 3.147 → $\sigma_i^S = \dfrac{-\sigma_i}{\sigma^2}, \quad i=1,2,3$

3-147 in vector form →

$$\sigma^S = \frac{-\sigma}{\sigma^2}, \quad \sigma^2 = \sigma^T\sigma$$

$$\dot{\sigma}^S = \frac{\cancel{\sigma^2}(-\dot{\sigma})}{\sigma^{\cancel{4}\,2}} - \frac{(-\sigma)(\dot{\sigma}^T\sigma + \sigma^T\dot{\sigma})}{\sigma^4} = \frac{-\dot{\sigma}}{\sigma^2} + \frac{(\sigma)(2\sigma^T\dot{\sigma})}{\sigma^4}$$

Sub. $\dot{\sigma}$ → $\dot{\sigma}^S = -\dfrac{\dot{\sigma}}{\sigma^2} + \dfrac{(\sigma)(2\sigma^T)\left(\frac{1}{4}\left[(1-\sigma^2)I_{3\times3} + 2[\tilde{\sigma}] + 2\sigma\sigma^T\right]\right)^B\underline{\omega}}{\sigma^4}$

$(2\sigma^T[\tilde{\sigma}])$ is 0 because $\sigma$ is crossed with itself.

$$= \frac{-\dot{\sigma}}{\sigma^4} + \frac{(\sigma)\frac{1}{2}\left[\sigma^T \cdot I_{3\times3} - \sigma^T\sigma^T\sigma[I_{3\times3}] \cancelto{0}{- 2\sigma^T[\tilde{\sigma}]} + 2\sigma^T\sigma\sigma^T\right]^B\underline{\omega}}{\sigma^4} \quad (1)$$

Let $a, b, c$ be $\in \mathbb{R}$

$$\sigma^T\sigma^T\sigma[I_{3\times3}] = [a\ b\ c][a\ b\ c]\begin{bmatrix} a \\ b \\ c \end{bmatrix}\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} = [a(a^2+b^2+c^2) \quad b(a^2+b^2+c^2) \quad c(a^2+b^2+c^2)]$$

$$\sigma^T\sigma\sigma^T = [a\ b\ c]\begin{bmatrix} a \\ b \\ c \end{bmatrix}[a\ b\ c] = [a(a^2+b^2+c^2) \quad b(a^2+b^2+c^2) \quad c(a^2+b^2+c^2)]$$

i.e. $\sigma^T\sigma^T\sigma[I_{3\times3}] = \sigma^T\sigma\sigma^T$. Use this in (1)

$$\dot{\sigma}^S = \frac{-\dot{\sigma}}{\sigma^4} + \frac{(\sigma)\left(\frac{1}{2}\left[\sigma^T I_{3\times3} + \sigma^T\sigma^T\sigma\right]^B\underline{\omega}\right.}{\sigma^4} = \frac{-\dot{\sigma}}{\sigma^4} + \frac{1}{2}\frac{(1+\sigma^T\sigma)}{\sigma^4}\sigma\sigma^{T\,B}\underline{\omega}$$

$$\therefore \boxed{\dot{\sigma}^S = -\frac{\dot{\sigma}}{\sigma^4} + \frac{1}{2}\frac{(1+\sigma^2)}{\sigma^4}\sigma\sigma^{T\,B}\underline{\omega}}$$

## Problem 3

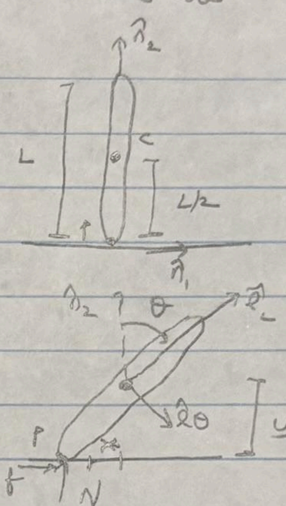
(2)

Jash Bhalerao
ASEN 5010
Spring 2025

HW #3

Problem 3 → 4.7

C – center of mass, P – point where rod touches the surface until it slips




$I_C = \frac{1}{12} mL^2$, $I_P = \frac{1}{12} mL^2 + m\frac{L^2}{4}$ (Parallel axis theorem)
$= \frac{1}{3} mL^2$

$y = \frac{L}{2}\cos\theta$, $\dot{y} = -\frac{L}{2}\dot{\theta}\sin\theta$, $\ddot{y} = -\frac{L}{2}\dot{\theta}^2\cos\theta - \frac{L}{2}\ddot{\theta}\sin\theta$

$x = \frac{L}{2}\sin\theta$, $\dot{x} = \frac{L\dot{\theta}}{2}\cos\theta$, $\ddot{x} = -\frac{L}{2}\dot{\theta}^2\sin\theta + \frac{L}{2}\ddot{\theta}\cos\theta$

$\hat{n}_2 = \cos\theta\,\hat{e}_L - \sin\theta\,\hat{e}_\theta$

Sum of forces in $\hat{n}_2$ → $m\ddot{y}\,\hat{n}_2 = (N - mg)\,\hat{n}_2 \rightarrow N = mg - \frac{mL\dot{\theta}^2}{2}\cos\theta - \frac{mL\ddot{\theta}}{2}\sin\theta$

@ Point of slippage → Sum of forces in x → $m\ddot{x}\,\hat{n}_1 = f_f = \mu N \hat{n}_1$

$\mu = \frac{m\ddot{x}}{N} = \frac{\cancel{m}\left[\frac{L}{2}(-\dot{\theta}^2\sin\theta + \ddot{\theta}\cos\theta)\right]}{\cancel{m}\left[g - \frac{L}{2}(\dot{\theta}^2\cos\theta + \ddot{\theta}\sin\theta)\right]}$ – (1)

Energy function → $V(\theta) = mgy = \frac{mgL}{2}\cos\theta$

$T(\theta,\dot{\theta}) = \frac{m}{2}\dot{y}^2 + \frac{m}{2}\dot{x}^2 + \frac{I_C}{2}\dot{\theta}^2 = \frac{m}{2}\left[\frac{L^2}{4}\sin^2\theta\,\dot{\theta}^2 + \frac{L^2}{4}\dot{\theta}^2\cos^2\theta\right] + \frac{1}{24}mL^2\dot{\theta}^2$

$E(t_0) = V_0 + T_0 = \frac{mgL}{2}$

$E(t_0) = V(\theta) + T(\theta,\dot{\theta}) = \frac{\cancel{mgL}}{2} = \frac{\cancel{mgL}}{2}\cos\theta + \frac{\cancel{m}L^{\cancel{2}}\dot{\theta}^2}{8} + \frac{\cancel{m}L^{\cancel{2}}\dot{\theta}^2}{24} \rightarrow \frac{g}{2} = \frac{g}{2}\cos\theta + \frac{L\dot{\theta}^2}{6}$

$\dot{\theta}^2 = \frac{3g}{L}(1-\cos\theta)$ – (2)

Torque @ point P → $L_P = I_P\ddot{\theta} = \frac{L}{2}\hat{e}_L \times -mg\,\hat{n}_2 = \frac{L}{2}\hat{e}_L \times (-mg\cos\theta\,\hat{e}_L + mg\sin\theta\,\hat{e}_\theta)$
$= \frac{L}{2} mg\sin\theta\,\hat{e}_3$

$\ddot{\theta} = \frac{\cancel{L}}{2}\cancel{m}g\sin\theta \cdot \frac{3}{\cancel{mL^2}} = \frac{3g}{2L}\sin\theta$ – (3)

Plug (2), (3) into (1) → $\mu = \frac{\frac{L}{2}\left[-\frac{3g}{L}(1-\cos\theta)\sin\theta + \frac{3g}{2L}\sin\theta\cos\theta\right]}{g - \frac{L}{2}\left(\frac{3g}{L}(1-\cos\theta)\cos\theta\right) + \frac{3g}{2L}\sin^2\theta)} = \frac{-\frac{3\cancel{g}}{2}(\sin\theta - \sin\theta\cos\theta) + \frac{3\cancel{g}}{2}\sin\theta\cos\theta}{\cancel{g} - \frac{3\cancel{g}}{2}(\cos\theta - \cos^2\theta) - \frac{3\cancel{g}}{2}\sin^2\theta}$

$$\boxed{\mu = \frac{-\frac{3}{2}\sin\theta + 3\sin\theta\cos\theta}{1 - \frac{3}{2}\cos\theta + \frac{3}{2}\cos^2\theta - \frac{3}{2}\sin^2\theta}}$$

## Problem 4

This problem can be divided into 3 different equations of motions: translational, rotational, and Euler angles. All these equations of motion are differential equations (either 1st order or 2nd order) and can be numerically integrated using Matlab's ODE45 solver. At the least, the solver requires an initial condition and a function that implements the equation of motion. All three sets of equations can be augmented into one vector to compactly script in Matlab. The augmented state vector is as follows:

$$state = [x^{N}_{CN}, y^{N}_{CN}, z^{N}_{CN}, x^{\cdot N}_{CN}, y^{\cdot N}_{CN}, z^{\cdot N}_{CN}, \omega_{PN,1}, \omega_{PN,2}, \omega_{PN,3}, \alpha, \beta, \gamma]^{T}$$

The equations of motion for each of the 3 sets are as follows:

Translational Equations of Motion:

Problem 4 → Translational EOMs:

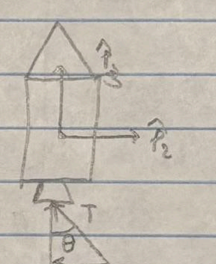
$${}^{N}\vec{x}_{CN} = [x, y, z, \dot{x}, \dot{y}, \dot{z}] \rightarrow {}^{N}\dot{\vec{x}}_{CN} = [\dot{x}, \dot{y}, \dot{z}, \ddot{x}, \ddot{y}, \ddot{z}]$$ where all these elements represent COM from inertial origin in inertial frame

Using super-particle theorem:

$$m\,{}^{N}\ddot{x}_{CN} = {}^{N}T_x$$
$$m\,{}^{N}\ddot{y}_{CN} = {}^{N}T_y$$
$$m\,{}^{N}\ddot{z}_{CN} = {}^{N}T_z - mg$$

${}^{N}T_x, {}^{N}T_y, {}^{N}T_z$ are components of thrust in inertial frame

$m = 1\,kg$, $g = 9.81\,\frac{m}{s^2}$




Thrust in principal frame → ${}^{P}[0, -T(t)\sin\theta, T(t)\cos\theta]$ ${}^{P}\vec{T}(t)$

$T(t) = 15\,N$ (if $t \le 10\,s$) & $0\,N$ (if $t > 10\,s$), $\theta = 2.5°$

${}^{N}\vec{T}$ can be found → ${}^{N}\vec{T} = [NP]\,{}^{P}\vec{T} = [PN]^{T}\,{}^{P}\vec{T}$

where $PN(t) = R_3(\gamma(t))\,R_2(\beta(t))\,R_1(\alpha(t))$

Rotational Equations of Motion:

Rotational EOMs →

${}^{P}L_c = {}^{P}r_{Nozzle} \times {}^{P}T(t)$ where ${}^{P}r_{Nozzle} = [0, 0, -3]\,m$

$$I_{11}\,\dot{\omega}_{PN}(1) = -(I_{33} - I_{22})\,\omega_{PN}(2)\,\omega_{PN}(3) + {}^{P}L_c(1)$$
$$I_{22}\,\dot{\omega}_{PN}(2) = -(I_{11} - I_{33})\,\omega_{PN}(1)\,\omega_{PN}(3) + {}^{P}L_c(2)$$
$$I_{33}\,\dot{\omega}_{PN}(3) = -(I_{22} - I_{11})\,\omega_{PN}(1)\,\omega_{PN}(2) + {}^{P}L_c(3)$$

where $I_{11} = 32.5\,kg\,m^2$, $I_{22} = 32.5\,kg\,m^2$, $I_{33} = 5\,kg\,m^2$

Euler angles Equations of Motion:

Euler EOMs $\rightarrow$ $\dot{\vec{\theta}} = B(\vec{\theta})\, \omega_{PN}$ where $\vec{\theta} = [\alpha, \beta, \gamma]^T$ & $\dot{\vec{\theta}} = [\dot{\alpha}, \dot{\beta}, \dot{\gamma}]^T$

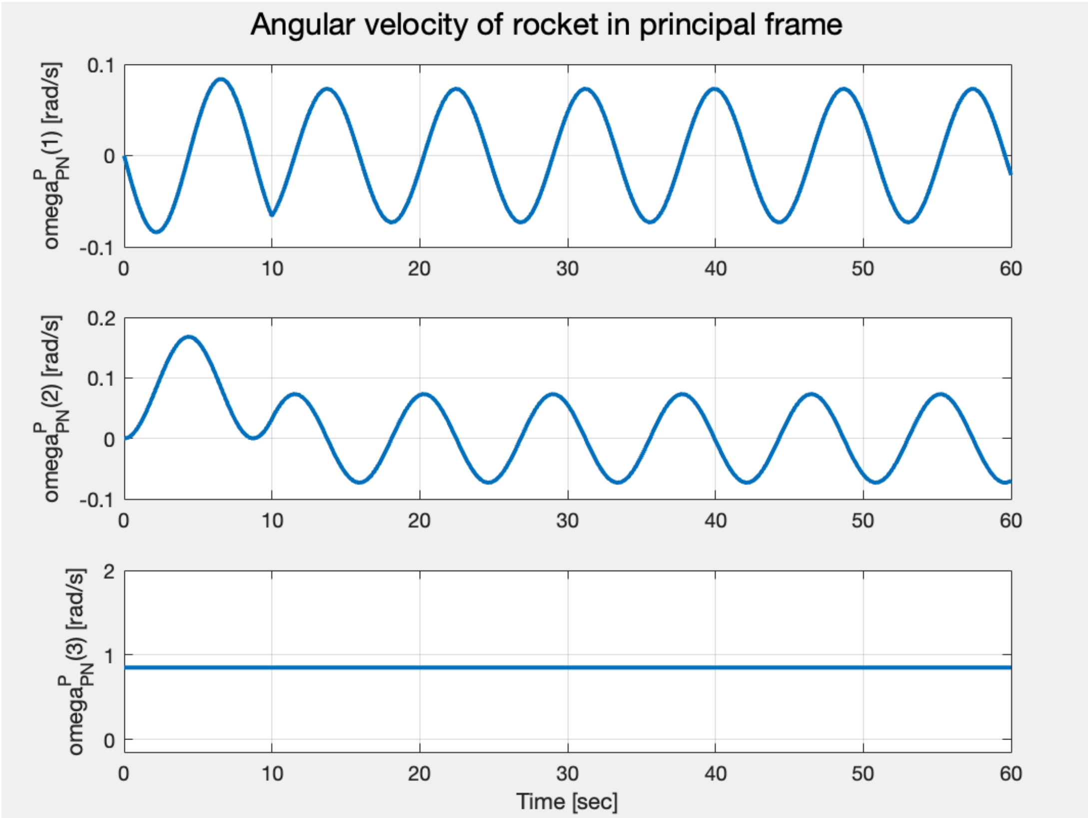
$$B(\theta) = \frac{1}{\cos\beta} \begin{bmatrix} \cos\gamma & -\sin\gamma & 0 \\ \cos\beta\sin\gamma & \cos\beta\cos\gamma & 0 \\ -\sin\beta\cos\gamma & \sin\beta\sin\gamma & \cos\beta \end{bmatrix}$$

All the initial conditions for the equations of motion are as follows:

IC for all EOMs $\rightarrow$ ${}^{N}\vec{X}_{(N),0} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \begin{matrix} m \\ \\ \\ \frac{m}{s} \end{matrix}$, $\vec{\omega}_{PN,0} = \begin{bmatrix} 0 \\ 0 \\ 0.85 \end{bmatrix} \frac{rad}{s}$, $\vec{\theta} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} rad$

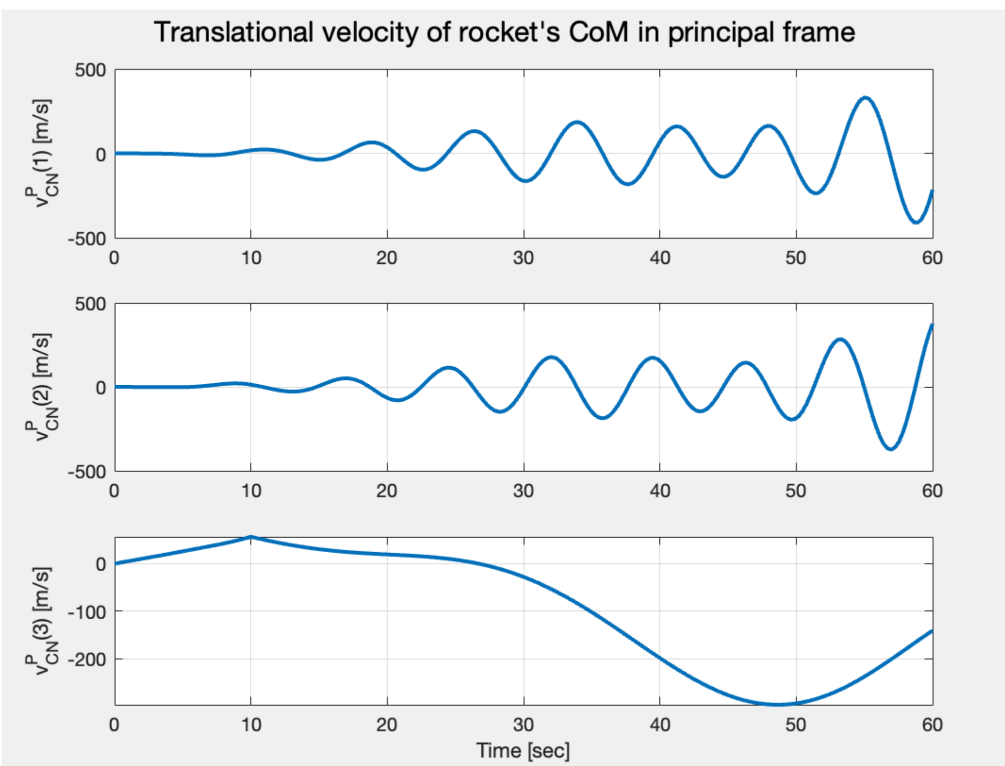
The plots are as follows:

## Part a)



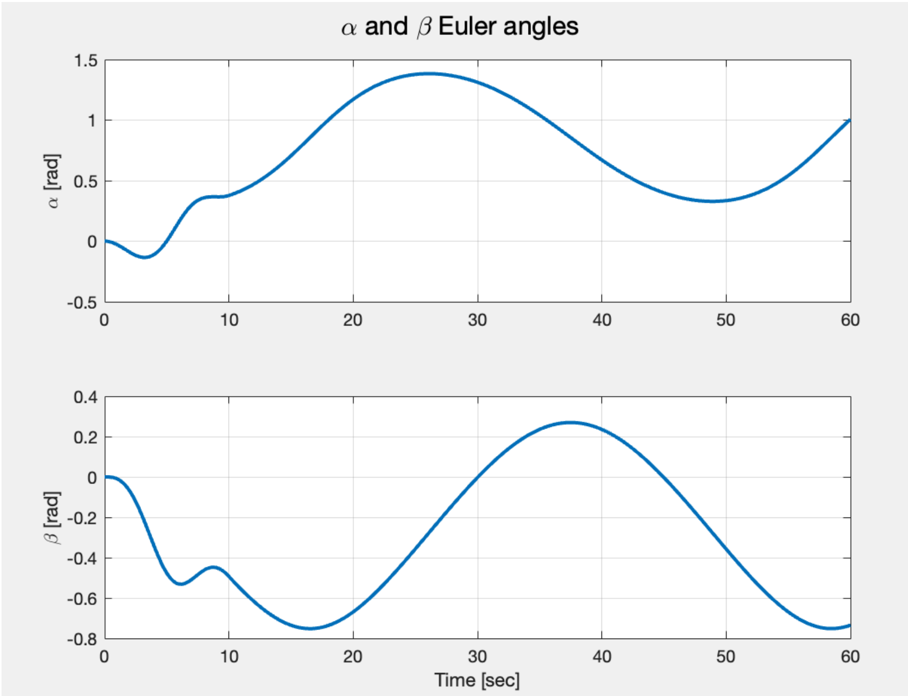
Angular velocity of rocket in principal frame
omega^P_PN(1) [rad/s]
omega^P_PN(2) [rad/s]
omega^P_PN(3) [rad/s]
Time [sec]


## Part b)

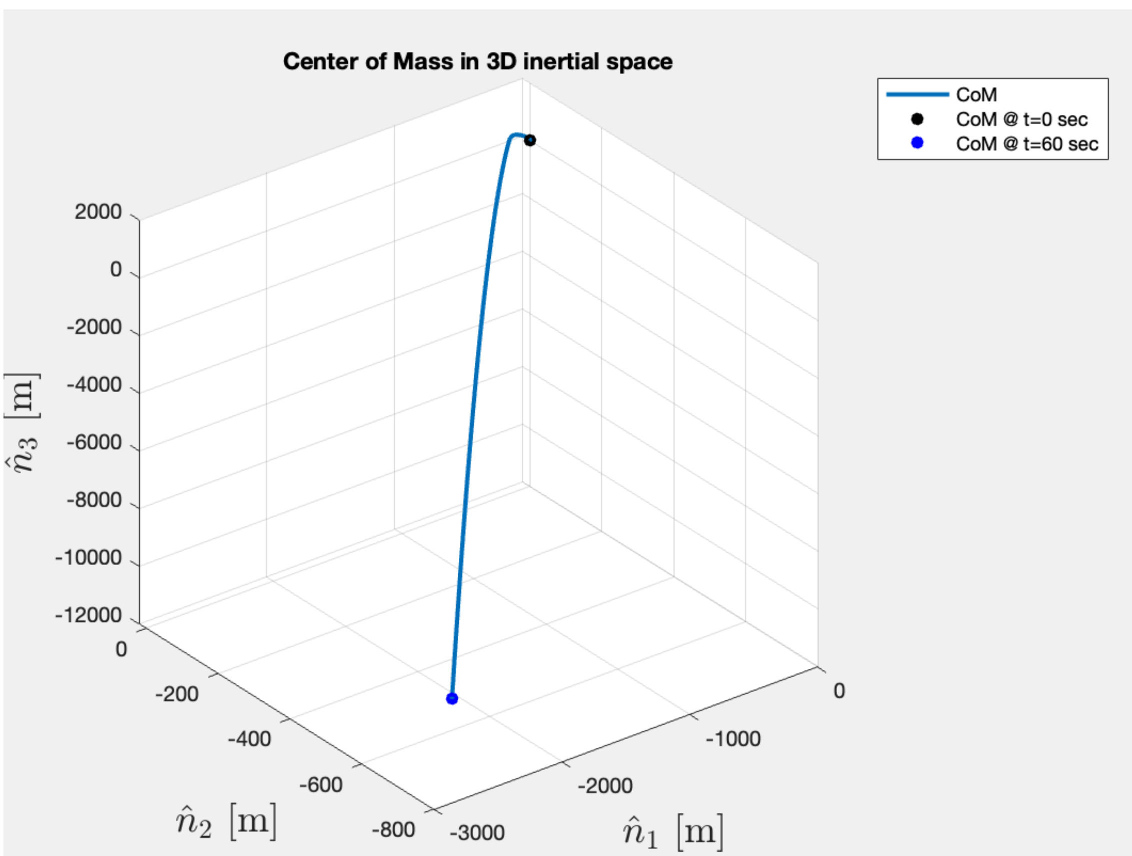


Translational velocity of rocket's CoM in principal frame
v^P_CN(1) [m/s]
v^P_CN(2) [m/s]
v^P_CN(3) [m/s]
Time [sec]

## Part c)


α and β Euler angles
1.5
1
0.5
0
-0.5
α [rad]
0
10
20
30
40
50
60
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
β [rad]
Time [sec]

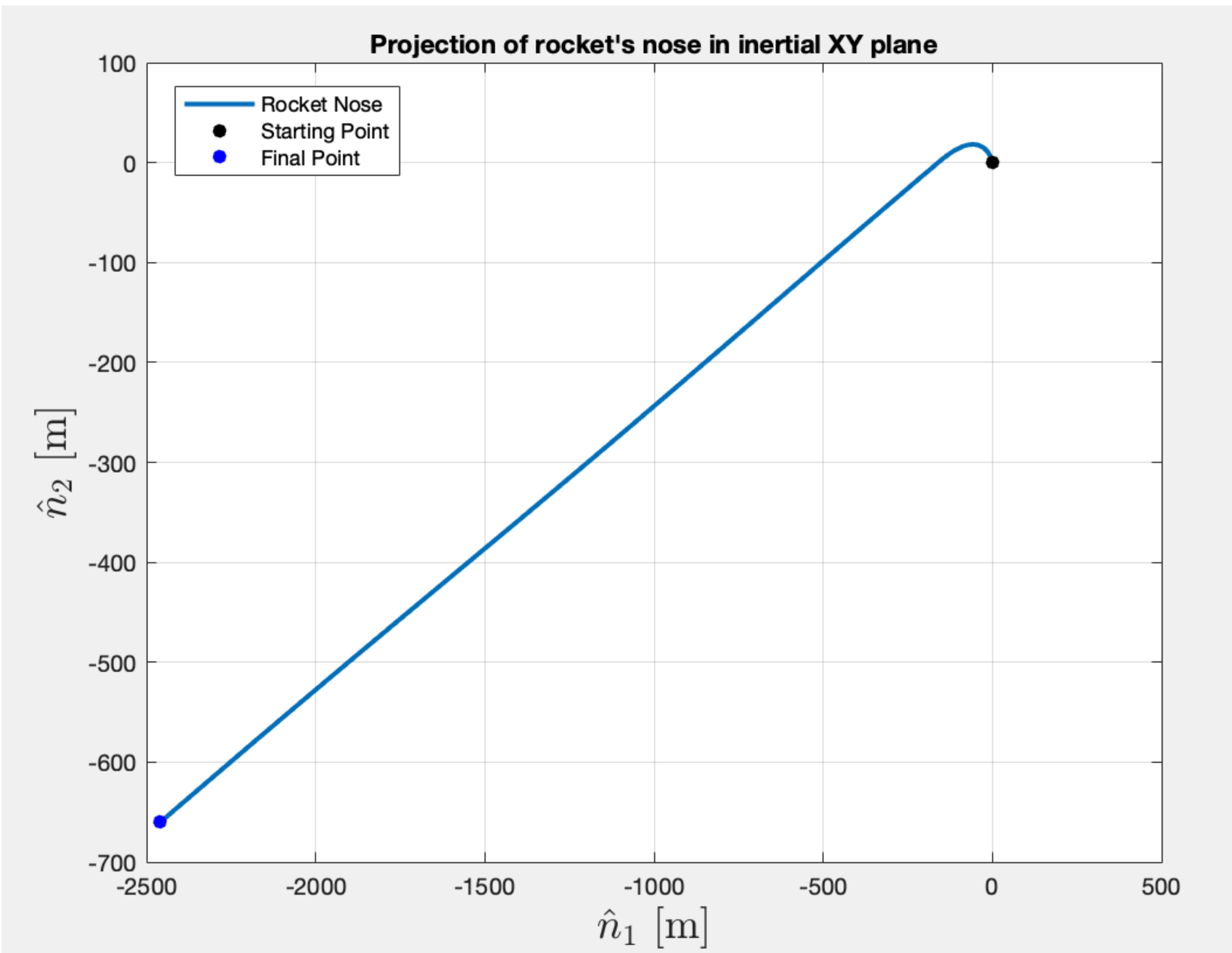
## Part d)


Center of Mass in 3D inertial space
CoM
CoM @ t=0 sec
CoM @ t=60 sec
2000
0
-2000
-4000
-6000
-8000
-10000
-12000
$\hat{n}_3$ [m]
0
-200
-400
-600
-800
$\hat{n}_2$ [m]
0
-1000
-2000
-3000
$\hat{n}_1$ [m]

**Part e)**
Rocket's nose in inertial XY plane is calculated by this equation:

$$r^N_{Nose} = r^N_{CN} + [PN]^T * r^P_{Nose}$$

where $r^P_{Nose} = [0,\ 0,\ 4]\ meters$



# Table of Contents



```
clear; clc; close all;

% ASEN 5010 - HW 3, Problem 4
% Spring 2025
% Jash Bhalavat

mass = 1; % kg
v_CN_P_0 = [0, 0, 0]'; % m/s
v_CN_N_0 = v_CN_P_0;
omega_PN_P_0 = [0, 0, 0.85]'; % rad/sec
euler_PN_0 = [0, 0, 0]'; % rad
g = 9.81; % km/s2
I_c_P = [32.5, 32.5, 5]'; % kg-m2
r_NozzleC_P = [0, 0, -3]'; % m
r_NoseC_P = [0, 0, 4]'; % m

r_CN_N_0 = [0, 0, 0]'; % [m]

tspan = [0, 60]; % sec

function thrust_P = thrust(time)
    % Thrust in Principal frame

    thruster_misalignment = deg2rad(2.5); % rad
    thruster_mag = 15; % N
    thruster_duration = 10; % sec
    thrust_parallel = 0; % [N] Passes CoM
    thrust_perp = 0; % [N]
    if time <= thruster_duration
        thrust_parallel = thruster_mag * cos(thruster_misalignment);
        thrust_perp = thruster_mag * sin(thruster_misalignment);
    end
    thrust_P = [0, -thrust_perp, thrust_parallel]'; % [N]
end

function out = L_c_P(time, r)
    % Torque at CoM in P frame
    thrust_at_time_P = thrust(time);
    out = cross(r, thrust_at_time_P); % [Nm]
end
```

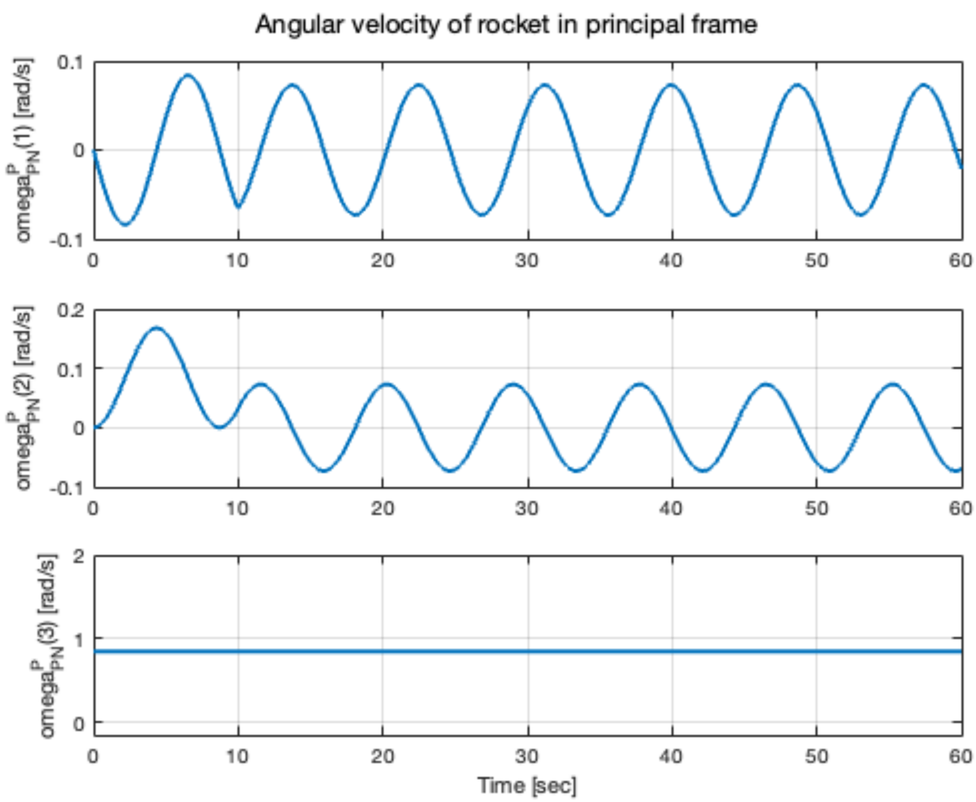
# EOM

```
state0 = [r_CN_N_0; v_CN_N_0; omega_PN_P_0; euler_PN_0];

[tout_state, state_out] = ode45(@(t, state)state_eom(t, state, mass, g,
I_c_P, r_NozzleC_P), [tspan(1), tspan(2)], state0);

function state_dot = state_eom(time, state, mass, g, I, r_NozzleC_P)
    % state - [x_N, y_N, z_N, x_N_dot, y_N_dot, z_N_dot, omega_PN_P(1),
omega_PN_P(2),
    % omega_PN_P(3), alpha, beta, gamma]'
    % state_dot - [x_N_dot, y_N_dot, z_N_dot, x_N_dotdot, y_N_dotdot,
z_N_dotdot, omega_PN_P(1), omega_PN_P(2),
    % omega_PN_P(3), alpha, beta, gamma]'

    gravity_N = [0 0 -g]';

    r_CN_N = state(1:3);
    v_CN_N = state(4:6);
    omega_PN_P = state(7:9);
    euler_PN = state(10:12);

    r_CN_N_dot = v_CN_N;

    PN = R3(euler_PN(3))*R2(euler_PN(2))*R1(euler_PN(1));

    thrust_at_time_P = thrust(time);
    thrust_at_time_N = PN' * thrust_at_time_P;
    v_CN_N_dot = (thrust_at_time_N + mass*gravity_N)/mass;

    L_c_P_at_time = L_c_P(time, r_NozzleC_P);
    omega_PN_P_dot(1,1) = -1/I(1) * (I(3) - I(2)) *
omega_PN_P(2)*omega_PN_P(3) + L_c_P_at_time(1)/I(1);
    omega_PN_P_dot(2,1) = -1/I(2) * (I(1) - I(3)) *
omega_PN_P(1)*omega_PN_P(3) + L_c_P_at_time(2)/I(2);
    omega_PN_P_dot(3,1) = -1/I(3) * (I(2) - I(1)) *
omega_PN_P(1)*omega_PN_P(2) + L_c_P_at_time(3)/I(3);

    B_theta = 1/cos(euler_PN(2)) .* [cos(euler_PN(3)), -sin(euler_PN(3)), 0;
                cos(euler_PN(2))*sin(euler_PN(3)),
cos(euler_PN(2))*cos(euler_PN(3)), 0;
                -sin(euler_PN(2))*cos(euler_PN(3)),
sin(euler_PN(2))*sin(euler_PN(3)), cos(euler_PN(2))];
    euler_PN_dot = B_theta * omega_PN_P;

    state_dot = [r_CN_N_dot; v_CN_N_dot; omega_PN_P_dot; euler_PN_dot];
end
```

# Part a

```
omega_PN_P_out = state_out(:,7:9);
```

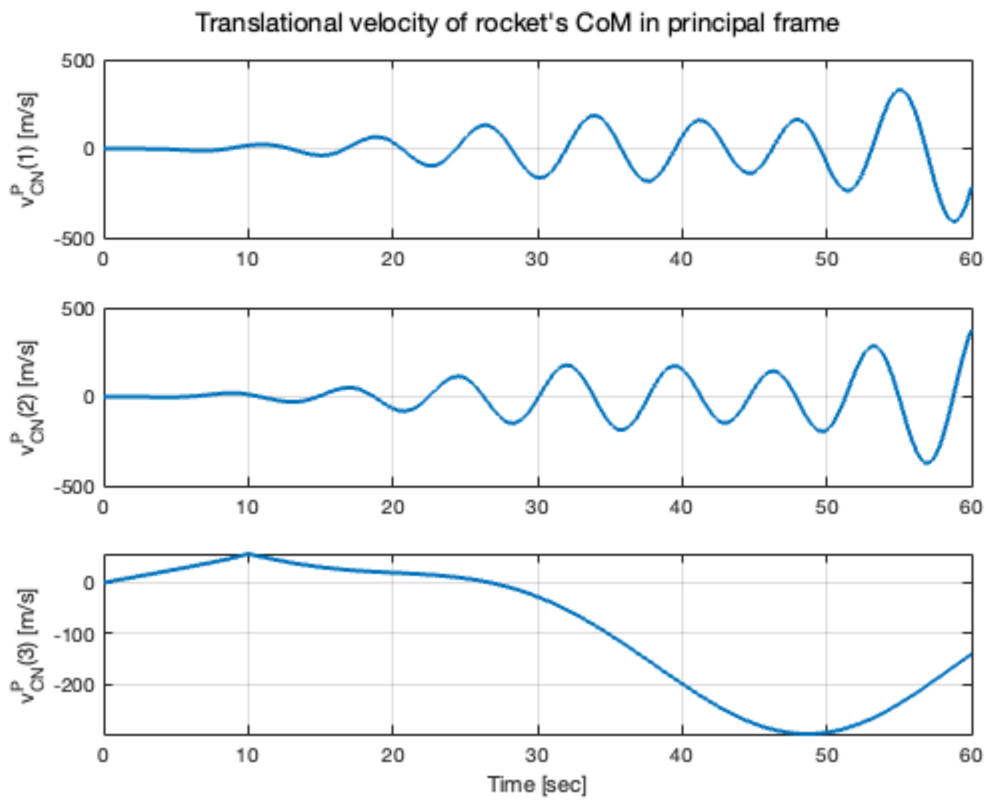
```
figure()
subplot(3,1,1)
plot(tout_state, omega_PN_P_out(:,1), 'LineWidth',2)
ylabel("omega_{PN}^P(1) [rad/s]")
grid on

subplot(3,1,2)
plot(tout_state, omega_PN_P_out(:,2), 'LineWidth',2)
ylabel("omega_{PN}^P(2) [rad/s]")
grid on

subplot(3,1,3)
plot(tout_state, omega_PN_P_out(:,3), 'LineWidth',2)
ylabel("omega_{PN}^P(3) [rad/s]")
xlabel("Time [sec]")
grid on
sgtitle("Angular velocity of rocket in principal frame")
```




# Part b

```
v_CN_N_out = state_out(:, 4:6);

for i = 1:length(tout_state)
    euler_PN = state_out(i, 10:12);
    PN = R3(euler_PN(3))*R2(euler_PN(2))*R1(euler_PN(1));
    v_CN_P_out(i,:) = (PN * v_CN_N_out(i, :)')';
```

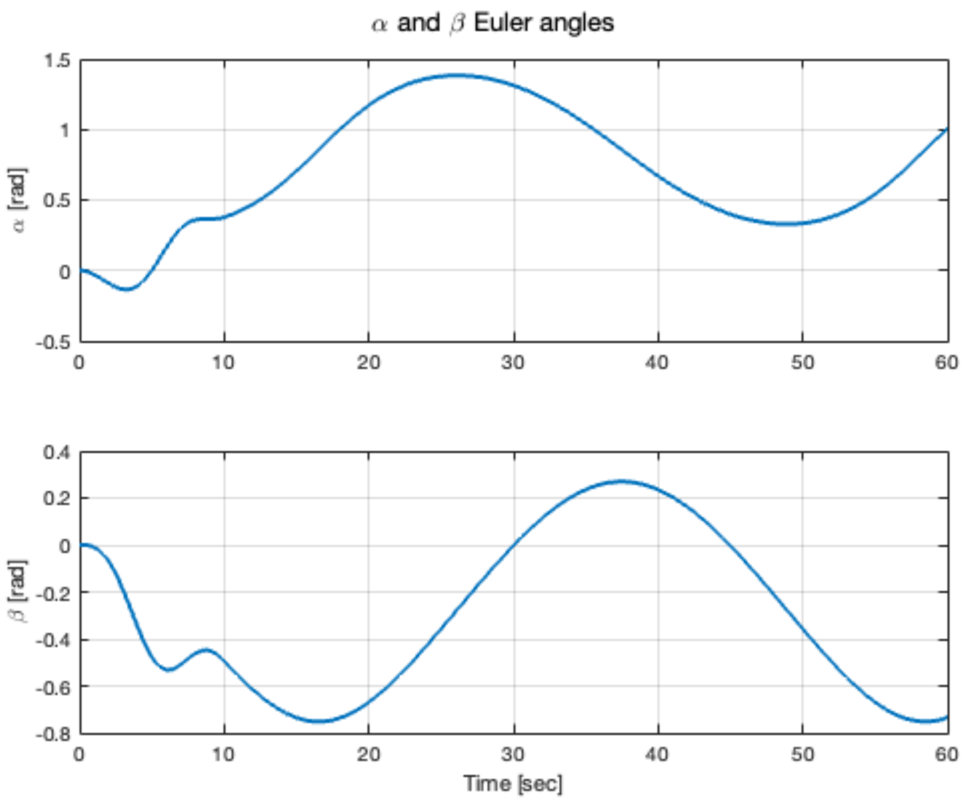
```
end

figure()
subplot(3,1,1)
plot(tout_state, v_CN_P_out(:,1), 'LineWidth',2)
ylabel("v_{CN}^P(1) [m/s]")
grid on

subplot(3,1,2)
plot(tout_state, v_CN_P_out(:,2), 'LineWidth',2)
ylabel("v_{CN}^P(2) [m/s]")
grid on

subplot(3,1,3)
plot(tout_state, v_CN_P_out(:,3), 'LineWidth',2)
ylabel("v_{CN}^P(3) [m/s]")
xlabel("Time [sec]")
grid on
sgtitle("Translational velocity of rocket's CoM in principal frame")
```




# Part c

```
euler_PN_out = state_out(:, 10:12);

figure()
subplot(2,1,1)
```

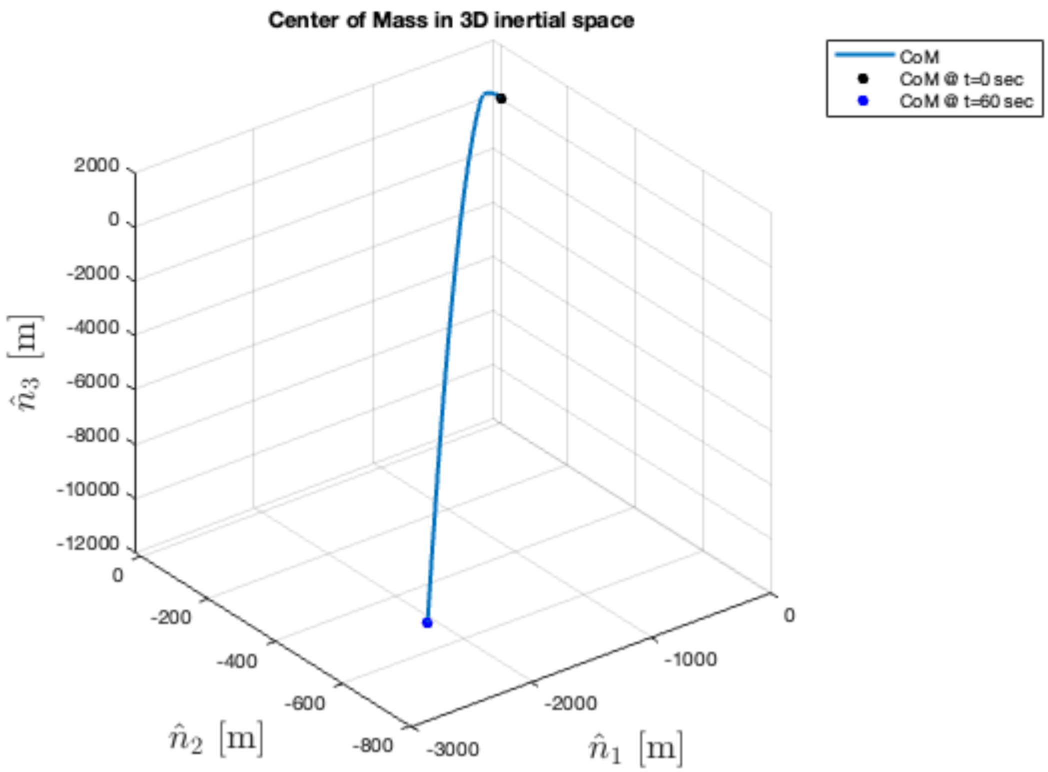
```
plot(tout_state, euler_PN_out(:,1), 'LineWidth',2)
ylabel("\alpha [rad]")
grid on

subplot(2,1,2)
plot(tout_state, euler_PN_out(:,2), 'LineWidth',2)
xlabel("Time [sec]")
ylabel("\beta [rad]")
grid on
sgtitle("\alpha and \beta Euler angles")
```

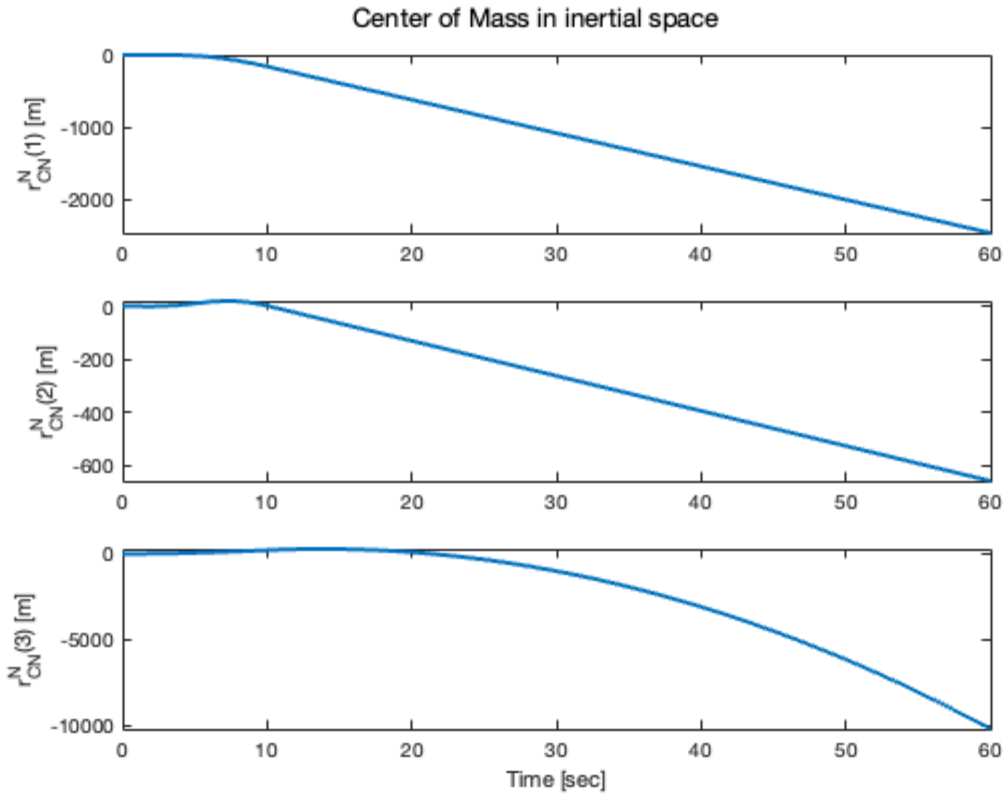



# Part d

```
figure()
plot3(state_out(:,1), state_out(:,2), state_out(:,3), 'LineWidth',2)
xlabel('$$\hat{n}_{1}$$ [m]','Interpreter','Latex', 'FontSize',18)
ylabel('$$\hat{n}_{2}$$ [m]','Interpreter','Latex', 'FontSize',18)
zlabel('$$\hat{n}_{3}$$ [m]','Interpreter','Latex', 'FontSize',18)
hold on
scatter3(state_out(1,1), state_out(1,2), state_out(1,3), 'filled', 'black')
scatter3(state_out(end,1), state_out(end,2), state_out(end,3), 'filled',
'blue')
legend("CoM", "CoM @ t=0 sec", "CoM @ t=60 sec")
grid on
title("Center of Mass in 3D inertial space")
```

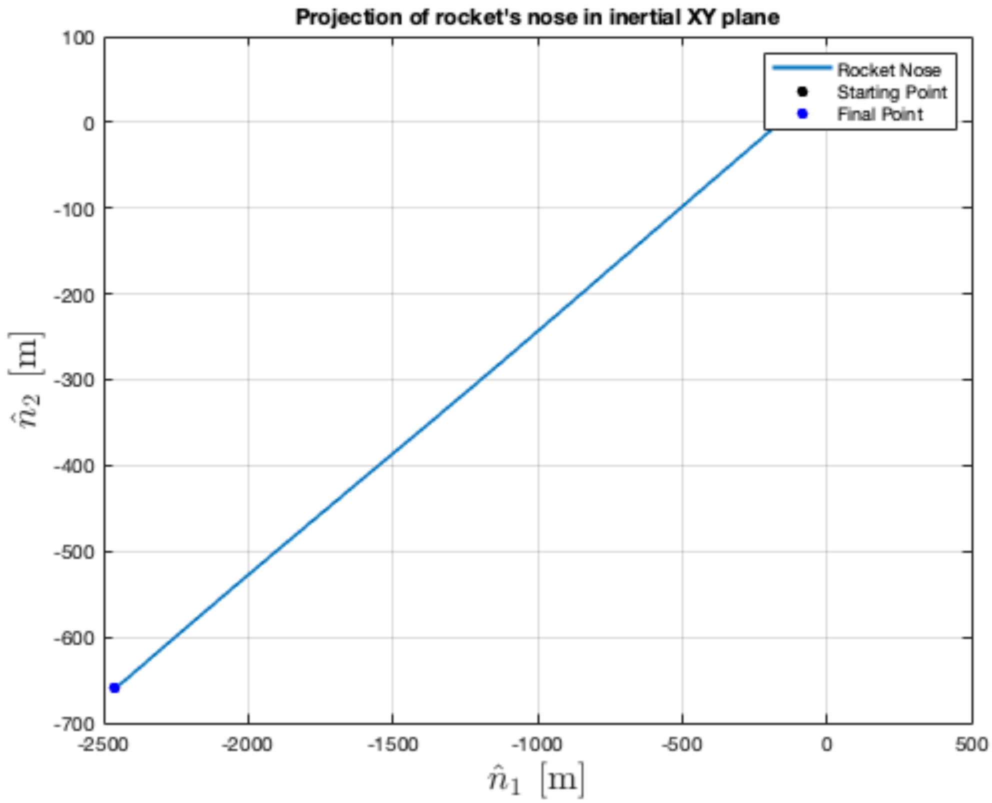
```
figure()
subplot(3,1,1)
plot(tout_state, state_out(:,1), 'LineWidth',2)
ylabel("r_{CN}^N(1) [m]")
subplot(3,1,2)
plot(tout_state, state_out(:,2), 'LineWidth',2)
ylabel("r_{CN}^N(2) [m]")
subplot(3,1,3)
plot(tout_state, state_out(:,3), 'LineWidth',2)
ylabel("r_{CN}^N(3) [m]")
xlabel("Time [sec]")
sgtitle("Center of Mass in inertial space")
```






# Part e

```
euler_PN = state_out(:,10:12);
r_CN_N = state_out(:,1:3);

for i = 1:length(tout_state)
    PN = R3(euler_PN(i, 3))*R2(euler_PN(i, 2))*R1(euler_PN(i, 1));
    r_NoseN_N(i,:) = (r_CN_N(i,:)' + PN' * r_NoseC_P)';
end

figure()
plot(r_NoseN_N(:,1), r_NoseN_N(:,2), 'LineWidth',2)
hold on
scatter(r_NoseN_N(1,1), r_NoseN_N(1,2), 'filled', 'black')
scatter(r_NoseN_N(end,1), r_NoseN_N(end,2), 'filled', 'blue')
legend("Rocket Nose", "Starting Point", "Final Point")
xlabel('$$\hat{n}_{1}$$ [m]','Interpreter','Latex', 'FontSize',18)
ylabel('$$\hat{n}_{2}$$ [m]','Interpreter','Latex', 'FontSize',18)
title("Projection of rocket's nose in inertial XY plane")
grid on
```

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