PORTSMOUTH COLLEGE, PORTSMOUTH, HAMPSHIRE

Designs on a Manned Mission to Mars

Blott-Matthews Challenge

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This report proposes a mission strategy for a crew to travel to Mars and conduct experiments from orbit. Acknowledging the risks involved in space exploration, particularly in take-off and landing stages, it is suggested to focus the first manned mission to Mars on building a solid foundation for future exploration. Considerations for transport design, propulsion methods and human protection are presented alongside the mission focus of testing take-off and landing using automated, reusable rockets. Recent developments in the private sector in re-usable rockets present an interesting prospect for transit from orbit to surface at Mars. The most suitable project is discussed and considerations for how to obtain data from repeated landings and take-offs are undertaken.

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Introduction & Project Goals:

Blott-Matthews Challenge: Mission to Mars

This project focusses on designing a successful manned mission to Mars. The key goals are to deliver a crew safely to Mars, perform important experiments on the surface of Mars, and return to Earth. Considerations of crew safety, ship design and whether costs can be reduced also play a part in the project.

Undertaken by a team of students from Portsmouth College, it is hoped that these core intentions of the challenge have been addressed and answered.

A Brief Consideration of our Journey to the Stars:

Throughout the history of space travel each mission has offered insights and improvements for the next. From the humble beginnings of the German V2 reaching the boundary of space to Neil Armstrong walking on the moon, a period of 27 years passed. There have been huge successes and devastating tragedies. In such a substantially large journey there are many risks and concerns, perhaps too many to justify a single mission. It is the opinion of this project design that to take a crew to Mars and return is an expensive and dangerous challenge in its own right. With this in mind, the decision to remove a manned landing aspect to the mission has been made. Many successful landings have occurred using a variety of landing designs, but never before have humans landed on a body with an atmosphere so far away should assistance be required.

Mission Strategy:

The focus of this mission is not to land on Mars. The primary goal is to reach Mars' orbit in order to carry out a series of test landings that will improve safety for future missions to Mars. The following project document includes considerations to allow a safe and successful manned mission to Mars orbit and a return to Earth. Key concerns include an overall design for the transport vessel, the most suitable propulsion method for inter-planetary travel, conditions necessary for the crew's survival, and the process of take-off and landing at Mars.

The experimental focus of this project is to undertake repeated tests from Mars' orbit to assess the safety of landing and returning to orbit. Using unmanned, reusable rockets and systems similar to sensors in crash test dummies it would be possible to analyse the forces experienced by a crew landing under the test conditions.

It is the intention of this strategy to allow for a mission completion in the late 2020s, preceding a planned NASA mission set for 2030s.[1] This mission will provide crucial information about the safety of the journey to Mars and identify a safe and reliable method for landing and returning to orbit. Secondary aims include observing the impacts of the journey on the astronauts and the ability of the astronauts to readjust to being on Earth physically and mentally.

Key Notes of Mission Process:

- All components to be assembled in Earth orbit before departure to Mars.

- A 'cargo' ship will be sent to Mars prior to Crew launch. This will contain a habitat and several launch stations for test rockets.
- Journey length: crew will travel **205 days** in total and will orbit Mars for **131 days**. Total: **336 days**
- Crew will transfer from transport ship to orbiting 'cargo' ship once they reach Mars.

Experiments while in Orbit of Mars:

Aims:

The primary objective of this mission is to test the landing and recovery of re-usable rockets form Mars orbit.

Issues:

Rocket design plays an important part in the success of this mission. The thin atmosphere affects the landing process, reducing the effectiveness of parachutes. The uneven terrain limits the type of landing to a vertical, rather than gliding, touch down.

Automated Take-off & Landing Tests:

There are several re-usable designs in production and development at the moment. They show merit and have had some success so far for reaching Earth orbit altitudes. It is likely that these systems will be at a stage of development to be utilised in our mission strategy prior to the year 2030. Each system uses different engine designs and stages of take-off that make them more or less suitable for our goals.

Virgin Galactic

This design uses a ‘piggy-back’ system requiring deployment from a plane. If in development the ability to take off under its own thrust is achieved it may be better suited.[2] The design can carry a payload of 600kg, which is not ideal, and landing is similar to shuttle returns. It is unlikely this design will be suitable.

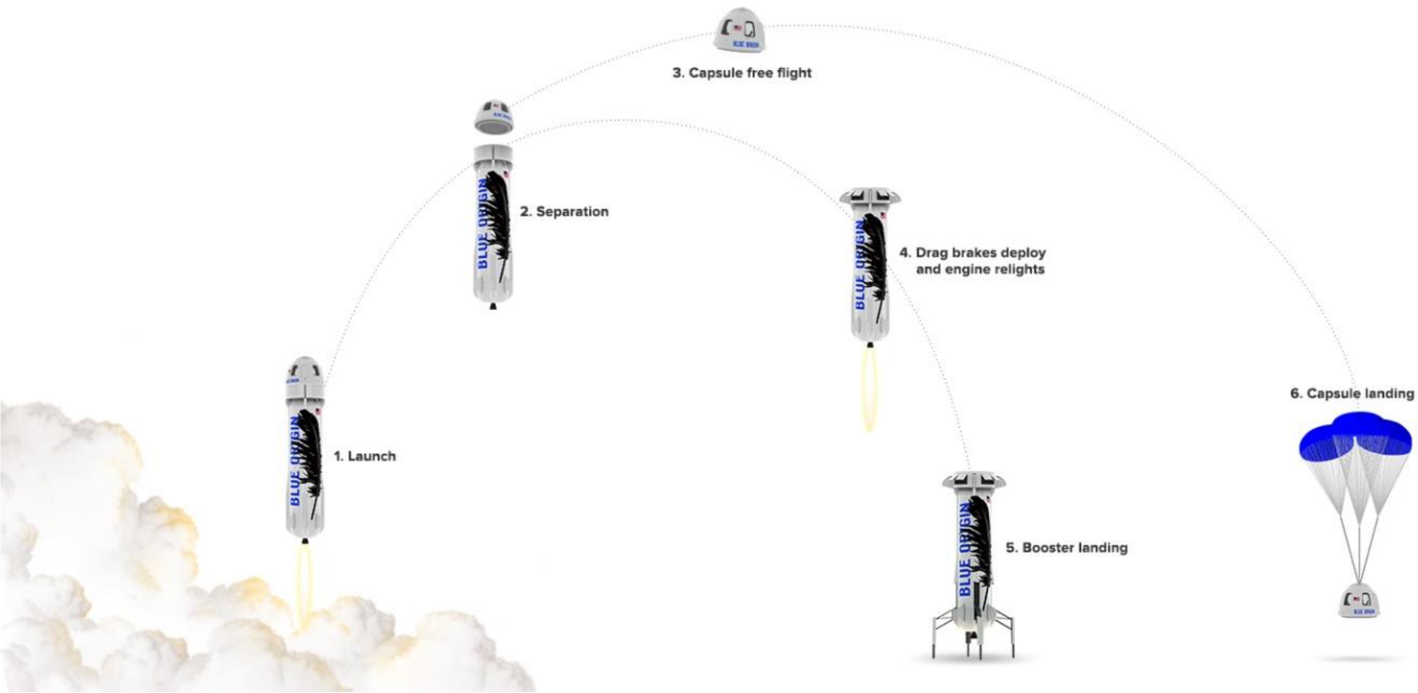
Space X

This design uses a two-stage Falcon 9 v1.1 rocket that can generate 1.3 million pounds of thrust.[3] It can deliver payloads up to 4,850kg to geostationary transfer orbit and has had successful test flights. Falcon 9’s first stage is modified with a reaction control system, four grid fins for steering and four deployable landing legs. Dropping the second stage off on its way to orbit, the first stage goes through a series of complex propulsive manoeuvres before guiding itself through the atmosphere towards a target landing site for a soft touchdown under the power of one of its Merlin engines to be re-used on a future flight.[4]

The two-stage design reduces the suitability for use in this mission as the need to reattach components reduces ease of operation in the Martian atmosphere.

Blue origin

This design uses a single-stage rocket, powered by a BE-3 engine. A maximum thrust of 11,000 pounds can be generated. The project has had success with a take-off and landing, with a subsequent success proving the 'reusable' design of the rocket.[5] The current designs for a manned take-off include the separation of rocket and capsule. It is hoped that with further development, and specialised focus for application to a Mars mission, it may be possible to remove this stage in the test rockets.[6]



This appears to be the most suitable design for testing reliable, re-usable Mars landing and return. Specialised and focussed design for this mission would require extensive work alongside the private company, with hopes that other engine designs could be tested using this system.

Data collection and Sensors:

Aims:

It will be important to collect information from each test landing and recovery to determine the most suitable process and design.

Issues:

External and structural analysis will be difficult in the conditions in orbit around Mars. A primary concern is the safety of future crewed missions, so determining the forces experienced by the astronauts is crucial.

Crash Test Dummies:

Crash test dummies are often used to measure the forces experienced by the human body in a variety of vehicle crashes. They can simulate the responses humans would have to things such as: impacts, deflections, accelerations, forces and moments that can be generated during a crash. Transducers in the dummy can characterise the physical forces experienced by the dummy. These specialised sensor systems provide data that can be analysed to better understand collisions or other scenarios.[7]

The sensor systems in these dummies could be used in the rockets to analyse the forces experienced by a crew. This data can be used to determine the most suitable landing and take-off process for future manned mission, and may detect dangers that have not been foreseen.

Space Suits and Spacewalks:

For there to be any analysis of the external structure of the rockets then the astronauts must conduct observations from outside the ship. Spacewalks are high risk and require specialised training, preparation and suitable suits for the astronauts.

Extravehicular Activity (EVA) suits are required for work performed outside of space craft. They include more protection from conditions experienced in space, such as protection from micrometeorites and extreme temperature change. They are pressurised and have a great deal of thermal insulation, affecting the flexibility of the suit.[8]

Cameras for External viewing:

Due to the high risks inherent in spacewalks it would be more suitable to use cameras that are attached to robotic arms outside of the ship. Controlled from within the space craft these arms could be manoeuvred such that a visual assessment of the test rockets external surface can be conducted without a spacewalk.

If there are any signs of damage that require repair or closer inspection then a spacewalk can be performed in that instance.

Ship Design:

Aim:

Design a spacecraft capable of safely transporting six humans with equipment to and from Mars providing suitable protection to crew and equipment.

Issues:

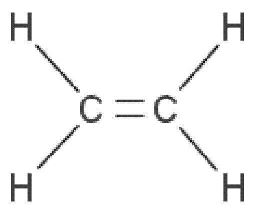
In space, outside of the earth's atmosphere there are many threats to human safety and technology such as; Electromagnetic Radiation, Solar flares, Bone loss, and Galactic cosmic rays (GCR's, high energy particles from the sun).[9]

Another primary concern is the means to produce electricity in order for various systems aboard to function.

Materials:

With a mission intending prolonged time in space there is high risk due to radiation, therefore materials must be used that will protect the crew. Aluminium is the preferred material for use in aircraft and NASA's orbiters as it can protect the aircraft from electromagnetic radiation however aluminium fails to provide sufficient protection from GCR's (which our atmosphere protects orbiters, ISS and the planet from).[10]

Polyethylene (plastic), however, is one of the best materials that can be used to reduce exposure to electromagnetic radiation, solar flares and the dreaded galactic cosmic ray; in fact it is 50% better in protecting us from solar flares and 15% better in protecting us from GCR's than aluminium. This is because the 'ethylene' component is high in hydrogen which is the best substance to block GCR's (our atmosphere contains a lot). As polyethylene can be easily manufactured to any measurement, bulked up versions of this plastic can be made such as RFX1. RFX1 has 3x the tensile strength of aluminium and 2.6x lighter making this a very useful material in reducing weight which is useful for the propulsion side of things.[10]



Polyethylene cannot offer perfect protection against GCR's but it is the best currently available. Future developments by projects within the ESA may produce more suitable materials, but there is no certainty we can rely upon these for our mission design. A possible solution to the risks of GCRs is to put human waste within the walls of the spacecraft. Human waste and urine is high in hydrogen which would make an excellent shield against GCR's.[9]

Another issue is that in space temperatures fluctuate depending on whether you are in the Sun's path. Temperatures rise to nearly 2000 Kelvin when entering Earth's atmosphere (which may be needed in the future), so it is important to protect both the spacecraft and its occupants from this. One of the best ways, which was used on NASA's orbiter, is reinforced carbon-carbon. This is useful as it would give extra support to the spacecraft as well as protecting the spacecraft from temperatures between 100 K and 2000 K, so would be able to resist temperatures in outer space.[11]

Electricity:

In order to provide power to the spacecraft and equipment, a source of electricity will be required. One such reliable source is solar energy, currently used by the international space station. The ISS uses solar arrays, made up of solar cells (purified silicon), that generate electricity using a process called photovoltaics to convert to electricity. Four sets of arrays can generate 84 to 120 kilowatts of electricity which is enough to power 40 homes. [12]

Gallium arsenide based solar panels are more effective at absorbing photons and, as a result, they have a higher energy output than silicon-based solar panels. The temperature coefficient is expressed as a percentage, and indicates the percentage decrease of the efficiency of the solar panel for every degree Celsius the temperature rises above 25^{o}C. Solar panels made from gallium arsenide have a temperature coefficient of 0, which means that there will be no performance loss if the temperature changes. As a comparison, silicon-based solar panels have a temperature coefficient of -0.41% per degree Celsius, which renders them a lot less efficient than gallium arsenide-based solar panels at capturing energy from the Sun. [13] As the temperature is likely to change drastically in space, gallium arsenide-based solar panels would be more suitable, and would yield a higher quantity of energy due to technology called 'photon recycling'. In this process, photons bounce off the back of the solar cell which allows them to be recaptured by the material and converted to electricity. As a result of this, more energy is captured where it would have been lost using traditional silicon-based solar technology.[14]

A recent development shows some promise as an effective alternative that could be used instead of, or alongside, solar array. Work is being done on a 'solar sail' that can generate electricity from the solar wind. By pointing a .4 inch copper wire toward the sun, connected to the sail, it is possible to generate an electric field which would collect electrons from the solar winds. These particles would be funnelled into a spherical receiver which would produce a current, some of which would be used to power the magnetic field but the rest could be used to power the spacecraft. This is still being developed by researchers in Washington, which means we currently cannot include this within the mission plan. However, observing the progress of these developments is in the best interest of this project going forward.[15]

Cargo Section Design:

Within this mission design a cargo section shall be sent to Mars orbit prior to crew journey. This ship will be a self -contained small scale space station intended for a life span of this mission. It should include a habitat area for everyday living of the crew and several docking areas for the test rockets to dock and be examined.

The habitat area should include a gym, sleeping quarters, food area, wash-room, medical centre, living space and a safe room with extra radiation shielding. Storage areas will also be required for the food and medical supplies that are needed on the mission.

There will need to be an airlock for space walks to perform external visual analysis of the test rockets. A number of docking areas for the test rockets that will allow for the crew to enter and assess each rocket will be required.

Specialised Design:

A difficulty for humans spending a prolonged time in space is the absence of gravity, resulting in astronauts suffering from bone and muscle loss. Therefore using the principles of circular motion we can simulate gravity by creating a centripetal force from a "Normal Force". This would prevent the bone and muscle loss as there would be Earth-like conditions.

The following allows us to calculate the required conditions to simulate gravity:

$$F_c=mv2r \qquad F=ma$$

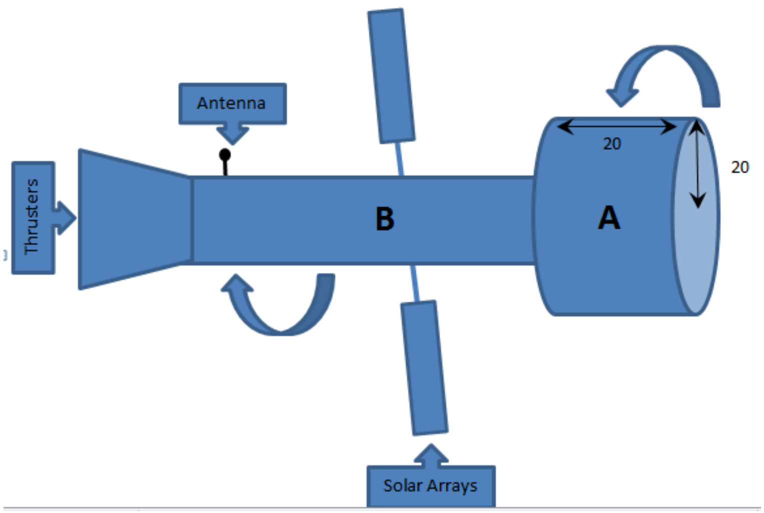
$$mg=mv2r$$

$$g=v2r \quad \therefore \quad v=gr$$

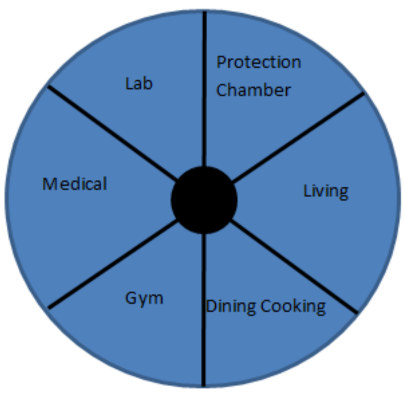
$$g=9.81ms-1 \qquad r=20m \qquad v=9.81\times 20$$

$$v=14ms-1$$

As just calculated the sections A and B will need to rotate at approximately 14ms-1 in order to simulate gravity. This roughly translates to one rotation every 9 seconds.



Section A



Section B

Manufacture and Assembly:

The general manufacturing process of satellites and other spacecraft follow a set framework. Components are assembled in clean room conditions, to remove bacteria and other contaminants, and are subjected to a range of tests. Teams of specialists work on each system and can be broken down into departments.[16]

- Structure Subsystem
- Data Handling Subsystem
- Attitude & Articulation Control Subsystem
- Telecommunications Subsystem
- Electrical Power Subsystem
- Temperature Control Subsystem
- Propulsion Subsystem
- Mechanical Devices Subsystem
- Other Subsystems

A list of departments for specialist teams

The main vessel will undergo the processes above, but the main assembly of the subsystems will happen in space. On-orbit assembly of separately launched components is an equally important aspect of the infrastructure enabling human access to space. The On-orbit assembly will require components being sent to a team at the international space station who will then bring it all together. On-orbit assembly is a relatively complex process, depending on several component processes to function correctly in sequence: the two (or more) spacecraft must rendezvous in space, match their orbits and orientations, then physically join through some mechanism. Robots are also an important part of assembly which will be built into the spacecraft modules used to help assembly. This will reduce human error, making the assembly perfect, however the manned team must regulate and calibrate the robots to keep them maintained. When transporting components into orbit efficiency is crucial.

Assembly Strategy

There are four possible options for the assembly process in orbit. The following shows a brief description of each option:[17]

1. **Self-Assembly:** Each module performs its own rendezvous and docking operations.
2. **Single Tug:** A single dedicated, reusable space tug performs all assembly operations, including shuttling modules from the parking to the assembly orbit.
3. **Multiple Tugs:** Each tug module performs only a certain number of assembly transfers; therefore, multiple tugs are required to complete the assembly task.
4. **In-Space Refueling:** A single tug spacecraft performs all assembly operations, but it is refueled after a certain number of transfers (new propellant tanks are launched or the tug is refueled from an orbiting depot).

To ensure accurate completion of the assembly process it would be best to keep the number of operations to a minimum. Therefore it is currently more suitable to use a single tug, which can be refuelled in orbit, to conduct the assembly process for all components of this mission.

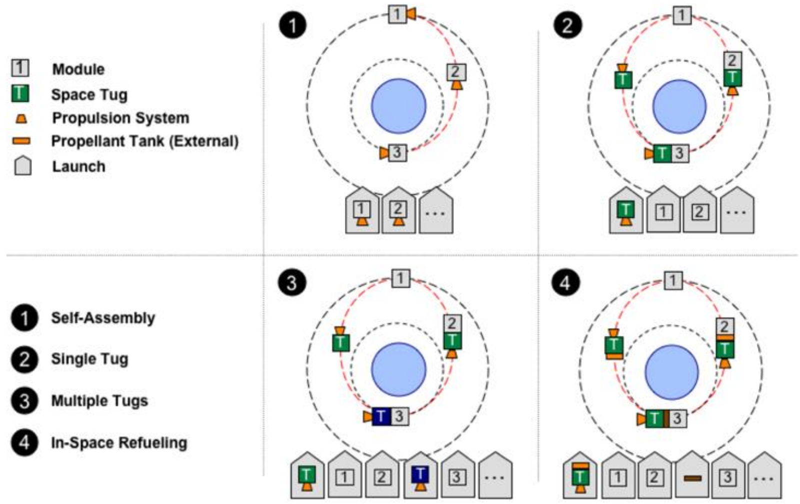


Figure 3.2: The four assembly strategies are illustrated. The inner circular orbit is the parking orbit, while the outer is the assembly orbit. Red dashed lines indicate the outbound and return transfers.

Propulsion:

Inter-planetary Travel:

Aims:

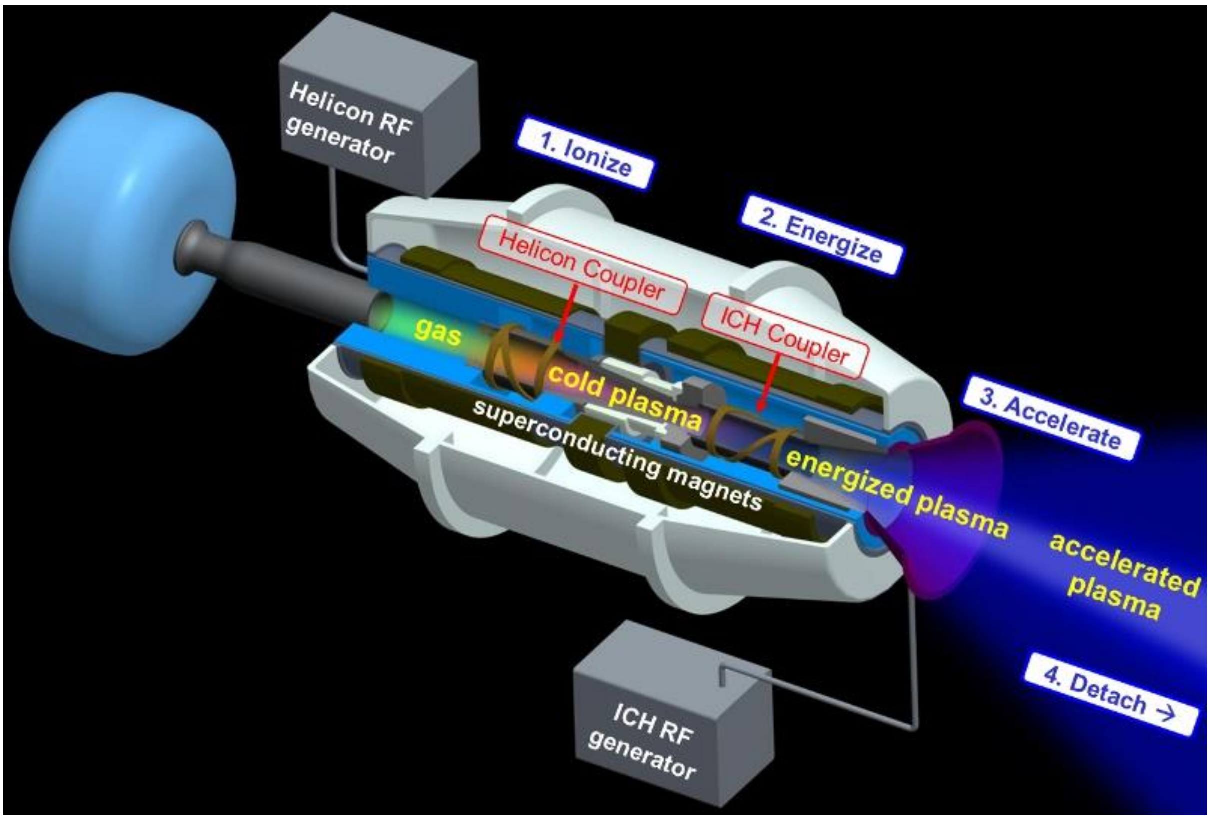
Choose the most suitable ion thruster for a return journey between Earth and Mars.

Issues:

It will be important to understand expected travel times and the "Mars-side" mission window for experimental work in orbit. Mass limitations require considerations of multiple vessels.

The Variable Specific Impulse Magnetoplasma Rocket (VASIMR)

VASIMR is a new type of electric thruster with many unique advantages. In a VASIMR engine gas such as argon, xenon, or hydrogen is injected into a tube surrounded by a magnet and a series of two radio wave (RF) couplers. In this design the couplers create a superheated plasma using the cold gas. Then the magnetic nozzle thermal motion of the plasma into a directed jet.[18]



The Variable Specific Impulse Magnetoplasma Rocket (VASIMR)

Principles of Operation

The primary purpose of the first RF coupler is to convert gas into plasma by ionizing it, or knocking an electron loose from each gas atom. It is known as the *helicon* section, because its coupler is shaped such that it can ionize gas by launching helical waves. Helicon couplers are a common method of generating plasma. After the helicon section, the gas is now "cold plasma", even though its temperature is greater than the surface of the Sun (5800 K). The plasma is a mixture of electrons and ions (the atoms they were stripped from). The newly formed electrons and ions carry charge and may then be contained by a magnetic field, shielding the rocket core from the plasma. The second coupler is called the *Ion Cyclotron Heating (ICH)* section. ICH is a technique used in fusion experiments to heat plasma to temperatures on the order of those in the Sun's core (10 million K). The ICH waves push only on the ions as they orbit around the magnetic field lines resulting in accelerated motion and higher temperature.

Thermal motion of ions around the magnetic field lines is mostly perpendicular to the rocket's direction of travel and must be converted into directed flow to produce thrust. The rocket uses a magnetic nozzle to convert the ions orbital motion into useful linear momentum resulting in ion speeds on the order of 180,000 km/h (112,000 mph).

VASIMR® Engine Compared to Other Electric Thrusters

The VASIMR® engine has three important features that distinguish it from other plasma propulsion systems:

The VASIMR® engine has the ability to more widely vary its exhaust parameters (thrust and specific impulse) in order to optimize mission requirements resulting in the lowest trip time with the highest delivered payload for a given fuel load.

The VASIMR® engine uses electromagnetic (RF) waves to create and energize the plasma within its core. In this way, the VASIMR® engine has no physical material electrodes in contact with the hot plasma. The removal of these electrodes in this design results in greater reliability, longer life, and enables a much higher power density than competing ion and Hall thruster.

The VASIMR® engine is able to process a large amount of power, meaning that it can then generate a larger amount of thrust. This larger thrust capability promises to make the VASIMR® engine useful for moving large payloads around low Earth orbit, transferring payloads from the Earth to the Moon, and transferring payloads from the Earth to the outer solar system. The VASIMR® technology is also highly scalable, meaning that higher power versions can be easily designed; making human missions powered by electric propulsion a reality.

Engine	Power (kW)	Thrust (N)	Specific Impulse (s)	Propellant
PPS-1350 Hall Thruster (SMART-1)	1.2	0.068	1640	Xe
NSTAR Ion Engine (Deep Space 1)	2.3	0.092	3300	Xe
NEXT Ion Engine	7.7	0.327	4300	Xe
VASIMR® VX-200	200	5	5000	Ar (Optional: D, N, Xe)

VASIMR® Engine Compared to Other Electric Thrusters

Fuel Sources

The VASMIR engine design can operate using a range of propellants. An important consideration is between Deuterium and a noble gas. Due to the possible risks of explosions when storing hydrogen it is more suitable to use argon as the propellant for this mission plan.

Power Sources

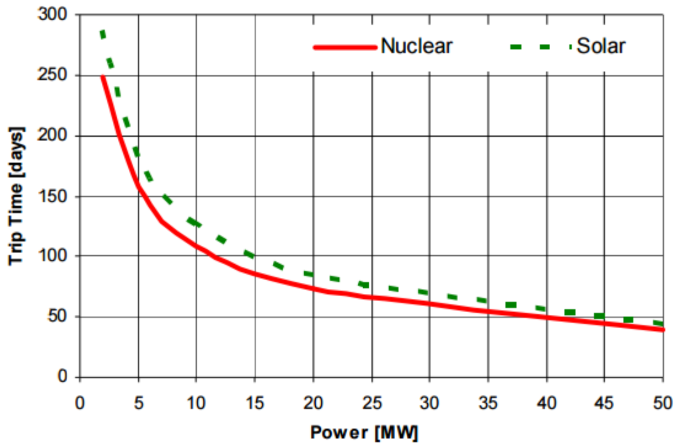
One of the key challenges in developing the VASIMR® engine is supplying power to it. A high-power electric thruster requires a lot of electricity, and generating that in space may require some engineering innovations. Below is a discussion of two options.

Solar Power

Solar power can be efficiently used for near-Earth VASIMR® missions, such as drag compensation for space stations, lunar cargo transport, and in-space refuelling. Recent advances in solar array technology show a significant increase in solar power utilization.

Nuclear power

A nuclear reactor has a very large amount of energy per unit mass; a reactor core has the highest energy density of any useful energy source on earth. This high energy density and scalability make nuclear reactors an ideal power source in space. A nuclear-electric powered spacecraft could dramatically shorten human transit times between planets and propel robotic cargo missions with a very large payload. Trip times and payload mass are major limitations of conventional and nuclear thermal rockets because of their inherently low specific impulse (less than 1000 seconds).



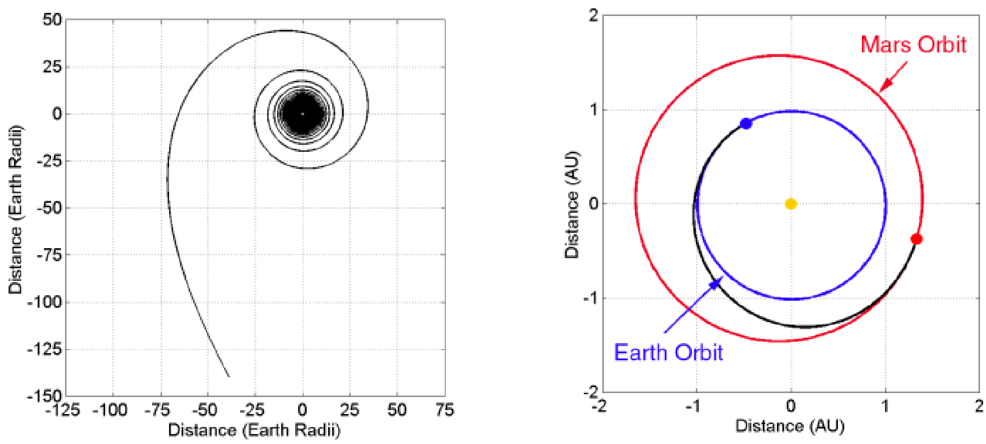
Comparing both power sources[19]

Travel time and mass

Trip to Mars

First we will send an unmanned "cargo" with all the equipment that will not be needed for crew during flight. It will also include return propellant and return habitat. The cargo will reach the Mars in 342 days.

Total mass carried: 200mT 60% payload (30mT Return Habitat, 30mT return propellant, 60mT equipment) [20]



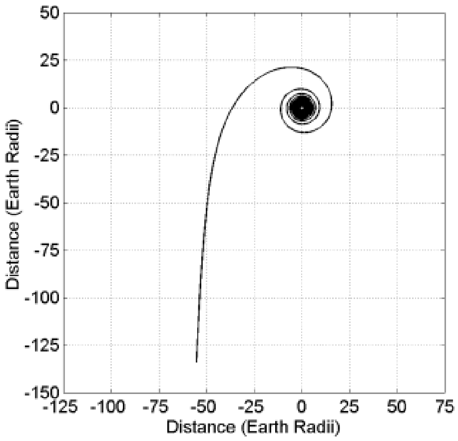
154 Day Spiral

288 Day Heliocentric Transfer

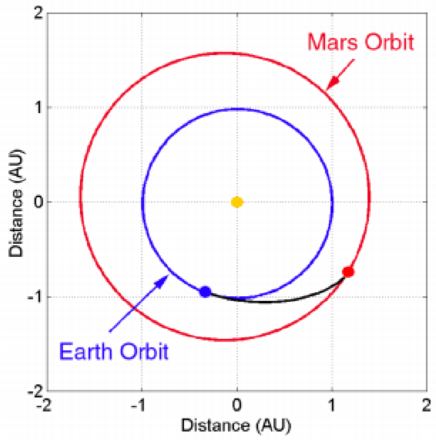
Cargo trip time

Then the ship with humans will be sent with all necessary equipment to reach Mars. The journey will take approximately 115 days. Once the ship has reached Mars the crew will use a transfer shuttle to dock with the "cargo" that awaits in Mars orbit. The inter-planetary transport ship will not be captured into a Mars orbit itself, but will follow a flight path that will return it to Mars for the return journey.

Total mass: 188mT 30% payload (31mT Habitat)

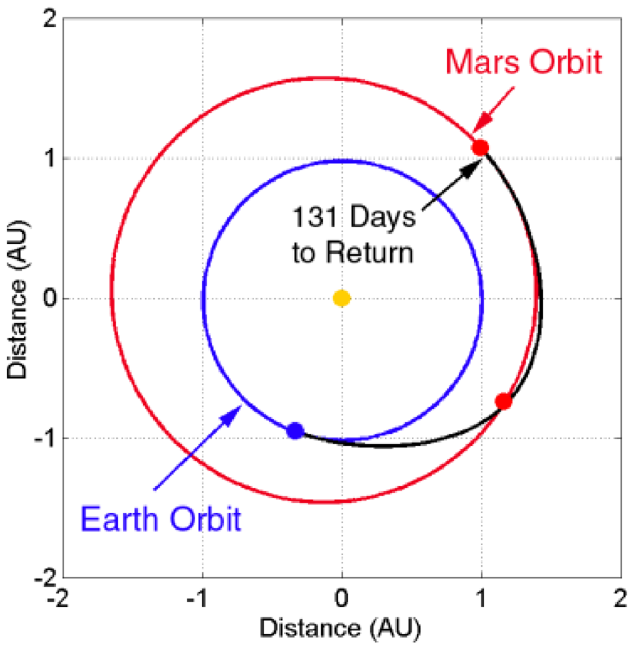


30 Day Spiral



85 Day Heliocentric Transfer

Humans' trip time



131 days for inter-planetary ship to reach Mars for return trip.

Returning

Once the inter-planetary craft returns to Mars after 131 days, the crew will transfer from the cargo section. Once the crew are on board the transport they will leave Mars and return to Earth. The return trip will take 90 days.

Mars Atmosphere:

Aims:

To identify a propulsion system that offers the most beneficial and suitable in-atmosphere thrust for landing and lift-off.

Issues:

The mass of fuel for in-atmosphere propulsion would reduce the amount of equipment that can be transported between Earth and Mars.

Principles of In-atmosphere Propulsion:

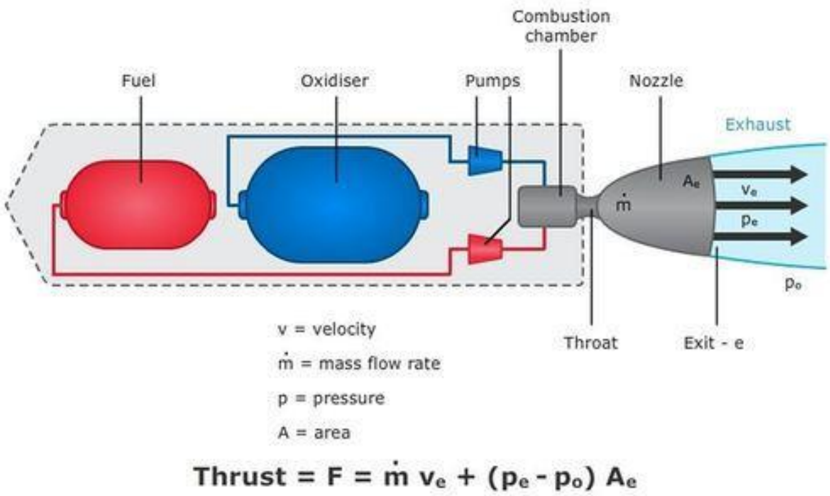
Ion-drive systems are ideal for free space travel, but much greater thrust is required to move through an atmosphere and enter orbit. For this 'chemical rockets' are utilised. The core principle of these systems is the combustion of a fuel sources to create propellant (exhaust) particles. Cryogenic propellants are used to increase useful reserves and as they are often safer than other forms of fuel.[21]

To understand the mechanics of rocket thrusters the ideas of momentum transfer will be applied.

Momentum = mass × velocity

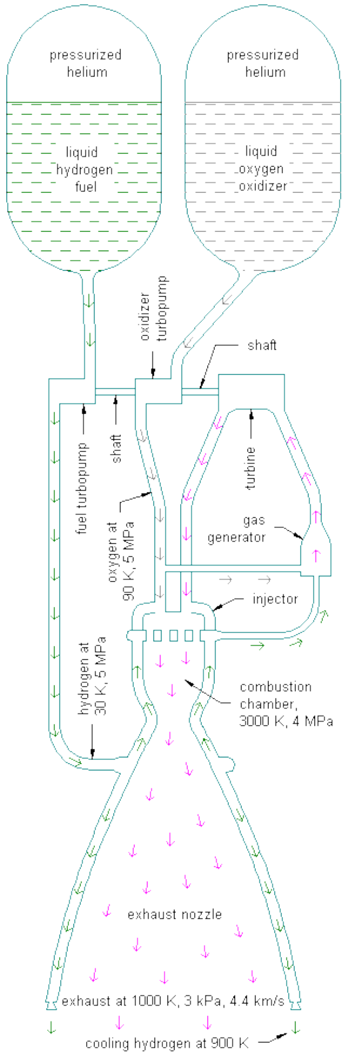
This equation explains the principles of how a rocket gains thrust. The propellant particles are expelled with very high velocities, but with such low mass their momentum is relatively small. The total momentum of the exhaust is the sum of all particle momentums.

Consideration of Newton's third law of motion: for every action there is an equal and opposite reaction, allows us to understand that momentum will be transferred from the exhaust particles to the rocket. Do to conservation of momentum the total momentum of the system must be zero, causing the momentum gained by the rocket to be equal to, but in the opposite direction to the exhaust.



Liquid Rocket Engine

The common liquid rocket is bipropellant; it uses two separate propellants, a liquid fuel and liquid oxidizer. These are contained in separate tanks and are mixed only upon injection into the combustion chamber. They may be fed to the combustion chamber by pumps or by pressure in the tanks.[22]



The J-2X Engine

The U.S. launch vehicles that will carry explorers back to the moon will be powered in part by a J–2X engine that draws its heritage from the Apollo-Saturn Program.[23]

It will power the upper stages of both the crew and the cargo launch vehicles. The engine will use gas generator power cycle and burn liquid hydrogen with liquid oxygen, both sustained in cryogenic states. Key features:[24]

1. It weighs approximately 5,300 pounds.
2. It produces 294,000 pounds of thrust.
3. It uses 217 gallons (82 litres) of propellant per second.

The RS-25 Engine

This engine design is frequently used as the space shuttle main engine as it is reliable and has proven success. It has been in operation for decades, with no large change to the overall design. This would mean it is a very reliable option should other engine options fail along the mission development process.[25]

Experimental Design:

The spacecraft that NASA is designing to take off from Mars, the Mars Ascent Vehicle (MAV), represents a formidable engineering challenge. There are key features of this design that make it attractive for use in manned Mars missions. The vehicle would need to be pre-assembled and sent to the red planet, before the astronauts arrive, where it would make its own propellant by squeezing it out of the thin Martian atmosphere.

The engines of the MAV will be powered by methane and liquid oxygen. All the ingredients needed to make that fuel—carbon, hydrogen, and oxygen—can be found on the red planet.

In theory, oxygen can be extracted from the Martian atmosphere, which is 95 percent carbon dioxide (CO2), and from liquid and frozen water (H20) buried beneath the surface. The leftover carbon and hydrogen would be combined to make liquid methane.[26]

If developments on this project proceed it may be possible to incorporate one of these engine designs into the mission. A chance to confirm the fuel extraction processes on Mars may assist greatly with future missions to Mars.

Take-off & Landing:

Landing on Mars:

Aims:

To design the most suitable descent strategy, using several stages, for a safe landing on the Mars surface. Within the mission plan these designs will be tested using automated landing craft.

Issues:

Reducing velocity in a safe manner is crucial for future manned missions. The thin Martian atmosphere will affect the efficiency of many designs, so considerations of a staged descent allow for the most suitable strategy.

Mars Descent:

In order to perform as many tests of landing and take-off as possible, fuel efficiency is of paramount importance. To reduce the need to burn as much fuel during descent a large parachute can be used to slow the craft down, this method has proven to be viable as part of a multi-stage descent strategy for several successful Mars landings.[27]

Speed of descent can be further reduced by increasing the drag forces acting on the lander using a large inflatable to increase air resistance. Inflatables are well suited to this task instead of using a lander with a large cross-section for air resistance; take-off will require air resistance to be minimised and after landing they can be deflated and retracted into the craft.

Small guiding rockets can be used to steer the lander more accurately to its designated touch down site. Once near the ground rocket engines should also be used to slow the rocket to a gentle touchdown. However, we have decided we want to try our best to minimize the use of these rocket engines as we want to save the fuel for take-off.

Furthermore, high velocity doesn't produce harmful injuries. What is dangerous is high acceleration or deceleration given at a certain time interval.

G = measure of acceleration
1g= normal
2g=twice as heavy
0g=weightless
9 or 10g= humans lose consciousness
<65g = considered fatal for an impact.

Principles of inflatable:

In a standard car air bags work like this:

The chemical at the heart of the air bag reaction is called sodium azide. A sharp deceleration will trigger an accelerometer to send an electric signal to an ignitor. The heat generated causes sodium azide to decompose into sodium metal and nitrogen gas, which inflates the air bags.

130 grams of sodium azide will produce 67 litres of nitrogen gas and the temperature required for this reaction is about 300 ^{o}C.

Take-off from Surface to Orbit:

Aims:

The focus of this mission is to assess the safety and success of re-usable rockets to land future crews on the surface of Mars and retrieve them.

Issues:

Considerations for the process of escaping a planet's atmosphere, and the differences between doing so on Earth and Mars, will result in optimum set-up designs for escaping atmosphere.

Earth Ascent:

To take off from the surface of the Earth and reach orbit a minimum velocity of 11.2 kms^{-1} is required. An ideal angle of 70-80 degrees, and a launch site close to the equator, will reduce the overall flight distance and take advantage of the Earth's rotation. Launching eastwards will reduce the overall thrust required by 5% due to the Earth's rotation.[28]

The docking process once in orbit can take up to 6 hours to ensure there are no errors and the relative velocities involved are small.

Mars Ascent:

Due to Mars having lower gravity and a thinner atmosphere, the overall thrust required by the rockets is reduced. This results in less fuel being required and suggests that a rocket capable of safe take-off and landing on Earth is suitable (with modification) for Mars landing and recovery. The escape velocity on Mars is 5kms^{-1}.[28]

The docking process once the rocket returns to orbit will follow the same procedures as Earth orbit. Ensuring no faults and the successful and safe recovery of the rocket.

Human Protection:

Atmospheric Control

Aims:

Maintaining a safe atmosphere within the ship is a primary concern for human travel to Mars. Removal of waste carbon dioxide, and the production of oxygen are critical to mission success.

Issues:

Humans produce carbon dioxide and use up oxygen through respiration. To ensure survival on the ship the atmosphere needs to be refreshed and maintained.

Removal of Waste CO_2

Waste CO_2 can be removed from the ship using LiOH. An advantage of using lithium hydroxide to absorb CO_2 is that it removes a large amount of CO_2 per kilogram of LiOH. This reaction has the overall equation of:

$$2LiOH\ (s) + CO_2\ (g) \quad Li_2CO_3\ (s) + H_2O\ (l)$$

However, this reaction occurs in two steps. In the first step, water is added to form lithium hydroxide monohydrate. In the second step, this reacts with carbon dioxide to form lithium carbonate and water. The equations of this two-step process are as follows:[29]

$$2\ LiOH\ (s) + 2\ H_2O\ (g) \quad 2\ LiOH{\cdot}H_2O\ (s)$$

$$2\ LiOH{\cdot}H_2O\ (s) + CO_2\ (g) \quad Li_2CO_3\ (s) + 3\ H_2O\ (g)$$

For every kilogram of LiOH used (41.8 mol), 920.5g (20.9 mol) of CO_2 is removed from the atmosphere onboard, making this method very effective.

However, lithium hydroxide is toxic. Inhalation, ingestion, or skin contact with LiOH may cause severe injury or death [30], so for this reason, protective clothing and goggles would need to be worn when replacing the canisters. This would also need to be done very carefully to ensure that no LiOH dust enters the cabin.

An alternative to LiOH, that could be more effective, is to use lithium peroxide (Li_2O_2) as a carbon dioxide scrubber. The reaction using lithium peroxide absorbs more carbon dioxide per kilogram and also releases oxygen as a by-product. The equation for this reaction is below:[31]

$$2\ Li_2O_2\ (s) + 2\ CO_2\ (g) \quad 2\ Li_2CO_3\ (s) + O_2\ (g)$$

For every 1kg of Li_2O_2 used, 961g of CO_2 is removed from the atmosphere onboard, which is 40.5g more than the mass of carbon dioxide that 1kg of LiOH can remove. This would make a big difference when considering the mass of the carbon dioxide scrubber that we would need to take on board the spacecraft.

348.8g of oxygen could be produced for every kilogram of lithium peroxide used, which could be fed into an oxygen canister ready to be fed back into the cabin by the atmospheric controls. Based on this, 911,004L of oxygen could be produced during the whole mission, which is around 2987L per day for six crew members.

As the production of oxygen is crucial for the survival of the crew members, Li_2O_2 will be used to absorb carbon dioxide on the mission because it produces oxygen as a by-product.

Lithium peroxide is extremely toxic. Inhalation, ingestion or contact with the skin or eyes with Li_2O_2 vapours, dust or the substance itself may cause severe injury, burns or death.[32] Again, strict precautions would need to be taken in order to prevent anyone from coming into direct contact with lithium peroxide.

Carbon Dioxide Exhalation

As the molar ratio between O_2 and CO_2 in the respiration equation is the same, and one mole of any gas occupies the same volume, the volume of carbon dioxide exhaled per minute is the same as the volume of oxygen inhaled per minute. As a result of this, one person will exhale roughly 0.2-0.3L (approx. 0.55g) of CO_2 per minute while resting and 3-6L while exercising. This means that 1826g of carbon dioxide will be exhaled per person per day based on them doing 2 hours of exercise per day. As a result, 11.4kg of lithium peroxide would be needed per day to remove the CO_2 produced by 6 crew members in one day from the cabin. For the whole mission for six people, 3477kg of lithium peroxide would be required.

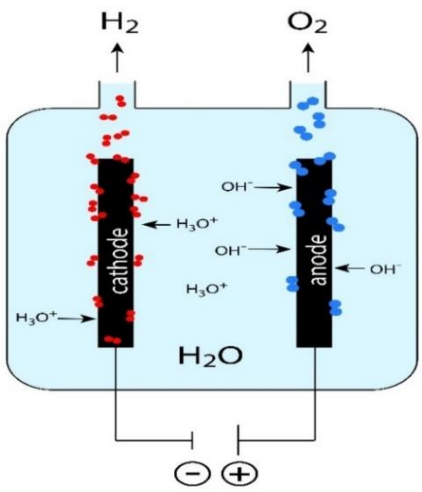
Oxygen Consumption

A person will breathe in 0.2-0.3L of O_2 per minute when resting, and between 3 and 6L of O_2 per minute when exercising.[33] Based on this, and doing 2 hours of exercise per day, each crew member would require around 996L of O_2 per day, and therefore 5976L would be required per day for six crew members. The reaction between lithium peroxide and carbon dioxide produces roughly half the amount of oxygen required per day, and therefore alternative methods of oxygen production will also need to be used.

Electrolysis of Water

The main source of oxygen in the cabin would come from the electrolysis of water to make oxygen and hydrogen. The H_2 by-product is vented out of the cabin into space.

$$H_2O \quad 1/2O_2 + H_2$$



Per kilogram of water, approximately 888g of oxygen could theoretically be produced, but to produce enough oxygen to provide six crew members with enough oxygen for one day, 8980L of water would be needed. However, excess oxygen will be required to make up the atmosphere within the breathable air cabin, so oxygen canisters will also be taken to Mars from Earth so that the atmosphere can be made.

Atmospheric Control

The gases that are fed into the cabin in the space station need to be at the same proportions as the atmosphere on Earth, so this would be controlled by a machine. Canisters holding nitrogen, oxygen, and carbon dioxide would need to be used, and the gases would be fed into the breathable air cabin in the appropriate quantities.

To take large quantities of these gases on board, they would need to be condensed within the cylindrical canisters. The wall thickness of the oxygen canisters that would be needed for the compression of O_2 was calculated using this equation:

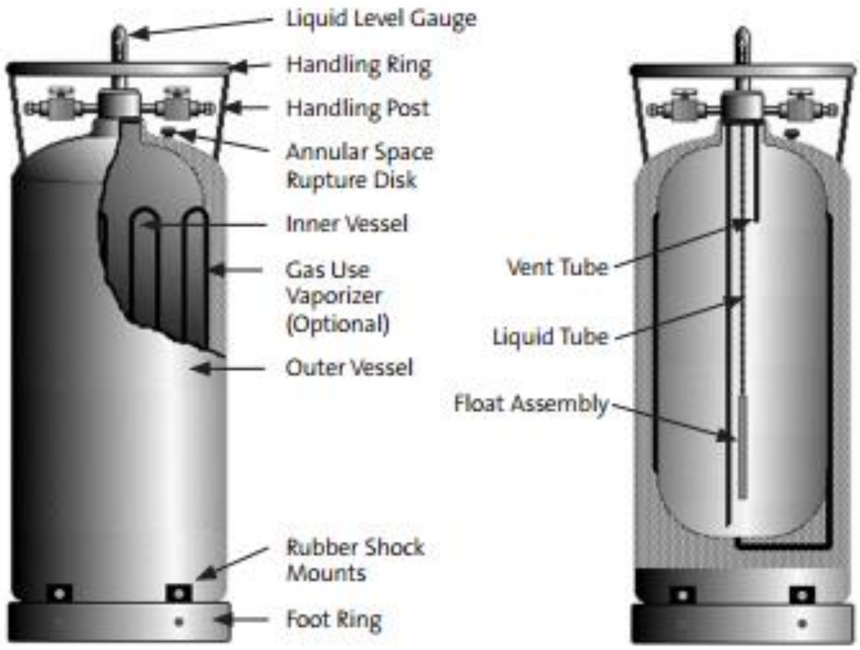
$$t = \frac{Pd_o}{2(FES_Y)} \text{ , (Eq. 3)}$$

where

t	=	minimum design wall thickness, in.,
P	=	internal pressure in pipe, psi,
d_O	=	OD of pipe, in.,
S_Y	=	minimum yield stress for pipe, psi (**Table 5**),
F	=	derating factor, 0.72 for all locations,
and		
E	=	longitudinal weld-joint factor [1.0 seamless, ERW, double submerged arc weld and flash weld; 0.80 electric fusion (arc) weld and electric fusion weld, 0.60 furnace butt weld].

The material that would be used for the cylindrical tanks is steel because it is very strong. In an ideal situation, oxygen would be cooled and pressurised to its critical point, which is at -119 degrees Celsius and 723psi (50atm). However, conditions on the spacecraft may not allow for this to be successful; it may be very difficult to keep the oxygen at a temperature this low, but if this were possible then a large volume of O_2 would be able to be stored in smaller containers. Using this equation, the wall thickness of the cylindrical canister required to hold oxygen at this temperature and pressure was 0.151 inches thick, which equates to roughly 3.78mm thick. This means that not a lot of steel would be required, which would reduce the mass of equipment required.

Alternatively, liquid oxygen could be used. This would allow more oxygen to be taken on board the spacecraft because liquid oxygen takes up more space than gaseous oxygen. One disadvantage of using liquid oxygen is that, although it is non-flammable, it is a very powerful oxidising agent: liquid oxygen will cause organic materials to burn rapidly and energetically if they come into contact with a source of ignition.[34] It is likely that this would not be a problem on the mission because the oxygen would always leave the storage tanks as a gas, but precautions would need to be taken in order to make sure no liquid oxygen comes into contact with anything. Safety is our main priority on this mission to Mars, so everything must be strictly controlled in order to make sure the safety of the crew members is not risked in any way. The cylinders used to store the liquefied oxygen will be cryogenic cylinders, which each have one or more vaporisers and a pressure control system. A cryogenic cylinder is constructed like a vacuum bottle: there is an inner vessel surrounded by an outer vessel. Between the vessels is a space that contains an insulating medium from which all the air has been removed, which keeps heat away from the liquid oxygen held within the inner vessel.[35]



[35]

The image above shows the side view of a cryogenic storage tank. The gas-use vaporiser shown above converts the liquid oxygen into its gaseous state as the liquid passes over the vaporiser. The pressure relief valve and annular space rupture disk protects the cylinder from pressure build-up. The capacity of one of these liquid containers can reach 450L[35], which equates to a volume of around 387,450L of gaseous oxygen since the expansion ratio of liquid oxygen is 1:861. The expansion ratio of a liquefied and cryogenic substance is the volume of a given amount of that substance in liquid form compared to the volume of the same amount of substance in gaseous form, at room temperature and normal atmospheric pressure.[36] The total amount of oxygen that will be consumed by the six crew members during the entire mission will be 1,822,680L, and therefore only 5 of these cylinders would need to be taken on the mission to supply enough oxygen for the entire trip. However, it would be sensible to take at least 10 of these cylinders as a safety net in case one of the other oxygen-production methods fails.

The cost of these Cryogenic liquid canisters is £2,068 per cylinder, or £20,680 in total for 10 cylinders.

On-board Water Resources and Usage:

Aims:

Once a sustainable atmosphere is achieved another consideration is the storage or production of water to be used for electrolysis, drinking and cleaning.

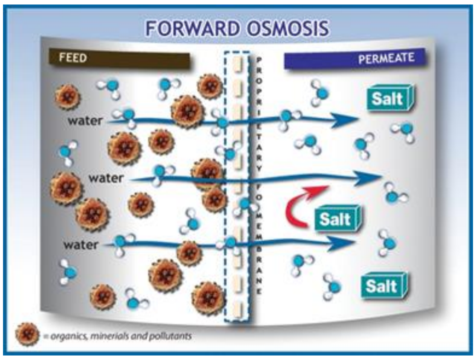
Issues:

The use of water in electrolysis, and consumption by the crew, would require a very large volume over the duration of the mission. The storage of this water is impractical so a reliable method of recycling waste water is required.

Water Recovery from Waste:

When recycling urine it requires two stages. It has to be first filtered using an activated carbon bed (to remove urea and alcohol). Following this stage the process of osmosis can be utilised to clean the waste water for re-use.[37]

Forward osmosis is a process that separates water from the things dissolved in it using a semi-permeable membrane. The semi permeable membrane would have to be extremely thin and porous to allow only the water molecules though. The 'unclean water' will pass though the membrane to go to a solution of a higher concentration. This higher concentration solution will often be called a draw solution and can contain a concentrated salt or sugar solution. This separates the slightly larger molecules, such as bacteria and solutes.[38]



[39]

Just like forward osmosis reverse osmosis separates water from the things dissolved in it using a semi-permeable membrane. However an applied pressure is used to overcome the osmotic pressure. This means it requires a lot more energy.[40]

Due to the requirements for energy input in reverse osmosis it is more suitable to use forward osmosis in the space craft.

Calculations:

Large amounts of water from urine, washing, the atmosphere and many other places can be recovered using forward osmosis. When in space the crew will not be showering like everyday people. Instead they will use a no rinse shampoo and clean their hair using a wet towel. Each person will have on litre of water to shower with a day. The average person drinks around 2 litres of water a day. However due to the crew members having to exercise a lot and some food may be required to be re-hydrated 4 litres a day sounds like a more reasonable amount to give them. So every crew member will get 5 litres a day to use meaning there will be 30 litres used. There will be 8980 litres used a day for electrolysis. Therefore the total amount of water used a day will be 9010 litres and 3297660 litres used for the whole journey. However by using forward osmosis and recycling the water a lot less water will need to be taken.

Exercise

Aims:

To provide the crew with all the necessary gym equipment for help prevent muscle and bone loss.

Issues:

If an astronaut does not exercise in space this can lead to muscle and bone loss. Also while in micro gravity body fluids move around resulting in the loss of plasma and a reduction in the bloods ability to carry Oxygen.

Gym Equipment in Space:

Exercise can increase the amount of plasma in your body, therefore combatting the effects of micro-gravity. The average person in space would have to exercise for 2 hours a day.[41] Due to having artificial gravity gym equipment such as: cross trainers, cycle machines, rowing machines and treadmills can be used on the inter-planetary ship. Each piece of equipment weights around 100kg so if 6 pieces of equipment are taken they would weigh in total 600kg.[42]

However in microgravity special equipment would have to be used. One piece of equipment is called the cycle ergometer; this is like a cycle machine where the person on it has to peddle. Another important piece of equipment is the treadmill; you can walk and jog just like on Earth but you would need to be put into a harness to hold them to the surface of the tread mill so they don't float away. Finally there is the advanced resistive exercise device; this is similar to weight lifting. It has a large bar that can be used for things such as squats and deadlifts. It also has a smaller bar that is used to exercise things like the biceps, triceps, abdominal muscles and back.[41][43]

Food

A further consideration for the mission to Mars is the amount and type of food to take.

The average person eats about 1.75kg of food per day. Therefore all six crew members would eat 10.5kg of food per day between them and the total amount of food for the whole journey is 3528kg.[44]

A large portion of the food will be dehydrated to give it a longer life. Hot water can be used to rehydrate many foods and making them taste better from when they were dried.[45]

Mission Summary:

The proposed mission would intend for launch within the second half of the 2020s in an attempt to precede other planned manned missions. The focus will be a proof of concept for assembly in Earth orbit, travel between the planets, and landing and recovery from Mars surface.

Assembly will be undertaken by constructing modules on Earth and using reusable rockets to place these modules in orbit. A tug in orbit will manoeuvre these components together where a combination of robots and space walks based from the ISS would allow complete assembly.

Specialised design for the transport space craft includes the simulation of Earth gravity, with the possibility of varying this to match Mars gravity over the journey not part of this mission scope. Observations of the benefits to reducing bone and muscle loss will follow from a successful mission.

Test rockets that are based upon reusable designs currently under development will be landed on Mars from orbit and then returned. Analysis of forces experienced by astronauts will be undertaken using sensor systems based upon crash test dummies. External visual assessments will also be performed to check for damage. It is hoped that this will allow for optimisation of landing design to ensure safety and efficiency for future manned missions.

Considerations for health and safety of the crew have been covered within the mission strategy. Production of a safe atmosphere and recycling of water are critical points addressed.

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