Mission H.O.M.E. – A Journey to Mars

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Abstract

Influenced by the recent success in the field of unmanned space exploration, we have designed a mission plan that would allow for a manned mission to Mars, Earth’s closest neighbor. The goal of this mission is to assess the feasibility of sustaining human life on Mars and to research several aspects of the planet, such as its environment and history. Through our research, we will determine what resources Mars could potentially provide, how to effectively utilize said resources, and if Mars was ever home to any forms of life. We have outlined a possible mission to Mars in which we have provided solutions for the several constraints humans would face on such a long duration mission, such as food and water storage, waste management, physical health and fitness, and other life support systems. In addition, we have determined flight trajectories, launch windows, and orbital transfers through extensive, yet precise, mathematical calculations in order to most accurately establish our mission’s timeline and required features. We have also rendered realistic models of the several new spacecraft and structures conceptualized specifically for the mission using the 3-D drafting program, Solidworks. We have concluded that while a vast amount of resources and funding would be necessary in order to provide solutions for the myriad of potential issues associated with such a high-risk mission, the actual implementation of such a mission is more than possible and is, in fact, probable within the next 20 years considering the development of certain required technologies.

Key Words

synodic period, gravitational potential energy, centripetal force, eccentricity, apses, Hohmann transfer, Oberth hyperbola, sphere of influence, impact parameter, parking orbit, Mars, BioSuits, EMU, ACES, ISRU
Introduction

Ever since human spaceflight commenced under the pressure of competition between the United States and the USSR about 50 years ago, significant advances have been made in space exploration. Since that time, the Apollo program successfully landed a man on the moon and countless unmanned probes and rovers have been launched into orbit, en route to investigate once unreachable celestial bodies. However, only recently has the National Aeronautics and Space Administration (NASA) seen provocative success in one of its oldest endeavors: the exploration of Mars. In fact, the most recent venture, Phoenix Mars Lander, successfully landed on the surface of Mars on May 25, 2008 and, unlike many of its predecessors, has seen a significant amount of success in its preliminary research regarding the search for water and traces of life on Earth’s closest relative.¹

The potential rewards of Martian exploration are immense - not only could the Red Planet provide critical data in the defining search for life, but it is also a potential goldmine of resources as well as a possible future second home for the human race. Until recently, unmanned spacecrafts such as Phoenix, and its most recent forerunners, Spirit and Opportunity, have been mankind’s greatest tool in examining the endless possibilities of understanding Earth’s closest relative. However, due to the recent increase in public interest as well as international competition, new technology has been developed and new tactics have been studied that would potentially allow for a manned mission to the surface of Mars.²

Therefore, we have deemed it necessary to carry out an experiment to assess the feasibility of sustenance of human life on Mars for extended periods of time. As a result, we have outlined a prototype for a mission to Mars, which we have named the Human On Mars Experiment Program, or H.O.M.E. Program.

There are many reasons why a manned mission to Mars has not yet been attempted. Limitations come from many places, for instance lack of technology, long length of the mission, and all the risks and uncertainties involved. While the moon is relatively close to Earth, Mars is months away. There would be difficulty in getting enough provisions – food, water, oxygen, energy and fuel – to last the entirety of the trip, as well as backup supplies. The health of the astronauts, both mental and physical, must be attended to. They must go through rigorous training to have the mental capability to endure such a long space mission, as well as the physical capacity.

We researched the previously mentioned issues and as a result of our research, we designed several spacecraft and land based structures specifically for what the mission would require. We also determined a realistic mission timeline with the constraining factors in mind, in hope to accommodate the challenges a mission to the Red Planet factually involves. Inclusive in this program are extensive calculations pertaining to trajectories, orbits, and launch windows, descriptions of mechanisms for life support, as well as models of all newly
designed structures and spacecraft. These models were rendered in the 3-D drafting program, SolidWorks.

**Background**

**Orbits and Trajectories**

Planning a mission to Mars involves a thorough understanding of the orbits and trajectories. Within the scope of this paper, a number of terms and concepts are essential to the comprehension of our proposed mission.

There are two types of orbits – open orbits and closed orbits. Closed orbits are either circular or elliptical. An orbiting body will move around another body, for example a planet, continuously along the same path. If a spacecraft is launched at the correct angle and speed, it can be made into a satellite that circles a planet and constantly remains the same height above the planet’s surface. The spacecraft is then said to be in a parking orbit. Open orbits or trajectories, on the other hand, are parabolic or hyperbolic escape paths used to escape the gravitational pull of a planet. Orbits can be changed, for example, from circular to elliptical, and vice versa. It is often necessary to transfer from one orbit to another during interplanetary travel, which is done by changing the velocity of the spacecraft.

There will be many stages of our mission in which a body will remain in a parking orbit for a period of time. This is to increase the chances of success during our mission. The most efficient orbital transfers can only occur under certain alignment of the planetary bodies – this time is called the launch window. The rotational period of Earth is 24 hours, thus if the spacecraft were to be launched from Earth, it would only have a launch window once every 24 hours. On the other hand, in a parking orbit, it is possible for a satellite to remain above the same point on a rotating body. Such a synchronized orbit would allow direct transmissions between a spacecraft and a base at all times. By placing our spacecraft in a parking orbit, we can reduce the period and have larger and more frequent launch windows.

**Calculations**

The planets revolve about the Sun in elliptical orbits that have sufficiently low eccentricities so we can approximate them as circles. Travel in space is dictated by the forces of gravitation from both the Sun and planetary bodies. It is necessary to transfer from one orbit to another during interplanetary travel, which is accomplished by thrusting to change the velocity of the spacecraft.

The easiest and lowest energy transfer between two unconnected circular orbits is through an elliptical orbit, named the *Hohmann transfer* after scientist Walter Hohmann. The Hohmann transfer requires two collinear thrusts that respectively cause the spacecraft to leave its initial parking orbit, and then a second that causes the spacecraft to enter a circular orbit about Mars. To escape or enter the gravitational field of a planetary body, known as the *sphere of influence* of this body, the spacecraft needs to either execute a parabolic or hyperbolic path. These are
discussed in further detail in the *Trajectory and calculations* section.

**SolidWorks**

SolidWorks is a computer designing program. It is commonly used engineering program that allows the user to create a three dimensional rendering of what essentially are two dimensional computer aided design (CAD) sketches. After the design has been made, users can view the model in 3-D as well as export sketches and pictures of the model. It is the program that we used to create our designs for this mission.

**Mission Summary**

Our mission begins with launching the pieces of the base that will house the astronauts on Mars into a parking orbit around the Earth, which we have set at 300 km. Launching objects out of the Earth’s atmosphere into orbit requires energy and relatively light and aerodynamic designs. Because our base must provide protection and life support for astronauts for over a year, we cannot compromise the size or design of the base. However, sending smaller parts into space will greatly simplify the process of launching our base. The parts will then be assembled in a parking orbit around the Earth, where they are free from the constraints of gravity and aerodynamics. From there, the base will then launch to Mars, enter its atmosphere, and decent onto the planet surface. Powerful retro-rocket firings on the base will decrease the impact of collision.

The base launch will precede the actual launch by approximately two years. The base will be timed to open and self-develop at the correct time. First and foremost, this will drastically decrease the amount of food, water, oxygen, and other resources to be carried on the spacecraft. This plan will also allow our astronauts to access ample resources upon landing on Mars, making their mission easier. Finally, the base landing on Mars will act as a safety check point. That is to say, if the environment of landing is not suitable for human life, there were errors in calculations, or if systems on the base should fail, we would be aware of the issue back on Earth without putting our astronauts at risk.

After the launch of the base, our spacecraft, with astronauts, will then be launched into a parking orbit around the Earth. As stated in the *Background* section, a parking orbit can greatly increase our opportunities for a launch. From Earth, our spacecraft will undergo a Hohmann transfer into the orbit of Mars, where it will once again be transferred to a parking orbit around Mars. The spacecraft will remain in this parking orbit, whereas our astronauts will descend onto the ready base in a lander. The original spacecraft will remain in a parking orbit around Mars. Again, a smaller structure is easier to send into or out of the atmosphere of Mars. Because the decent onto Mars will only be a matter of hours, it is unnecessary for the entire spacecraft to land. Upon completion of the mission, the astronauts will return to the spacecraft orbiting Mars in a return craft that is already at the base. They will then return to Earth on the spacecraft that is already in space.
Timeline of Launch

The launch windows for our mission will occur respectively at February 2031 and March 2033 (Citation: Wikipedia). Mars and Earth line up with respect to each other every 2.135 years (this period is known as the synodic period). For example, launch windows occurred August 2005 and October 2007, which we can write in decimal format as \( \frac{2007}{12} \approx 2007.67 \). Since the period is 2.135 years, then other launch windows can be written in the form \( 2007.67 + 2.135n \) for integers \( n \); for consecutive \( n = 11, 12 \), we get February 2031, March 2033, which will be our launch dates for the base and the spacecraft, respectively.

The journey to Mars will take approximately six months; details are located under Trajectory and calculations. The astronauts will stay on Mars for a period of a year before returning.

Trajectory and Calculations

The elliptical orbits of Mars and the Earth look as follows:

Figure 1(a,b). The first diagram shows the elliptical orbits; the orbits will be approximated as circles for calculational ease. The scale ratio here is approximately 0.75 inches : 1AU.

For the sake of simplicity of calculations, we let the orbits be (1) coplanar (2) concentric (3) circular. Our path will have three distinct segments: A circular parking orbit about the Earth, an elliptical transfer from the Earth to the orbit of Mars, and then a circular orbit about Mars. Data for Mars, Earth, and the Sun can be found in Appendix A, along with specific calculations.
\[ V = 2370 \frac{\text{m}}{\text{s}} \] is necessary to propel a shuttle into orbit. For a satellite to keep this altitude, the force of gravity upon the satellite must provide sufficient centripetal force for revolution about the Earth, with a tangential speed of \[ V_{E \text{ orbit}} = 7726 \frac{\text{m}}{\text{s}} \]. The escape velocity of the spacecraft from the orbit in space at a distance of \( r_E + h \) from the center of the Earth can also be computed using the transformation of kinetic energy into potential energy: \[ 10,926 \frac{\text{m}}{\text{s}} \].

The next step involves an elliptical transfer (known as the Hohmann transfer) from the orbit of Earth to that of Mars, which relies upon gravity from the Sun. With known distances, the speeds of the spacecraft at the periapsis and apapsis (closest and farthest points, respectively) are found to be \[ V_{ES} = 32729 \frac{\text{m}}{\text{s}}, \quad V_{MS} = 21475 \frac{\text{m}}{\text{s}} \].

To enter our desired elliptical orbit, we use a hyperbolic escape trajectory, known as the Oberth hyperbola. This allows the spacecraft to immediately enter the elliptical orbit, leaving a residual speed of \[ V_\infty = V_{ES} - V_E = 2940 \frac{\text{m}}{\text{s}} \] at a point far from the Earth. This escape requires a speed of \[ \Delta V = 11,314 \frac{\text{m}}{\text{s}} \] or a thrusting of \[ V_{E \text{ orbit}} = 3,560 \frac{\text{m}}{\text{s}} \] (II). We can also compute the angle of the spacecraft's trajectory with respect to the motion of the Earth. To find this, we note that the spacecraft's velocity should be parallel to the Earth's motion when the spacecraft exits the region affected by Earth's gravity (this region is known as the sphere of influence of the Earth). For Earth against the Sun, the radius of this sphere is \[ 145 \times \text{the radius of the Earth} \]. The angle turns out to be \( \nu_\infty = 106.2^\circ \).

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Figure 2 (a,b,c). The three diagrams, respectively, show the transfer from a circular orbit about the Earth to the ellipse, the to and return journey of the spacecraft, and the transfer from the elliptical transfer to an orbit about Mars. All three are exaggerated to show detail.

The satellite has a height of \( h = 300 \text{ km} \) above the Earth. From the law of conservation of energy, the satellite must convert some of its kinetic energy into gravitational potential energy to reach this altitude; from this we find that
Figure 3. Asymptotic overview showing the hyperbolic path of the spacecraft parallel to the Earth's orbit.

We know that the period of this journey, by Kepler's Laws, is $P = 8.5$ months. Mars and Earth are aligned up at February 2031, March 2033 (see Timeline of launch), so the spacecraft must be launched 8.5 months ahead, respectively at May 2030, July 2032.

When the spacecraft reaches the apsis of the orbit, the relative velocity of the spacecraft to Mars is $|V_\infty| = 24,140 - V_{2M} = 2665 \frac{m}{s}$. Our goal is to have the spacecraft revolve in a circular orbit, where the spacecraft hovers over the same spot above Mars at all times, which would allow easy communication. This Martianosynchronous orbital period is given by Kepler’s Laws to be at a radius of $r = 20,437,500$ m. Using conservation of energy, the spacecraft reaches a speed of $V_p = 3363 \frac{m}{s}$, where $V_p$ is the speed of the spacecraft at the closest point of the hyperbolic flyby of Mars.

Since our goal is to achieve a permanent circular orbit of the spacecraft about Mars, we require that the gravitation force by Mars provides a sufficient centripetal force, or $V_{M \text{ orbit}} = 1450 \frac{m}{s}$. Thus, as the spacecraft makes the flyby, it must decrease its speed by $\Delta V = V_p - V_{M \text{ orbit}} = 1913 \frac{m}{s}$ (III). In conclusion, the velocity budget for this journey is $\Delta V_T = (I) + (II) + (III) = 2370 - 3500 + 1913 = 7843 \frac{m}{s}$.

We would like to launch our lander into the Martian atmosphere. We can approximate the speed of the lander using the conservation of energy. The lander uses a system of backwards thrusts to dramatically reduce its speed upon entering the atmosphere, and then uses a parachute to reach a low terminal velocity. A system of inflatable balloons will soften the impact of the lander on the Martian surface.

The return craft, which goes with the base on the first trip, will be used to return the crew back to the orbiting spacecraft. The return journey will follow a similar elliptical orbit, except the order is now backwards: the journey starts with leaving from Mars, and reaches the Earth. Specifically, the same orbital speeds about Mars and the Earth and the same elliptical orbit applies, so the journey will be of approximately the same duration and have a similar shape.

For a more detailed version of the calculations, refer to Appendix B.

**Scientific Errors**

Outside of natural error introduced by measurement problems, certain errors are introduced with several of the assumptions
used to perform these calculations. The plane of Mars with respect to that of Earth is tilted at $1.85^\circ$, and Mars and Earth have eccentricities respectively of $\approx 0.0933$ and $0.01671$. Earth's orbit, at extremes, differs only about $2\%$ from its average radius (1 AU), while the Martian orbit differs by about $10\%$. The problems we discussed above at all times used a "patched-conic" solution, during which we switch between different conic section orbits instantaneously (such as the sharp bound at the sphere of influence). They also assume that the masses are point sources, and that there are at most 2 bodies affecting the spacecraft's trajectory at any point. Certain design specifications, such as that the acceleration of a rocket occurs instantaneously, can be assumed because of the relative distances. In all of these cases, the percentage differences are fairly small, yet all extremely significant.  

**Design Constraints**

**Life Support**

**Food and Water**

Needless to say, humans cannot go for long without food or water, thus, we would need a system for providing these essentials for our astronauts.

**Oxygen**

Because there is a lack of oxygen in outer space and on Mars, there must also be a way to provide the astronauts with oxygen in the spacecraft, on the base, and in their spacesuits for times they are outside these structures.

**Physical Exercise**

While on Earth, the force of gravity actually helps keep bones and muscles strong by acting against them every time the human body moves. This keeps bone and muscle mass high enough to support the efficient movement of our own weight. In space, however, gravity is nonexistent and therefore astronauts require other means to maintain strength in their bones and muscles as well as their overall health. During prolonged weightlessness, the bone density and muscle mass of the body decreases significantly. This is extremely dangerous considering astronauts need to remain strong to perform certain emergency procedures as well as the actions of day-to-day life upon their eventual return to Earth. Should muscle mass decrease, it is possible to build it back up to strength through therapy. Bone mass; however, is significantly more difficult to restore.

In addition to the potential decrease of bone and muscle mass, the issue of plasma-loss also proves potentially dangerous. In microgravity, a force of gravity so low that weightlessness occurs, plasma, is lost throughout the body. Being that plasma is where the red blood cells of the body are located, there is less blood available to carry oxygen to the heart. Another potential effect of microgravity is Orthostatic Intolerance. This causes light-headedness if one were to stand up or sit down too quickly. The body attempts to combat this by increasing its heart rate and blood pressure in order to keep blood returning to the heart. Harmful effects to the
body, such as these, must be reduced to a minimum during our mission.

Medical Concerns

Human health in space goes further than just physical fitness, however. The complexity of the human body’s reaction to space’s habitat is a puzzling aspect of space travel. When humans are exposed to low gravities, different body systems, as well as muscles, are thrown off of the regular cycle.

The first challenge an astronaut is faced with during space travel is space motion sickness. There will be an early duration where nausea and vertigo will cause the most problems for individuals in space. Astronauts must be equipped with vomit disposal options at times of extreme nausea so that the hassles of cleaning up will be kept to a minimum. A common risk following motion sickness is problems with the vestibular system, which involves the inner ear, therefore affecting balance. However, such complications are usually temporary and far from severe.

Other issues are prominent later in the journey, depending on how long a space mission lasts. The circulatory system needs to become accustomed to the change in gravity; therefore, a rapid heart beat is likely. Linked to blood flow, a condition known as Fluid Surplus is triggered for the same reasons. Triggered, meaning the body does is not actually affected but instead is tricked into believing it is. This condition can only affect the body by acting as a catalyst for dehydration; therefore water intake is very important while in space.

Spacesuits

When going into space, astronauts use two different spacesuits – one to use upon entering and leaving the Earth’s atmosphere, and another for exploration of foreign planets. The Advanced Crew Escape Suit, or ACES, weighing 80 lbs, is the suit currently being used by NASA astronauts during the ascent and reentry portion of missions. Its basic function is to protect astronauts during the changes in conditions inside and outside the Earth’s atmosphere. The suit is made of Nomex, and includes a helmet that allows for clear vision and communication, gloves that can be pressurized, leather boots that prevent swelling of feet from pressurization and ankle injuries, a life raft and light sticks for survival emergencies.

The spacesuits used by astronauts after entering outer space, however, calls for a drastically different design. They must provide oxygen for its user to breathe, as well as remove the exhaled carbon dioxide. In addition, the space suit must be able to maintain a steady air pressure similar to what the Earth exerts on its inhabitants. Without this pressure, blood and other body fluids would not be able to remain in their liquid states. Similarly, in space, depending on the position of the sun, temperatures range from -100°C to 120°C, clearly not suitable for humans. A space suit would provide the necessary temperature control, giving insulation while at the same time...
have a cooling system to prevent fogging and dehydration through perspiration. Finally, the lack of gravity in space makes changing direction impossible without the implication of a force in the direction of motion. A mechanism for dictating motion is also necessary.

Currently, the suit used to on moonwalks and other space activities is the Extravehicular Mobility Unit, or the EMU. However, our mission to Mars is drastically different from past missions, and as a result, the EMU fails to serve our purposes. Primarily, on Earth, the EMU weighs over 300 pounds, and is made of thirteen (13) layers of material, including Nylon, spandex, Dacron, Mylar, Gortex, Kevlar, and Nomex. This was never a problem in space or on the Moon, because gravity is not present. But Mars has its own gravitational field, roughly one third of the Earth’s gravity (3.7m/s^2). This means that the suit would still weigh about 100 pounds on Mars, something impractical to expect astronauts to explore and perform experiments in. Also, it exerts a pressure of 0.29 atm on the astronaut in the form of air pressure inside the spacesuit. This poses a major safety concern - if the suit were to ever be ripped or damaged in any way, it would immediately begin to depressurize, posing a life-threatening factor for our astronauts. In addition, the portion of the suit around the upper torso resembles a vest and is made of stiff fiberglass. Though the arms, legs, and gloves are made of soft material to allow for mobility, movement is still difficult because of its many layers, bulky design, and heavy weight. Thus, for our mission to Mars, we needed to find an alternative to allow for optimum performance.

**Artificial Gravity**

The disappearance of the force of gravity in outer space leads to certain symptoms, collectively known as the space adaption syndrome (SAS). Prolonged periods of weightlessness lead to various adverse health conditions for astronauts. These effects include disorientation, headaches, vomiting, and nausea. Over long periods, such as a journey to Mars would take (at minimum a six-month trip), include the atrophy of muscles and bones and the weakening of the cardiovascular and immune systems. In space, the effect of gravity by planetary bodies is nearly negligible. The implementation of a system to imitate gravity on the spacecraft is therefore necessary.

**Waste Management**

A person outputs a significant amount of waste products, on average 0.4 kg of solid waste, thus leading up to over a ton of organic wastes over the course of a multiyear journey. Additional waste comes from products of daily routines, such as paper, food, clothing, hygiene supplies, and so forth. These can accumulate over the course of six months to lead to many tons of waste.

**Engineering Decisions**

**Crew**

There will be six astronauts manning the Mars spacecraft. Of these, at least one person will be selected from a medical
background and three from engineering backgrounds, though all the crew members should have strong technical abilities. Candidates and their backgrounds will be carefully analyzed, with points of interests including physical health and mental strength. These astronauts will be put through a rigorous training program to take place over the course of five years, with the first three involving more intermittent training. This program will emphasize physical fitness and technical training to prepare for the demanding conditions of prolonged space travel.

The crew members will carry out most of their actions during the journey in a crew cabin, which is located in the center of the spacecraft. The astronauts are responsible for heading controls, maintaining communications with Earth, and handling technical issues on the spacecraft. On the Mars base, they will be performing various experiments to evaluate the potential of Mars (with regards to resources and colonization possibilities). The cabin, as well as most of the spacecraft, will have a circulating oxygen supply, and provides other necessities. Daily exercising and gravitational adjustment training to maintain fitness, as well as life support systems, are discussed in later sections.

Spacecraft

The spacecraft for the mission to Mars has many key features, including durability against the vacuum of space, a sufficiently high thrust-to-mass ratio for propulsion, and accommodations for the astronauts on the journey.

Construction

The spacecraft will be built in a parking orbit in space by automated robots. This allows a greater degree of freedom for initiating the launch sequence, because considerations like weather or aerodynamics are no longer present. The ship is also constructed in space because it saves a lot of fuel that would be used to get the ship out of the atmosphere.

The external layer of the spacecraft is to be built out a durable alloy of conventional light-weight metals, including aluminum, magnesium, and titanium. An internal layer of insulation is to be constructed using plastics and fiber-reinforced carbon compounds. These carbon fiber materials are cheaper and lighter than the metals, yet are strong enough to withstand the conditions of space. 8

Design

![Diagram](image)

Figure 4a. Design of the H.O.M.E. spacecraft. This craft is what will transfer
astronauts from Earth to Mars. It will be assembled in a parking orbit around the Earth, and, after arrival, remain in a parking orbit around Mars for a year until the time of departure.

Basic Design

The spacecraft is 200 feet in length, and at widest is 100 feet. A nose (Figure 4a – A) of length 15 feet and height 12 feet, with a window (reinforced layer of glass and plastic) contains the majority of navigation and communication controls, with enough space to fit 6 astronauts. A cylindrical central body, (Figure 4a – E), includes the living cabins of the astronauts, and other life support systems. The back body, (Figure 4a – C), provides storage for additional living supplies (food/water), but mostly contains fuel. The wings, (Figure 4a – D), are not actually there to make the ship aerodynamic, they are there to create a large space for the solar panels, which complement the ship’s fuel propulsion system. The fuel propulsion system is located in the back of the ship (Figure 4a – C).

Fuel

On the journey to Mars, the rocket ship and base thrusters will use fuel consisting of liquid hydrogen and liquid oxygen. This fuel combination will be used in the Space Shuttle main engines because they are both cold liquefied gases, most efficient in keeping the combustion chamber and nozzle cool.\(^9\)

Systems

Food

The food brought on the ship will be stored in the back (Figure 4a – D) as well, in several different ways. It can be thermo stabilized, which is processing with heat to destroy microorganisms and enzymes that cause spoiling. Food can also be irradiated or preserved by exposure to ionizing radiation or freeze dried, which is extracting the moisture from food using very cold temperatures. It can also simply be dehydrated, or stored normally. However, it can only be stored normally if there is no chance of spoiling. The beverages can be stored as powders, and rehydrated when needed.\(^{10}\) In addition to the food that is brought on the mission, there will also be hydroponically grown plants. Hydroponically grown plants are an alternative to growing plants in soil. They would be grown in solutions filled with nutrients. When grown normally, the soil is usually the medium that the minerals are stored in for the plant, but when grown hydroponically, the solution contains all of the water and nutrients for the plant to survive. The hydroponic facility will have to have its own area, separate from other places, so the plants are not disturbed by anything while growing, this is where the base comes in, designed with green houses between rooms to allow for different needs each group of plants may require. The facilities will also need to have gravity, so it will be located in the section of the ship that will produce gravity. The hydroponic
facilities need it because the plants need to know which way to sprout, without it, they will not.\textsuperscript{11}

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Water

Water brought on this mission will be stored in the back portion of the spacecraft (Figure 4a – C). Water will not have to be a problem during this mission because it can be recycled. Compared to what we would have to bring otherwise, only a small amount of water will have to be brought on board. A large part of the water that will be recycled is from urine. The urine would first undergo a distillation process that separates the liquid from the gas. After this, it will be mixed with the other water waste and is treated with a water processor. Then, the gas and solid parts are removed, and the liquid is filtered for additional purification and then undergoes a high-temperature catalytic reaction. Scientists claim that this strategy would create water cleaner than U.S. tap water.\textsuperscript{12} There will also be dehumidifiers, which will collect the water that leaves the human body while breathing and perspiring. Little water will have to be taken on the mission due to the collective efforts of Karen Pickering, a researcher at NASA’s Johnson Space Center in Houston, and others who are designing a system that can recycle up to 99 percent of water on the base.\textsuperscript{13}

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Oxygen

Along with the water recycling system, an oxygen generating system is also being developed. The two will work together to control the life support and the regenerative environmental systems. The system will use water to generate breathable oxygen for the crew. It will tap into the water supply, and separate the hydrogen and oxygen, and then send the hydrogen into space. On normal days, the system will produce 12 pounds per day, which is enough for the six astronauts that we are sending to Mars. During experiments and airlock depressurization, oxygen can be lost, and during those times, the system will produce 20 pounds of oxygen per day. Because of this system, more water will have to be brought; however, it still will not take up as much space as oxygen. In addition to the oxygen gained from this system, the oxygen created by the plants in the greenhouse will also be able to be harnessed and used for the crew.\textsuperscript{14}

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Exercise

Physical exercise will take place in the portion of the ship that has artificial gravity generated (Figure 4a – B) (see following section, Artificial Gravity). Exercise stimulates the production of plasma
in the body, increases a body’s red blood cell count, and as a result, increases the ease in which astronauts breathe. It also increases blood flow and circulation, further preventing the chance of fainting.

While the required duration of exercise for astronauts varies anywhere from half an hour to nearly three hours, there are three main exercises used to maintain an astronaut’s strength. The first piece of equipment is called the Cycle Ergometer. This machine simulates pedaling on a bicycle and is the easiest to check heart rate and work done. The second, perhaps most traditional, piece of equipment is the treadmill. This simulates walking or running on Earth and is the best way to keep bones and muscles in the best possible condition. Harnesses are attached to the astronauts to hold them to the treadmill’s surface. The third main exercise device is the Resistance Exercise Device (RED), which simulates weight lifting with rubber resistance chords attached to pulleys.\textsuperscript{15} It also must be noted that exercises vary depending on space agency.

\textit{Artificial Gravity}

A large circular rotating room in the shape of an annulus (Figure 4a – B) will be constructed on the exterior of the spacecraft. If the angular velocity is adjusted properly, the centripetal force would cause the astronaut in the room to experience acceleration similar to that of Earth’s gravity. In particular, from \( \frac{3g}{r} = r\omega^2 = g \approx 32 \frac{L}{s^2} \), it is possible to compute the angular velocity with respect to the radius of the centrifuge.\textsuperscript{16} Human and animal experiments suggest that prolonged exposure to the rotation may also lead to motion sickness. An additional possibility is the difference of the centripetal force at the head and feet of the astronaut. Thus it is recommended that each astronaut spend somewhere from one to five hours in the room. As the astronauts initiate their journey, the speed of the rotational room will be faster to adjust to the gravity difference, and then decreased to allow them to adapt to the Martian gravity. This process is reversed on the return trip.\textsuperscript{17}

Our rotating room has an inner radius of 64 feet and an outer radius of 74 feet. Using the equation from the previous section, \( \omega^2 = \frac{32}{74} \Rightarrow \omega = 0.659 \text{ rad/sec} \). Approximating the human as six-feet tall, the centripetal acceleration at the head is \( 29.4 \text{ m/s}^2 \), a difference of 8\% between the forces on the head and feet of the astronaut, which is tolerable.

A system of airlocks will be implemented to allow the body to rotate without exposing astronauts to the vacuum of space. Due to the lack of air resistance, the room will be able to spin for a significant amount of time before slowing down due to internal friction; thus it will not require too much energy after being initialized.

\textit{Waste Management}

Waste materials will be divided into re-usable materials and non-re-usable materials. The latter can be exposed to the vacuum of space to be made more compact.
through a specialized external tube, and sealed in tight plastic bags and stored away.

Organic carbon-based compounds, including human feces, will be heated in combustion chambers to around 600° Fahrenheit to be made into food.¹⁸ The water will then be replaced in a cycle: urine and sweat will be collected and heated to boiling, then cooled, then filtered, then mineralized to form drinking water (and thus cycled for the entire journey, along with backup stored water). The CO₂ emissions (waste from respiration) are to be shifted by the air systems to the plant chambers, which in turn restore oxygen.¹⁹

**Landing Craft**

![Figure 5. Design of the H.O.M.E. landing craft. Once the spaceship is in a parking orbit around Mars, this landing craft will detach and take our astronauts to Mars’ surface.](image)

The H.O.M.E. Lander, the actual craft landing the crew on Mars land, is designed for the smoothest and safest possible ride for all astronauts secured inside while being as compact as feasible; it is approximately 12 feet tall and 12 feet wide. The crew will secure and brace themselves in a circular formation around the cabin of the landing craft as they begin their journey to the surface. The landing craft will begin by undocking from the main ship and using its main thrusters to guide itself onto a trajectory that will allow for entry into Mars’s atmosphere.

At about 125 km above the surface, the landing craft will enter the atmosphere and begin to slow itself down with friction. Due to the extreme temperatures generated during reentry, the landing craft has been constructed with a thermal protection system and heat shield to ensure minimal damage. Once the speed of the landing craft has decelerated to approximately Mach 1²⁰, the parachute (Figure 5b. - A) will be deployed in order to further decelerate the landing craft. The parachute is made out of polyester and nylon and has a triple bridle, the lines that connect the parachute to the craft, made out of Kevlar.²¹ Once the parachute is opened, the landing radar is activated in order to properly guide the landing craft to its landing zone.

Once the landing craft reaches an altitude of approximately 1 km above the Martian surface, the parachute is jettisoned and the rocket assisted descent (RAD) is activated as the landing thrusters are throttled up to further decelerate the landing craft.²² When constant stable velocity is reached, the precautionary balloons, or airbags (Figure 5b. - B), are deployed just
before touchdown to ensure the smoothest landing possible. These airbags are designed to cushion the craft in case it lands on rocks or rough terrain and are made out of a synthetic material called Vectran. (See Figure 5b). Once the H.O.M.E. Lander has successfully landed on the surface, the airbags will gradually deflate and the astronauts will disembark.

![Figure 5b. Picture of the landing craft when it deploys after entry into the Martian atmosphere.](image)

**Base**

**Basic Design**

The base that our astronauts will actually be living in on Mars will be a pyramid shape, with dimensions of 80x80x80 ft, just large enough to accommodate the 8 domes and power generator that will be within it. Different pieces of it will be sent into a parking orbit around the Earth and assembled in outer space. Again, this takes away the need to make an aerodynamic base. The base will reach Mars using the same procedure that the ship does, that is, going through a parking orbit around the sun, an elliptical transfer, and a parking orbit around Mars before descent onto its surface.

![Figure 6a. Design of the base that will go to Mars two years before the actual spacecraft does. The solar pannels, shown unfolded here, actually are folded up as an outer layer to the base.](image)

The base will be made up of two layers – the outer layer will be able to open up to expose solar panels (Figure 6a.- A) after landing on Mars, and an inner pyramid will remain. We decided to use the pyramid shape for our base because it was what allowed the most efficiently in making two layers of shelter. Our alternative, a dome shaped outer layer, would have made it a lot more difficult to design solar panels that could fold outwards. The thrusters located beneath the base will slow it down during its descent. Legs will extract to allow it to land,
and will contract once again upon situation on the planet.

Figure 6b. A transparent view of the base, showing the power generator in the center and the 8 domes in the pyramid. Note that in this figure, the solar pannels are neglected for simplicity.

In the center of the dome is a cylindrical shaped power generator (Figure 6b. – A) Around the generator will be eight (8) smaller domes (Figure 6b. – B to I), each 10ft in radius, connected by pipe-like walkways. The domes will be specialized to serve a specific purpose. This will include:

- a fitness room, in which astronauts will need to exercise daily
- sleeping quarters including beds and bathrooms
- a medical room for injuries and illness
- a lab, in which experiments will be carried out
- a storage of waste
- a storage room for scientific equipment such as spacesuits
- a “breathing room that holds pure oxygen. Because a large portion of the air humans are accustomed to breathing is made of nitrogen, astronauts cannot adjust quickly to the pure oxygen they will breathe when they are in spacesuits. Thus, they must go into said “breathing room” to accustom themselves to breathing in pure oxygen before donning a spacesuit and going out on Mars surface. All other rooms of the dome will contain air emulating that of Earth.

The walkways that connect the domes together will also serve as greenhouses, where the plants for food will grow. All “rooms” will be interconnected by these walkways, allowing astronauts to get around with ease.

Having many separate rooms allows for increased safety. If systems should fail in one dome, that dome can be cut off from the others, such as if toxic exposure were to occur. Also, by using the walkways as greenhouses, there will be multiple ones so that in case systems should fail in one, there will still be an ample food supply until said facility is repaired.

**Power**
Power for the base will be supplied by the solar panels attached on the base. Since the atmosphere of Mars does not have clouds, the sun will always be present a majority of the time, making solar panels the most efficient option in providing the base with the electricity it needs to keep all its systems running. If an emergency were to occur, the power plant in the middle of the base (Figure 6b. – A) would tap into the emergency power stage located in a separate section of the tower and keep the base running until solar panels start functioning again. Since the base will be sent two years before the actual launch of our mission, there will be ample time to store energy in the power plant. Upon arrival of our crew, electricity to run the basic features of the H.O.M.E base will already have been established.

Food and Water

Food that will be grown on Mars will be sent ahead of the spacecraft, with the base. The greenhouse will be pressurized because the low pressure of Mars makes the plants react as if they were experiencing a drought, which eventually kills them. They will also have to include a heat control system, because the temperature on Mars during the day and night varies much more than that of Earth. Because Mars is farther from the Sun, it will need to have high-power full spectrum lamps to make up for the loss of sunlight. The soil on Mars is much like the soil many people have in their backyards. Thus, the soil used for the greenhouse will be taken from the surface of Mars. However, that soil is not necessarily the best quality, so it will be mixed with more nutrients in top soil, or peat moss. The plants in the greenhouse will use carbon dioxide collected from other portions of the base to use in photosynthesis and growth, while producing oxygen that will be collected and used for the base.

The storage of water on the base will be identical to the storage of water on the spacecraft.

Exercise

The same exercise mechanisms on the spaceship will be available in the exercise room of our base on Mars, in the exercise room of the base.

Medicine

Aside from the cardiovascular and vestibular systems, other things to address medically while on Mars are toxic exposure and traumatic injury. Both of these are dealt with on Earth as well as on Mars and space in general. Treatment would most likely not differ much from that on Earth. However, the section in which the contamination took place would be sealed off from the rest of the base until all toxins are cleared away. In case of traumatic injury, astronauts will be treated immediately in order to decrease the chance of infection or blood loss.

For treatment of injuries, one of the sections of the Mars base will be designated as a sterilized, quarantine room (Behind A - not shown in Figure 6b). This room will be equipped with medical care units of all types ranging from endotracheal tubes to different kinds of antibiotics and life support machinery, as well as a limited blood bank made up of plasma, platelets, and red blood
cells coming from the O- blood group, so that all astronauts may receive blood transfusions from the bank if need be. It will also contain various instruments and life support systems, including a medical table with restraints for treatment. Several reference books and databases will also be a key necessity in guaranteeing the best care for astronauts in the event that a situation arises. Most importantly, this room will need to be subject to artificial gravity; this is necessary to keep the fragile body in recovery mode and allow medical procedures to occur with ease.

Spacesuits

For the reasons mentioned in the Design Constraints, we plan to use an alternative to the traditional spacesuit— the BioSuits of Ms. Nava Newman. Made of spandex and nylon, their key difference from the traditional EMU is the fact that they provide mechanical pressure rather than air pressure, and as a result, they are skintight rather than large and unwieldy. To provide for basic needs, astronauts will carry a primary life support subsystem (PLSS) as a backpack. The PLSS will hold water, oxygen tanks, carbon dioxide filters, electricity through a rechargeable battery. There will also be a secondary oxygen pack that contains about 30 minutes worth of oxygen. The chest portion of the suit will still be gas pressurized, and a unit mounted on the chest will contain all the controls and displays necessary for the astronaut to operate, specifically communication radios and monitors of respiration rate, heart rate, temperature, and other data. Astronauts will wear a helmet made of polycarbonate plastic. Oxygen flows into it from behind the head, and it will be connected to the two previously mentioned oxygen sources through a chord. Over the helmet is a structure called the Extravehicular Visor Assembly (EVA), which filters sunlight, provides resistance to possibly impacts, and light devices. Communication also occurs from within the helmet through a hands-free radio as well as microphones and speakers.

These BioSuits are extremely well-tailored for our mission. On the BioSuit will be lines that determine its mobility – these lines of non-extension will provide stiff support for the portions of the body that don’t bend, and at the same time, allow joints to easily move around. Each suit will be custom made for each individual, and would allow our astronauts to conduct the necessary experiments and explorations. In addition, these BioSuits would be safer than traditional space suits. Because the EMU is air pressurized a puncture in the spacesuit would cause pressure to decrease dramatically and require the astronaut to return to the shuttle immediately. When the BioSuit is torn, which most likely will happen on the terrain of Mars, it can easily be wrapped and repaired, allowing the rest of the suit to maintain its pressure level. In addition, the BioSuit may be adjusted to different levels of resistance, helping astronauts maintain their muscle strength as well. The BioSuit is predicted to be made available in 10 years, making it the best option for our planned mission.

Gravity

On Mars, the gravitational acceleration on the surface is approximately
38% of that on Earth. It is therefore possible for astronauts to gradually adjust to the gravity provided by Mars (for sake of comparison, the gravitation constant on the surface of the Moon is approximately 16.5% of that on Earth). A small radius centrifuge, operating on a system similar to that described in Artificial Gravity, will supply occasional periods of gravity adjustment.

**Waste Management**

Waste materials will be stored in storage pod and transported to space at the end of the stay, exposed to the vacuum, then sealed, then disposed in space (to prevent contamination on the Martian surface). Similar processes of reheating to recycle water and food as were implemented on the spacecraft will apply. Residue materials will be left in the modules and sealed off when the return craft leaves. Again, CO\(_2\) will be funneled into greenhouse to expedite process of plant-growing and to replenish oxygen supplies.

Organic carbon-based compounds will be heated in combustion chambers to around 600° Fahrenheit to be made into food. As outlined earlier, the water will be replaced in a cycle for the entire journey, along with backup stored water. Tables analyzing the sources of waste products during human spaceflight can be found in the following citations, also analyzing their compositions and their typical volumes and masses.

**Return Craft**

**Basic Design**

This return craft will be in charge of returning the Mars crew to the spacecraft waiting in parking orbit around Mars for their journey back to Earth. This craft will be sent ahead as an element of the base. It will measure approximately 50 feet tall and will leave Mar’s surface in the same manner a traditional rocket would leave Earth’s atmosphere.

![Figure 7. H.O.M.E. return craft. Our 6 astronauts will leave Mars’ surface in this craft, which will reattach to the spacecraft.](image)

‘Like traditional rockets that leave earth, the craft will be constructed in a spire design to reduce drag and resistance upon exit. It will be divided into two major sections, the storage bay (Figure 7 – B) and crew cabin (Figure 7 – A). The storage bay below the cabin will serve to carry a reasonable amount of equipment, scientific experiment subjects, or any other items the crew deems necessary to return to orbit with. The crew cabin above, where the astronauts will enter for their trip back up into orbit, is designed so that the crew will be able to lock themselves into bracing along the inner exterior of the cabin in a circular arrangement.

In order to ensure minimal risk, the return craft has been constructed with many of the same systems and physical protection and enforcement as other spacecraft.
designed for entry and/or exit of an atmosphere. After liftoff, once the return craft has successfully left Mars’s atmosphere and entered orbit, the craft will engage its thrusters to guide itself on a course for rendezvous and docking with the main ship waiting in a parking orbit around Mars.

**Fuel**

In order to keep the ongoing theme of living off Mars and traveling light, we have decided that fuel used for the return trip will be manufactured on the Martian surface. Earth and Mars both have atmospheres consisting of carbon dioxide, nitrogen, argon, and oxygen. Because of this similarity in atmospheric composition, we can make fuel a renewable resource with only a few elements brought from Earth. This process would qualify under NASA’s plan of action known as "In Situ Resources Utilization," or ISRU, which assesses the resources available on foreign bodies such as Mars and finds a way to utilize them.²⁹

In our mission, we have decided to transport liquid hydrogen to Mars. Hydrogen yields up to 18kg of rocket propellant per kg of hydrogen.³⁰ Once on Mars, the liquid hydrogen will react with carbon dioxide, the most abundant component of the atmosphere. This would be made possible by using a set of atmospheric processors which would ventilate and superheat the gases in Mars’ atmosphere, ionizing them and splitting them into component atoms.³¹ This way, carbon dioxide will be filtered out and the rest of the gases can be released back into the atmosphere.

The contained carbon dioxide will then be processed with the hydrogen in the reservoir and left to react. This reaction would result in methane and water. At the same time, water will go through electrolysis, that is, an electric current passed through the compound will split its atoms apart, creating hydrogen and oxygen.

The last step of the reaction involves the methane released from the previous reaction and the oxygen derived from the water. The chemical reaction would result in a powerful rocket propellant. The procedure first puts methane and oxygen through an automated chemical processing unit, which would produce the pumpable admixed chemical material for the respective fuel substitution. Two small natural nuclear fission reactors would then take care of a self-sustaining nuclear chain reaction so that this cycle will be guaranteed to repeat itself often out. This method started up close to two billion years ago when groundwater in Oklo (Central Africa, Gabon) filtered through crevices in rocks and mixed with uranium ore to trigger a promising fission reaction.³² In earlier tests, fission reactions have been proven to sustain for hundreds of thousands of years, until a chain reaction can no longer be supported. “Each of the reactors would contain around 35 kg of enriched uranium, a concentrated form of the nuclear fuel to react.” ³³

This fuel manufacturing method will eliminate unnecessary supplies of fuel from being taken to Mars. This method is self sufficient, since the hydrogen byproduct left behind from the electrolysis can be looped back into the atmospheric processor to begin the fuel production cycle over again. This allows for a large energy yield with a small amount of hydrogen. One may argue against using dangerous new technology, but in reality, nuclear fission reactors make a mission to Mars most economical. In addition to the economic advantages, nuclear fission does not create atmospheric pollution. Antimatter propulsion, solar sails, and other propulsion ideas all seem like safer ways to create energy; however these are still futuristic concepts that are not
practical for the next few decades. Thus, we have decided on nuclear fission as our method of fuel production.

This fuel will begin to be manufactured as soon as the base reaches the surface of Mars. This way, upon the arrival of our astronauts, they will have a running supply of fuel for their work on Mars.

**Conclusion**

In order to carry out the H.O.M.E. mission, our design team conducted rigorous research to find the best options to make a successful manned mission to Mars. We researched the challenges that must be overcome to carry out this mission. Figuring out how life support systems such as water, food, and oxygen would be created or transported was one of our greatest challenges, and will continue to be so for years. All designing had to be made with the space constraints in mind including economic options and incomprehensibly extensive complexity in life systems. For example, bringing everything from earth would not be an option when traveling light is necessary. For this reason we found a means for making fuel on Mars using its resources. Similarly, food will be grown in greenhouses on Mars within the base. We made major engineering decisions that allows for the optimum performance of each craft. The pyramid base shape allows for a simple design of two outside layers, so that the solar panel shell is made efficient on Mars. It also homes a good amount of space for the astronauts with the ability to separate any sections that may fail without risking the wellbeing of the mission. The landing craft is compact and efficient in landing the crew by using a parachute to decelerate and precautionary airbag deployment to ensure a smooth landing. The ship is rigged with dependable artificial gravity to maintain the crew’s health as they adjust to space travel. All our major design decisions allowed us to plan a successful mission to an unknown planet.

In the future after H.O.M.E, similar issues will still have to be considered when planning other trips to Mars. However, we hope that the research and decisions we made in our mission will better shape future attempts. Building a greater atmosphere will need to be assessed as the years pass, so will other methods for food and water, until the atmosphere is able to withstand the two. Until this is made possible oxygen supply will be one of the greatest challenges to overcome. Mars has a great potential for colonization, however, multitudes must be involved to carry out such an extensive process. Convincing the world of the need to discover Mars is one of the biggest tasks. The work involves years worth of testing and making changes but with the progress made already in the space program, a manned mars mission is at its prime time to undergo serious consideration.

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gratitude to Blase Ur, a wonderful coordinator, mentor, and teacher.
Appendix A

| Earth | | Mars | | Sun |
|-------|-----------------|-----------------|-----------------|
| Gravitation parameter ($\mu_E$) | $3.986\times10^{14} \text{ m}^3/\text{s}^2$ | Gravitation parameter ($\mu_M$) | $4.297\times10^{13} \text{ m}^3/\text{s}^2$ | Gravitation parameter ($\mu_S$) | $1.327\times10^{20} \text{ m}^3/\text{s}^2$
| Semi-major axis ($a_E$) | 1 AU = 1.496$\times10^{11}$ m | Semi-major axis ($a_M$) | 1.524 AU = 2.280$\times10^{11}$ m | |
| Orbital velocity ($V_E$) | 29,700 m/s | Orbital velocity ($V_M$) | 24,140 m/s | |
| Radius ($r_E$) | 6.378$\times10^6$ m | Radius ($r_M$) | 3.393$\times10^8$ m | |
| Sphere of influence | 9.245$\times10^8$ m | Sphere of influence | 5.781$\times10^8$ m | |
| Surface escape velocity | 5.027 m/s | Surface escape velocity | 11,186 m/s | |

Relevant Equations

About Physics:

Forces ($F = ma$, Newton’s Second Law) –

Gravitational: $F_G = \frac{GM_1M_2}{r^2}$ where $G$ is the universal gravitation constant,

Centripetal: $F_C = m \frac{V^2}{r}$.

Energy ($W = E$) –

Kinetic: $K = \frac{1}{2}mv^2$,

Gravitational potential: $U = -\frac{GM_1M_2}{r}$.

About Conic Sections:

The shape of a conic section is determined by a certain dimension and an eccentricity, $\epsilon$, that defines out circular the section is. An ellipse has an oval shape (see dashed trajectory in Figure
Y for example), with a major axis spanning its longer length and a minor axis spanning its shorter length. The semi-major axis has length \( a \), and the distance from the center of an ellipse to a focus is \( c \). Then \( \epsilon = \frac{c}{a} \). The equation of an ellipse can be written in the form

\[
r = \frac{a(1 - \epsilon^2)}{1 + \epsilon \cos \theta}
\]

where \( \theta \) parameterize the points of the ellipse in terms of the distance from one focus. The quantity \( a(1 - \epsilon^2) = p \) is the semi-latus rectum of the ellipse. Some equations that come from physics regarding an object in an elliptical orbit include:

\[
H = rV \cos \phi = r_A V_A = r_P V_P = \sqrt{\mu}, \quad E = \frac{V^2}{2} - \frac{\mu}{r} = -\frac{\mu}{2a}
\]

where \( H \) is the specific angular momentum, \( E \) is the energy. A circle is a specific ellipse that has an \( \epsilon = 0 \). A hyperbola has \( \epsilon > 1 \), but similar equations for ellipses apply to a hyperbola.

Appendix B

Detailed Calculations

The elliptical orbits of Mars and the Earth look as follows:

(Figure 1(a,b). The first diagram shows the elliptical orbits; the orbits will be approximated as circles for ease of computation. The scale ratio here is approximately 0.75 inches : 1AU.)

However, for the sake of simplicity of calculations, we let the orbits be (1) coplanar (2) concentric (3) circular, with the Sun at the center. We describe the error caused by these assumptions under the Calculational Errors section.

Our path will take three distinct segments: An escape by the spacecraft into a circular parking orbit about the Earth, an elliptical transfer from the orbit of the Earth about the Sun to the orbit of Mars about the Sun, and then a landing from the orbit about Mars to the surface of Mars. Data for Mars, Earth, and the Sun can be found in Appendix A.
(Figure 2 (a,b,c). The three diagrams, respectively, show the transfer from a circular orbit about the Earth to the ellipse, the to and return journey of the spacecraft, and the transfer from the elliptical transfer to an orbit about Mars. All three are exaggerated to show detail.)

We consider an orbit of a satellite at a height of \( h = 300 \text{ km} = 3 \times 10^5 \text{ m} \) (arbitrarily picked to be close to the orbits of other satellites) about the surface of the Earth. In order for an object to reach this altitude (in our case, we are shuttling the necessary parts/supplies), the conservation of energy from kinetic to potential applies:

\[
\frac{1}{2}mV^2 = \frac{GMm}{r_E} - \frac{GMm}{r_E + h} = \frac{hm\mu}{r_E(r_E + h)},
\]

where \( \mu = GM \) is the gravitational parameter of an astronomical body. It follows that an initial shuttle thrusting of \( V = 2370 \frac{m}{s} \) is necessary.

For a satellite to maintain this altitude, the force of gravity upon the satellite must provide sufficient centripetal force for revolution about the Earth, or

\[
\frac{V^2}{r} = \frac{\mu}{r^2} \Rightarrow V_{\text{orbit}} = \sqrt{\frac{\mu_E}{r_E + h}} = 7726 \frac{m}{s}.
\]

The escape velocity of the spacecraft from the orbit in space at a distance of \( r_E + h \) can be computed using the transformation of kinetic energy into potential energy:

\[
\frac{1}{2}mV^2_{\text{esc}} = \frac{hm}{r} \Rightarrow V_{\text{esc}} = \sqrt{\frac{2\mu_E}{r_E + h}} = 10,926 \frac{m}{s}.
\]

The next step involves the elliptical transfer (known as the Hohmann transfer) from the orbit of Earth to that of Mars, which relies upon the gravitation provided by the Sun. Thus the sun is at one of the foci of the ellipse. We can now calculate some general properties of the ellipse (shown in Figure 2(b); variables are explained in Appendix A):

\[
2a = a_E + a_M \Rightarrow a = 1.888 \times 10^{11} \text{ m}
\]
\[
c = a - a_E = 3.92 \times 10^{10} \text{ m}
\]
\[
\epsilon = \frac{c}{a} = 0.2076
\]
\[
p = a(1 - \epsilon^2) = 1.807 \times 10^{11} \text{ m}
\]
The specific angular momentum of the orbit is

\[ H = a_{ES}v_{ES} = a_{MS}v_{MS} = \sqrt{\mu_s} = 4.896 \times 10^{13} \]

\[ \implies v_{ES} = 32729 \frac{m}{s}, \quad v_{MS} = 21475 \frac{m}{s} \]

To enter our desired elliptical orbit, we have two options:

- Use a parabolic escape trajectory to exit the Earth orbit, and then make a thrust to enter the elliptical orbit. Note that a parabolic escape trajectory leaves a \( V_\infty = 0 \frac{m}{s} \), where an infinite distance from the Earth is defined at the points where the gravity of the Earth no longer has a strong effect upon the spacecraft.
- Use a hyperbolic escape trajectory, which will cause the spacecraft to automatically enter the elliptical orbit. This leaves a finite \( V_\infty = V_{ES} - V_E = 2940 \frac{m}{s} \).

The latter option requires less energy, and is known as the Oberth hyperbola. Indeed,

\[ E = \frac{V_{ES}^2}{2} = \frac{V_E^2}{2} - \frac{\mu}{r} \]

\[ \implies V = \sqrt{V_{ES}^2 + V_\infty^2} = \sqrt{\frac{2\mu}{r_{ES} + h} + (V_{ES} - V_E)^2} = \sqrt{10926^2 + 2940^2} = 11,314 \frac{m}{s} \]

To achieve a speed of \( V \), we only need to fire a thrust in addition to the \( V_{orbit} \). Thus

\( \Delta V = 11,314 - 7726 = 3,560 \frac{m}{s} \) (II). This firing will be sufficient to carry the spacecraft from the Earth to Mars.

Another point to take into account is the angle with which the satellite should be launched with respect to the tangential velocity of the Earth about the Sun. The sphere of influence of a certain body is defined as the region in which that body has greater gravitational influence than any other bodies. Using

\[ F = \frac{-Gm_1m_2}{r^2} \]

the ratio of two gravitational forces upon a single object is

\[ \frac{F_{m_2}}{F_{m_1}} = \left( \frac{r_1}{r_2} \right)^2 \frac{m_2}{m_1} \].

For the sake of convention, we define the sphere of influence of a mass \( m_2 \) to be the region at which

\[ r_{SOI} = r \left( \frac{m_2}{m_1} \right)^{0.4} \].

For Earth against the Sun, this value is \( 9.25 \times 10^8 \text{ m} \), or \( \approx 145 \times \text{the radius of the Earth} \). At the end of the Oberth hyperbola, which is at the edge of this sphere of influence, our satellite should be aligned with the direction of the Earth about the Sun \( (V_{SO}) \). From \( \theta = \cos^{-1} \left[ \frac{1}{c} \left( \frac{p}{r} - 1 \right) \right] \) and the approximation that \( r_\infty >> p \), we find that \( \theta \approx \cos^{-1} \left( 1/e \right) \).
We know that the period of this journey is half of the period of the elliptical orbit, and by Kepler's Laws,

\[ P = \pi \sqrt{\frac{a^3}{\mu_G}} = 2.237 \times 10^7 \text{ s} = 8.5 \text{ months} \]

Mars and Earth are lined up at February 2031, March 2033 (see Timeline of launch). Thus, the spacecraft must be launched 8.5 months ahead, respectively at May 2030, July 2032. At this point, the spacecraft will enter the sphere of influence (SOI) of Mars. Since Mars is traveling at \( \frac{24,140}{s} \) about the Sun, the relative velocity of the spacecraft at the periapsis for the Hohmann ellipse is
\[ |V_{\infty}| = 24,140 - V_{M} = 2665 \frac{m}{s}. \]

To determine whether the spacecraft will fly about Mars and get captured by its gravity or if it will crash into Mars, we define the impact parameter, which is a condition that determines whether or not a flying object will collide with another due to gravity. Our goal is to have the spacecraft revolve in a circular orbit, where the spacecraft hovers over the same spot above Mars at all times, which would allow quick communication. This Martian synchronous orbital period

\[ P = 2\pi \sqrt{\frac{r^3}{\mu_{M}}} \implies r = \sqrt[3]{\frac{\mu_{M} P^2}{2\pi^2}} = 20,437,600 \text{ m}. \]

is given by Kepler's Laws to be Using conservation of energy, the spacecraft reaches a speed of

\[ \frac{V_{\infty}^2}{2} = \frac{V_{p}^2}{2} = \frac{\mu_{M}}{r_{p}} \implies V_{p}^2 = \frac{2\mu_{M}}{r} + V_{\infty}^2 \implies V_{p} = 3363 \frac{m}{s}, \]

where \( V_{p} \) is the speed of the spacecraft at the periapsis (closest point) on the hyperbolic flyby of Mars.

Since our goal is to achieve a permanent circular orbit of the spacecraft about Mars, we require that the gravitation force by Mars provides a sufficient centripetal force, or

\[ \frac{V^2}{r} = \frac{\mu}{r^2} \implies V_{\text{orbit}} = \sqrt{\frac{\mu_{M}}{r}} = 1450 \frac{m}{s}. \]

Thus, as the spacecraft makes the flyby, it must decrease its speed by

\[ \Delta V = V_{p} - V_{\text{orbit}} = 3363 - 1450 = 1913 \frac{m}{s}. \] (III)

In conclusion, the velocity budget for this journey is

\[ \Delta V_{T} = (I) + (II) + (III) = 2370 + 3500 + 1913 = 7,843 \frac{m}{s}. \]

Finally, we would like to launch our lander into the Martian atmosphere. We can approximate the speed of the lander using the conservation of energy:

\[ \frac{1}{2}mV_{\text{orbit}}^2 - \frac{1}{2}mV^2 = \frac{m\mu}{r} - \frac{m\mu}{r_{M}} \implies V = 6745 \frac{m}{s}. \]

The lander uses a system of backwards thrusts to dramatically reduce its speed upon entering the atmosphere, and then uses a parachute to reach a low terminal velocity. A system of inflatable balloons will soften the impact of the lander on the Martian surface.

The return craft, which goes with the base on the first trip, will be used to return the crew back to the orbiting spacecraft. The return journey will follow a similar elliptical orbit, except the order is now backwards: the journey starts with leaving from Mars, and reaches the Earth. Specifically, the same orbital speeds about Mars and the Earth and the same elliptical orbit applies, so the journey will be of approximately the same duration and have a similar shape.
Appendix C

Additional Pictures of SolidWorks Designs

Figure 1. Additional views of our spacecraft

Figure 2. Additional views of the H.O.M.E. lander.
Figure 3. Additional view of the Mars base.

Figure 4. Additional views of the return craft.
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