visioneering: a mission to mars

Esther Lim*[1], Shuya Gong*[2], Leslie Ojeaburu*[3], India Perez-Urbano*[4], Daniel Wang*[5]

1: Faculty of Arts and Sciences, Harvard University; Department of Human Evolutionary Biology.
2: School of Engineering and Applied Sciences, Harvard University;
3: Faculty of Arts and Sciences, Harvard University;
4: Faculty of Arts and Sciences, Harvard University; Department of Sociology.
5: School of Engineering and Applied Sciences, Harvard University.
All authors contributed equally to this work. Division of work responsibilities detailed in section following conclusion.

Abstract

January of 2060: The human population on Earth has well exceeded 10 billion. With the alarmingly high carbon dioxide levels and the inevitable global warming taking a toll on planet earth, many coastal regions like New York City and parts of Japan are flooded with seawater, making the end to drinkable water nearer and nearer.

Our five-marsonaut team, The VIS10NEERS, is impassioned to make a successful journey to Mars in order to find drinkable water to save planet Earth. The goal of this expedition is to land at least one of the crew on Mars, retrieve the treasure (water), and then return safely back to low Earth orbit.

This mission will not be easy. There are many obstacles and challenges that stand in our way. One of our goals is to calculate the minimum amount of propulsion energy required for the voyage. Toward this end, we must analyze the logistics of the launch, trajectory, durations of each stage of the journey, propulsion energy, type of fuel, and energy required for life-support for the crew.

Introduction

A mission to Mars has long fascinated scientists, entrepreneurs, politicians, sci-fi geeks, and the general masses. It has been a long standing dream to send a crew to the Red Planet, a mission that has been fictionalized, theorized, and simulated time and time again. At the time of this printing, there has not yet been a single successful manned mission to Mars. We can only conclude that as of yet, the resources do not exist or that required technologies have not yet been invented. The following document is presented to summarize a boldly approached mission, applying knowledge derived from the course AP50a, past NASA explorations, and the own inventions of the VIS10NEERS for a successful mission. It is organized by engine specifications, determination of mass, fuel analysis, time frame, phases of mission (see below), and human sustainability. We hope that you will find the contents hereafter helpful and essential.

Fig. 1: The Vis10neers team and mentor

Phase 1: *Launch from Earth to parking orbit*	Phase 2: *Injection into transfer orbit*	Phase 3: *Insertion into Mars orbit*	Phase 4: *Injection into transfer orbit back to earth*	Phase 5: *Insertion into a low-altitude parking orbit around Earth*

Launch date, time, and location
Trajectory of probe/rocket/jettisoned structs
Duration of the specified phase of the mission
Energy required for specified phase and entire mission; proposed type and quantity of fuel(s)

Engine Specifications

Engine Type: SRSM

- $1 \text{ lb} = 4.448 \text{ N}$
- Thrust 3.3×10^6 lb $= 1.4678400 \times 10^7$ N
- $q = 1.3 \times 10^6$ lb $= 589670$ kg
- propellant: perch Cl/Al
- $J_{sp} = 270$ s
- Burn time: 75 s

$270 \text{ s} = (1467840 \text{ N})/(\mu * 9.81 \text{ m/s}^2)$

$\mu = 554.17$ kg/s

This calculation is very important in our determination of mass of fuel needed.

Mass

From previous NASA research, we know that we need an approximate mass ratio of 91:6:3 of fuel, structural parts, and payload, respectively. We calculate our payload based on the needs of 5 astronauts for approximately two years in space, and factor in masses of rockets and structural considerations from previous missions.

Rockets: $1.18 * 10^6$ kg rockets
Probe: $1.2 * 10^4$ kg probe
Payload: $1.0 * 10^3$ kg payload
Rocket Body: $2.0 * 10^5$ kg rocket body
Total: $1.393 * 10^6$ kg total

Escape velocity → v^2 = 2GME /rE
ME = Earth's mass: 5.974 x 10^24 kg
MR = Mass of rocket (5 astronauts + food + capsule/vehicle + rockets + fuel)
rE = Earth's radius = 6.371 x 10^6 m
vE = 1.119 x 10^4 m/s, or 25,026 miles per hour

We calculate the mass of fuel needed for take off by considering the launch velocity. This equation can be found in Phase 1 and is detailed below, but our launch speed is in the ballpark of 2500 m/s. With this, we calculate the mass of fuel used in launch using the equation $\Delta v = v_{eq} \ln((\text{mass}_{before})/(\text{mass}_{after}))$

$$\Delta v = v_{eq} \ln(\text{mass}_{before}/\text{mass}_{after})$$
$$2{,}500 \text{ m/s} = 2{,}646 \text{ m/s} \ln(\text{mass}_{before}/1{,}393{,}000 \text{ kg})$$
$$\text{mass}_{before} = \text{mass of rocket} = 3{,}583{,}292\text{kg}$$
$$\text{mass of fuel} = 2{,}190{,}292 \text{ kg}$$

Fuel

There were two different types of fuel that we used for this mission. The first fuel was Aluminum with Ammonium Perchlorate as the oxidizer. This fuel had an ISP of 210 s and an energy density of 9 MJ/kg. [1]

This solid fuel propellant was used only for the launching stage of the mission for two main reasons. The first reason is due to the nature of solid fuels. These cannot be throttled so once the propellant is ignited it will burn until completion, this allows us to place the fuels in strap-on boosters and jettison the tanks once we reach the desired altitude post-launch. The second reason is due to the high propellant density of Ammonium Perchlorate, this means we can pack a greater mass of fuel into a smaller volume. Aluminum with Ammonium Perchlorate also provides a large amount of thrust, which is needed to escape earth's atmosphere and gravity.

The second fuel that was used was liquid hydrogen with liquid fluorine as the oxidizer. This fuel can be throttled and was therefore used for times in the mission when quick velocity changers were necessary in low-gravity environments. It has an specific impulse (Isp) of 400s and has a comparatively large energy density of 142 MJ/kg.[2]

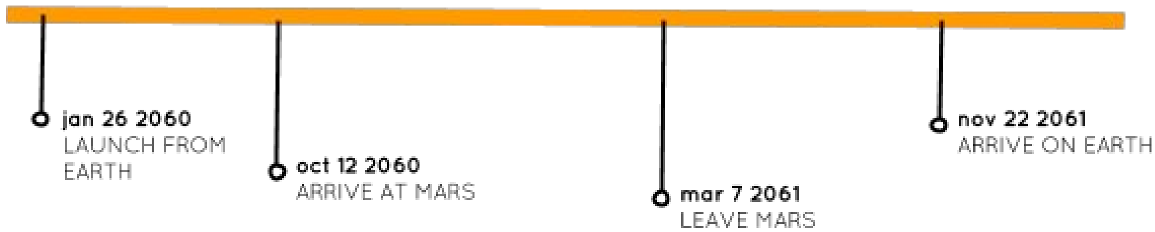
We use this fuel to calculate the initial energy needed to get off the ground, as

9MJ/1kg = energy derivative of fuel
2.190×10^6kg = mass of the fuel needed to launch from Earth
When we set these equal to each other, we get that 9MJ/1kg= xMJ/ 2.190×10^6kg
Solving for x, we get that x = $1.971 * 10^7$ MJ

1 http://www.braeunig.us/space/propel.htm
2 http://www.braeunig.us/space/propel.htm

Timeline

Overall, this trip will take 23 months. We can break this down into four large legs: getting to Mars, touching down in Mars, exploring Mars, and getting back to Earth. We slate our launch date for January 26, 2060.



The reasoning for this is that there is an opposition - where Mars, Earth, and the Sun line up along an origin- every 26 months. The last occurrence of this opposition was April 8, 2014. Thus, there will be an opposition on October 8, 2059. We then calculate that we must launch from Earth when there is an angle of 0.3π between the two planets for optimal trajectory, as the planets are travelling at different velocities. The equations below serve as reasoning for this specific angle. Note that the orange circle represents the sun, blue circle represents Earth and the red one represents Mars.

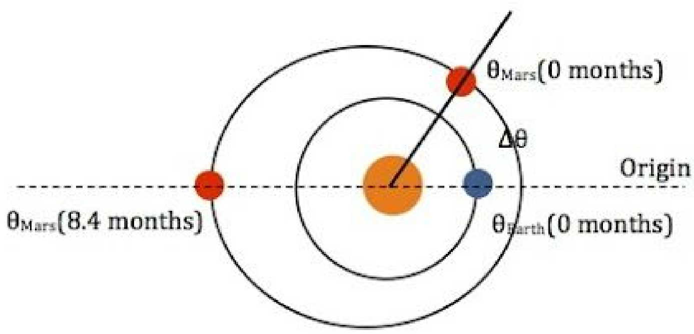
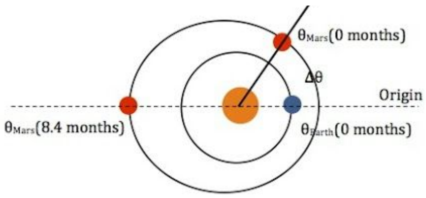


Fig 2. From Earth to Mars



$$\frac{\theta}{2\pi} = \% = \frac{t}{t}$$

According to these calculations, it will take 3.6 months for Mars to travel 0.3π in its orbit, and therefore will be in opposition with Earth 3.6 months from our launch date. As the opposition is October 8, 2059, our launch date needs to be January 26, 2060.

We calculate that it takes 8.4 months to travel from Earth to Mars. Thus, we will arrive on Mars on October 12, 2060. We then conclude that we have a time frame of 4.8 months before the orbits align again for an optimized trajectory back to Earth. Refer to the below diagrams for a more thorough understanding of calculations.

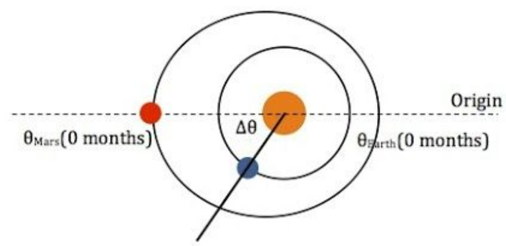


Fig 3. At launch from Earth

Fig 4. Upon landing on Mars

The angle between Earth and Mars upon landing on Mars is 0.4π. To ensure optimal trajectory conditions, we must again make sure that the angle between Earth and Mars is again 0.3π upon launch from Mars in order to catch the next opposition and land on Earth in 8.4 months. We must calculate how much time we have on Mars for these conditions to be met. Starting with the initial condition of 0.4π between the two planets, we calculate how long it will be to reduce this angle by 0.1π.

$$\theta_{Earth} = \frac{2\pi t}{t_{Earth}}$$

$$\theta_{Earth} = \frac{2\pi(8.4 months)}{(12 months)}$$

$$\theta_{Earth} = 1.4\pi$$

$$\Delta\theta = \theta_{\mathrm{Earth}} - \theta_{\mathrm{Mars}} = 1.4\pi - \pi = 0.4\pi$$

$$\theta_{\mathrm{Mars}} - \theta_{\mathrm{Earth}} = 0.1\pi$$

With these calculations, we have roughly 5 months to explore Mars and collect data samples. We will launch from Mars on March 7, 2061, and based on similar calculations as above, we will return back to Earth on November 22, 2061, eight months after launch from Mars.

Phase 1: Launch from Earth's surface into a parking orbit

The first mathematical question is: when exactly do we launch? First, we realize that the orbits of both the Earth and Mars are almost circular. In our calculations, we assumed the following two things: 1) the orbits are both the Earth and Mars are circular, and 2) the radii are equal to their respective semimajor axes (1.00 AU for Earth and 1.52 AU for Mars).

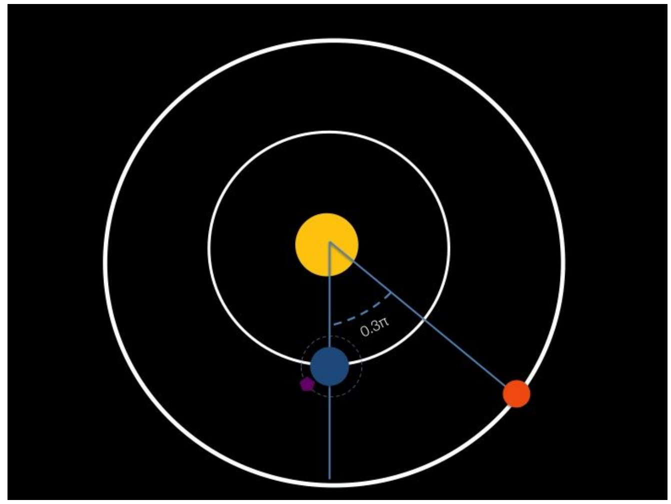


Fig. 5: Position of planets at launch from Earth

To find the period of Mars, we use Kepler's third law:

$P = 365\,a^{3/2}$

where **P = period in days**

a = semimajor axis (in AU)

According to our calculation, the period of Mars is 687 days, and the period of Earth is 365 days.
This information helps us calculate when we can launch our rocket on a minimum-energy transfer orbit. Since there is an opposition on October 8, 2059, that means that Mars will create a 0.3 π angle with Earth at 3.6 months after opposition. The specific calculations are included above with the timeline. Thus, we will launch from Earth on January 26, 2060.

We would depart closer to the equator of the Earth, so as to maximize the relative velocity of the rocket at launch, and near the East Coast of the United States in order to utilize the boost from the Earth's spin, as we are launching eastward as well. The rationale for launching near the equator is that an object on Earth's surface is already moving very rapidly, and because the Earth's spin is fastest on the equator, we can get an extra boost, saving fuel. The specific launch station we will be using is one that was dedicated in 1960 along the "Space Coast" in Florida, on Cape Canaveral.[3]

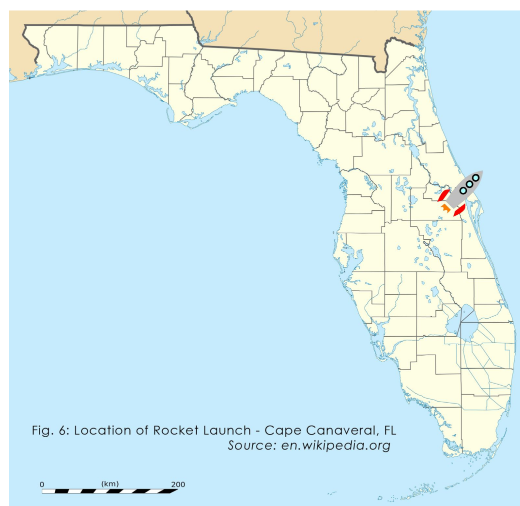


Fig. 6: Location of Rocket Launch - Cape Canaveral, FL
Source: en.wikipedia.org

In addition, we must also consider that we only have a 300-km height to accelerate to our desired velocity, as we still want to stay inside of Earth's gravitational pull to get the Hohmann orbit and not waste fuel on horizontal acceleration. The energy to get off the ground: 1.97*10^7MJ, as derived from our fuel considerations, included above. To determine our desired velocity, we look at

$$\Delta \mathbf{v} = \sqrt{2ad} = \sqrt{2 * 9.8 m/s^2 * 300,000 m} = \mathbf{2424.87\ m/s}$$

Phase 2: Injection into a transfer orbit

[3] http://www.space.com/8811-rockets-launched-florida.html

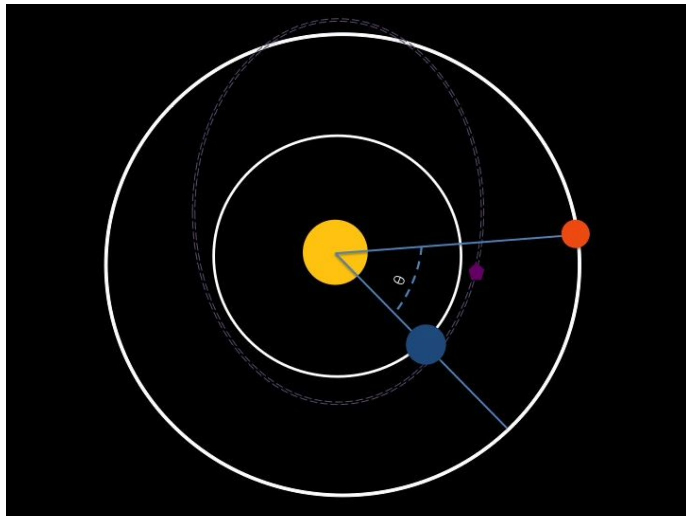


Fig. 7: Position of planets after initial launch

The second phase of the mission involves transferring the space probe from the 300 km parking orbit above Earth's surface to an elliptical Hohmann that will intercept Mars' orbit around the Sun. Before this maneuver is performed, the solid rocket boosters (SRBs) used for the aluminum/ammonium perchlorate mixture for the launch phase will be jettisoned. This will reduce the mass for the remaining phases of the mission, thus saving fuel and reducing the overall energy required for the energy.

The shift from the parking orbit around Earth to the Hohmann transfer orbit will be executed by a simple change in momentum. Thus, since the mass of the craft remains constant, it is sufficient to calculate to the change in velocity required in order to make the transfer. To determine the magnitude of this change in velocity, we must first determine the initial speed of the probe. Since we are considering the probe as part of a system centered about the Sun, we can assume that the probe, once in the 300-km parking orbit, has a velocity relative to the Sun equal to the velocity at which Earth revolves around the Sun. Furthermore, we can assume that the distance between the probe and the center of the Earth is miniscule compared to the distance between the Earth and the Sun.

To calculate the speed at which Earth revolves around the Sun, we use the following equation:

$$V_{Earth\ Orbit} = \sqrt{\frac{GM_{Sun}}{r_{Earth} + orbit\ height}}$$

Since we have determined that the distance between the Earth and the probe is negligible, we can reduce the above equation to:

$$V_{Earth\ Orbit} = \sqrt{\frac{GM_{Sun}}{r_{Earth}}}$$

Substituting in values, we find:

$$V_{Earth\ Orbit} = \sqrt{\frac{(6.67 * 10^{-11} m^3 kg^{-1} s^{-2})(1.99 * 10^{30} kg)}{1.5 * 10^{11}\ m}}$$

$$= 2.97 * 10^4\ m/s$$

Next, we must decide the velocity required for the desired Hohmann transfer orbit. To determine the trajectory, we note that the ellipse must start at Earth on one side and end at Mars on the other side of the Sun. Thus, the semi-major axis of the desired ellipse is: (Where 2a represents the length of the major axis)

$$2a = R_{Mars} + R_{Earth}$$

Using the follow equation, we can derive the velocity required to achieve the desired elliptical transfer orbit: (Where G is the gravitational constant).

$$V_{Probe} = \sqrt{GM_{Sun}\left(\frac{2}{R} - \frac{1}{a}\right)}$$

After inserting values, we obtain the following:

$$V_{Probe} = 3.27 * 10^4 \, m/s$$

$$3.27 * 10^4 \frac{m}{s} - 2.97 * 10^4 \frac{m}{s} = 5{,}700 \frac{m}{s}$$

Thus, we can determine that the change in velocity required to shift from the parking orbit around Earth to the specific Hohmann transfer orbit is an **increase by 5700 m/s.** This change in momentum will allow the probe to enter the desired Hohmann transfer orbit we selected to make it to Mars.

To determine the amount of time (T) that probe will remain in the transfer orbit, we draw upon Kepler's 3rd Law for an ellipse:

$$T^2 = \frac{4\pi^2}{GM_{Sun}}(a^3)$$

If we divide by the constants for Earth's orbit, we get:

$$T^2 = (a^3)$$

In this case, 'a' is equal to the distance of Mars and Earth, in terms of astronomical units (AUs). Thus, a = 1 AU + 1.52 AU = 2.52 AU.

Using these values, we obtain:

T = 1.4 years

However, since we are only concerned about half of the ellipse (which is equivalent to getting to Mars), we divide by 2 to obtain:

T = 1.4 years / 2 = 0.7 years = ~8.5 months

Thus, using Kepler's 3rd Law, we have determined that the voyage from Earth to Mars using a Hohmann transfer orbit will take roughly 8.5 months to complete.

Phase 3: Insertion into Mars orbit

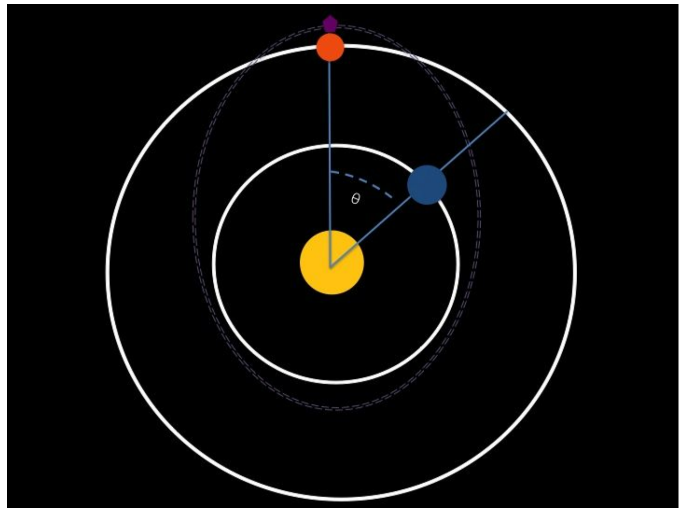


Fig. 8: Position of planets while in Mars orbit

It is October 2060, the 9th month of our trip. We are at the apex of our transfer orbit and Mars is to our left. We are traveling at a speed of 3.27 x 10^4 m/s which we determined by using the equation below and plugging in the known mass of the Sun, the radius of Mars, and the aphelion (a) which is given by the radius of Mars's orbit around the Sun.

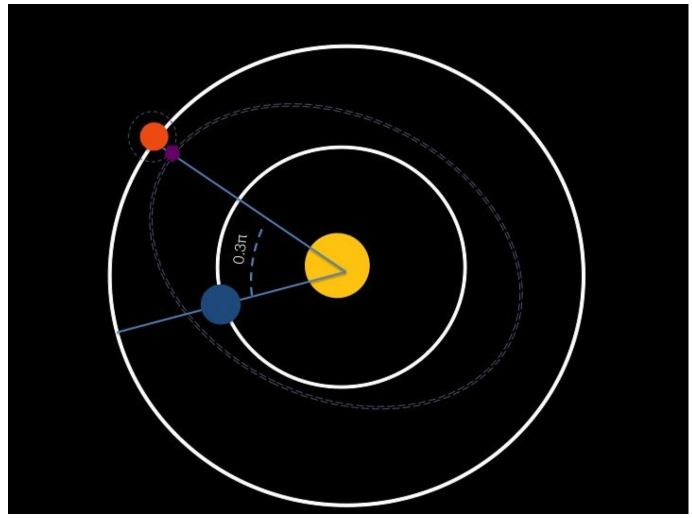
$$V_{Hohmann} = \sqrt{GM_{Sun}\left(\frac{2}{r_{mars}} - \frac{1}{a}\right)}$$

This velocity, however, is too large. To allow us to successfully plan a Mars landing we must enter into a low-altitude parking orbit of around 300 km, this orbit is at a lower energy state than our current orbit. To do this we must utilize our understanding of momentum and decrease our velocity. To determine the necessary end-velocity we can use the equation below. By plugging in the mass and the radius of Mars we arrive at a velocity of about 2.4 x 10^4 m/s. This is a 8600 m/s decrease from our current speed in the Hohmann transfer orbit.

$$V_{Mars\ Orbit} = \sqrt{\frac{GM_{Mars}}{r_{Mars} + orbit\ height}}$$

To change our velocity by this amount, we must utilize our understanding of momentum. By firing our propellant in the direction opposite our current direction of movement, we can slow down enough to orbit at an appropriate parking orbit. The energy needed to accomplish this is 1.63 x 10^8 MJ. This was found using the rocket equation and the energy density of liquid hydrogen. The relevant equations are found below, context can be found in the reference and summary of calculations.

Phase 4: Injection into transfer orbit back to Earth



As previously mentioned, our mission is to minimize energy and we can do so on our injection into the transfer orbit to get to Earth. Just like how we went from Earth to Mars, we have to make sure that the $\Delta\theta$ from Earth-Sun-Mars is 0.3π (please see page 4 to see the calculations on how we derived our value of 0.3π). This value is significant because it takes 3.6 months for Mars to travel 0.3π angle with Earth.

According to our calculations, Mars will create this 0.3π angle with Earth in March of 2061. At this time, we will inject our spacecraft into the transfer orbit to get back on Earth.

Returning to Earth involves our spacecraft to initially move in the opposite direction to the motion of Mars. First, we know that the energy density of our fuel (liquid hydrogen) is 142 MJ/kg. Now we must determine how much fuel (x) it will take to get into the transfer orbit:

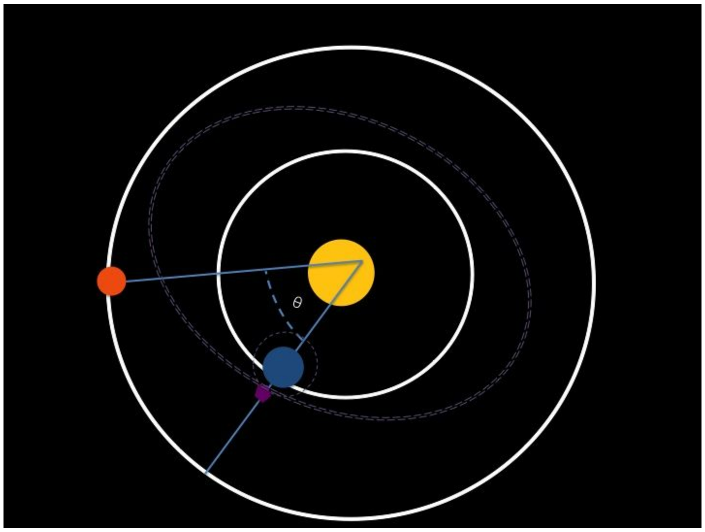
$$\Delta v = v_{eq} \ln((\text{mass before})/(\text{mass after}))$$
$$-3000 \text{ m/s} = 2646 \ln(x/15000 \text{ kg})$$
$$1.13 = \ln(x/15000)$$
$$3.095 = x/15000$$
$$x = 46{,}434.8475$$

That means that it must take 31,434.85 kg of fuel to get into the transfer orbit. With this information, we can calculate the energy:

$$142\text{MJ/kg} = x \text{ MJ}/31434.85 \text{ kg}$$
$$x = 4.46 \times 10^6 \text{ MJ}$$

Thus, the energy that is needed to get into the Hohmann transfer orbit is 4.46×10^6 MJ.

Phase 5: Insertion into a low-altitude parking orbit around Earth



We will arrive in Earth's parking orbit on November 22, 2061, almost two years after our initial launch off of Earth's surface.

At this point, we will be returning with a much smaller vehicle load given that we will have utilized most (if not all) or our fuel and life support equipment. In addition, we will be returning without our fuel capsules because they would have been jettisoned throughout the mission, further reducing our load.

Although it would seem intuitive that the amount of fuel needed to leave the Hohmann's transfer orbit would be the same as the amount of fuel needed to enter the transfer orbit (Step 2), we must consider this change in mass. A smaller spacecraft would mean that it would need less of an impulse to reach the same amount of change in energy and, thus, less fuel. The amount of fuel needed will be 3.2E4kg and the energy needed will be $4.58x10^6$MJ. The total amount of energy needed for the entire trip will be an order of magnitude of 14 MJ.

Human Sustainability

One of the major considerations involved investigating what is necessary to make human Mars missions practical, sustainable, and affordable. The human body is not designed to survive in a closed environment outer space.

Table: Requirements for Sustaining Life for a Single Astronaut (NASA)

Consumables	kg/pers.-day	Wastes	kg/pers.-day
Gases Oxygen	**0.8**	**Gases** Carbon Dioxide	**1.0** 1,00
Water Drinking Water Content of Food Food Preparation Shower and Hand Wash Clothes Wash Urine Flush	**23.4** 1.62 1.15 0.79 6.82 12.50 0.50	**Water** Urine Perspiration/ Respiration Fecal Water Shower and Hand Wash Urine Flush Clothes Wash Humidity Condensate	**23.7** 1.50 2.28 0.09 6.51 0.50 11.90 0.95
Solids Food	**0.6** 0.62	**Solids** Urine Feces Perspiration Shower and Hand Wash Clothes Wash	**0.2** 0.62 0.03 0.02 0.01 0.08
Total	24.8	Total	24.9

In the vacuum of space, the removal of gases (including oxygen) and pressure will cause decompression sickness and gas embolisms. It takes less than two minutes for the person to die from exposure to vacuum in space. [4]

This is precisely why it is important to design a life-sustaining space environment provided with a substantial amount of oxygen, water, and food to sustain ourselves. As seen in the table above, one astronaut requires 24 kg/day during orbit. The sum of consumables and wastes is 49.7 kg/day per astronaut. In a 260-day journey outer space for five astronauts, that would be a total of 64,610 kg!

We did discuss about the possibility of having plants during our mission. Plants are an excellent aid to a regenerative life support system by supplying food, regenerating oxygen from carbon dioxide, converting wastewater into drinking water. While they provide many benefits, the feasibility of plants in a microgravity closed environment is not yet feasible. The transpiration, which feeds the plant by making the water and nutrients travel upward from the root, would not work effectively. The stems and roots may not grow with the lack of gravity. This is one interesting area of human sustainability that deserves some more research.

[4] Landis, Geoffrey A. (7 August 2007). "Human Exposure to Vacuum". www.geoffreylandis.com. Retrieved 2012-04-25.

Conclusion

Overall, this team of marsonauts discovered that there is a reason people say "It's not rocket science". Rocket science is a very detailed, exacting, and critical art. Even though pains were taken to apply concepts and principles directly from the course of instruction, we noticed that our calculations and numbers were very different from our peers. This is due to the uncertainty of the final frontier, and the variables used in fuel, machinery, payload, and orbital design.

Division of Responsibilities

As noted in the authorship details, all five authors of this work contributed equally. Specific task groups are as follows.

Project Proposal & Design: All Authors
Poster Design: Shuya Gong
Presentation Design: All Authors
Calculations: All Authors
Final Text & Figures: All Authors

Special Breakdowns

India Perez-Urbano: I was responsible for calculating the timeline for the mission and the necessary launch dates. For the report, I wrote the timeline portion and Step 5 section. I did preliminary research on previous theoretical approaches to missions to Mars, the different trajectories available to us, and the type of fuel to use. I also assisted in calculations for the amount of fuel needed, the energy density of the fuel, and the amount of energy needed for each step of the mission.

Leslie Ojeaburu: I was responsible for the justification of the types of fuel that we used for this trip and for Step 3 of this mission. For the report, I wrote the portion on the fuels we used and I also detailed the part of the trip where we transferred from a hohmann transfer orbit to a parking orbit on mars. I also assisted in the calculations for the mass of fuel used, the amount of energy needed for the mission, and provided supporting calculations for the time it would take to travel half the period of the hohmann transfer orbit.

Shuya Gong: I was responsible for the design of the poster and the structure of the final report. I also helped with research on the different phases of the launch, types of fuel and engine, and focused on the launch phase of the mission, specifically with the best time, geographical location, and reasons for in reference to the rocket launch. I also edited and generated diagrams and images for the project.

Esther Lim: I was responsible for assisting with the basic mathematical concepts and re-checking the calculations for the timeline and for the velocities. I also helped design the poster. I took charge in organizing the final report (including content layout out the report), including the abstract, the launch, Step 4, and human sustainability.

Daniel Wang: I was responsible for the calculations to determine the momentum, energy, and resources required for the second stage of the mission - transitioning from the parking orbit around Earth to the Hohmann transfer orbit. I also performed the calculations to determine the transit time required to travel the Hohmann transfer orbit from Earth to Mars. Finally, using the specific impulse of the fuels we selected, I was responsible for calculating the mass of the fuel we needed for each leg of the trip. I performed these calculations using the rocket equation presented in class. I worked backwards from the last leg of the mission, since I knew the final mass of the rocket (assuming there is no fuel left at the end of the mission).

Word Count

Words: 4037
Figures: 12 x 200= 2400
Equations: 13 x 40 = 520
Total: 3527 + 2400 + 520 = 6447

Reference and Summary of Calculations and Figures

Calculation for the Mass and Energy Used:

$$\Delta v = v_{eq} \ln \left(\frac{Mass\ Before}{Mass\ After}\right)$$

Step 5: From Hohmann Transfer to Earth Parking Orbit:

$$\Delta V = -3000 m/s$$

$$V_{eq} = 400s \times 9.8 \frac{m}{s^2} = 3920$$

$$Mass\ After = 15{,}000\ kg$$
$$Mass\ Before = x$$

$$3000 \frac{m}{s} = 3920 \frac{m}{s} \times \ln \left(\frac{x}{15000\ kg}\right)$$

$$0.765 = \ln \left(\frac{x}{15000\ kg}\right)$$

$$2.149 = \frac{x}{15000\ kg}$$

$$\boldsymbol{x = 32,244\ kg\ Fuel}$$
$$+15{,}000\ kg\ Payload$$

$$\boldsymbol{47244.78\ kg\ of\ total\ mass}$$

$$142 \frac{MJ}{kg} \times (3.22 \times 10^4\ kg) = \boldsymbol{4.58 \times 10^6\ MJ}$$

Step 4: From Mars Parking Orbit to Hohmann Transfer:

$$\Delta V = 8600 m/s$$
$$V_{eq} = 400s \times 3.11 \frac{m}{s^2} = 1244 \frac{m}{s}$$
$$Mass\ After = 47244.78\ kg$$
$$Mass\ Before = x$$

$$8600 \frac{m}{s} = 1244 \frac{m}{s} \times \ln \left(\frac{x}{47244.78\ kg}\right)$$

Step 3: From Hohmann Transfer to Mars Parking Orbit

$$\Delta V = 8600 m/s$$
$$V_{eq} = 400s \times 3.11 \frac{m}{s^2} = 1244 \frac{m}{s}$$
$$Mass\ After = \mathbf{4.73 \times 10^7\ kg}$$
$$Mass\ Before = x$$

$$8600 \frac{m}{s} = 1244 \frac{m}{s} \times \ln\left(\frac{x}{4.73 \times 10^7\ kg}\right)$$
$$6.91 = \ln\left(\frac{x}{4.73 \times 10^7\ kg\ kg}\right)$$
$$1002.24 = \frac{x}{4.73 \times 10^7\ kg\ kg}$$
$$\mathbf{x = 4.74 \times 10^{10}\ kg\ Fuel}$$
$$+4.73 \times 10^7\ kg\ Payload\ and\ fuel$$

$$\mathbf{\sim 4.74 \times 10^{10}\ kg\ of\ total\ mass}$$
$$142 \frac{MJ}{kg} \times (4.74 \times 10^{10}\ kg) = \mathbf{6.73 \times 10^{12}\ MJ}$$

Step 2: From Earth Parking Orbit to Hohmann Transfer

$$\Delta V = 3000 m/s$$
$$V_{eq} = 400s \times 9.8 \frac{m}{s^2} = 3920$$
$$Mass\ After = 4.74 \times 10^{10}\ kg$$
$$Mass\ Before = x$$

$$3000 \frac{m}{s} = 3920 \frac{m}{s} \times \ln\left(\frac{x}{4.74 \times 10^{10}\ kg}\right)$$

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