Department Aerospace Engineering

Faculty of Engineering & Architectural Science

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Question 1 – Straight Line Motion

1) Derive expressions for the components of Thrust that are required to propel a vehicle, at a constant speed along a straight-line between the L4 and L5 locations.

2) From the movie Gravity, calculate an approximate constant linear speed for the Soyuz Capsule from the I.S.S. to Tiangong S.S. Use this information how long will it take for you to travel from the L5 point to the L4 location.

From the movie gravity, Dr Stone too about 1 minute to travel 100km distance between the International Space Station and Tiangong Space Station.

$$V_{avg} = \frac{100km}{60s}$$

$$V_{avg} \approx 1.667\,\frac{km}{s}$$

Using the average speed of the Soyuz capsule from the movie, the time it would take to get from L5 to L4 location is as follows

$$t = \frac{y}{\dot{y}}$$

Where y is the distance between L5 and L4, and $\dot{y}$ is equal to the average speed

$$t = \frac{2 \cdot r_{12}\sin(60°)}{V_{avg}}$$

$$t = \frac{2 \cdot (384400\ km)\sin(60°)}{1.667\,\frac{km}{s}}$$

$$t \approx 466060.23\ s$$

$$t \approx 5.39\ days$$

Thus, it would take about 5.39 days to get from L5 to L4 locations.

3) Plot the resulting Thrust vs time curves for each of the thrust components, over the duration of your mission from the L5 to L4 location. Prove that a single thrust source could or could not produce straight-line motion.

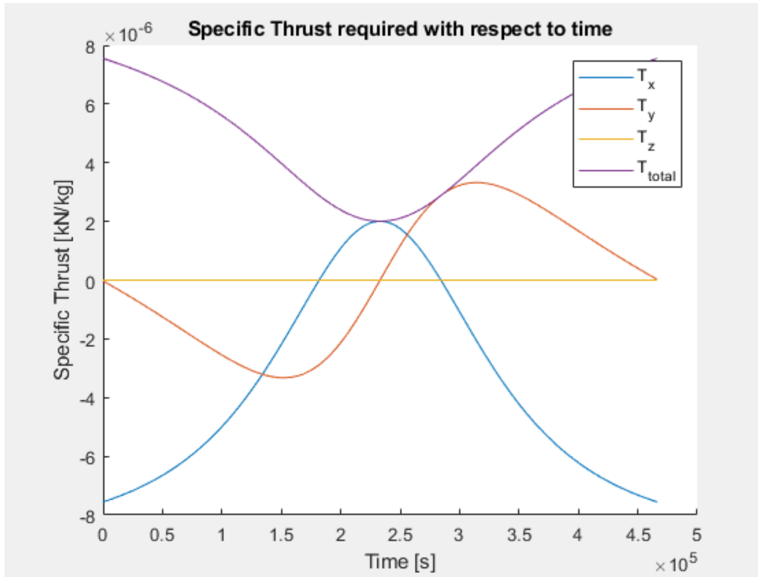

Figure 1 – Specific thrust as a function of time.

When looking at the thrust required with respect to time, it can be seen that in terms of the magnitude required for the total thrust it is possible for a single thrust source to handle it. But when it comes to the changes in the direction of the thrust vector, it is not possible to make abrupt changes in the direction of thrust when there is only one source.

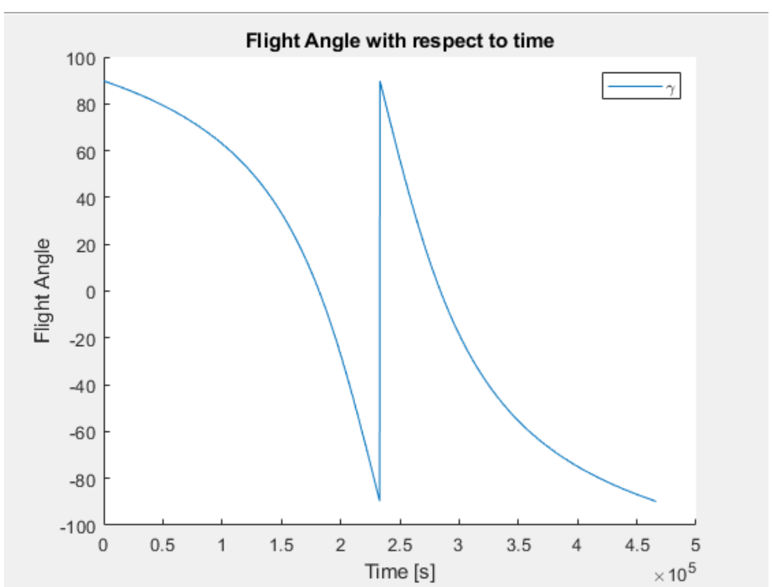

Figure 2 – Flight angle with respect to time.

Figure 2 above shows the abrupt change in direction and was calculated as follows

$$\gamma = \arctan\left(\frac{T_x}{T_y}\right)$$

Thus, even with a very powerful thrust source the fact that the mission requires an instantaneous change in velocity from one direction to another means that it must at least two thrust sources. The first source would have to cover the first half of the trip range from 90 degrees to -90 degrees with respect to the flight path, while the second takes care of the second half with the same range.

4) Calculate the total impulse required to complete this straight-line maneuver.

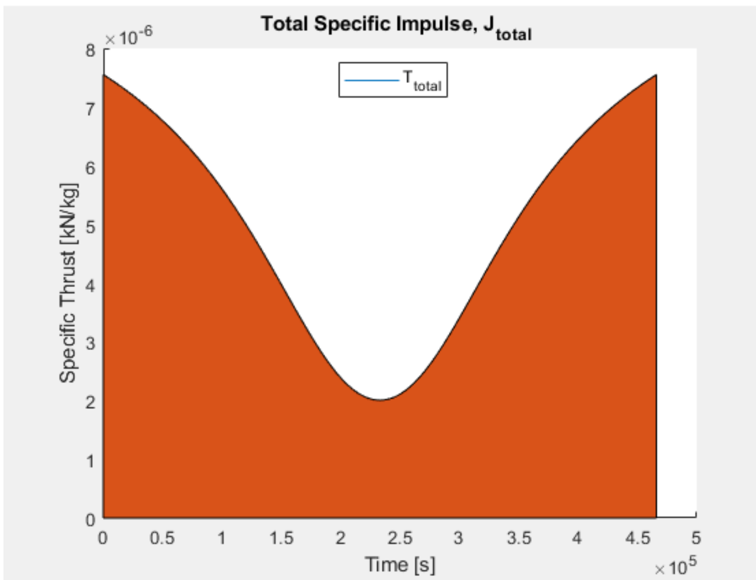

Figure – Total Specific Impulse

To calculate the total impulse, the thrust components overtime must be numerically integrated using the trapz function in MATLAB. Once the specific impulse components are determined, the magnitude of the total specific impulse can be calculated using Pythagorean theorem.

$$J_x = trapz(t\,, T_x) = 1.87542395208518\,\frac{km}{s}$$

$$J_y = trapz(t\,, T_y) = 0.925449859128774\,\frac{km}{s}$$

$$J_z = trapz(t\,, T_z) = 0\,\frac{km}{s}$$

$$|J_{total}| = \sqrt{\left(1.87542395208518\,\frac{km}{s}\right)^2 + \left(0.925449859128774\,\frac{km}{s}\right)^2 + (0)^2}$$

$$|J_{total}| = 2.09133269515308\,\frac{km}{s}$$

$$|J_{total}| \approx 2.09\,\frac{km}{s}$$

Question 2 – Hohmann Transfer based Phasing

5) Compare this straight-line motion to an equivalent phasing maneuver for two satellites orbiting the Earth at the same distances as the Moon, 384400 km, and separated by 120°.

a) What is the percent difference in the Impulses required to produce these motions?

$$\%Difference_{Impulse} = \left| \frac{J_{SL,total} - J_{PM,total}}{J_{PM,total}} \right| \times 100\%$$

$$\%Difference_{Impulse} = \left| \frac{2.09133269515308 \frac{km}{s} - 0.17268949770509 \frac{km}{s}}{0.17268949770509 \frac{km}{s}} \right| \times 100\%$$

$$\%Difference_{Impulse} = 1111.04\%$$

b) What is the percent difference in the times required to produce these motions?

$$\%Difference_{Time} = \left| \frac{t_{PM,total} - t_{SL,total}}{t_{SL,total}} \right| \times 100\%$$

$$\%Difference_{Time} = \left| \frac{1580998.50893385s - 466060.231300633s}{466060.231300633s} \right| \times 100\%$$

$$\%Difference_{Time} = 239.23\%$$

c) Comment on the impact of these differences. Under what circumstances, if any, would the reduction in time be worth the increased impulse costs of a straight-line motion? Or is it not worth it?

$$\frac{\Delta m}{m} = 1 - e^{-\frac{\Delta V}{I_{sp} \cdot g_0}}$$

$$\left(\frac{\Delta m}{m}\right)_{PM} \approx 0.03836$$

$$\left(\frac{\Delta m}{m}\right)_{SL} \approx 0.37733$$

The 1111% difference in impulse between the straight-line motion and phasing maneuver will results in a higher mass ratio. For an $I_{SP} = 450s$, the mass of propellant is going to be about 37.73% of the initial total mass of the spacecraft for the straight-line motion. When compared to the phasing maneuver with the same I_{SP}, the mass of the propellant would only be about 3.84% of the initial total mass of the spacecraft. This difference is significant when looking at cost of launching objects in space. As a reference over the course of the space shuttle's operation, the average cost of launching into the low-earth orbit is about was about $60,000 per kg. Once techno

$$t_{days} = \frac{t_s}{60 \cdot 60 \cdot 24}$$

$$t_{PM} = 18.30\ days$$

$$t_{SL} = 5.39\ days$$

When it comes to the percent difference in time between the two maneuvers, it is evident that the straight-line motion is far superior in getting from one location to another. Being in an emergency, travelling in 5.39 days compared to 18.30 days will make a difference if the crew has suffered life threatening injuries. Other than that, the amount of fuel and money saved when utilizing the phasing maneuver will outweigh the time savings of a straight-line motion.

Overall, travelling in a straight-line motion in space will not be worth it when every aspect of the mission is considered. When astronauts are sent for a mission in space, everything is carefully planned. They go through years of training and studying to be able to be as prepared as possible. Before any major problems arise, both the team on the ground and in space are already communication to avoid it.

d) Do you think that emergency rescue and/or escape missions are possible?

I think emergency rescue and escape missions are possible. The factors that needs to be considered are the costs, and the available technology. As years progress, more resources from the government, and private sector go into funding research and development in the space related missions. Some notable private companies whose goal is to make space travel cheap are SpaceX, Blue Origin, and Virgin Galactic. The renewed gain popularity of space exploration the pass decade will likely result in cheaper cost. This will make it almost a guarantee that escape pods and emergency rescues will be added. Especially once Space tourism starts to become as easy as getting in an airplane to get to another distant location.

e) What are the moral and ethical issues surrounding flights without escape capabilities.

When trying to calculate the morality rate of space flight, it is difficult since it varies depending on how they are counted and who are included. But according to NASA, as of August 2020 the current fatality rate is about 3.2% when counting the number of deaths to the total number of people that have been to space. This number is low when compared other causes of death here on the ground, but the lives lost are still people. It is not guaranteed for every space mission to be successful, and the ethical issues surrounding flight without escape comes down to whether the astronauts are willing to take the risk for something that they believe in. At the end of the day, none of these astronauts and cosmonauts are being forced into going to space. Everyone has their own reason whether it is patriotism, fulfillment of a childhood dream or doing something that they are passionate about. These men and women are selected and trained based on their knowledge and how they would manage situations. Every mission is planned and goes through rigorous testing phase before having any person in it.

Question 3 – Escape Device

6) Given your understanding of the thrusts required for maneuvering in space, what capabilities would you require for the design of:
    a. Personal Jetpack (one was built and used by NASA, 3 time in 1984)

After having a better understanding of how objects move through outer space, the main capabilities required for a jetpack are linear motion, rotational motion, viable propulsion system, and method of connecting to the user. Although it has been proven for continuous linear motion to be unrealistic in space, burst of linear motion are still required to do various orbital maneuvers. It is essential for a jetpack to have the capability to move in all three axes both in the positive and negative direction in order to both stop and go. Another essential feature is having the ability to rotate in both clockwise and anticlockwise about all three axes. To achieve this, the thruster must be a given distance from the center of mass of the system. Lastly, the jetpack would require a propulsion system. This system encompasses both the method of propulsion and the propellant. For outer space application, although drag is minimal the cost of launching into space depends a lot on the mass. Thus, minimizing fuel requirement will be a major design consideration. Lastly, the jetpack must be attached to the user with some form of strap, harness, or as part of the space suit.

    b. Escape pod (currently these is no such thing on either the Space Shuttle or the I.S.S.)

The main capabilities required for an escape pod are ensuring the safety of the users, minimal fuel requirements, a method of decelerating, controls for maneuvering to the targeted location, propulsion system, and heat protection. To get everyone home safely, the escape pod must fit the desired number of people depending on the design requirement. An average person can only handle about 12 g's before suffering any permanent damage. Thus, it is ideal both for minimizing fuel consumption and deceleration to get into a transfer orbit that slowly lowers the spacecraft to the ground opposed to diving head on downward. By deploying parachutes once closer to the ground, it would further help with decelerating the spacecraft. Having control surfaces will help if one of the requirements is to hit a specific location. But since the purpose of an escape pod is to be used at any given time, it is difficult to hit a specific location. Thus, having a bigger target such as the ocean can solve this issue. Propulsion system is required for changing orbit as well deceleration is needed. When gong through the atmosphere, extremely high temperature will be experienced by the spacecraft. Heat shield is one of the main requirements to ensure the crew gets home safely.

7) Moral/Technical Question: Did Astronaut Matt Kowalski really need to let go?
    a. What are the technical reasons why he should or should not have needed to let go?

Astronaut Matt Kowalski should not have let go because based on the scenario set by the movie the main celestial body present was Earth whose gravitational force is acting opposite to the direction of where he appeared to be going. It does not appear from any shot that there is any mass significant in size to be pulling him other than Earth. Also, once he released his tether, hi was moving slow to not be required to let go. A few seconds after he let go, he appeared to have stopped when in fact he should have kept moving.

    b. What are the moral reasons why he should or should not have let go?

Based on the scenario that that movie had portrayed, Astronaut Matt Kowalski's decision to let go was the correct choice morally speaking. Since the jetpack was out of fuel, and the rope appeared to be coming off there was not much of a choice. Based on how fast they approached the space station and the disorienting movements they had to go through it was unlikely that the rope would have held onto both. If this had happened in real life, knowing that the only choice is either to sacrifice one life or lose both, not everyone would have made the decision to let go. When it comes to space travel, there is not one to help in case of emergencies. Decisions are made by the astronauts based on the information they are given.

    c. Space and Sacrifice, what does this movie say to you? Do you believe that escape pods and rescue equipment are necessary?

This movie portrays a situation that possible to happened but is not likely to occur because space travel requires more calculation and thinking than everything done on the ground. Before a mission starts, various testing and calculations are done to ensure the safety of the crew. For example, when SpaceX launched the first manned mission to I.S.S on their crew dragon spacecraft, they did not proceed with their scheduled launch date due to the harsh weather. Space flight is cannot be done manually because humans are not capable of making small and precise measurements compared to computers. As of right now, I do not believe that escape pods are necessary for space flight given that the missions are only for selected people. And to be selected, there is a long process to ensure that the person is capable of solving difficult problems. Once space flight becomes available to public, then having escape pods and rescue equipment may become a necessity due to the difference in physical and mental capacity of a regular person to an astronaut.

8) Design your own jetpack or escape pod. Present all the calculations and details needed to describe your design. Construct a 2 minute, self-narrated, presentation of your design.

References

[1] Bray N. Dunbar B. Kennedy Space Station. Space Shuttle and Space Station. USA. [Online].Available:https://www.nasa.gov/centers/kennedy/about/information/shuttle_faq.html

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[5] Stefanov W., Space Station Orbit Tutorial. USA. [Online]. Available: https://eol.jsc.nasa.gov/Tools/orbitTutorial.htm

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Appendix

1.1 Sample Calculations

8. Escape Pod Design Calculations

Constants

$$G = 6.6742 \times 10^{-20} \frac{km^3}{kg \cdot s^2}$$

$$m_E = 5.974 \times 10^{24}\ kg$$

$$\mu = G \cdot m_E = 3.9872 \times 10^5 \frac{km^3}{s^2}$$

$$r_{a,ISS} = 6378 + 410 = 6788\ km$$

$$r_{p,ISS} = 6378 + 330 = 6708\ km$$

$$r_{p,TE} = 6378 + 80 = 6458\ km$$

Step 1: Velocity of E.P. on the International Space Station orbit

$$e_{ISS} = \frac{r_{a,ISS} - r_{p,ISS}}{r_{a,ISS} + r_{p,ISS}}$$

$$a_{ISS} = \frac{r_{a,ISS} + r_{p,ISS}}{2}$$

$$V_{ISS} = \sqrt{2 \cdot \left(\frac{\mu}{r_{ISS}}\right) - \left(\frac{\mu}{2 \cdot a_{ISS}}\right)}$$

$$h_{ISS} = V_{p,ISS} \cdot r_{p,ISS}$$

$$V_{\perp,ISS} = \frac{\mu}{h_{ISS}}(1 + e_{ISS}\cos(\theta))$$

$$V_{r,ISS} = \frac{\mu}{h_{ISS}}(1 + e_{ISS}\cos(\theta))$$

Step 2: Velocity of E.P. on the Transfer Ellipse at the Apoapsis

Target $r_{p,TE} = 6458km$ is constant while $r_{a,TE}$ varies and is equal to the r_{ISS}.

$$e_{TE} = \frac{r_{a,TE} - r_{p,TE}}{r_{a,TE} + r_{p,TE}}$$

$$a_{TE} = \frac{r_{a,TE} + r_{p,TE}}{2}$$

$$h_{TE} = \sqrt{r_{a,TE} \cdot \mu \cdot (1 - e_{TE})}$$

$$V_{a,TE} = \frac{h_{TE}}{r_{a,TE}}$$

$$V_{p,TE} = \frac{h_{TE}}{r_{p,TE}}$$

Step 3: Calculate the Delta V's

$$\Delta V_{tan} = V_{a,TE} - V_{\perp,ISS}$$

$$\Delta V_{rad} = 0 - V_{r,ISS}$$

$$\Delta V_{total} = \sqrt{\Delta V_{tan}^2 + \Delta V_{rad}^2}$$

1.2 MATLAB


```
%Project 1
format longG
```

1.2.1 Question 1 Straight-line Motion

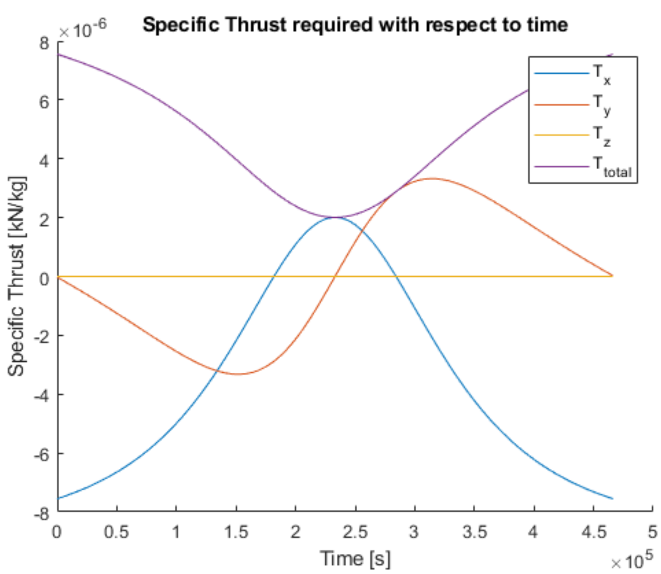
1. Derive the expression for the Thrust components to get from L5 to L4 in a straight line.

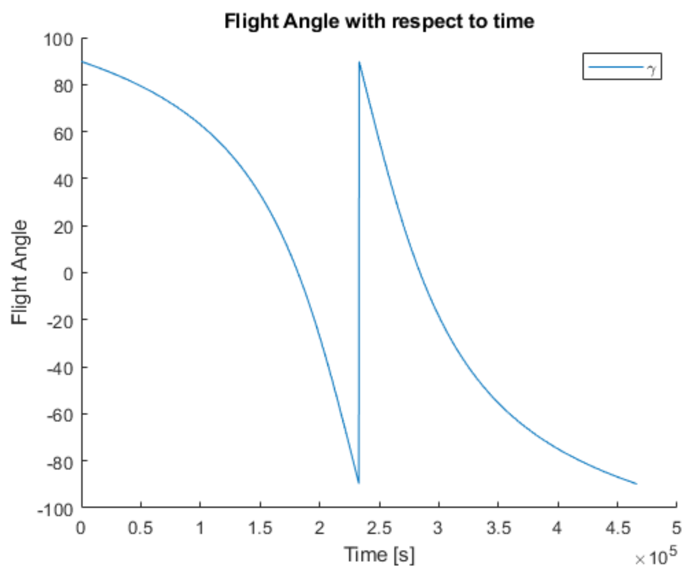
```
% Specific Thrust in the x direction


%T_x = ((mu_1./r_1.^3)*(x+pi_2*r_12))+((mu_2./r_2.^3)*(x-pi_1*r_12));
%T_y = ((mu_1./r_1.^3).*y)+((mu_2./r_2.^3).*y);
%T_z = 0;

% Thrust in the y direction

% Thrust in the z direction

% 2.How long will it take for you to travel from L5 to L4

%V_avg       = 1.428571; %[km/s] calculated based on the movie

r_12        = 384400; %[km]
V_avg = 100/(70); %[km/s]
delta_y     = 2*r_12*sind(60);
t_avg       = delta_y/V_avg;%[s]


% 3. Plot the resulting Thrust vs. Time for each component
% Constants
G           = 6.6742e-20; %[km^3/kg*s^2]
m_1         = 5.974e24; %[kg] mass of the Earth
m_2         = 73.48e21; %[kg] mass of the Moon
mu_1        = G*m_1;%[km^3/s^2]
mu_2        = G*m_2;%[km^3/s^2]

mu = G*(m_1+m_2);

pi_1 = m_1/(m_1+m_2);
pi_2 = m_2/(m_1+m_2);

x = r_12*cosd(60);
y_min =-r_12*sind(60);
y_max =r_12*sind(60);
y_dot = V_avg;
```

```
big_omega = sqrt(mu_1./r_12.^3);

% Varries

theta = linspace (-60, 60, 1000);
%y = linspace (y_min, y_max, 1000);

r_1 = x./cosd(theta);
r_2 = (r_12-x)./cosd(theta);
y = r_2.*sind(theta);

% Specific Thrust Components [kN/kg]
T_x = ((mu_1./r_1.^3).*(x+pi_2*r_12))+((mu_2./r_2.^3).*(x-pi_1*r_12))...
    - 2.*big_omega.*y_dot - big_omega.^2.*x;
T_y = ((mu_1./r_1.^3).*y)+((mu_2./r_2.^3).*y)-big_omega^2*y;
T_z = linspace(0,0,1000);
T_total = sqrt(T_x.^2+T_y.^2+T_z.^2);

t_range = (y./y_dot)+t_avg/2;


figure
title('Specific Thrust required with respect to time');
hold on
plot (t_range, (T_x));
plot (t_range, (T_y));
plot (t_range, (T_z));
plot (t_range, T_total);
legend ('T_x','T_y','T_z', 'T_t_o_t_a_l');
xlabel ('Time [s]');
ylabel ('Specific Thrust [kN/kg]')
hold off


% figuring out the direction
 gamma = atand(T_x./T_y);

 figure
title('Flight Angle with respect to time');
hold on
plot (t_range, gamma);
legend ('\gamma');
xlabel ('Time [s]');
ylabel ('Flight Angle')
hold off


% 4. Calculate the total impulse required to complete this straight-line
% maneuver.

figure
title('Total Specific Impulse, J_t_o_t_a_l ');
```

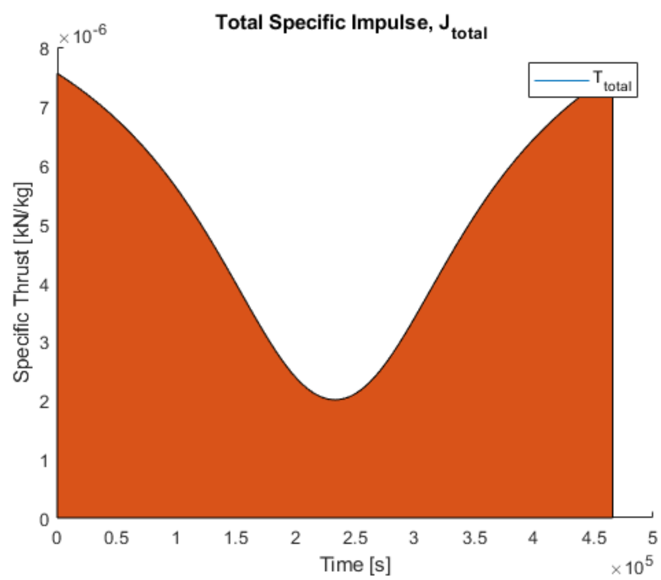
```
hold on
plot (t_range, T_total);
area(t_range, T_total)
legend ('T_t_o_t_a_l');
xlabel ('Time [s]');
ylabel ('Specific Thrust [kN/kg]')
hold off

J_x = trapz(t_range, abs(T_x)); %[km/s]
J_y = trapz(t_range, abs(T_y)); %[km/s]
J_z = trapz(t_range, T_z); %[km/s]
J_total  = sqrt (J_x^2+J_y^2+J_z^2); %[km/s]


fprintf('The total impulse required to complete the straight-line maneuver is %0.3f km/s\n',
J_total);

g = 9.81; %[m/s^2]
mass_ratio = 0.99:-0.001:0.05;
Isp = -(J_total*1000)./(g.*log(1-mass_ratio));

figure
hold on
title ('Mass Ratio as a function of ISP');
plot (Isp, -log10(mass_ratio))
plot ([0 Isp(923)],[-log10(mass_ratio(923)) -log10(mass_ratio(923))]);
plot ([Isp(923) Isp(923)], [-log10(mass_ratio(923)) 0]);
xlabel('Specific Impulse (Isp), [s]')
ylabel('-log_1_0(Mass Ratio)');
hold off
```

```
The total impulse required to complete the straight-line maneuver is 2.091 km/s
```

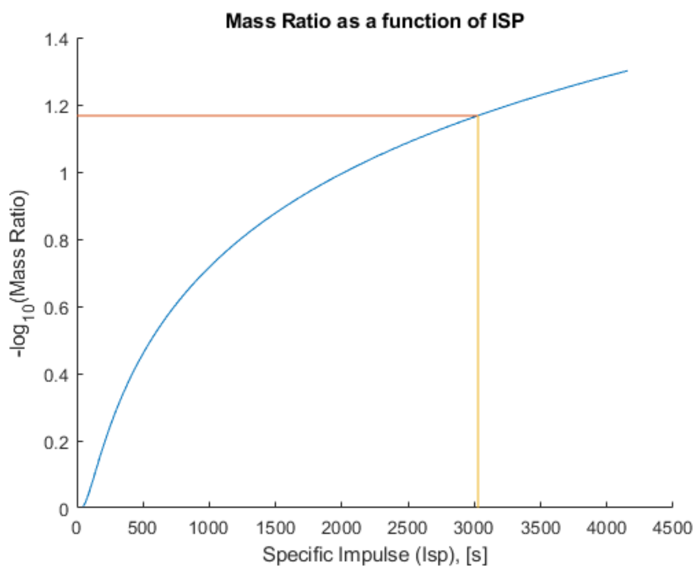




Flight Angle with respect to time
Flight Angle
Time [s]
$\times 10^5$
γ
100
80
60
40
20
0
-20
-40
-60
-80
-100
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5



Total Specific Impulse, J_{total}
Specific Thrust [kN/kg]
Time [s]
$\times 10^{-6}$
$\times 10^5$
T_{total}
8
7
6
5
4
3
2
1
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5



1.2.2 Question 2 Hohmann Transfer based Phasing

```
% Circular Orbit
T_cir = (2*pi*r_12^(3/2))/sqrt(mu_1); %[s]
% time it takes to get from L4 to L5 along the circular orbit
t_2 = ((360-120)/(360))*T_cir; %[s]

V_cir = sqrt(mu_1/r_12); %[km/s]

% Elliptical Orbit
T_ell       = t_2; %[s] Period of the Elliptical Orbit
r_a         = r_12; %[km] Radius of Apoapsis
a = ((T_ell*sqrt(mu_1))/(2*pi))^(2/3); %[km]
r_p = 2*a - r_a;
e = (r_a-r_p)/(r_a+r_p); %eccentricity of the transfer ellipse

% eqtn 2.7 from text: r_a = (h^2)/(mu(1-e))

h = sqrt (r_a*mu_1*(1-e));

V_ell = h/r_a;

V_delta = V_ell - V_cir; %[km/s]


fprintf('\n\nWhat is the percent difference in the impulses required ');
fprintf('to produce these two motions?\n\n');

Imp_per_diff  = abs(100*((J_total-abs(V_delta))/(V_delta)));

fprintf('Straight-line motion requires %0.2f percent more impulse compared to the phasing
manuever \n\n'...
    ,Imp_per_diff);
Time_per_diff = abs(100*((T_ell-max(t_range))/(max(t_range))));
```

```
fprintf('Phasing manuever requires %0.2f percent more time compared to the straight-line motion
\n\n'...
    ,Time_per_diff);

%Comment on the percent difference
isp = 450;

mass_ratio_pm = 1-exp(-abs(V_delta*1000)/(isp*g));
mass_ratio_sl = 1-exp(-abs(J_total*1000)/(isp*g));
```

```
What is the percent difference in the impulses required to produce these two motions?

Straight-line motion requires 1111.04 percent more impulse compared to the phasing manuever

Phasing manuever requires 239.23 percent more time compared to the straight-line motion
```

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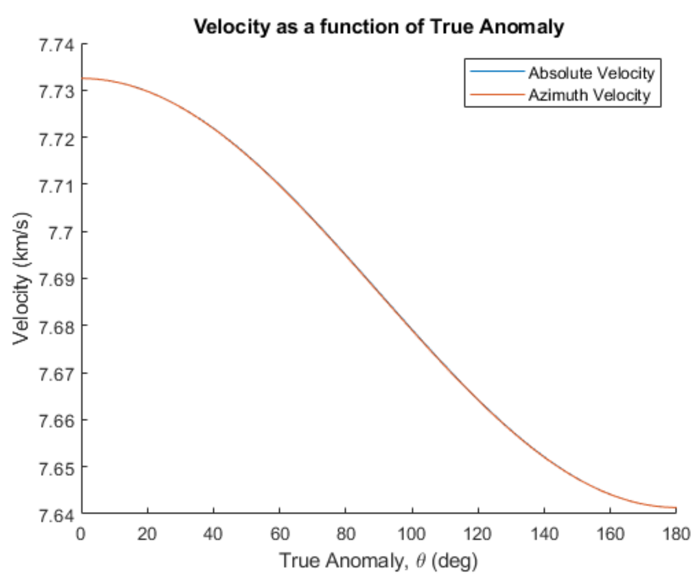
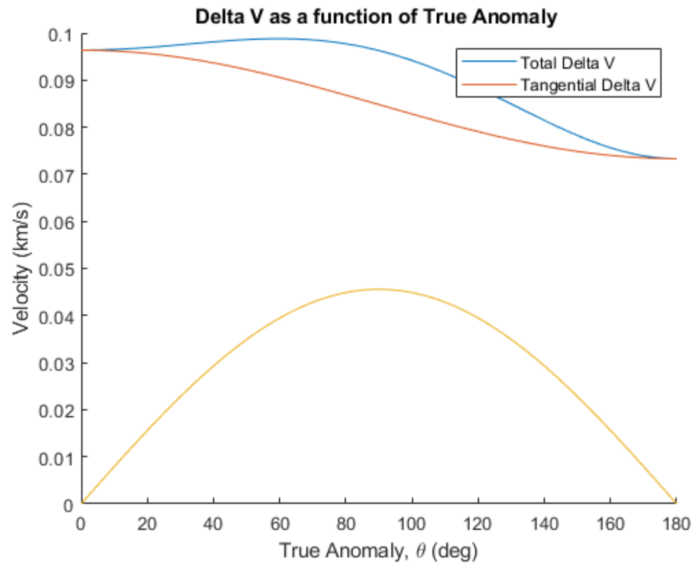
1.2.3 Question 3 Escape Pod Design

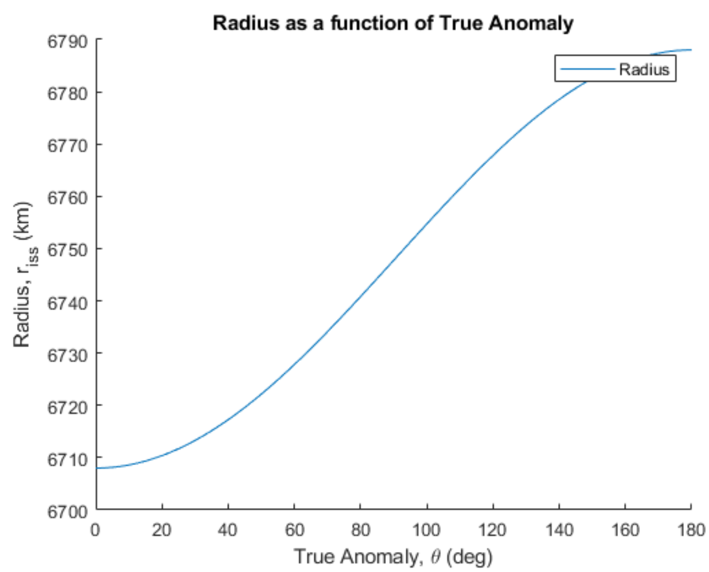
```
clc
clear all
close all
% The escape pod will be design for the International Space Station.
% There are six people living up in the station at a time therefore the pod
% must accomodate all six crew member.

% The design goal for the escape is to use as little energy as possible and
% to land the crew on board safety on the ground.

% constants
G           = 6.6742e-20; %[km^3/kg*s^2]
m_1         = 5.974e24; %[kg] mass of the Earth
mu          = G*m_1; %[km^3/s^2]

r_a_iss = 6378 + 410; %[km]
r_p_iss = 6378 + 330; %[km]


e_iss = (r_a_iss-r_p_iss)/(r_a_iss+r_p_iss);
a_iss = (r_a_iss+r_p_iss)/2; %[km]
b_iss = a_iss.*sqrt(1-e_iss.^2); %[km]
T_iss = (2*pi*a_iss^(3/2))/(sqrt(mu)); %[s]

% Step 1: Calculate the velocity of the international space station.
%r_iss =  linspace(r_p_iss, r_a_iss, 181);

theta_iss = linspace(0,180, 181); %[deg]
%r_iss = sqrt((b_iss.*sind(theta_iss)).^2+(a_iss.*cosd(theta_iss)).^2);
r_iss = (a_iss.*(1-e_iss.^2))./(1+e_iss.*cosd(theta_iss));
```

```
for i=1:181
    V_iss = sqrt(2.*((mu./r_iss)-(mu./(2*a_iss)))); %[km/s]
    if i==1
    V_p_iss=V_iss(i); %[km/s]
    h_iss = V_p_iss*r_p_iss;
    end
    if i==181
    V_a_iss=V_iss(i); %[km/s]
    end

    V_azi_iss = (mu/h_iss).*(1+e_iss.*cosd(theta_iss)); %[km/s]
    V_rad_iss = (mu/h_iss).*(e_iss.*sind(theta_iss));%[km/s]
end

% Step 2: Calculate the velocity of at various points of the transfer
% ellipse

r_a_te = r_iss;%[km]
r_p_te = linspace(6378+80, 6378+80, 181); %[km]
a_te = (r_a_te+r_p_te)./2; %[km]

e_te = (r_a_te-r_p_te)./(r_a_te+r_p_te);
h_te = sqrt(r_a_te.*mu.*(1-e_te)); %[km^2/s^2]

V_a_te = h_te./r_a_te;
V_p_te = h_te./r_p_te;

% Step 3: Calculate the delta V's.

% we know that
% V_a_te = V_azi_iss + delta_V_tan
% 0 = V_rad_iss + delta_V_rad
% delta_V_total = sqrt(delta_V_tan^2+delta_V_rad^2);

delta_V_tan = V_a_te - V_azi_iss; %[km/s]
delta_V_rad = 0 - V_rad_iss; %[km/s]
delta_V_total = sqrt(delta_V_tan.^2+delta_V_rad.^2); %[km/s]

% Plot Results

figure (1)
hold on
title ('Velocity as a function of True Anomaly');
xlabel ('True Anomaly, \theta (deg)');
ylabel ('Velocity (km/s)');
plot (theta_iss, V_iss);
plot (theta_iss, V_azi_iss);
%plot (theta_iss, V_rad_iss);
legend ('Absolute Velocity', 'Azimuth Velocity');
hold off

% figure (2)
% hold on
```

```
% plot (theta_iss, V_p_te);
% hold off

figure (3)
hold on
title ('Delta V as a function of True Anomaly ');
xlabel ('True Anomaly, \theta (deg)');
ylabel ('Velocity (km/s)');
plot (theta_iss, delta_V_total);
plot (theta_iss, abs(delta_V_tan));
plot (theta_iss, abs(delta_V_rad));
legend ('Total Delta V', 'Tangential Delta V');
hold off

figure (4)
hold on
title ('Radius as a function of True Anomaly');
xlabel ('True Anomaly, \theta (deg)');
ylabel ('Radius, r_i_s_s (km)');
plot (theta_iss, r_iss);
legend ('Radius');
hold off
```







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