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1 Question 1 – Earth to Mars Mission

a) *In the movie sunshine, how long did it take for the Icarus 2 to reach mercury?*

In the movie Sunshine, it took them 16 months to reach mercury which is roughly 547.5 days and can be seen at 10:55 in the film [1].

b) *This travel time to Mercury is significantly different than NASA's 7 years journey. Is the travel time in the movie sunshine possible or impossible? Use Hohmann Transfer to compare the travel time.*

To perform a Hohmann Transfer from Earth to Mercury, there are several assumptions that will be made. All bodies involved in the analysis are point masses, the orbits are Keplerian, both Earth and Mercury have a circular orbit around the Sun equal to their semi-major axis.

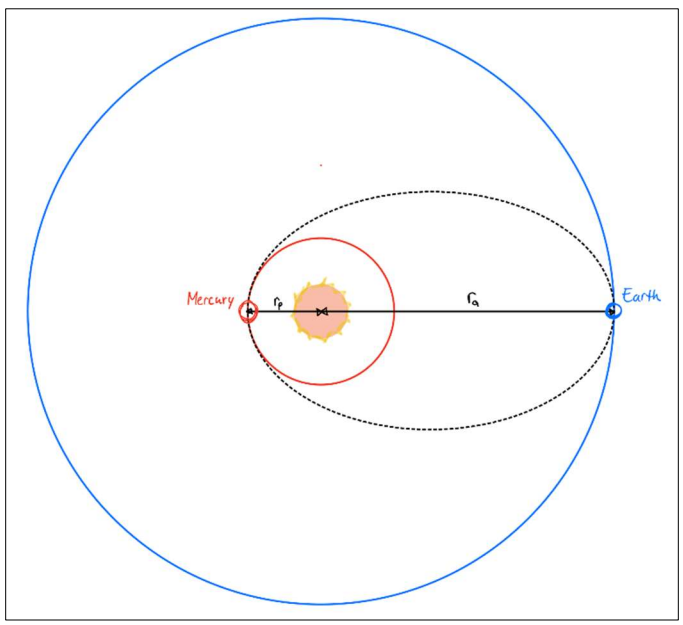

Figure 1.1 Hohmann Transfer from Earth to Mercury

List of given information referenced from the appendix of the textbook and the instructions for this project [2]:

Table 1.1 – Orbital parameters for the celestial bodies [2].

	Radius (km)	$\mu\ (km^3/s^2)$	Semi-Major Axis (km)
Sun	696000	13271200000	–
Mercury	2440	22030	57.91×10^6
Earth	6378	398600	149.6×10^6

For the transfer ellipse, let $r_{a,TE} = 149.6 \times 10^6\ km$ and $r_{p,TE} = 57.91 \times 10^6\ km$

Calculate the eccentricity of the transfer ellipse, e_{TE}

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

$$e_{TE} = \frac{149.6 \times 10^6\ km - 57.91 \times 10^6\ km}{149.6 \times 10^6\ km + 57.91 \times 10^6\ km}$$

$$e_{TE} = 0.441858223700063$$

Calculate the semi-major axis of the transfer ellipse, a_{TE}

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

$$a_{TE} = \frac{149.6 \times 10^6\ km + 57.91 \times 10^6\ km}{2}$$

$$a_{TE} = 103755000\ km$$

Calculate the period of the transfer ellipse, T_{TE}

$$T_{TE} = 2\pi\sqrt{\frac{a_{TE}^3}{\mu_{sun}}}$$

$$T_{TE} = 2\pi\sqrt{\frac{(103755000\ km)^3}{13271200000}}$$

$$T_{TE} = 1.822797076600517 \times 10^7\ s$$

$$T_{TE} \approx 211\ days$$

Thus, it would take about $105.5\ days$ to get travel from Earth to Mercury using a Hohmann transfer based mission. In the film, Icarus 2 took about 547.5 days which is about 5.2 times more than it took using the Hohmann transfer ellipse. When compared to NASA's messenger mission, it is about 4.67 times shorter. Due to the fact that the film is set 30 years from now and it fell within the theoretical minimum and time from an actual mission, it is safe to say that the time it took Icarus 2 to reach mercury in the film is theoretically possible.

c) How long would a Hohmann transfer based mission to Mercury and back actually take in days?

It would take about 211 days to go from earth to mercury and back to earth using a Hohmann transfer as calculated from the previous section.

d) Explain why NASA's MESSENGER took 7 years that it did.

Calculate velocity at the periapsis of the transfer ellipse, $v_{p,TE}$

$$v_{p,_TE} = \sqrt{2\left(\frac{\mu_1}{r_{p,TE}} - \frac{\mu_1}{2a_{,TE}}\right)}$$

$$v_{p,TE} = \sqrt{2\left(\frac{13271200000\frac{km^3}{s^2}}{57.91 \times 10^6\ km} - \frac{\left(13271200000\frac{km^3}{s^2}\right)}{2(103755000\ km)}\right)}$$

$$v_{p,_TE} = 57.483\frac{km}{s}$$

Calculate velocity of mercury about the sun, v_{merc}

$$v_{merc} = \sqrt{\frac{\mu_1}{r_{p,TE}}}$$

$$v_{merc} = \sqrt{\frac{13271200000\frac{km^3}{s^2}}{57.91 \times 10^6\ km}}$$

$$v_{merc} = 47.872\frac{km}{s}$$

Required Change in Velocity to get into Mercury's Orbit, ΔV_{merc}

$$\Delta V_{merc} = v_{merc} - v_{p,_TE}$$

$$\Delta V_{merc} = 47.872\frac{km}{s} - 57.483\frac{km}{s}$$

$$\Delta V_{merc} = -9.611\frac{km}{s}$$

NASA took 7 years to get into mercury's orbit because it had to slow down enough to be captured by Mercury's orbit while trying to avoid getting sucked in by the sun's gravitational pull. Looking at the Hohmann transfer, the periapsis of the transfer ellipse is located on the orbit of mercury. From what was learned in class as well as the calculations, the greatest velocity is at the periapsis (calculate v at periapsis) [2]. In order to orbit mercury, the MESSENGER had to slow enough to get in the sphere of influence of the planet. Simply relying on the thrusters aboard the spacecraft is not attainable. As seen on the calculations above, the spacecraft would have to retrofire $9.611\frac{km}{s}$ to get into mercury's orbit using Hohmann transfer. Saturn V is one of the most powerful rocket ever built and has specific impulse of 2.58 km/s at sea level [3]. Using that as reference, we would need about 4 Saturn V in order to make this maneuver.

e) Explain how the Icarus 2 could or could not have taken the time that it took.

The time it took Icarus 2 to reach Mercury in the film is about 5.2 times longer it would take a Hohmann Transfer Maneuver. Considering all the assumptions made in the calculations, taking the time it did in the film can be possible in real life. As said previously, the two main hurdles are avoiding getting sucked in by the Sun and slowing down enough to be captured by Mercury. As mentioned before, it would not be possible without utilizing orbital energy and other celestial bodies as was done by NASA. Considering the time that the film is set, about 30 years into the future it is difficult to project how space technology would have advance. Based on the current trend of private companies developing more powerful and reusable rockets, then it would likely be possible for Icarus 2 to reach Mercury within the timeline set in the film. One of the most power rocket in service right now is Space X's Falcon heavy with specific impulse of 2.765 km/s at sea level [4]. The technological advancement from the last 50 years has not been a lot when just looking at the specific impulse of Saturn V and Falcon Heavy. But more at the same time, it is hard to predict how fast private sectors and government agencies can accelerate this growth. Thus, the time it took Icarus 2 is possible when considering the setting and when comparing the values with the theoretical minimum and an actual mission to mercury.

f) Explain why Hohmann transfer's results are so different and why it was or was not used by either NASA or Icarus 2.

Hohmann transfer assumes that the bodies involved are point mass located the core. The spacecraft wants to get close enough to be captured by Mercury's gravitational force. Using the Hohmann transfer, the spacecraft will meet up with mercury at the periapsis of the tranfer ellipse. Thus the delta V required to change orbit is about 9.611 km/s which is a substantial amount. NASA did not use this method because of the limitation with

propulsion technology. It is hard to say why Icarus did not use this method, but based on the fact that the director sought advice from a leading experimental physicist Brian Cox it may have to do with how it is possible for Icarus 2 to travel the length of time they did [5].

2 Question 2 – Icarus 2 Rendezvous with Icarus 1

a) *Calculate the path that the Icarus 2 would have to take to rendezvous with the Icarus. Assume that both the Icarus and the Icarus 2 are in orbits around mercury similar to the elliptical orbits of NASA's Mercury mission.*

In the movie, Icarus 2 will be around 10 to 15 thousand miles apart once it intercepts the orbit [1]. Taking the average distance from the range provided, it can be approximated that the linear distance between Icarus 1 and 2 will be 12,500 miles which is about 20,000 km.

Assuming that Icarus 2 will only perform impulse maneuver at the periapsis and apoapsis of its, there are two possible solutions to the problem. The goal is to solve both and discuss the advantage and disadvantages of both solutions.

2.1 Elliptical Orbit

Before solving the two possible cases, there are information that are common for both of the cases which are the parameters for their current elliptical orbits. The subscript that will be used to denote these parameters are eo.

Table 2.1 – Orbital Parameters for the elliptical orbit

Parameter	**Values**
Apoapsis radius, $r_{a,eo}$	$11740\ km$
Periapsis radius, $r_{p,eo}$	$2640\ km$
Semi-major axis, a_{eo}	$7190\ km$
Eccentricity, e_{eo}	0.6328233658
Period, T_{eo}	$25808.69\ s$

Refer to the appendix for sample calculations and MATLAB script for full detail.

2.2 Case 1: Big Circular Orbit

Icarus 2 transfers to a circular orbit with radius equal to r_a of the elliptical orbit specified in the instructions. For this case, it will be denoted as big circle and subscript bc.

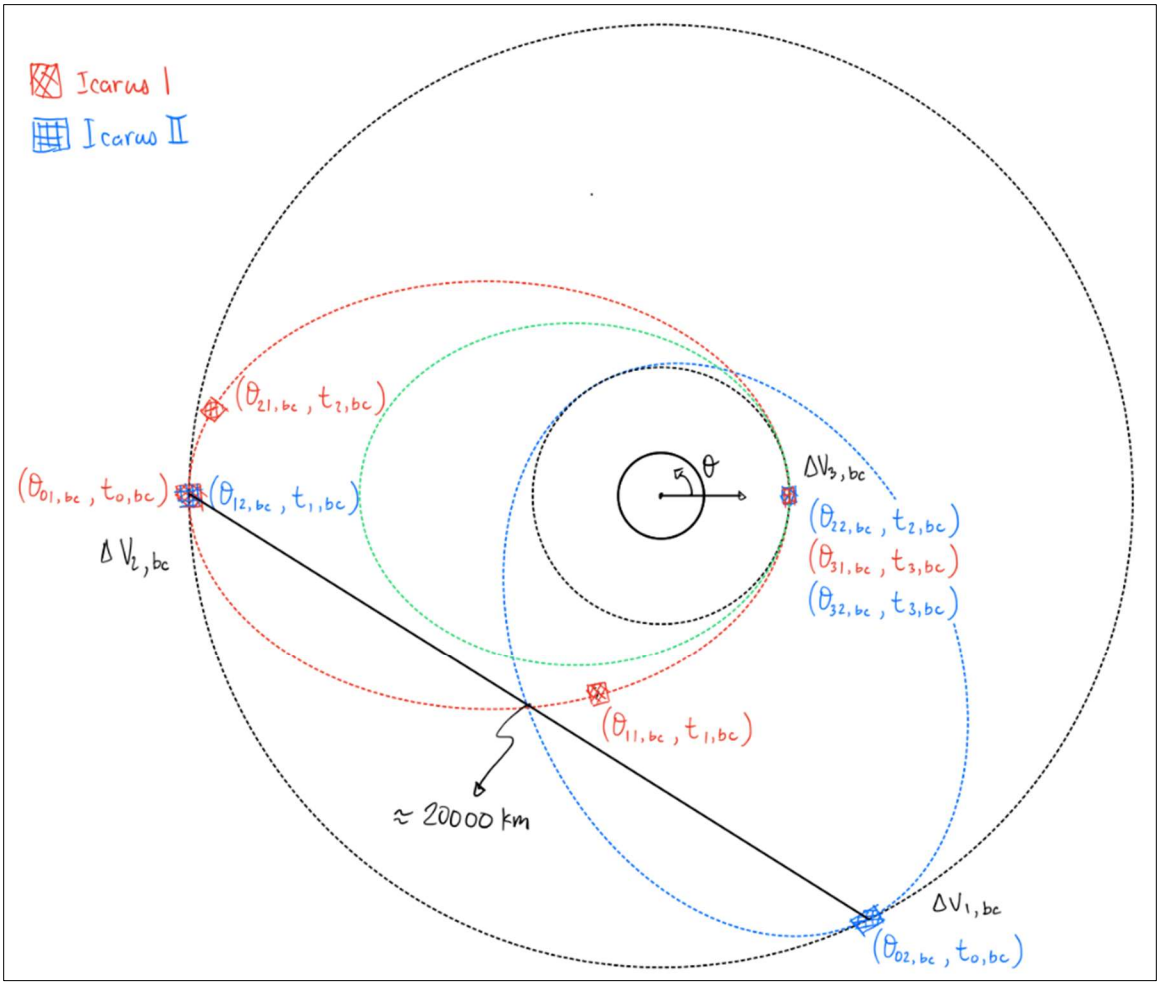

Figure 2.1 – Icarus 2's path using the big circular orbit

Steps:

1) Calculate the orbital parameter of the big circular orbit.
    a. Velocity, V_{bc}
    b. Period, T_{bc}
2) At $t_{0,bc} = 0\ s$, Icarus 2 will perform a maneuver to get into the circular orbit with radius $r_{a,eo}$.
3) Calculate $\Delta V_{1,bc}$ at location $(\theta_{02,bc}, t_{0,bc})$ to get to the big circular orbit
4) Calculate the time elapsed, $t_{1,bc}$ to get from $\theta_{02,bc}$ to $\theta_{12,bc}$
5) Calculate $\theta_{11,bc}$ given the time elapsed, $t_{1,bc}$.
6) Calculate $\Delta V_{2,bc}$ at location $(\theta_{12,bc}, t_{1,bc})$ to get to Icarus 1's orbit
7) Calculate the time elapsed, $(t_{2,bc} - t_{1,bc})$ to get from $\theta_{12,bc}$ to $\theta_{22,bc}$
8) Calculate $\theta_{21,bc}$ given the time elapsed, $t_{2,bc}$.
9) Calculate the time elapsed, $(t_{3,bc} - t_{2,bc} - t_{1,bc})$ to get from $\theta_{21,bc}$ to $\theta_{32,bc}$
10) Calculate the parameters of the transfer ellipse
    a. Let Period $T_{te,bc} = (t_{3,bc})$
    b. Semi-Major axis, $a_{te,bc}$
    c. Eccentricity, $e_{te,bc}$
11) Calculate $\Delta V_{3,bc}$ at location $(\theta_{12,bc}, t_{1,bc})$ to get to the transfer ellipse

Table 2.2 – Summary of locations of Icarus 1 and 2 at different times.

Icarus	**(Location, Time)**	**Location (deg)**	**Time (s)**
1	$(\theta_{01,bc}, t_{0,bc})$	$180°$	$0s$
	$(\theta_{11,bc}, t_{1,bc})$	$-107.33°$	$36375s$
	$(\theta_{21,bc}, t_{2,bc})$	$172°$	$49280s$
	$(\theta_{31,bc}, t_{3,bc})$	$0°$	$78985s$
2	$(\theta_{02,bc}, t_{0,bc})$	$-63.19°$	$0s$
	$(\theta_{12,bc}, t_{1,bc})$	$180°$	$36375s$
	$(\theta_{22,bc}, t_{2,bc})$	$0°$	$49280s$
	$(\theta_{32,bc}, t_{3,bc})$	$0°$	$78985s$

2.3 Case 2: Small Circular Orbit

Icarus 1 transfers to a circular orbit with radius equal to r_p of the elliptical orbit specified in the instructions. For this case, it will be denoted as small circle and subscript sc.

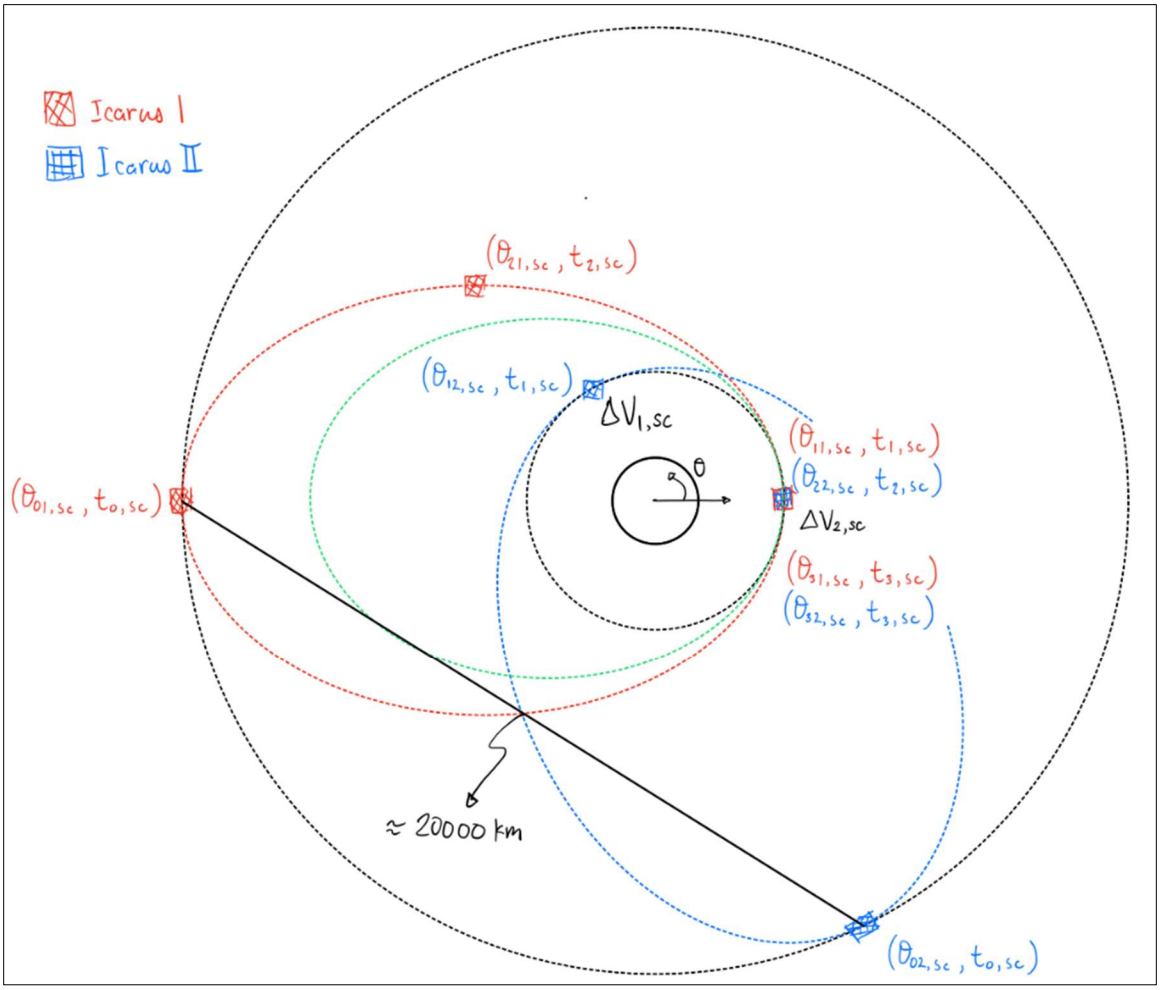

Figure 2.2 – Icarus 2's path using the big circular orbit

Steps:

1) Calculate the orbital parameter of the small circular orbit.
    a. Velocity, V_{sc}
    b. Period, T_{sc}
2) Calculate the time elapsed, $(t_{1,sc} - t_{0,sc})$ for Icarus 2 to reach the periapsis of its current orbit, $\theta_{12,sc}$
3) Calculate $\theta_{11,sc}$ given the time elapsed, $(t_{1,sc} - t_{0,sc})$
4) At $t_{1,sc}$, Icarus 2 will perform a maneuver to get into the circular orbit with radius $r_{p,eo}$.
5) Calculate $\Delta V_{1,sc}$ at location $(\theta_{12,sc}, t_{1,sc})$ to get to the small circular orbit
6) Calculate the time elapsed, $(t_{2,sc} - t_{1,sc} - t_{0,sc})$ to get from $\theta_{12,sc}$ to $\theta_{22,sc}$
7) Calculate $\theta_{21,bc}$ given the time elapsed, $t_{2,sc}$.
8) Calculate the time elapsed, $(t_{3,sc} - t_{2,sc} - t_{1,sc} - t_{0,sc})$ to get from $\theta_{12,sc}$ to $\theta_{22,sc}$
9) Calculate the parameters of the transfer ellipse
    a. Let Period $T_{te,sc} = (t_{3,sc} - t_{2,sc} - t_{1,sc} - t_{0,sc})$
    b. Semi-Major axis, $a_{te,sc}$
    c. Eccentricity, $e_{te,sc}$
10) Calculate $\Delta V_{2,bc}$ at location $(\theta_{12,bc}, t_{1,bc})$ to get to the transfer ellipse

Table 2.3 - Summary of locations of Icarus 1 and 2 at different times.

Icarus	**(Location, Time)**	**Location (deg)**	**Time (s)**
1	$(\theta_{01,sc}, t_{0,sc})$	$180°$	$0s$
	$(\theta_{11,sc}, t_{1,sc})$	$0°$	$12904.3s$
	$(\theta_{21,sc}, t_{2,sc})$	$129.54°$	$16783.3s$
	$(\theta_{31,sc}, t_{3,sc})$	$0°$	$38713.0s$
2	$(\theta_{02,sc}, t_{0,sc})$	$-63.19°$	$0s$
	$(\theta_{12,sc}, t_{1,sc})$	$116.81°$	$12904.3s$
	$(\theta_{22,sc}, t_{2,sc})$	$0°$	$16783.3s$
	$(\theta_{32,sc}, t_{3,sc})$	$0°$	$38713.0s$

b) What total impulse would be required to rendezvous with the Icarus?

Table 2.4 – Summary of the changes in velocity for both cases.

Velocity	**Case 1**	**Case 2**
ΔV_1	$0.539788231506565\frac{km}{s}$	$0.802543225888344\frac{km}{s}$
ΔV_2	$0.539788231506565\frac{km}{s}$	$0.047911966471364\frac{km}{s}$
ΔV_3	$0.189717159604015\frac{km}{s}$	–
ΔV_{total}	$1.269293622617146\frac{km}{s}$	$0.850455192359708\frac{km}{s}$

c) Discuss the results and whether it is worth it for Icarus 2 to make this rendezvous.

Based on the results from calculating for the two cases, it is clear that Case 2 it the more favorable path to take as it would require the least fuel to expend as well as less time for Icarus 2 to rendezvous with Icarus 1. Once in the same radius as Icarus 1, it would only require about 10.75 hours for Icarus 2 to meet with it. In this part of the film, before any of the mistakes were made with forgetting to correct the angle of sun shield, and the bio room getting destroyed, meeting with Icarus 1 is still a possibility choice. If Icarus 2 is using a rocket similar to the Falcon Heavy, it would have enough fuel to meet with Icarus 1 leave to go for the primary mission towards the sun [4]. Icarus 2 will have about $1.06409\frac{km}{s}$ $\Delta V\ to\ spare$. Thus, it is possible for Icarus 2 to make this detour and still complete the primary mission with twice the fire power of having 2 nuclear bombs.

Calculate the $\Delta V\ to\ spare$ if Icarus 2 were using Falcon Heavy rockets:

$$\Delta V\ to\ spare = I_{sp,sea\ level\ FalconHeavy} - 2 \times \Delta V_{total,Case2}$$

$$\Delta V\ to\ spare = 2.765\frac{\mathrm{km}}{\mathrm{s}} - 2\left(0.850455192359708\frac{km}{s}\right)$$

$$\Delta V\ to\ spare = 1.06409\frac{km}{s}$$

3 Question 3 – Escape Plan

In the movie sunshine, the opening of the Icarus Airlock and the jumping to reach the Icarus 2 is seen as a tragic act of group desperation. But in both cases, is this even possible? Using the equations of motion developed in Project 1, analyze the forces required to propel yourself or 3 other astronauts across from Icarus 1 to 2.

Problem Statement:

In the movie sunshine, 4 out of the 7-remaining crew of Icarus 2 are stranded aboard Icarus 1. There is a 20-meter gap between the two spacecraft, and the atmosphere is leaking fast. Determine how much thrust is required in order to make the escape seen in the film.

Based on an article by Alexander Bolonkin, animal experiments show that rapid and complete recovery is the norm for exposures of fewer than 90 seconds [6]. Taking this value to calculate the average velocity that the crew travelled between the two spacecraft, the thrust required can be determined using the equations of motion for three body systems derived in project 1.

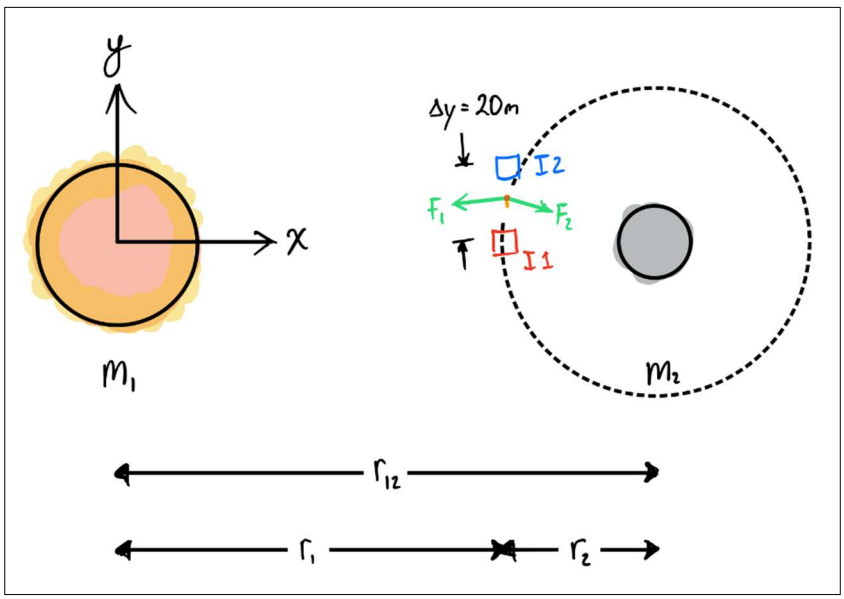

Figure 3.1 – Free body diagram for the three body problem

Figure 3.1 shows the forces acting on the crew as they travel a straight-line motion from Icarus 1 to Icarus 2. The two other bodies involved in the analysis are the Sun denoted by the subscript 1 and Mercury denoted by subscript 2.

The equation of motion from project 1:

$$\ddot{x} - 2\Omega\dot{y} - \Omega^2 x = -\frac{\mu_1}{r_1^3}(x + \pi_2 r_{12}) - \frac{\mu_2}{r_2^3}(x - \pi_1 r_{12}) + \frac{T_x}{m}$$

$$\frac{T_x}{m} = \frac{\mu_1}{r_1^3}(x + \pi_2 r_{12}) + \frac{\mu_2}{r_2^3}(x - \pi_1 r_{12}) - 2\Omega\dot{y} - \Omega^2 x$$

$$\ddot{y} - 2\Omega\dot{x} - \Omega^2 y = -\frac{\mu_1}{r_1^3}y - \frac{\mu_2}{r_2^3}y + \frac{T_y}{m}$$

$$\frac{T_y}{m} = \frac{\mu_1}{r_1^3}(x + \pi_2 r_{12}) + \frac{\mu_2}{r_2^3}(x - \pi_1 r_{12}) - \Omega^2 y$$

$$\ddot{z} = -\frac{\mu_1}{r_1^3}z - \frac{\mu_2}{r_2^3}z + \frac{T_z}{m}$$

$$\frac{T_z}{m} = 0$$

Table 3.1 – List of parameters used in the analysis

Descriptions	**Symbols**	**Values**	**Units**
Mass of the Sun	m_1	1.989×10^{30}	kg
Mass of Mercury	m_2	330.2×10^{21}	kg
Distance from Sun to Mercury	r_{12}	57.91×10^6	km
Distance from Sun to Icarus 1	r_1	57898260	km
Distance from Mercury to Icarus 1	r_2	11740	km
Sun's mass ratio	π_1	0.999999833986956	–
Mercury's mass ratio	π_2	1.6601×10^{-7}	–
Sun's Standard gravitational parameter	μ_1	1.32712×10^{11}	$\frac{km^3}{s^2}$
Mercury's standard gravitational parameter	μ_2	22030	$\frac{km^3}{s^2}$
Standard gravitational parameter	μ	1.3275×10^{11}	$\frac{km^3}{s^2}$

This table contains the values for all the parameters used in the analysis. Sample calculations can be found in the appendix and the MATLAB script.

Given a Sun-centered reference frame, the variables involved in the analysis will be as follows:

Table 3.2 – Variables for a straight-line motion.

Position	**Velocity**	**Acceleration**	**Forces**
$x = constant$	$\dot{x} = 0$	$\ddot{x} = 0$	$F_x = varries$
$y = varries$	$\dot{y} = constant$	$\ddot{y} = 0$	$F_y = varries$
$z = 0$	$\dot{z} = 0$	$\ddot{z} = 0$	$F_z = constant$

The constant velocity of the crew in the y-direction can be calculated as:

$$\dot{y} = V_{avg} = \frac{20m}{90s} \approx 0.2222\frac{m}{s}$$

The constant inertial angular velocity can be calculated as:

$$\Omega = \sqrt{\frac{\mu}{r_{12}^3}} = \sqrt{\frac{1.3275 \times 10^{11}\frac{km^3}{s^2}}{57.91 \times 10^6\ km}} = 8.26774 \times 10^{-7}\frac{rad}{s}$$

Using MATLAB to calculate and plot, the Thrust vector for a single source propulsion is $0.159694\ N\ [-89.999951°\ w.r.t. +y\ axis]$

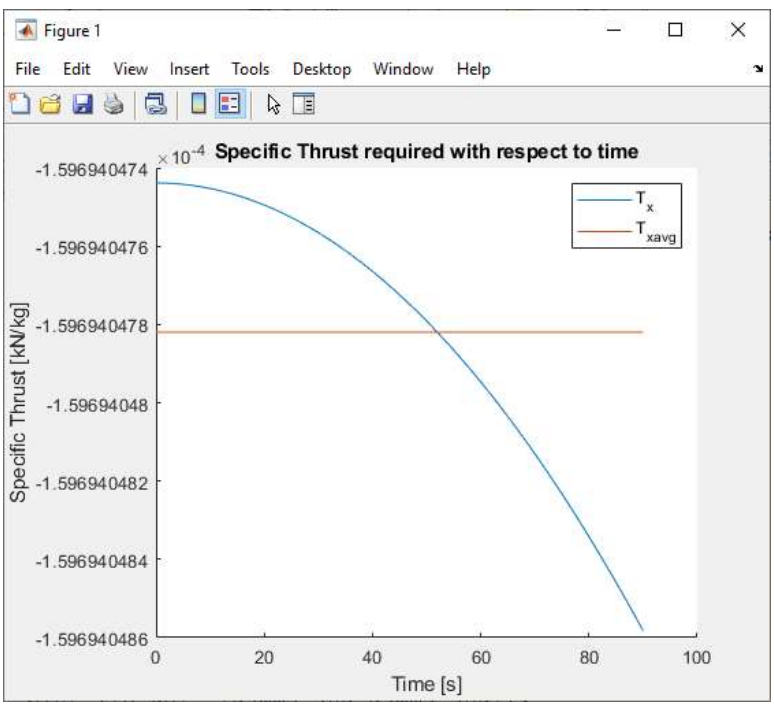

Figure 3.2 – Specific Thrust in the x-direction with respect to time.

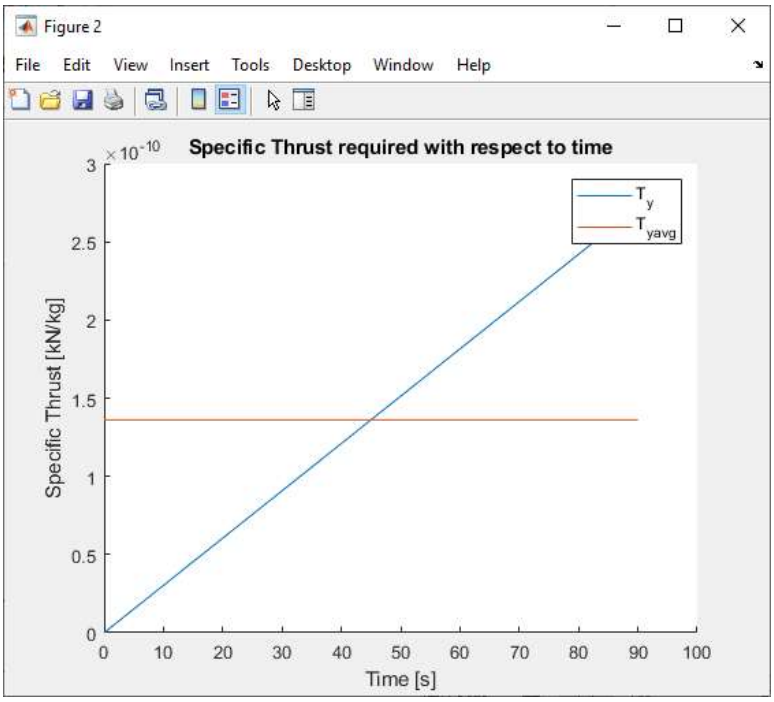

Figure 3.3 – Specific Thrust in the y-direction with respect to time.

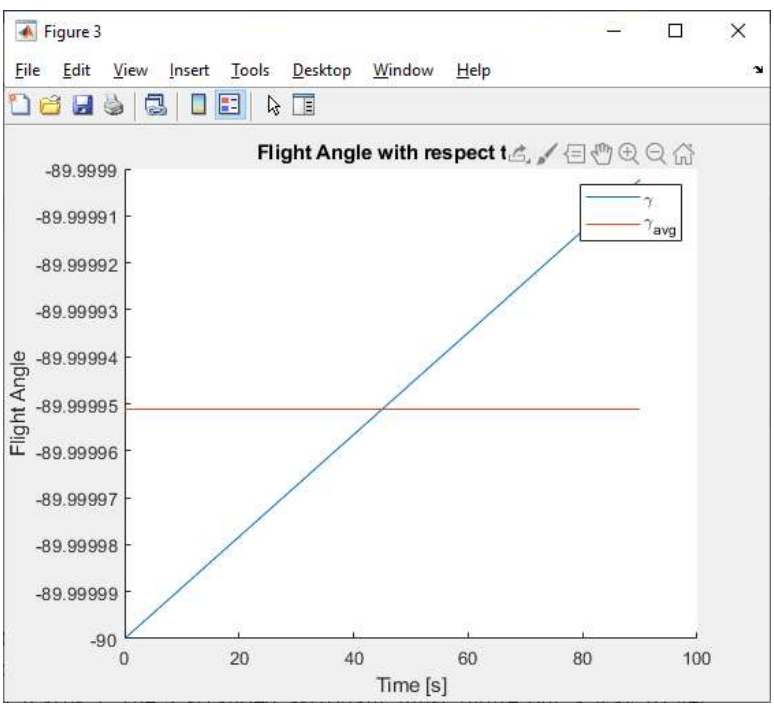

Figure 3.4 – Flight path angel with respect to time.

a) What conclusion can you draw from these results?

The required thrust vector for a single source propulsion is 0.159694 N [-89.999951deg w.r.t. +y-axis]. Based on the values calculated, majority of the thrust component is in the negative x-direction towards the sun's direction. Looking at the relative distances between all of the bodies in this analysis, the direction of the required thrust is valid. This makes sense because although the sun has a significantly larger mass, 6 million times mercury, the distance between them is also large that the gravitational force on crew is smaller compared to the gravitational force from mercury. The main concern is the direction of the thrust. In the movie, the airlocks of the two spacecrafts are almost perfectly aligned. The main source of thrust came from the pressure difference between the airlock and outer space. This makes direction of thrust in the movie is in the positive y-direction when referring to Figure 3.1. Thus, the crew's attempt to jump from one spacecraft to another in the way the film portray is physically impossible. In order for the scene in the movie to be more accurate, the crew should have been ejected about 90 degrees counterclockwise to how the movie did. Or once the crew were ejected, the spacesuit had to have a constant thrust of $-0.159694\ N$ towards the sun.

b) Moral/Technical Question: Voting

When it comes to making decisions that involves life and death, it can be difficult to pick the right or best solution. Whether it is best to make the decision as a group or by an individual such as the leader or an expert in the problem. In this film, it was more often that an individual was making the big decision for everyone. At the end, it had resulted in everyone dying, but at the same time completing the mission they set out to do.

Figure 3.5 below is an infographic from NASA showing significant space flight accidents and close calls. On May 22, 1969, the Apollo 10 had switch misconfiguration resulted in lunar module control problems [7]. This mission almost resulted in a moon landing crash, but due to commander Thomas Stafford decision to manually control the module they all stayed alive. This example shows that in space, there is not there to help you. Astronauts train to best of their ability to prepare for as many situations as they can.

When it comes to decision making in space, it becomes significantly more difficult to do compared to when on the ground. Dr. Elisa Ferre said, "Astronauts are primarily trained in physical fitness and given the right equipment, but are rarely proficient in how their brain functions will work millions of miles away from earth, when making decisions away from the comfort of terrestrial gravity." [8]. This supports the side that argues that it is better to rely on other when making decisions in space because ground team for example are under less stress as they are not facing the same environment.

I believe that when it comes to decision making, there are three choices. The first one is democratic, the second one is authoritarian, and lastly is selfish decision. Deciding as a group is good long term because it does not put all the power to one person who may or may not have your best interest. It allows an individual to have a voice and be somewhat in control of their fate. The downside with this method is that it requires time and thus the best when it comes to emergency situation where time has its highest value. The second one is individual decision made by others. This method is a coin flip because relying on another person to save yourself can be difficult. The only time this is beneficial is when time is limited and the person making the decision is an expert with the problem that you are facing. This gives you the highest chance of survival. Any other situation, this should be avoided. Last is individual decision made by the person in an emergency situation. This is should be your last resort. As mentioned before your brain capacity is not 100% plus the immense stress and pressure that you are under lowers your chance at making the best decision. Canadian Astronaut Chris Hadfield, "Most of the time you only really get one try to do most of the critical stuff and the consequences are life or death." [8]. Only having one try to make a life or death decision should only be reserved as the last option. In space, having a hierarchy for decision making would be the best because it would both save a lot of time as well as having the highest chance of success.

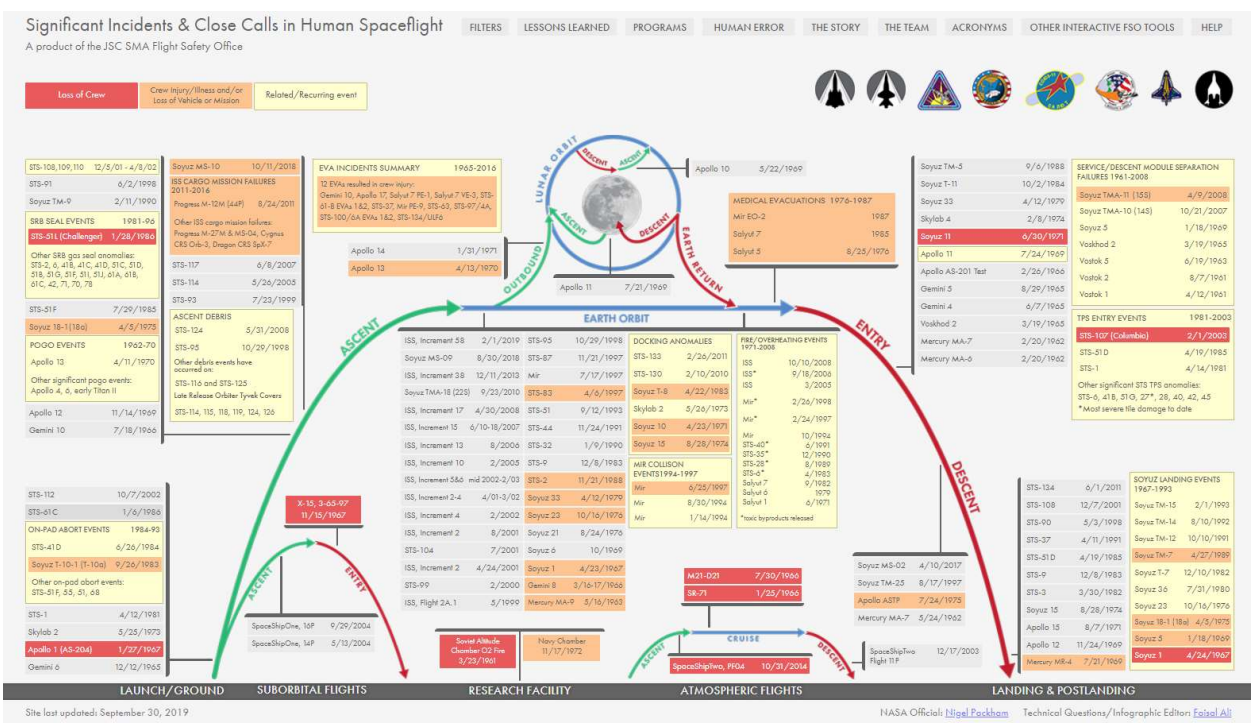

Figure 3.5 – Significant Incidents & Close Calls in Human Spaceflight [7].

c) Design a better plan that would save all 4 members

Problem Statement:

Four of the remaining seven crew of Icarus 2 is stranded aboard Icarus 1 after the connection between the airlocks of either spacecraft have decoupled. Given the lack of resources and power of Icarus 1, the 4 stranded astronauts must figure out a way to get back to Icarus 2.

Flaws with the proposed solution in the film.

1) The assumption and representation that the force exerted onto the astronauts by the pressure difference between the airlock and space will propel them in a straight line is not true.
2) Unsuited astronauts simply holding on to the suited astronaut is what lead one of the three crew members to stray away.
3) Although they needed one person to manually open the airlock, there are some ways to go around that problem. Especially when at the end, all that was needed was to press button.

My proposed solution:

From the calculations below, the atmospheric pressure in the airlock is enough to propel the astronauts out of Icarus 1. But given the flaws mentioned previously, there are minor adjustments that are needed for the mission to be possible and successful.

1) Once the airlock is opened, the crew can only rely on the forces from the major celestial bodies which were the Sun and planet Mercury.

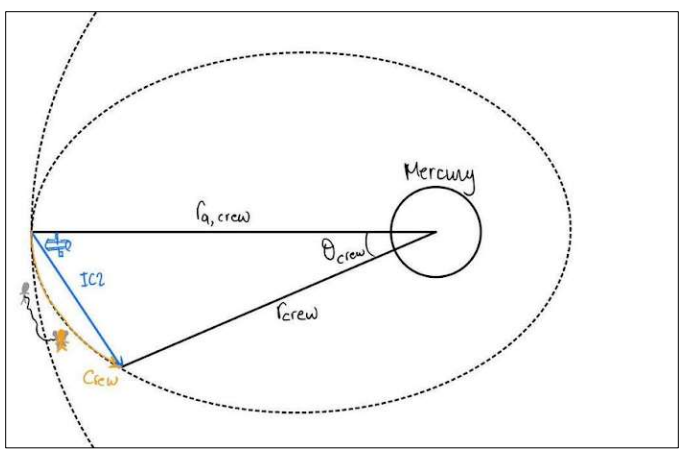

Figure 3.6 – Mission Analysis for the proposed solution.

Instead of the crew travelling in a straight-line motion, they will change orbit and rendezvous with Icarus 2 that will travel in a straight-line. The goal is find the total delta v required for Icarus 2 to meet up with the crew as well as the direction is has to travel towards. The steps are outlined below.

i) Calculate the force from the pressure difference between the airlock and space.

The frontal area can be approximated using Capa's height of 5 feet 7 inches, rounded to 6 feet which is approximately $1.8288m$ and the width of NASA's Primary Life Support System Pack (PLSSP) of 25 inches which is about $0.635\ m$ [9].

$$A_{capa} = 1.8288m \times 0.635m$$

$$A_{capa} = 1.161288\ m^2$$

The pressure inside the airlock can be approximated to be $101.3kPa$ given that the normal pressure in the I.S.S. as such [10].

$$F_{airlock} = A_{capa} \times P_{airlock}$$

$$F_{airlock} = 1.161288\ m^2 \times 101300\ Pa$$

$$F_{airlock} = 117638.4744\ N$$

ii) Calculate the velocity once the crew exits the airlock

To find the acceleration of the crew, we can use Newton's second law. To approximate the mass, we can use the current weight of the actors in the film as well as the mass of an astronaut's space suit from NASA. Capa is about 155 lbs (70.3068kg), Mace is about 175 lbs (79.3787kg), Searle is about 180 lbs (81.6466), Harvey is about 75kg, and NASA's space suit is about 280lbs (127.006kg) [11].

$$a_{airlock} = \frac{F_{airlock}}{m_{crew}}$$

$$a_{airlock} = \frac{(117638.4744N)}{(433.3381kg)}$$

$$a_{airlock} = 271.47\frac{m}{s^2}$$

To find the velocity the exit, use kinematics where the length of the airlock can we approximated as 2 meters referencing one of I.S.S.'s airlock dimensions [12].

$$v_{airlock} = \sqrt{2 \cdot a_{airlock} \cdot d_{airlock}}$$

$$v_{airlock} = \sqrt{2 \cdot \left(271.47 \frac{m}{s^2}\right) \cdot (2\ m)}$$

$$v_{airlock} = 32.95 \frac{m}{s}$$

iii) Determine orbital parameter of the crew's trajectory.

Crew's semi-major axis, a_{crew}

$$a_{crew} = -\frac{\mu_2}{2\left(\frac{v_{crew}}{2} - \frac{\mu_2}{r_{a,crew}}\right)} = 9118.06\ km$$

Crew's shortest radius, $r_{p,crew}$

$$r_{p,crew} = 2a_{crew} - r_{a,crew} = 6496.12\ km$$

Crew's eccentricity, e_{crew}

$$e_{crew} = \frac{r_{a,crew} - r_{p,crew}}{r_{a,crew} + r_{p,crew}} = 0.28755$$

An average astronaut can hold their breaths for at least 90 seconds before losing consciousness [13]. In space, astronauts can last about 15 seconds without a suit before going unconscious. Using this time will increase the chance of survival of the crew.

Time elapsed from exiting Icarus 1 to Crew's current location, $t_{12} = 15\ s$

Calculate the period of the ellipse, T_{crew}

$$T_{crew} = 2\pi \sqrt{\frac{a_{crew}^3}{\mu_2}} = 36857.55\ s$$

Calculate the Mean anomaly, M_{crew}

$$M_{crew} = 2\pi \left(\frac{t_{12}}{T_{crew}}\right) = 0.00255708\ rad$$

Calculate the Eccentric Anomaly, E_{crew} using Algorithm 3.1 in from the Textbook. [1]

$$E_{crew} = kepler_{E(e_{crew}, M_{crew})} = 0.003589\ rad$$

Calculate the True Anomaly, θ_{crew}

$$\theta_{crew} = 2 \arctan\left(\sqrt{\frac{1 + e_{crew}}{1 - e_{crew}}} \tan\left(\frac{E_{crew}}{2}\right)\right) = 0.00482502\ rad$$

Find the radius of the crew's location after the time elapsed

Calculate angular momentum, h_{crew}

$$h_{crew} = \sqrt{r_{a,crew} \cdot \mu_2 (1 - e_{crew})} = 13574.29 \frac{km^2}{s}$$

Calculate radius after time elapsed, r_{crew}

$$r_{crew} = \frac{h_{crew}^2}{\mu_2} \frac{1}{1 + e_{crew} \cos(\pi + \theta_{crew})} = 11739.94\ km$$

iv) Determine the distance and direction Icarus would have to travel to meet with the crew.

Calculate the distance between the initial and final location of the crew, $r_{crew,12}$

$$r_{crew,12} = \sqrt{r_{crew}^2 + r_{a,crew}^2 - 2 r_{crew} r_{a,crew} \cos(\theta_{crew})} = 56.65\ km$$

Calculate the flight path angle of the straight-line motion

$$\gamma_{ic} = 90° - \arcsin\left(\frac{r_{crew}}{r_{crew,12}} \sin(\theta_{crew})\right) = 1.56597 rad = 89.72°$$

Calculate total velocity

$$V_{total,IC} = \frac{r_{crew,12}}{t_{12}} = 4.01 \frac{km}{s}$$

Thus, in order for Icarus one to rendezvous with the crew it must have the desired velocity of $4.01 \frac{km}{s}$ in the direction $89.72°$ relative to its current trajectory.

2) In order to ensure everybody gets to safety, the two astronauts without a suit should be secured to the using the belt strap around their shoulder by the person pulling opening the airlock. Proceed with wrapping themselves with the wall insulation because it will protect them from the Sun's radiation. In the International space station, the material used for wall installation is mylar coated which drastically improve the station's ability to keep heat from radiating out of the station [14]. They should also by strapped behind the suited astronaut opposed to his sides. This will minimize the injuries since the suit is more durable than the wall insulations used in the film.
3) In order to save four out of four astronaut that were stranded, person that has to press the button will have a tether attached to him and will be pulled three astronauts initially released. Figure 4.1 shows a possible material that can be used as tether. Figure 4.2 shows the spacesuit bag which can be used to contain and keep Searle safe. It will not be as strong and durable as the suit, but since he will be exposed to space the longest, this is the second-best solution given that there is only one suit. In order to push the button, the beams or a fire extinguisher can be used to extent Searle reach.

After addressing the three main flaws in the film, and assumptions based on similar data, all four crew members stranded in Icarus 1 should make it back to Icarus 2 alive.

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4 Appendix

4.1 Sample Calculations

Calculate the eccentricity of the transfer ellipse, e_{TE}

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

$$e_{TE} = \frac{149.6 \times 10^6\ km - 57.91 \times 10^6\ km}{149.6 \times 10^6\ km + 57.91 \times 10^6\ km}$$

$$e_{TE} = 0.441858223700063$$

Calculate the semi-major axis of the transfer ellipse, a_{TE}

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

$$a_{TE} = \frac{149.6 \times 10^6\ km + 57.91 \times 10^6\ km}{2}$$

$$a_{TE} = 103755000\ km$$

Calculate the period of the transfer ellipse, T_{TE}

$$T_{TE} = 2\pi\sqrt{\frac{a_{TE}^3}{\mu_{sun}}}$$

$$T_{TE} = 2\pi\sqrt{\frac{(103755000\ km)^3}{13271200000}}$$

$$T_{TE} = 1.822797076600517 \times 10^7\ s$$

$$T_{TE} \approx 211\ days$$

4.2 Movie Scenes

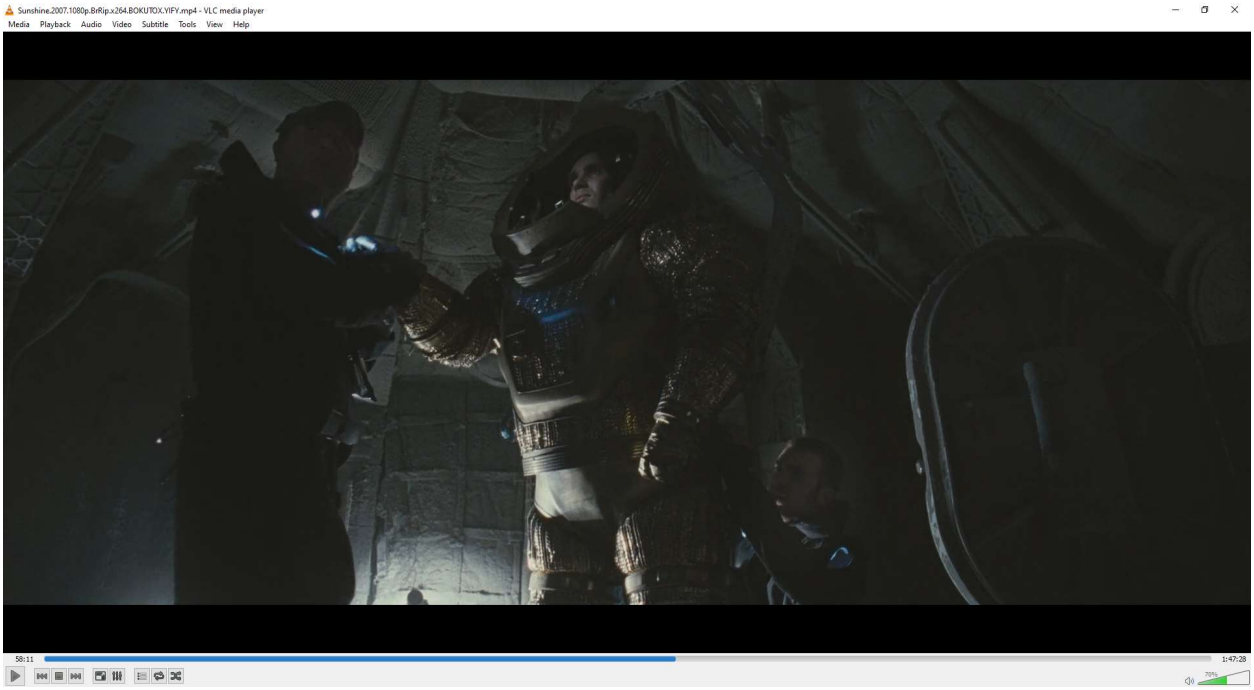


Figure 4.1 – Wall straps [1]

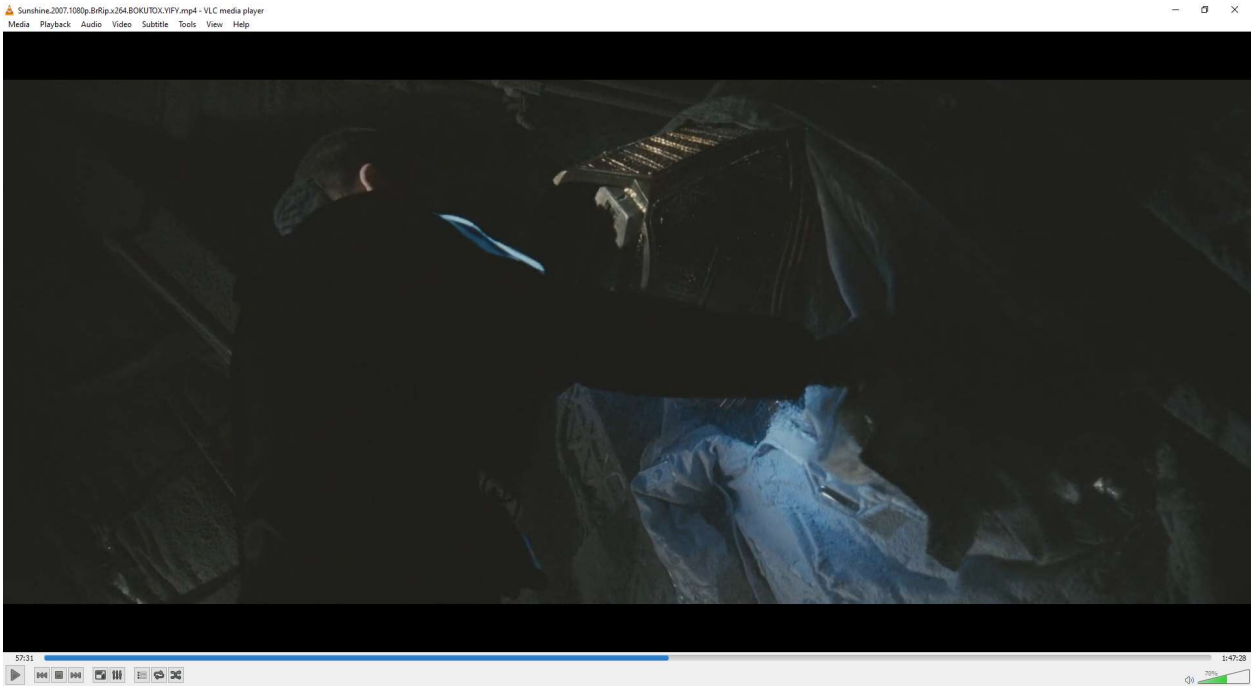


Figure 4.2 – Spacesuit bag [1]

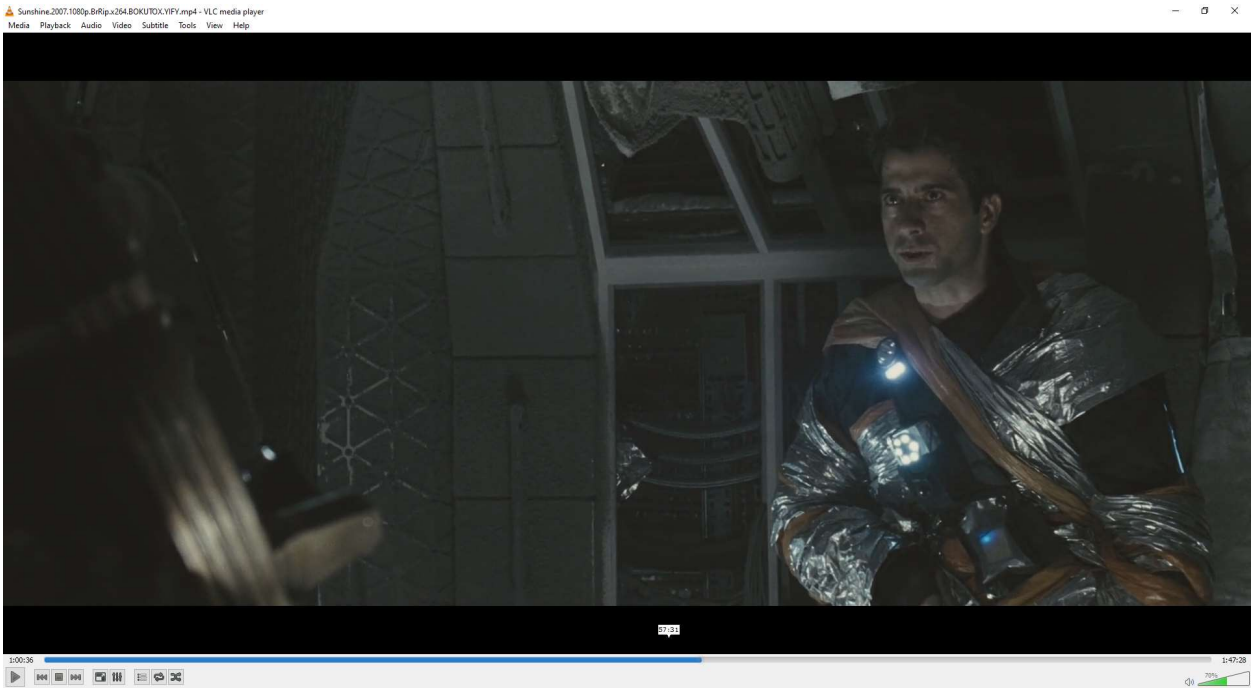


Figure 4.3 – Shoulder straps [1].

4.3 MATLAB

Question 1 28
Question 2 29
Question 3 Straight-line Motion From Icarus 1 to 2 31
Part C 36

```
format long
```

Question 1

```
r_a = 9300+2440; %[km]
r_p = 200+2440; %[km]

a_merc = 57.91e6; %[km]
a_earth = 149.6e6; %[km]

mu_1        = 132712000000;%[km^3/s^2]
mu_2        = 22030;%[km^3/s^2]
mu_3        = 149.6e6; %[km^3/s^2]

% calcualte the eccentricty of the transfer ellipse, e_te

e_te = (a_earth-a_merc)/(a_earth+a_merc);

% calculate the semi-major axis of the transfer ellipse, a_te

a_te = (a_earth+a_merc)/2; %[km]

% calculate the period of the transfer ellipse, T_te

T_te = 2*pi*(sqrt(a_te^3/mu_1)); %[s]

fprintf ('\nQ1) Thus, it would take %f days', T_te/(24*60*60));
fprintf (' for a Hohmann Tranfer based mission to reach mercury and back\n');

% Velocity at the periapsis

v_p_te = sqrt(2*((mu_1/a_merc)-(mu_1/(2*a_te)))); %[km/s]

% velocity of mercury

v_merc = sqrt(mu_1/a_merc); %[km/s]

% calculate delta V
delta_V_merc = v_merc-v_p_te;
```

```
Q1) Thus, it would take 210.971884 days for a Hohmann Tranfer based mission to reach mercury and
back
```

Question 2

```
% Calculate the minimum fuel expended to rendezvous with ic1
% Figure out the initial position and orientation of the orbits
% using cosine law, find the angles between the r_a of the two ellipse


d_ic12 = 20000; %[km] which is  around 12500 miles

theta_apse = acos((2*r_a^2-d_ic12^2)/(2*r_a^2)); %[rad]

% parameter for the elliptical orbit
a(1) = (r_a+r_p)/2;
e(1) = (r_a-r_p)/(r_a+r_p);
T_ell(1) = 2*pi*(sqrt(a(1)^3/mu_2));
v_a = sqrt(2*((mu_2/r_a)-(mu_2/(2*a(1))))); %[km/s]
v_p = sqrt(2*((mu_2/r_p)-(mu_2/(2*a(1))))); %[km/s]

% paramter for big circular orbit
v_bc(1) = sqrt(mu_2/r_a);
T_bc(1) = 2*pi*(sqrt(r_a^3/mu_2));

% paramter for small circular orbit
v_sc(1) = sqrt(mu_2/r_p);
T_sc(1) = 2*pi*(sqrt(r_p^3/mu_2));

% Case 1: IC2 transfers using big circular orbit

t_bc(1) = ((2*pi-theta_apse)/(2*pi))*T_bc(1); %[s]

theta_bc_IC2(1) = theta_apse - pi;
theta_bc_IC2(2) = pi;
theta_bc_IC1(1) = pi;

% find location of IC1 after t_bc(1)

    time_ratio_bc(1) = mod((t_bc(1)+0.5*T_ell(1)),T_ell(1))/T_ell(1)
    % note that time ratio has to always start from the periapsis at 0 rad.

    Me(1) = (time_ratio_bc(1))*2*pi; % Mean Anomaly
    E(1) = kepler_E(e(1), Me(1)); % Eccentricy Anomaly

    theta_bc_IC1(2) = (2.*(atan(sqrt((1+e(1))./(1-e(1))).*tan(E(1)/2))));



% calculate the time it takes for IC1 to reach apoapsis
    theta_bc_IC1(3) = 0-theta_bc_IC1(2);
    E(2) = 2*(atan(sqrt((1-e(1))./(1+e(1))*tan(theta_bc_IC1(3)/2))));
```

```
    Me(2) = E(2)-e(1)*sin(E(2));
    t_bc(2) = 0.5*T_ell(1)+((Me(2)/(2*pi))*T_ell(1));

% transfer ellipse 1
    a_bc(1) = (mu_2*(t_bc(2)/(2*pi))^2)^(1/3);

    % since the a_bc(1) is less than the r_a, it is not possible to
    % manuever to a transfer ellipse

    % we have to wait til IC2 reaches periapsis
    t_bc(3) =  0.5*T_ell(1); %[s]

% find the location of IC1 after t_bc(3)
    % time_ratio_bc(1) = (0.5*T_ell(1)+(t_bc(1)))/T_ell(1)
    %time_ratio_bc(1) = (t_bc(1)-0.5*T_ell(1))/T_ell(1)
    time_ratio_bc(2) = mod((T_ell(1)-t_bc(2)),T_ell(1))/T_ell(1)
    % note that time ratio has to always start from the periapsis at 0 rad.

    Me(3) = (time_ratio_bc(2))*2*pi; % Mean Anomaly
    E(3) = kepler_E(e(1), Me(3)); % Eccentricy Anomaly

    theta_bc_IC1(3) = (2.*(atan(sqrt((1+e(1))./(1-e(1))).*tan(E(2)/2))));

% tranfer ellipse 2 with same a
    t_bc(4) = t_bc(2);
    r_bc_a = 2*a_bc(1)-r_p; %[km]
    e(2) = (r_bc_a-r_p)/(r_bc_a+r_p);

    v_bc_p = sqrt(2*((mu_2/r_p)-(mu_2/(2*a_bc(1))))); %[km/s]

% delta V's

    delta_V_bc(1) = abs(v_bc(1)-v_a); %[km/s]

    delta_V_bc(2) = abs(v_a-v_bc(1)); %[km/s]

    delta_V_bc(3) = abs(v_bc_p-v_p);%[km/s]

    delta_V_bc_total = sum(delta_V_bc);

% Case 2: IC2 transfer using small circular orbit

    t_sc(1) = 0.5*T_ell(1); %[s]

    theta_sc_IC2(1) = theta_apse - pi;
    theta_sc_IC2(2) = theta_apse;
    theta_sc_IC1(1) = pi;
    theta_sc_IC1(2) = 0;


    t_sc(2) = ((2*pi-theta_sc_IC2(2))/(2*pi))*T_sc(1);
    % find location of IC1 after t_sc(2)

    time_ratio_sc(1) = mod((t_sc(2)),T_ell(1))/T_ell(1);
```

```
    % note that time ratio has to always start from the periapsis at 0 rad.

    Me(4) = (time_ratio_sc(1))*2*pi; % Mean Anomaly
    E(4) = kepler_E(e(1), Me(4)); % Eccentricy Anomaly

    theta_sc_IC1(3) = (2.*(atan(sqrt((1+e(1))./(1-e(1))).*tan(E(4)/2))));

    % time it would take for IC1 to comeback to periapsis from its current
    % location of theta_sc_IC1(3)

    t_sc(3) = T_ell(1) - t_sc(2); %[s]

    % calculate the semi-major axis required for the transfer ellipse for
    % phasing maneuver

    a_sc(1) = (mu_2*(t_sc(3)/(2*pi))^2)^(1/3);

    % since semi-major axis is larger than r_p, it is possible to do the
    % phasing maneuver at this time.

    r_sc_a = 2*a_sc(1)-r_p; %[km]
    e(3) = (r_sc_a-r_p)/(r_sc_a+r_p);

    v_sc_p = sqrt(2*((mu_2/r_p)-(mu_2/(2*a_sc(1))))); %[km/s]

    % delta V's

    delta_V_sc(1) = abs(v_p-v_sc(1)); %[km/s]
    delta_V_sc(2) = abs(v_sc_p-v_p);%[km/s]
    delta_V_sc_total = sum(delta_V_sc);

% a) calculate the path icarus 2 has to take to rendezvous with icarus 1.

% Case 1: results



% Case 2: results
```

```
time_ratio_bc =

   0.909437210916518   0.424517453873302


time_ratio_bc =

   0.909437210916518   0.424517453873302
```

Question 3 Straight-line Motion From Icarus 1 to 2

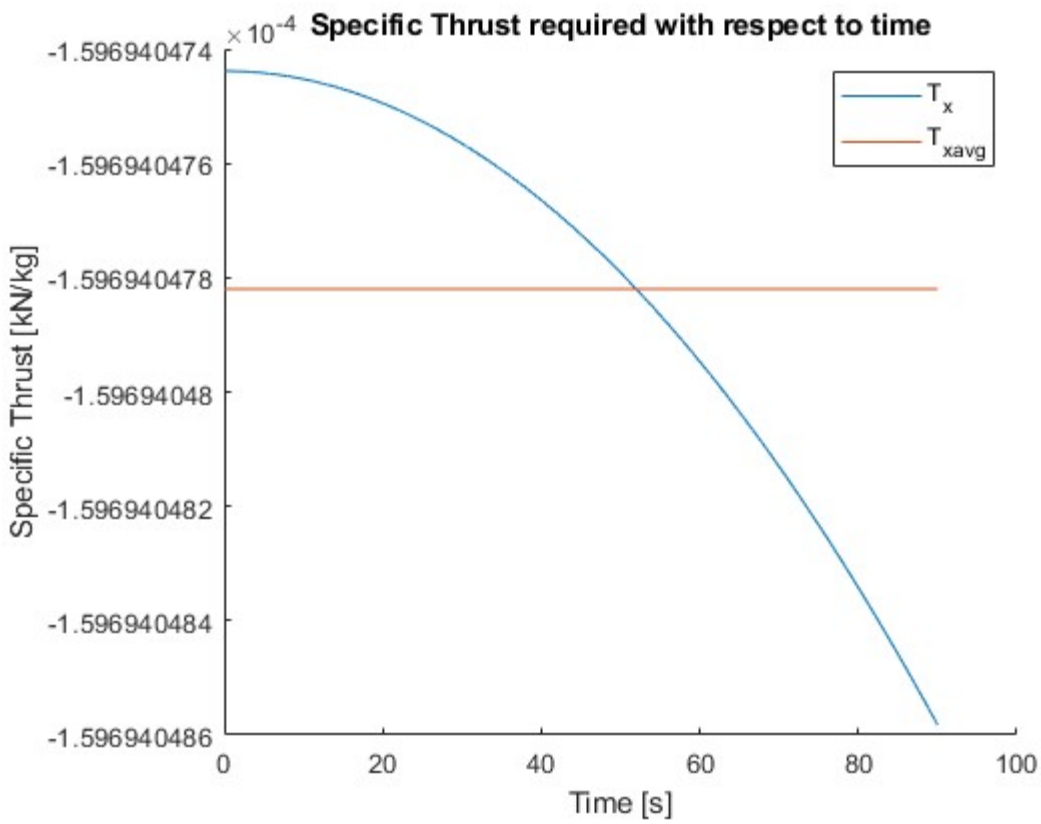
Derive the expression for the Thrust components to get from L5 to L4 in a straight line.

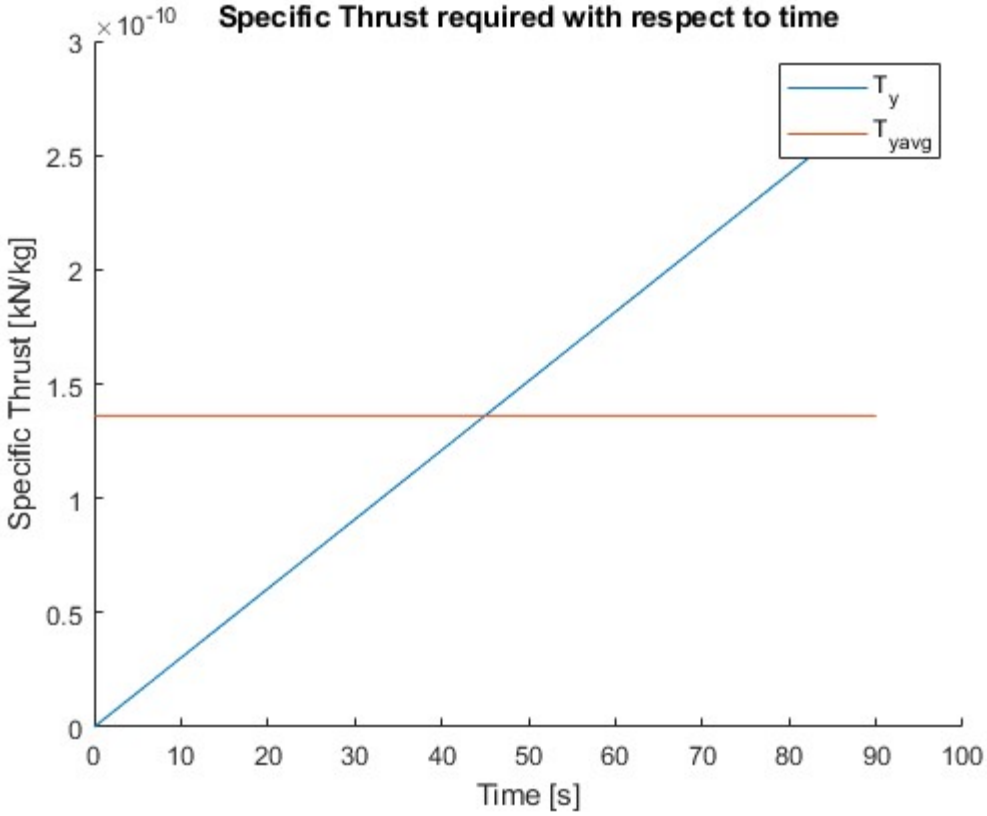
```
% Specific Thrust in the x, y, and z direction
%T_x = ((mu_1./r_1.^3)*(x+pi_2*r_12))+((mu_2./r_2.^3)*(x-pi_1*r_12));
%T_y = ((mu_1./r_1.^3).*y)+((mu_2./r_2.^3).*y);
%T_z = 0;


% How long will it take for you to travel from Icarus 1 to Icarus 2

r_12        = 57.91e6; %[km]
V_avg       = 0.02/(90); %[km/s] 20 sec in the movie
delta_y     = 0.02; %[km]
t_avg       = delta_y/V_avg;%[s]


% Plot the resulting Thrust vs. Time for each component
% Constants
G           = 6.6742e-20; %[km^3/kg*s^2]
m_1         = 1.989e30; %[kg] mass of the Sun
m_2         = 330.2e21; %[kg] mass of Mercury
mu_1        = 132712000000;%[km^3/s^2]
mu_2        = 22030;%[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);

big_omega = sqrt(mu./r_12.^3);

% Varries

r_2 = 9300+2440;
r_1 = 57.91e6-r_2;

theta_max = asind(0.02/(r_2));
theta = linspace (0, theta_max, 1000);


y = r_2.*sind(theta);

x = r_1*cosd(theta);
y_min =0;
y_max =20;
y_dot = V_avg;


% 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_x_avg = mean(T_x);
T_y = ((mu_1./r_1.^3).*y)+((mu_2./r_2.^3).*y)-big_omega^2*y;
T_y_avg = mean(T_y);
T_z = linspace(0,0,1000);
```

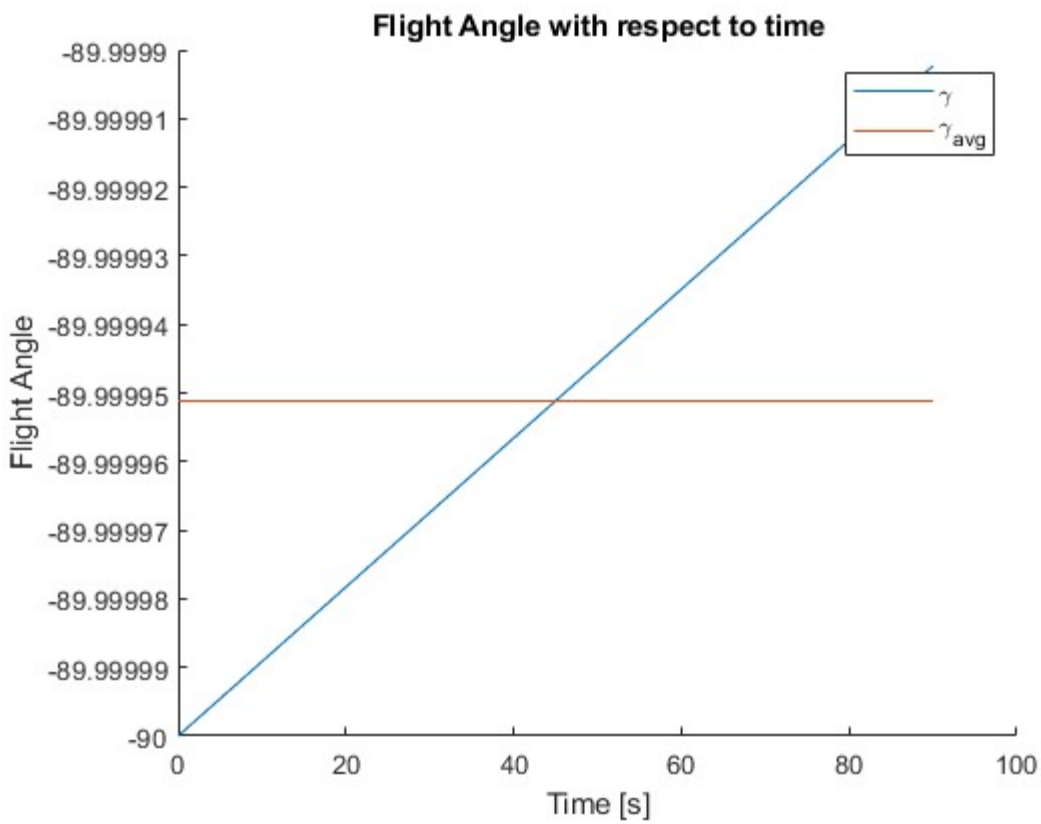
```
T_total = sqrt(T_x.^2+T_y.^2+T_z.^2);
T_totavg = mean(T_total)

t_range = (y./y_dot);

figure
title('Specific Thrust required with respect to time');
hold on
plot (t_range, (T_x));
plot ([0 90], [T_x_avg T_x_avg]);
xlim ([0 100]);
%ylim ([-1.6e-4 -1.58e-4]);
legend ('T_x', 'T_x_a_v_g');
xlabel ('Time [s]');
ylabel ('Specific Thrust [kN/kg]')
hold off

figure
title('Specific Thrust required with respect to time');
hold on
plot (t_range, (T_y));
plot ([0 90], [T_y_avg T_y_avg]);
xlim ([0 100]);
legend ('T_y', 'T_y_a_v_g');
xlabel ('Time [s]');
ylabel ('Specific Thrust [kN/kg]')
hold off

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

figure
title('Flight Angle with respect to time');
hold on
plot (t_range, gamma);
plot ([0 90], [gamma_avg gamma_avg]);
xlim ([0 100]);
legend ('\gamma', '\gamma_a_v_g');
xlabel ('Time [s]');
ylabel ('Flight Angle')
hold off

Thrust_vector = sqrt(T_x_avg^2+T_y_avg^2);

fprintf ('Thus, the Thrust Vector is %f N[ %f ]', Thrust_vector*1000, gamma_avg)

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

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  = 1000*sqrt (J_x^2+J_y^2+J_z^2); %[km/s]
```

```
fprintf('The total impulse required to complete the straight-line maneuver is %0.4f m/s\n',
J_total);
```

```
T_totavg =

     1.596940478200589e-04

Thus, the Thrust Vector is 0.159694 N[ -89.999951 ]The total impulse required to complete the
straight-line maneuver is 14.3725 m/s
```




Specific Thrust required with respect to time
× 10^-10
3
2.5
2
1.5
1
0.5
0
Specific Thrust [kN/kg]
0
10
20
30
40
50
60
70
80
90
100
Time [s]
T_y
T_yavg


Flight Angle with respect to time
-89.9999
-89.99991
-89.99992
-89.99993
-89.99994
-89.99995
-89.99996
-89.99997
-89.99998
-89.99999
-90
Flight Angle
0
20
40
60
80
100
Time [s]
γ
γ_avg

Part C

Part c)

```
% i) calculate the force from the pressure difference

A_capa = 1.8288*0.635; % approximates a rectangular frontal area
% Capa's height in real life is 5ft7in, rounding it to 6ft gives about
% 1.8288m, and a Primary life support system pack for NASA's space suit is
% 25in or about 0.635m.

P_airlock = 101300; % [Pa] based on the I.S.S.'s normal room pressure.

F_airlock = A_capa*P_airlock; %[N]

% ii) calculate the final velocity after the force from airlock is finished

m_crew = 70.3068+79.3787+81.6466+75+127.006; %[kg] 356.2273 rounded to 360 kg
% was determined by adding Capa, Mace, Searle, Harvey, and NASA's space
% suit's weight in 2020

a_airlock = F_airlock/m_crew; %[m/s^2]

d_airlock = 2; %[m]
% given that I.S.S.'s airlock is about 2m long

v_airlock = sqrt(2*a_airlock*d_airlock); % [m/s] Unpowered Velocity of the crew


% iii) determine where Icarus 2 should be located to catch the crew.

v_ic1 = sqrt(mu_2/r_2);%[km/s]

v_crew = v_ic1 - (v_airlock/1000); %[km/s]

% calc semi-major axis of new orbit
a_crew = -mu_2/(2*((v_crew/2)-(mu_2/r_2)));

% calc r_p_crew

r_p_crew = 2*a_crew-r_2;
r_a_crew = r_2;

% calc eccentricity of crew's orbit

e_crew = (r_a_crew-r_p_crew)/(r_a_crew+r_p_crew);

% given that it an average NASA Astronaut can hold their breath for about
% 90 seconds and the same time before suffering from embolism and die.

% calc theta_crew
    % given the time elapsed
 t_12 = 15; %[s]
```

```
    % calc T_crew
    T_crew = 2*pi*sqrt(a_crew^3/mu_2); %[s]
    % calc M_crew
    M_crew = 2*pi*(t_12/T_crew); %[rad]
    % using Algorithm 3.1, calc E_crew
    E_crew = kepler_E(e_crew, M_crew);
    % calc theta_crew
    theta_crew = 2*atan(sqrt((1+e_crew)/(1-e_crew))*tan(E_crew/2));

% find the radius of the crew's location after 15 seconds
    % angular momentum
    h_crew = sqrt(r_a_crew*mu_2*(1-e_crew));
    % radius after t_12
    r_crew = h_crew^2/(mu_2*(1+e_crew*cos(pi+theta_crew)));

% find the distance between
    r_crew12 = sqrt(r_crew^2+r_a_crew^2-2*r_crew*r_a_crew*cos(theta_crew))

% calc the flight path angle required to meet up with the crew

    gamma_ic2 = (pi/2)-asin((r_crew/r_a_crew)*sin(theta_crew))

% calculate the total velocity to go from intial location to final

    V_total_ic2 = r_crew12/t_12; %[km/s]

% velocity x-component

    v_x_ic2 = V_total_ic2*sin(gamma_ic2);

% velocity y-component

    v_y_ic2 = V_total_ic2*cos(gamma_ic2);

% velocity of IC2 before manuever

    V_ic20 = sqrt(mu_2/r_2);

% total Delta V

    V_total_ic2 = sqrt((V_ic20-v_y_ic2)^2+v_x_ic2^2)

% set the travel time to 45 sec to increase that chance of survival.

 T_ic2 = 2*pi*sqrt(r_2^3/mu_2); %[s]

 theta_ic12 = (t_12/T_ic2)*2*pi; %[rad]

 d_ic12 = 2*r_2*sin(theta_ic12/2); %[km]
```

```
r_crew12 =
```

```
  56.645545682063343


gamma_ic2 =

   1.565971331845385


v_total_ic2 =

   4.010927452366870
```

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