The Martian Battery

Proposal for the Mission to Mars Blott-Matthews Challenge 2015

Oaklands Catholic Sixth Form College
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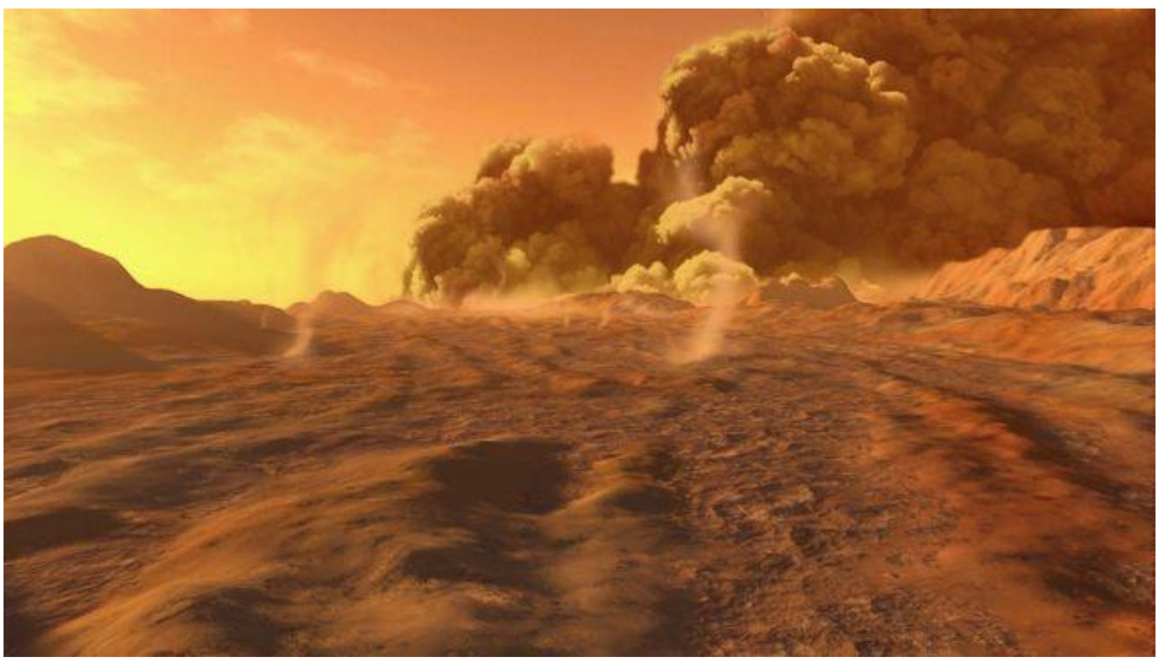


Contents:

Please ctrl+click on the main headings to move directly to that page.

Team Members:

Carys Thompson: My job in the Mission to Mars project has been to set up an aim for the time we spend on Mars, and to work out the trajectory of the rocket. Alongside taking part in the Blott-Matthews Challenge, I am studying Maths, Physics, Further Maths and Music and am also writing a dissertation as my Extended Project Qualification based on the question 'Is Time Travel Possible?' This will look at how time travel is achieved on small scale in everyday life and will use Einstein's Theory of Relativity to explore some theoretical applications of time travel which could be possible in the distant future. I hope to continue to study at a university and look forward to everything Physics has to offer, particularly in the field of astrophysics and cosmology.

Thomas Ellis: I am an AS student currently studying Physics, Mathematics, Economics and Government and Politics. I have a particular interest in the human side of this project; here, I will try to think long-term about comfortable, sustainable living arrangements on Mars. My other interests include playing sports such as cricket and rugby as well as working as a waiter and as a football referee.

Georgina Page: I am studying Maths, Physics, Chemistry and Geography at AS level. With these subjects I hope to go into environmental engineering or astrophysics because I am interested in designing how people can live in different situations like in space or the constantly changing planet that we live on. This is why I have designed the space ship that will get to Mars and back.

Ed Tizzard: I am also an AS student on the Oaklands Catholic School Mission to Mars team currently studying Maths, Physics, Chemistry and Government & Politics. I chose these subjects because I am not a fan of essays and enjoy the logic of Maths and the sciences. My interests include squash and football outside of school. My part of the project was communication, satellite research, radiation protection and took a leading role in team meetings.

Joe Hurd: I am taking part in this project as I find space exploration fascinating and it fits perfectly with my choice of A-levels as I am doing Maths, Further Maths, Chemistry and of course Physics. As my subjects are heavily Maths-based I have been set on propulsion methods and working out the amount of rockets needed as it relies a lot on calculations. In my spare time I enjoy going to my local archery club as well as going swimming.

Oliver Newman: I am currently studying Maths, Physics and Product Design. I have always been fascinated with the vastness of our universe and would one day like a career in Astronomy, of which I plan to study at University. It is because of my interest in astronomy that I decided to partake in this challenge as I thought it would be a great opportunity to have this experience.

Summary

In this document we have planned an 32 month mission to land on the surface of Mars and set up an energy harvesting system. In order to get there we have designed a ship to reach the planet named the Revelation, complete with radiation protection, aeroponics for food and a heating and lighting system. To land on Mars we are going to use two crafts one similar to Apollo 11 and the second using a supersonic inflatable aerodynamic decelerator. Once on the surface the astronauts will stay in 3D printed nylon pods held together with UV glue.

The mission objective is to harvest energy from Mars' frequent and powerful storms using turbines and a system of satellites to then get it back to Earth.

It will make the journey by using a mixture of space shuttle rockets as well as efficient ion thrusters. By following the set trajectory the journey will take 8.5 months each way, along with a year and 3 months on Mars bringing total mission time to 32 months.

Acknowledgments

We would like to thank Richard Blott and Charles Matthews for the opportunity to partake in such an exciting competition, as well as the sponsors and their representatives for their generous offers of guidance. Also, thanks to our Physics teacher Mrs Liz Arthurs for keeping us motivated throughout the project!

Our thanks go out too to Mr Quinn, Headmaster of Oaklands, who gave the go-ahead to brand our report with the Oaklands crest.

Finally, our thanks go to you, the reader, for taking the time to entertain our proposal.

The Aim- Solving Earth's Energy Crisis:

Demand for energy has and is continuing to increase exponentially through the industrial and technological age. The sad truth is that this will only get worse! Earth's energy consumption is predicted to double in the next 35 years, and therefore even less energy will be available for engineering projects. And with 85% of our current energy coming from coal, oil and gas, how will we support the massive increase in demand when our resources are finite? In order to save scientific advancements (which require huge amounts of energy) and keep mankind heading forwards, we must find solutions to this problem- quickly! Imagine the technology which could be available if science had unlimited access to energy once again. It is time to make machines and wonders only found in science fiction a reality. It's time to solve the energy crisis.

The Rage of the Red Planet

Introduction:

Mars shows strong promise of providing the energy so desperately needed on Earth, the raging storms and swirling winds which haunt the planet currently go to waste, but show immense potential as an energy source.

The Science:

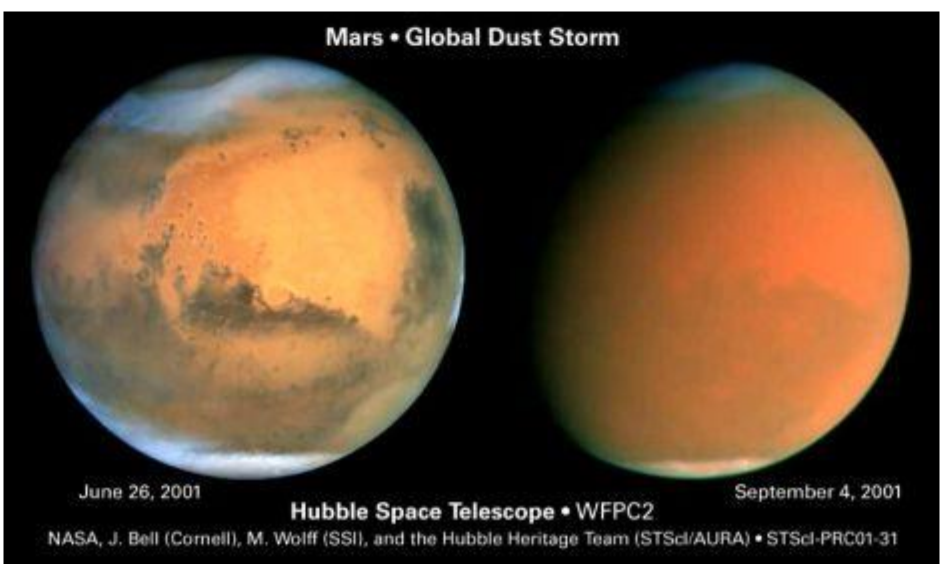
Storms on Mars begin in the same way as storms here on Earth do, heat from the sun heats the air closest to the surface of Mars and leaves the air above cool. Due to the heat energy, these particles near the surface begin to vibrate more, and therefore increase their volume, reducing their density. The less dense particles then rise upwards through the air, taking Martian dust with them. These particles collide with the cold particles above them making the air unstable, which is the cause of all dust devils, continental storms and global storms which occur on Mars.

However, although Martian storms have the same origin as Earthly ones, they are far more impressive. The first encounter we had with a Martian storm was during the Mariner 9 Mission[1].This was a NASA spacecraft, the first craft ever to orbit Mars. It was hoped that this craft would be able to observe Mars and provide us with more information about the red planet. It arrived in 1971, and witnessed a brutal storm which encompassed the whole of Mars. It was so gigantic that the tip of Mars' tallest ex-volcano, Olympus Mons, which stands at 24km high was the only thing which could be seen on the planet. This global storm shows us just how powerful Mars' weather can be. Global storms such as this one can rage on Mars for months at a time, and 10 have been recorded on Mars over a century, averaging out at approximately one global storm every ten years.

All storms on Mars originate as dust devils[2], which are similar to the tornadoes that we have here on Earth. They cover less area than Martian storms. Although, having said that, they're still impressive at around 2km long and 10km high, making them 10 times larger than Earthly tornadoes! Dust devils whip the sandy Martian terrain around at speeds of over 70mph, but although they carry all this power, they are common occurrences on Mars. Simply accepted as 'ordinary' in terms of Martian weather.

Every year we have observed continental storms on Mars, which last weeks or even months at a time. These storms grow from dust devils, to cover the areas of entire continents, and have speeds of 100mph. Most of the larger Martian storms occur around the period of perihelion (when Mars is at its closest point to the sun). Mars approximately takes twice as long to orbit the sun as Earth does, and so the period spent in perihelion is elongated, allowing surface temperature to build substantially and storms to brew.

Then of course, as mentioned before, Mars has global storms. These can either be the result of separate continental storms grouping together to cover phenomenal areas, similar to the storm observed in 1971, or they can simply grow from one dust devil. This was the case in 2001, when a dust devil began in Hella's Basin (a Martian crater 9km deep). The storm grew to cover the whole basin, and then overflowed, covering the whole of Mars in under 2 weeks' time! The global storm was so large that astronomers with the weakest of telescopes could clearly see it from Earth! Here's a picture of it from Hubble...



As you can now see, the insane amount of wind power that is circling Mars as we speak is simply too good to overlook! The incredible combination of size, duration and power of Martian storms, is nothing like we have ever seen here on Earth. We have never witnessed storms so large they cover every inch of our planet's surface, or storms which have the capability to relentlessly rage for months on end. Nature has provided us with a planet bursting with potential, and what do we use it for? Nothing. Fantastic opportunities are completely overlooked, but imagine what we could do if we harnessed the winds of Mars! With more power, we could fling our civilization into the future, making discoveries and inventions which could improve lives globally!

Conclusion:

That is why the objective of our Mission to Mars is to set up a wind turbine system from which we shall begin to reap the benefits of Mars' immense energy source. As mentioned earlier, as the Earth heads into an energy crisis we will need to explore every possible avenue for energy generation, not just for the benefit of science, but for the benefit of mankind. We believe that by harnessing the energy of Mars' storms, we will begin to fix the supply and demand problem we as a planet have found ourselves in, and will be able to progress as a species. Also, Martian weather is not a finite resource, like oil and gas. This will result in our mission having long term benefits, and ultimately being worthwhile. 'The Martian Battery' is a mission worth investing in, and most importantly, since wind power is eco-friendly- neither Mars nor Earth's atmosphere will suffer at our hands. All of the benefits of having energy with none of the damage!

Turbines

Introduction:

If we are to set up a turbine farm on Mars we need to have some idea of which turbines we're going to want to use.

Investigating Turbines:

Turbines seen today all have 3 blades. This is to make them more visually attractive and quiet. However, on Mars we don't need to worry about how attractive the turbines look, so we can use turbines with 2 blades which work just as well but are noisier and arguably uglier. This will save time while assembling the turbines and will save unnecessary material needing to be transported to Mars, therefore saving money. The average turbine built here on Earth is around 3MW and has rotor blades of 50m in length. This will be a good size of turbine to take to Mars with us, because fewer people are needed to assemble an average sized turbine than a larger offshore turbine. This will allow us to assemble turbines quickly, resulting in optimum energy generation. It is possible to create the tower of the turbine from steel, which is far lighter than concrete, and so will be easier to transport and put up.

In the newest Siemens turbines [2], such as the SWT-7.0-154, the nacelle has internal climate control, making this turbine able to function in harsh conditions. Temperatures at Martian mid-latitudes drop to -60 degrees, and even lower in the North and South, therefore this technology would be crucial to our turbines to allow them to withstand the low temperatures Mars can drop to. Also, the Siemens turbine is fitted with Direct Drive Technology, in which the nacelle forms a self-contained unit where the power from the wind is converted into electricity. It would be a good idea for our turbines to also be equipped with this, as this would prevent our astronauts from having to build an outdoor hub capable of withstanding Martian weather in which to create energy from the wind power.

The Siemens turbines are also examples of High Wind Ride turbines. Usually turbines are programmed to shut down if the mean wind speed after 10 minutes exceeds 25m/s. However, the Siemens turbines continue to function and create energy no matter how fast the wind is. They do this by intelligently reducing output power at high speeds, but still continue to create power whatever the weather. This would be an ideal quality for our turbines to have, considering they should withstand winds which are far faster than winds here on Earth. This will let turbines still function during the planet encircling storms which rage for months on end.

Due to Mars' atmosphere being far thinner than the atmosphere here on Earth, more wind is needed on Mars to actually begin spinning the blades of the turbine. One best 3MW turbines of today, the V90-3.0MW by Vestas[1], requires only 3.5m/s of wind to get the blades spinning. Since for every 10m/s of wind on Earth, 30m/s of wind on Mars would be needed, we can calculate that in order to work the Vestas turbine on Mars, 10.5m/s of wind would be required. This is hardly an issue, considering the usual wind speeds of Martian storms which were stated above. Additionally to the turbine working during storms, the average wind speed on Mars is around 20m/s, allowing the turbines to easily generate electricity even when there is no storm due to this exceeding the 10.5m/s required.

A 3MW turbine weighs around 100 tonnes, including the reinforcing steel. The cement can be taken as powder, mixed with water and set once the astronauts have arrived at Mars. It takes approximately one month to assemble 3 of these turbines, and from watching the YouTube video of how the turbines are assembled I learned just how easy of a construction project they are. The turbines in the video are larger than the ones we'll construct, being approximately 335m tall as opposed to our 80m turbines. Also, the turbines in the video have 3 blades. This makes them heavier than ours and therefore they take longer to construct, however the video[3] is helpful as a guide for visualize the process.

The other interesting thing from the video is the fact that not many men were required to assemble the turbine. This shows that if our astronauts work as a team, they should easily be able to replicate the work done by the construction workers. We will want to put up the turbines as close to Mars' equator as possible, from previous Martian weather reports[4] this is where storms are most frequent.

For the project we will need two large Mars buggies. They both must carry a crane. One of which must be equipped with a digger, and the other with a cement mixer. These vehicles will allow the construction of all 42 turbines, and will be lowered to Mars along with the turbine materials. Since a concrete truck weighs around 25 tonnes, a 90m crane (perfect, since our maximum height is only 80m) weighs around 22 tonnes and a digger around 8 tonnes, I estimate that the weight of the two buggies will be around 77 tonnes together.

If it takes around 8.5 months to reach Mars and 8.5 months to fly home, we will have 15 months in which to construct turbines. If we leave a month for setting up and packing at the beginning and end of the mission, then if we were to build 3 turbines a month, we would have created 42 3MW turbines in 14 months. If these were situated on Earth, they would power 48000 UK homes. However, this figure will be greatly increased by the brutal, lengthy Martian storms which will allow extra energy generation, and also by the High Wind Ride technology available, allowing them to generate electricity constantly.

Cost:

The average cost of building wind turbines is $1.3 million per MW of turbine. So therefore, I estimate that the entire 126MW wind turbine project will cost 126 x $1.3million, which will be a total of $163.8 million, which is equal to £122.2 million.

The average cost of running a household is £9,590. Our windfarm will power at least 48000 UK homes and so in one year only we will make £460.3 million worth of energy. This covers the cost of building the windfarm almost four times! Also, for every year the wind turbines run, we will be making money. So, after just 20 years we will have made over £9 billion worth of ecofriendly energy.

Conclusion:

The larger amount of energy production will help us to become less dependent on coal, oil and gas and will help us to find alternative energy for our power hungry world.

Satellite (microwave emitter)

The weight of some satellites is around 700Kg with some reaching up to about 5900Kg. Considering our satellite is going to transmit microwaves from its Mars orbit back to Earth it will have to be quite heavy because that kind of equipment will not be light.[1] 6 tonnes should cover it. The cost of said satellite will be around $20 million. The energy will be collected from the turbines and transmitted with microwaves up to the satellite orbiting Mars When it is above the base camp. This energy is stored in batteries within the satellite and then transmitted in microwaves once again back to a satellite orbiting Earth when they line up. This satellite will then be connected to the ground using a carbon nanotube covered cable because microwaves, unlike on Mars, will not transmit through waves through Earth's atmosphere as well because water vapour would interfere with the waves.

Getting to Mars:

This section considers the journey to Mars in a highly detailed and methodical fashion, using relatively advanced calculations based on existing and researched knowledge of astrophysics.

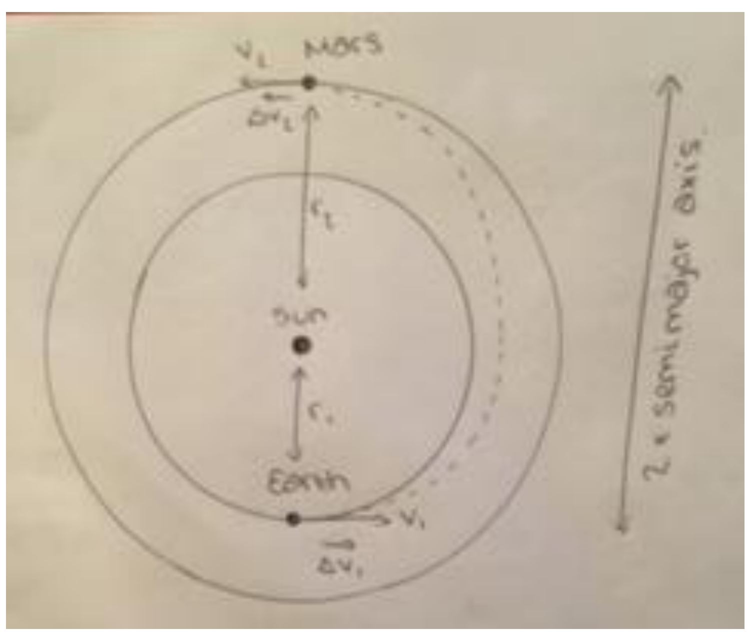
Trajectory

Introduction:

Our planet Earth is part of the solar system, and along with the other planets, it orbits the sun. It moves too slowly to escape the pull of the sun's gravity but not slowly enough to be pulled into the sun. The velocity of the Earth is perfect for keeping it in orbit. Therefore it manages to travel massive distances, without requiring rocket fuel or expensive propulsion methods to create changes in velocity- the changes needed to keep it in orbit are all natural.

If we could manage to take advantage of this natural phenomena, perhaps we too could travel extensive distances cheaply. The idea is that our rocket could act almost like a planet, and set up an orbital path of the sun. Then, once we've achieved the initial change in velocity, we can turn off the rockets and simply drift along our created orbit, over to Mars. This will take advantage of the sun, saving us money on propulsion.

If we are to plan out this trajectory to Mars, so that we manage to drift over without overshooting the planet, or getting there too soon, we have to consider our position in the solar system...



The Time Taken to reach Mars:

For the purposes of explanation, the distance between the sun and Earth = r_1, and the distance between the sun and Mars = r_2.

Our mission starts on Earth, which is already moving at a velocity of v_1, so we have an advantage already of having the Earth's velocity as a kick start. Our aim is to end further away from the sun, in line with Mars' orbit and be travelling at Mars' velocity (which is v_2) to allow us to land on Mars and keep up with it as it continues to race around the sun.

From Earth, we will burn our fuel to create an initial change in velocity (Δv_1). This will allow us to escape Earth's orbit and to create an elliptical orbit of our own. This is shown by the dotted line. Once we are travelling fast enough to remain in orbit completely under the influence of the sun, we will turn off our propulsion method.

However now, the rocket will be trapped in an elliptical orbit, and will continue circling the sun on that path unless we do something to change it. When we reach the point that Mars passes during its orbit, we will have to make another change in velocity (Δv_2) in order to make our orbit match Mars'. Then, we'll be able to follow Mars' orbital path and land on Mars.

This method is called the Hohmann Transfer, and it's currently the most efficient method known for inter-planetary travel.

Kepler's Third Law[1]:

$\mathbf{P^2=a^3}$

(Where p is the time taken to compete an entire orbit on any orbital path and 'a' is the semi major axis of that orbit.)

This law can be applied to the elliptical path we're following, in order to work out the time it will take us to reach Mars if we use minimum fuel by relying on the sun.

The semi major axis of an orbit is the radius of the orbit at its largest point. And so, in order to calculate the semi major axis of our elliptical orbit, we need to measure from perihelion (the point at which our orbit is closest to the sun) to aphelion (the point where our orbit is furthest away from the sun) which will give us a measurement for the diameter of our orbit at its largest point.

For our orbit, the diagram clearly shows that the point of perihelion is when we are next to Earth, and the point of aphelion is when we are next to Mars. Therefore, from the diagram, since the diameter between these points is the distance from Earth to sun added to the distance from Mars to sun, this can be written as r_1+r_2.

So, the semi major axis of our orbit is $(r_1+r_2)/2$. Which is essentially that the largest radius of the orbit = the largest diameter of the orbit halved.

We then substitute in the known values for r1 and r2 to give us an answer. r1 (the distance from the Earth to the sun) is equal to 1 astronomical unit. This is how we measure distances in space, since to measure in m or km results in lots of standard form calculation! Relative to the distance from the Earth to the sun, r2 (the distance from Mars to the sun) is equal to 1.52366 astronomical units, and so to calculate the semi major axis of our orbit (a), we calculate:

$a= (r1+r2)/2$

$a= (1+1.52366)/2$

a=1.26183 astronomical units

Therefore, using Kepler's Third Law (which is outlined above), if we were to use the least amount of fuel possible, the time take to complete an entire orbital path:

$P^2=a^3$

$p^2=1.26183^3$

p= the square root of (1.26183^3)

p=1.417 years.

Therefore, since the time taken to complete a whole trip would get us to fly straight past Mars and come back home, the time taken to reach Mars (m):

$m=p/2$

$m=1.417/2$

m=0.71 years

This means that using Kepler's Third Law, and the Hohmann's Transfer, we can estimate that it will take around 8.5 months to reach Mars. The Hohmann's Transfer orbit is the most economical method of reaching Mars. Since propelling ourselves to Mars will be the most expensive aspect of our mission, we have made saving in this area a priority, and so will use the cheapest method possible to reach Mars.

What would our change in velocity need to be to reach Mars?

To begin with, we must know what velocity we start from, and what velocity we're trying to reach. Earth's velocity (v1) and Mars' velocity (v2) are given by the equations:

Where G= Gravity from the sun
M*= Mass of the sun

$$V_1 = \sqrt{\frac{G m_*}{r_1}}$$

$$V_2 = \sqrt{\frac{G m_*}{r_2}}$$

For the beginning of our orbit, we already have v1. We then add some velocity in order to escape Earth's orbit. We begin our trip when our orbit is at its closest point to the sun, which is also called perihelion, and so our velocity at perihelion (Vp):

$$V_p = V_1 + \Delta V_1$$

Now we are on the transfer orbit. Then when we've drifted around our orbit, and are approaching aphelion, which is the point where our orbit is furthest away from the sun. The velocity we're traveling at aphelion (Va) then requires another change in velocity in order to allow us to move along Mars' orbit, so:

$$V_2 = V_a + \Delta V_2$$

However, although we have values already for v1 and v2, we can't work out the change in velocities required to reach Mars until we know what the velocity of our rocket would be at perihelion (Vp) in the orbit, and at aphelion (Va) in our orbit. To work these values out we'll use the equations of the conservation of angular momentum and conservation of energy:

The equation needed to work out the angular momentum at perihelion is:

$$L = m V_p r_1$$

m = Mass of the rocket
L = angular momentum

The equation needed to work out the angular momentum at aphelion is:

$$L = m V_a r_2$$

The laws of angular momentum then tell us that angular momentum is conserved, and therefore, these two equations must be equal:

$$m V_a r_2 = m V_p r_1$$

This is one of the equations we'll work with. The other is the equation for conservation of energy. The energy at perihelion is given by:

$$\mathcal{E} = \frac{1}{2} m V_p^2 - \frac{G m m_*}{r_1}$$

We can also use this equation to work out the energy at aphelion:

$$\mathcal{E} = \frac{1}{2} m V_a^2 - \frac{G m m_*}{r_2}$$

Therefore, due to the conservation of energy:

$$\frac{1}{2} m V_p^2 - \frac{G m m_*}{r_1} = \frac{1}{2} m V_a^2 - \frac{G m m_*}{r_2}$$

Now we have all our equations ready, we have to do some algebraic manipulation in order to find the changes in velocity needed for us to reach Mars!

Firstly we need to use the equation of the conservation of angular momentum in order to express Va in terms of Vp. We can do this by canceling the mass of the rocket on both sides of the equation and dividing by r2. So, to show the workings:

$$\cancel{m} V_a r_2 = \cancel{m} V_p r_1$$

$$V_a = \frac{V_p r_1}{r_2}$$

Then we can substitute the Va we've just created into the equation for conservation of energy, in order to eliminate the Va in that equation, and allow us to work with Vp only so we can get a result for it. Again, we can cancel the mass of the rocket throughout the equation:

$$\frac{1}{2} \cancel{m} V_p^2 - \frac{G \cancel{m} m^*}{r_1} = \frac{1}{2} \cancel{m} V_a^2 - \frac{G \cancel{m} m^*}{r_2}$$

$$\frac{1}{2} V_p^2 - \frac{G m^*}{r_1} = \frac{1}{2} \left(\frac{r_1}{r_2} V_p \right)^2 - \frac{G m^*}{r_2}$$

The right hand side can also be written as: (by expanding the bracket)

$$\frac{1}{2} \left(\frac{r_1}{r_2} \right)^2 V_p^2 - \frac{G m^*}{r_2}$$

To delete the halves we multiply by 2 through the whole equation and since we want to get the values containing Vp all on one side, and push all of the other values to the other side, we get:

$$V_p^2 - \left(\frac{r_1}{r_2} \right)^2 V_p^2 = \frac{2 G m^*}{r_1} - \frac{2 G m^*}{r_2}$$

Now we want to take out Vp as a common factor on the left hand side. Also out of the right hand side we can take a factor of 2Gm*:

$$V_p^2\left(1-\left(\frac{r_1}{r_2}\right)^2\right) = 2Gm^*\left(\frac{1}{r_1}-\frac{1}{r_2}\right)$$

We then simplify by expanding the fractions, in order to do this, the denominators must be the same!

$$V_p^2\left(1-\left(\frac{r_1}{r_2}\right)^2\right) = 2Gm^*\left(\frac{1}{r_1}-\frac{1}{r_2}\right)$$
$$V_p^2\left(\frac{r_2^2}{r_2^2}-\frac{r_1^2}{r_2^2}\right) = 2Gm^*\left(\frac{r_2}{r_1r_2}-\frac{r_1}{r_1r_2}\right)$$
$$V_p^2\left(\frac{r_2^2-r_1^2}{r_2^2}\right) = 2Gm^*\left(\frac{r_2-r_1}{r_1r_2}\right)$$

Finally, we want Vp on its own, so we need to do a bit more working, taking everything from the left hand side which isn't Vp on to the right. To divide by a fraction, we multiply by the reciprocal of the fraction, and so:

$$V_p^2 = 2Gm^*\left(\left(\frac{r_2-r_1}{r_1r_2}\right)\left(\frac{r_2^2}{r_2^2-r_1^2}\right)\right)$$
$$V_p^2 = 2Gm^*\left(\frac{r_2^2(r_2-r_1)}{r_1r_2(r_2^2-r_1^2)}\right)$$
$$V_p^2 = 2Gm^*\left(\frac{r_2(r_2-r_1)}{r_1(r_2^2-r_1^2)}\right)$$

That last line of working is simply canceling r2 from the top and bottom of the fraction. If you take the bracket ($r2^2$ and $r1^2$) and expand it, you would find that:

$$(r_2^2-r_1^2)=(r_2-r_1)(r_2+r_1)$$

Therefore, one of the resultant brackets will cancel with the bracket on the top of the fraction, leaving you with a value for Vp.

$$V_p^2 = 2Gm^* \left(\frac{r_2}{r_1(r_2+r_1)}\right)$$

$$V_p = \sqrt{2Gm^* \left(\frac{r_2}{r_1(r_2+r_1)}\right)}$$

We can now put this value and our value for v1 which was calculated earlier, into the simpler equation in order to give us the change in velocity needed at the beginning of our orbit:

$$V_1 = \sqrt{\frac{Gm_*}{r_1}}$$ and $$V_p = \sqrt{2Gm^* \left(\frac{r_2}{r_1(r_2+r_1)}\right)}$$

into the equation:

$$V_p = V_1 + \Delta V_1$$

To find the change in velocity needed at the beginning of our trip, which would be:

$$\Delta V_1 = \sqrt{\frac{GM_*}{r_1}}\left(\sqrt{\frac{2r_2}{r_1+r_2}} - 1\right)$$

Then, in order to find the change in velocity needed at the end of our trip, you have to substitute the value for Vp, into the equation for the conservation of angular momentum to find the value of Va:

$$V_p = \sqrt{2Gm^* \left(\frac{r_2}{r_1(r_2+r_1)}\right)}$$

into

$$\cancel{m} V_a r_2 = \cancel{m} V_p r_1$$
$$V_a = \frac{V_p r_1}{r_2}$$

And then finally, once you've calculated a value for Va, you can use the value for Mars' velocity in order to work out the change in velocity needed at aphelion.

$$V_2 = \sqrt{\frac{Gm_*}{r_2}}$$

and

$$V_a = \frac{V_p r_1}{r_2}$$

into the equation:

$$V_2 = V_a + \Delta V_2$$

$$\Delta V_2 = \sqrt{\frac{Gm_*}{r_2}}\left(1 - \sqrt{\frac{2r_1}{r_1+r_2}}\right)$$

Now that we've created equations to allow us to work out both changes in velocity needed to reach Mars, you can put in the known values:

$G= 6.67x10^{-11}$
$M^*= 1.99x10^{30}kg$

And also the distances r1+ r2 in metres

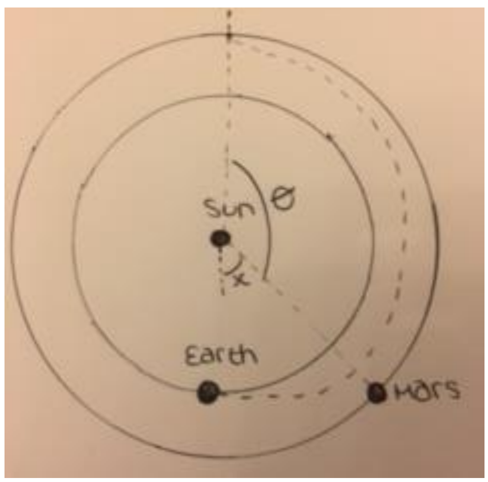
Then the change in velocity needed at perihelion= 2.94km/s
And the change in velocity needed at aphelion = 2.65km/s

So in total, to reach Mars, we require a change in velocity of 5.59km/s

The great news is that in order to get back from Mars, we can use the same transfer orbit. This keeps fuel usage at a minimum. So, to return from Mars, we need a change in velocity of 2.65km/s at aphelion. The thrusters will be providing this change in velocity with the thrusters acting in the other direction, in order to make us slower than Mars' orbit, and to allow us to begin our transfer orbit once again. Then in order to make ourselves travel at Earth's speed once again, we will need another change in velocity of 2.94km/s to slow us back to Earth's orbital pace from our transfer orbit. Then we'll have reached home safely.

Working out when to take off:

If we were to take off when Mars was at a certain point, then because it takes 8.5 months to get there, by the time we reach that point Mars won't be there anymore. Therefore, we need to work out the optimum time for launch which will allow us to meet Mars, taking into account that Mars moves and so do we. Using the diagram below, we can work this out:



As we know it takes Earth 8.5 months to complete half a transfer orbit and appear on the opposite side of the sun. We ideally want Mars to also have reached this point after the 8.5 months we spend flying, and so in order to work out when to take off, we must work out how far around its orbit Mars would be 8.5 months before the proposed landing time. Then we take off when Mars is at this point, meaning that we meet it in 8.5 months' time.

Working out where Mars will be when we need to take off, we use theta to denote the angle that Mars is from the meeting point. We can then from this work out the angle (x in the diagram) Mars must be ahead Earth when we take off.

We can work this out using the ratio:

$$\frac{T_m}{P_m} = \frac{\theta}{360}$$

Where:

Tm= the time Mars takes to meet the meeting point in years
Pm= the period of Mars' orbit (total time for orbit)

This gives time taken as a ratio, which is set equal to the ratio of the angle.

Now we can rearrange to work out theta.

$$\frac{0.71}{1.88} = \frac{\theta}{360}$$

$$\left(\frac{0.71}{1.88}\right)360 = \theta$$

$$\theta = 136^{\circ}$$

Since theta= 136 degrees, then Mars must be 136 degrees away from the meeting point when we take off. Therefore, angle x must be 180- theta, which equals 44 degrees.
Therefore, when we take off, Mars must be 44 degrees ahead of the Earth.

Returning home:

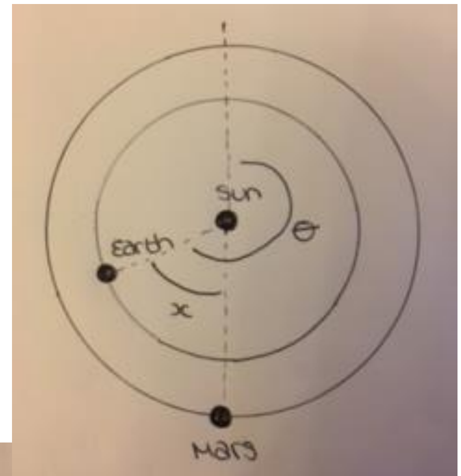
I've already explained the change in velocity needed to get home above, however, this would require us waiting for another optimum time. Mars and Earth continue moving while we're on Mars, and so in order to get home, we have to wait for a point where we will end up meeting Earth exactly after 8.5 months of flying.

Again, we can use the same method:

$$\frac{0.71}{1} = \frac{\theta}{360}$$

$$0.71 \times 360 = \theta$$

$$\theta = 256^{\circ}$$



$$\frac{T_E}{P_E} = \frac{\theta}{360}$$

Therefore we must take off from Mars when Earth is 256 degrees from the meeting point. This will allow us to meet it in 8.5 months' time, and arrive safely home. Since we're at 180 degrees, then the angle Earth needs to be behind Mars when we take off to get home (x in the diagram) would be 256-180= 76 degrees.

Now that we know the angles required when we take off, we can work out the maximum time we will spend on Mars. This will be the time it takes for the orbits to shift from being in the first position (when Mars is 44 degrees ahead of Earth) to the second position (when Earth is 76 degrees behind Mars)

Using the simulator in the links, we can see that Mars is roughly 44 degrees ahead of Earth in late March of 2018. This would be when we want to take off to reach Mars. Since it takes 8.5 months to reach Mars, then we will arrive at Mars in mid-December of 2018. The next possible window for return (when Earth is 76 degrees behind Mars) using the simulator, is mid-March of 2020. This lets us know how long we have on Earth to put up turbines and do other Mars activities before having to take off again. The time we spend on Mars before having to take off to get home would be 15 months, which would take us to mid-March 2020. The rocket would therefore return safely home for the end of November in the year 2020. This solves our timings for the mission, making the mission last a total of 32 months.

Propulsion

Introduction:

Our group plan is to send the whole of the equipment along with return fuel, the astronauts and the settlement in one giant ship. The reasoning behind this was to make the least additional mass by having one mass efficient ship rather than lots of smaller ones which need repeated equipment. The ship leaving Earth orbit will receive a boost from the Rocketdyne Block I SSME Space shuttle rocket which provide the thrust to get into space. The longer space journey will be powered by Ion thrust as they have a high thrust to weigh ratio and are incredibly efficient (full description below).

It would be composed of an orbiting vessel which would have food needed to sustain a crew of two as well as fuel for the return journey and a landing craft to safety bring the astronauts to the surface of Mars. As well as a big bulk load of equipment and a return shuttle separately.

The take-off and landing cycle would be similar to the Apollo moon mission but with a twist the equipment landing on Mars would be dropped in two parts, the bulk of the equipment and the return ship would be dropped first in the right place and the astronauts would have a slower descent in the landing shuttle. A benefit of the first drop having no people on board is that it can partially solve the problem of landing a gigantic ship. With humans on board the landing is limited to 3G to prevent the astronauts being killed. But as the equipment is much more resilient and so less fuel and equipment will be needed for the descent of the craft.

After the allotted time on Mars, just over a year at 15 months, they will then be able to get into the fueled space shuttle and leave Mars which will coincide with the preplanned orbital route back to Earth.

The return from Mars to Earth will be similar to the journey to it but the other way around with a conventional rocket boost on the whole station to leave orbit into space and then Ion thrust to return back to Earth.

Method of propulsion - Ion Thrusters:

One of the more modern types of rocket propulsion is Ion propulsion, which ionises noble gases for example Argon or (more commonly used) Xenon and fires the ions behind to create thrust. With 1.9% of Mars' atmosphere composed of Argon (compared to just 0.9% on Earth) means that upon arrival it would be economical, both in the sense of fuel mass and cost, to utilise this potential fuel by means of vacuum distillation. The ion thruster used on Deep Space One had a diameter of 20cm[1] and required an average of just 100g of Argon per day to run and had a mass of around 25kg including cables. As they were designed for deep space missions they have been purpose built to run for long periods of time and the 20cm diameter gives them an area (not actual area of dish) of around 0.2 x 0.2= 0.04m^2 (using the diameter to form a 20 x 20 cm square as circles don't tessellate) which means that large numbers of them could fit in a relatively small area. For example, 100 would take up around 0.20 x 0.20 x 100 = 0.04m^2.

However, the downside is that currently the most powerful ion thrusters which have been made (primarily by NASA) like NASA's Evolutionary Xenon Thruster (or NEXT for short) have a thrust of 236mN and using 6.9 kW of power[2]. Although NASA predict that the next ion thruster will have almost twice as much thrust as the NEXT model[3] so the impulse of the new thrusters used on this mission would be around 9.77 MNs and consequently the thrust around 472mN. Compared to the gigantic mass of the spaceship (2720 tonnes) the acceleration would be almost unnoticeable but as they are so efficient and have such long run times (of many years as shown on Deep Space One) they can contribute in a big way to the total change in velocity of an object.

The fuel mass of an ion thruster is equivalent to 0.1kg of xenon a day (as on Deep Space One [6]) so if the journey took 6 months I would expect the required xenon per thruster to have a mass of 0.100 x 8.5 x (365/12) which is 25.9 kg added on to the mass of 26kg for the thruster gives a combined mass of around 51.9kg. However xenon is quite costly and other noble gases can be used in these thrusters, assuming in the next few years they will be able to optimise the thrusters for argon (which shares many of the requirements with xenon) the mission would be much cheaper. 1kg of argon costs around $4 25.9 x 4 gives a cost of $104 (£68) to fuel each thruster for the duration of the journey.

Estimating the mass of the total ship:

The International Space Station has a total mass of 925,000 pounds (from NASA.gov), if you divide it by 2.2 (the standard Pounds to kilos conversion) you get a mass of 420,000 kg (or 420 metric tonnes). To work out the mass of the main vessel (which I'm assuming can be scaled up to the volume of the craft) the mass of the four solar array panels would need to be taken off and as each has a mass of around 7.71 four of them would have a mass of 30.8 tonnes. 420-30.8 = 389 tonnes (389.2 rounded) which is my basis for the next set of calculations.

As an early estimation before any dimensions were put to the vessel I assumed the craft would be 2 times bigger scaling up the three month habitation and research vessel to a craft which would be used for a half year journey **778** tonnes.

As this craft would be travelling in space for a long time a large amount of power would be needed and for this we settled on a nuclear fission reactor run on Uranium, and estimate of the mass of this would be based on a nuclear submarine. The Ohio type nuclear submarine has a mass of 1.5×10^7 kg or 15,000 tonnes, as the exact plans of these ships are guarded by the countries who own them, I am assuming that 1/20th of the mass of this submarine is taken up by the reactor and its shielding. 5% of 15,000 = **750** tonnes and as there is a very minimal leakage of radiation from the core, it is actually a safe way to generate the amount of power we need for the journey. An A1B nuclear reactor (as featured in an Ohio type submarine) has a typical output power of 150 MW which should be ample to cover our needs.

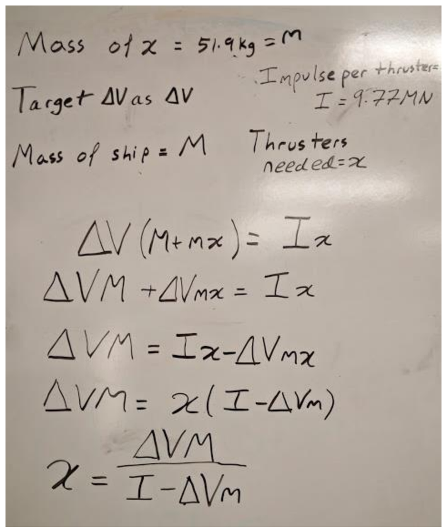
The launch mass of a space shuttle is 2040 tonnes_4 with an external tank using liquid hydrogen and fuel with a mass of 739 tonnes as well as solid booster rockets with fuel of mass 504 tonnes. The combined mass of the fuel is therefore 1240 tonnes (1243 to 3sf) the gravity of mars is $3.71ms^{-2}$ compared to Earth's $9.81ms^{-2}$ assuming air resistance on Mars is in the same ratio to the gravitational field strength the amount of fuel required to take off would be (1240 x 3.71)/9.81 which is equivalent to 469 tonnes of fuel. 1240-469 = 771 tonnes of fuel less than taking off earth. This can then be taken off the mass of the shuttle to determine the mass of the craft which will be used to take off Mars again, 2040-771=**1270** (3sf) tonnes. The cost of this was $375 million in December 1988 when the US consumer price index was 118.3 as it is now 237.8 (in November 2015) (237.8/118.3) x 100 gives an approximate inflation rate of 201%, $375 x 2.01 = $754 million dollars. $754 million is equivalent to around £498 million.

Adding all of these components together 1270 + 750 + 778 + 420 (for turbines) gives just under 3220 tonnes. 250 tonnes will be added to accommodate for the mass of the materials needed for the building of the settlement and the solar panels needed to power its everyday usage as well as the landing equipment. This gives a final estimate of **3470** tonnes for the total mass of the ship which would be what I will use as an estimate for the main frame of the ship.

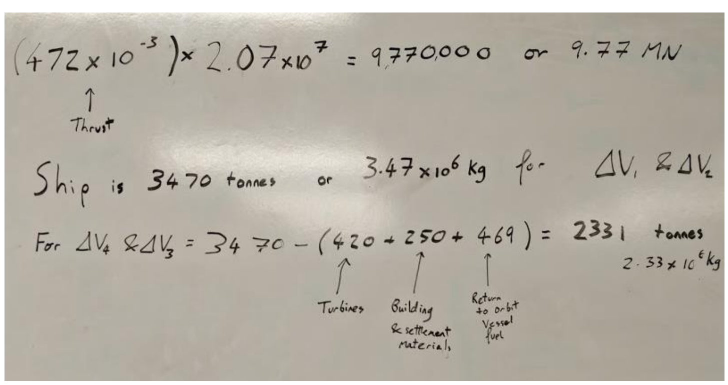
How many thrusters would be needed?

To work out the amount of thrusters mended it has to be broken down into four parts then reversed as the ship will needed to be able to return.

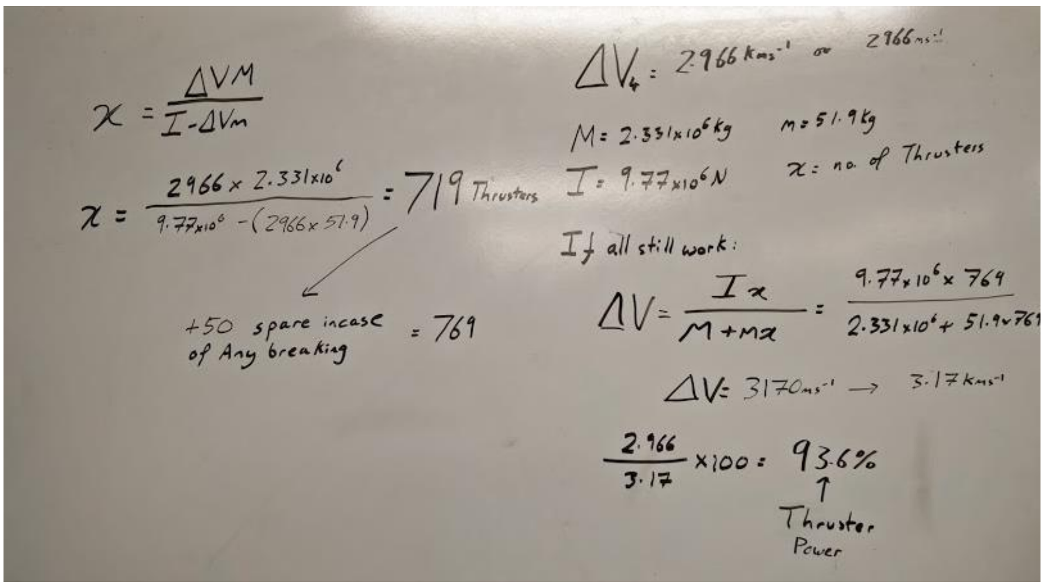
The first step I am looking at is the last one, working out how many Ion thrusters are needed to achieve the velocity needed for the final delta-V change from Mars to Earth's orbit. Shown through rearranging the momentum equation as well as converting the thrusters thrust into an impulse.



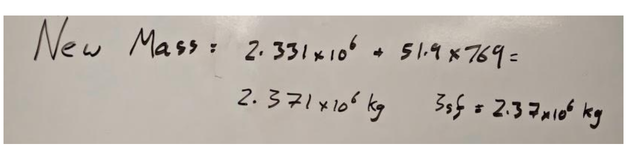
The change in time being limited to 8.5 months or 2.07×10^7 seconds and the impulse of the thrusters being 472mN giving an Impulse of 9.77×10^6 Ns ($1.58 \times 10^7 \times 472 \times 10^{-3}$). The ship's mass would be the total 3470 tonnes without the mass of the turbines 420 tonnes, the Building materials 250 tonnes and the rocket which will take back off Mars' fuel which has a mass of 469 tonnes. This gives a value of 2331 tonnes for the mass of the ship.

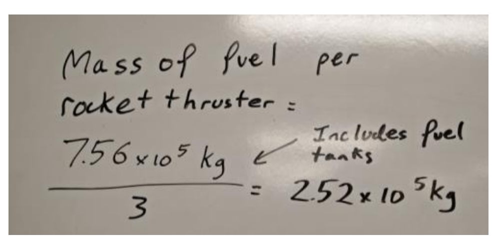


It gives a value of 719 Ion thrusters needing to be active (or a few larger ones equivalent to 719 present day ones) for the most cost effective way of achieving the required velocity change. As a safety precaution, an extra 50 will be added in order to compensate in case a few malfunction or extra thrust is needed bringing the number to 769 thrusters. However with no breakages it will provide a Delta-V of 3.17km/s which would mean engines running at 93.6% to stay at the target of 2.966 km/s.

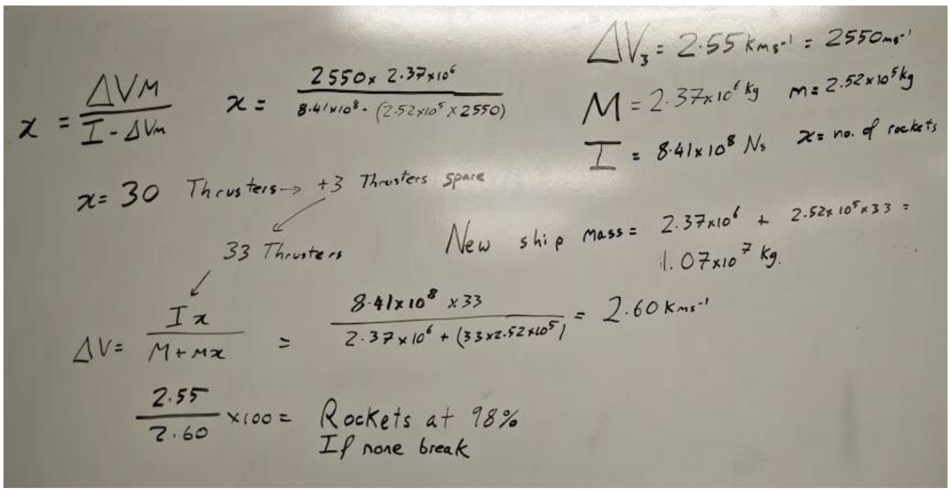


The journey from Mars' orbit or (delta-V 3) to space again. For this I have to use the closest available comparison, again a space shuttle. Using the ESA's website[7] I have found that a space shuttle has three Rocketdyne Block I SSMEs each with a thrust of 1.752MN and a burn time of 480s. This gives a total impulse of ($1.752 \times 10^{-6} \times 480$) 8.41×10^{8} Ns. By rearranging the momentum equation as shown below to achieve the number of rockets needed to meet Delta-V required (in the same way as the ion thrusters but with the mass value (2.52×10^{5} kg) and impulse of the rockets instead). At this point M (mass of the craft needs to be adjusted to include the mass of the thrusters (shown in the picture) before the calculations can be completed.



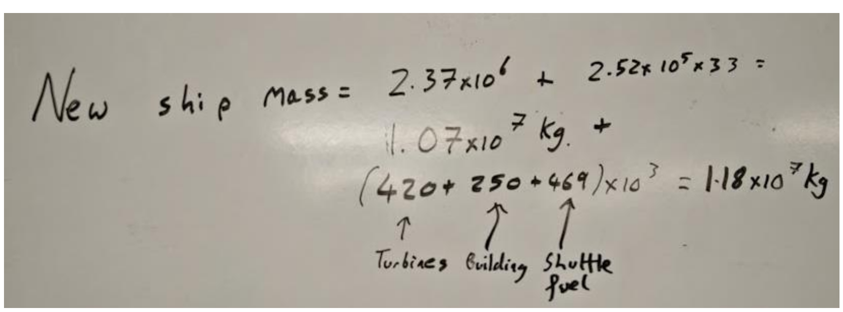


Substituting into the equation gives a value of 30 rockets, again in order to ensure the consequences of a rocket malfunctioning are kept to a minimum, an extra three will be added (10%). Working out the change in velocity with the extra 3 brings the Delta-V above the target and so if there are no breakages the rocket need to be running at 98% to stay on the correct trajectory.



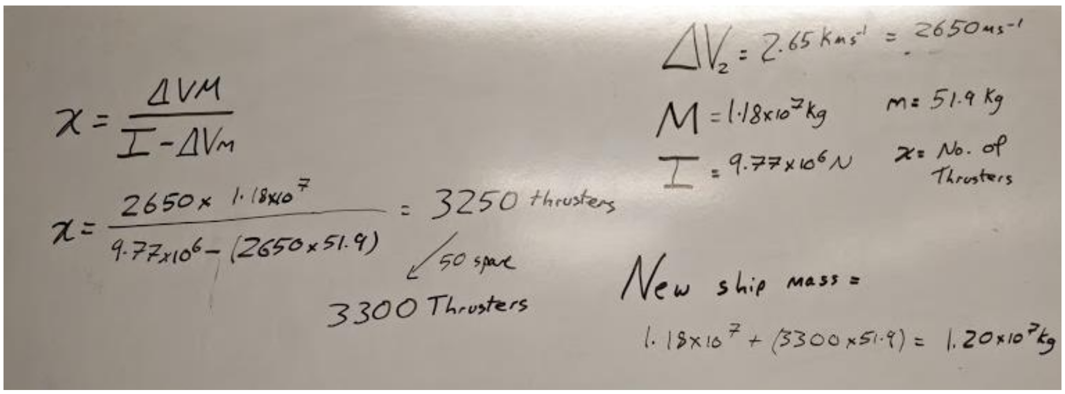
However as the fuel for these rockets are so heavy it brings the total mass of the ship up to 10,700 tonnes or 1.07×10^7 kg. As well as that the mass of the turbines, building materials and the shuttle fuel will need to be added again bringing the total up to a massive 11,800 tonnes or 1.18×10^7 kg.

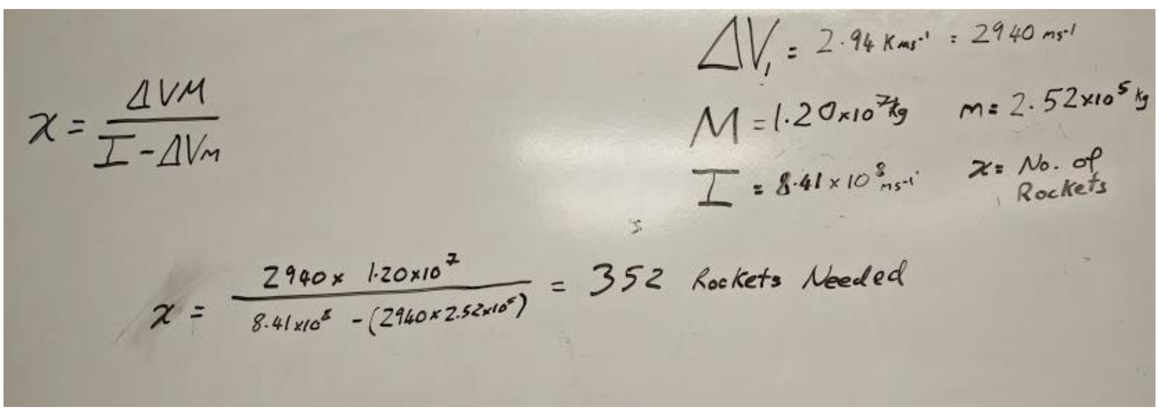
Again like Delta-V 4 the change Delta-V 2 would be worked out in a similar way using a rearranged form of the momentum equations, this time giving a result of 3250 thrusters. An extra 50 will need to be added again to ensure that any of them breaking would not impact the overall safety of the crew and the mission. Most of these thrusters will be discarded on the way to Mars as only 769 are needed for the journey back, however that



seems very wasteful of good mass and so could be sent off with explosions for more momentum(See future development). The calculations are shown in the picture.

Finally the first delta-V the one to leave Earth's orbit in the first place can be calculated.





Now the final mass of the rocket for all the other stages is known at a total of 12,000 tonnes or 1.2×10^7 kg. This enables the first Delta-V requirement to be calculated, that one which would enable the ship to leave Earth orbit. By doing the momentum equation for the final time it gives a total of 352 rockets. There will be no spares of these as I assume the ship will be in full working order on its departure from Earth. This gives a total of 385 rockets.

Cost:

The cost of 8.5 months' worth of argon per thruster = £68 as shown earlier; the total number of 8.5 months' thruster fuel needed is 3300 + 769 giving a total of 4069 portions. 4069 x 68 gives a total Argon cost of £277,000.

Liquid Hydrogen costs NASA \$3.66/kg whereas oxygen costs just \$0.16/kg[8] assuming the rocket fuel is 50/50 of the 2.52 x (33+352) tonnes of fuel used. The cost of hydrogen would be 252 x 10^3 x 0.5 x 385 x \$3.66 = \$178 million (£117 million) and for oxygen 252 x 10^3 x 385 x \$0.16 would cost \$15.5 million (£10.2 million).

This gives a total of £127.2 million fuel cost + £498 million for the shuttle which will be leaving Mars, brings the fuel cost up to £625.2 million.

Future development:

Below is a section of ideas and information about paths which the Mars projects could take in regards to propulsion, a few of these ideas are in the near future or just need more advanced rocket science than we are capable of at the present moment in time.

Two-part ship:

Although we have planned a single ship perhaps in the future a two part mission could be used to benefit the health and wellbeing of the astronauts as well as costs of food and oxygen.

The first would be a slow and very heavy ship containing the bulk of the equipment which would be sent 18 months before the second ship. This would have all of the turbines and equipment needed to set them up on board as well as the other things like shelter we would need for establishing a settlement. As there would be no humans on board it removes the need for breathable air on board so the air space could be filled with other useful gases such as extra nitrogen supplies for the aquaponics. As well as a lot less overall weight due to being able to remove most of the radiation shielding as the equipment won't stop functioning due to solar winds. The total flight time of this craft would be around two years and would contain a take-off craft to return to and orbiting section of the second craft.

The second would be the manned craft with only the essentials needed to keep the astronauts alive and healthy including aquaponics to feed them, CO_2 scrubbers and some extra space to live in. Further benefits would include less deterioration of the astronauts' muscles as a reduced journey time means less time with no gravity and therefore better health. The journey time can hopefully be cut down to as lower as it would be smaller so requires less thrust to go faster hopefully in around 6-9 months.

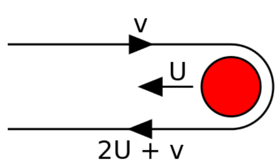
The reason we didn't use this method was that we couldn't figure out a flight path for the bigger ship to take long enough to reach Mars and coincide with the arrival of the second ship without wasting more fuel on a longer path than it would save.

Momentum gained through discarding fuel tanks:

Another way to generate even more extra thrust is by using a small explosion to discard parts of the ship like the fuel tanks behind the ship when they are no longer needed, as this is in space with no force resisting the motion the overall velocity will actually be beneficially affected by discarding the pieces (calculated using the laws of momentum). However, further knowledge of explosives is needed to get accurate numbers but in future this may be a cost-optimising solution.

Using the Moon for a gravitational assist:

As there is no pre-determined trajectory to Mars using the moon as a slingshot may be beneficial in optimising the costs and duration of the mission. The moon is moving at a speed of 3,680 km/h which means that can be used to boost the speed of the ship. If we use the correct trajectory we could get a significant speed boost the calculation being U + (U + v) = 2U + v. This is shown in the diagram.



4*

Therefore a predicted maximum velocity gain would be around (2*3680) = 7360 km/h which is a possible way to improve costings. Again we have not been able to find an optimum path which would make this detour worthwhile.

Getting down to Mars' surface

There will be two crafts to go down to the surface. The first will be of minimal space which will hold only the astronauts and enough fuel to get down and back up. The second will hold all the equipment needed when down there and this one can stay down on Mars permanently.
The first craft would be relatively easily to get down there as we can use the idea of the Apollo 11 where we have a small light craft with thrusters coming from the base to allow a safe descent. As the gravitational field strength is 3.73 MS–2, we could allow the craft to fall for most of the journey, slowly building up velocity and then activate the thrusters to slow the descent in time to get the craft to land safely without damaging itself or the astronauts. This will be done so that minimal fuel is used up and there will be enough for

the ascent at the end of the trip. The craft, like Apollo 11, will have footpads at the base to provide stability when landing.
The second craft will be unmanned and much heavier weighing at around 1000 tonnes, this mean that it will fall much faster and be harder to slow the descent. As it is unmanned, it could land with a greater velocity than the first as we would not need to worry about a suitable speed for humans to survive. We will need to still find a suitable speed to obtain when landing as we would not want to damage the equipment when it makes contact. For this we can use an adapted version of the Curiosity spacecraft. Where we can use a large amount of fuel for rockets to slow the descent. Engineers are also developing a Supersonic Inflatable Aerodynamic Decelerator (SIAD). This will drastically reduce velocity with increased drag, and combined with the rocket thrusters, we could reach a speed in which no harm will come to the equipment. We could also pad the craft out with air bags which will then soften the landing, to ensure more safety of the equipment.

To enter the atmosphere, to prevent overheating from the descent, we will need to protect both crafts with Aeroshells which encase the craft in a heat proof protecting layer to keep both astronauts and equipment safe. When landing we will need a large flat area of land to provide a smooth landing.

Supersonic Inflatable Aerodynamic Decelerator

Cost:

The descent will be quite a lot as 250 tonnes of fuel will be needed to get the crafts down and then for the human craft to get back up again. The SIAD will probably cost will come to £2,000,000 to make the descent as it will involve advanced technology and will need to be very big to attach to the equipment craft.

Conclusion:

We will use two crafts to get down to Mars' surface, one small craft similar to the Apollo 11 and a much larger craft for the equipment. The smaller craft will be minimal in size as it will hold only the astronauts. The larger craft will hold all the necessary equipment for the mission when down there. This craft will also have the Supersonic Inflatable Aerodynamic Decelerator, this will be vital for the descent as it is able to lower multi-tonne crafts.

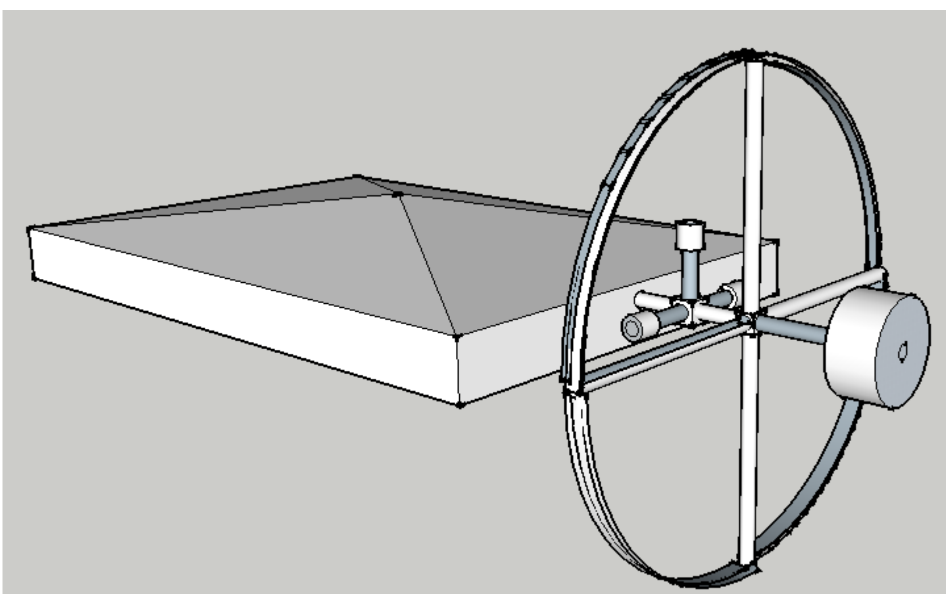
Living on Board:

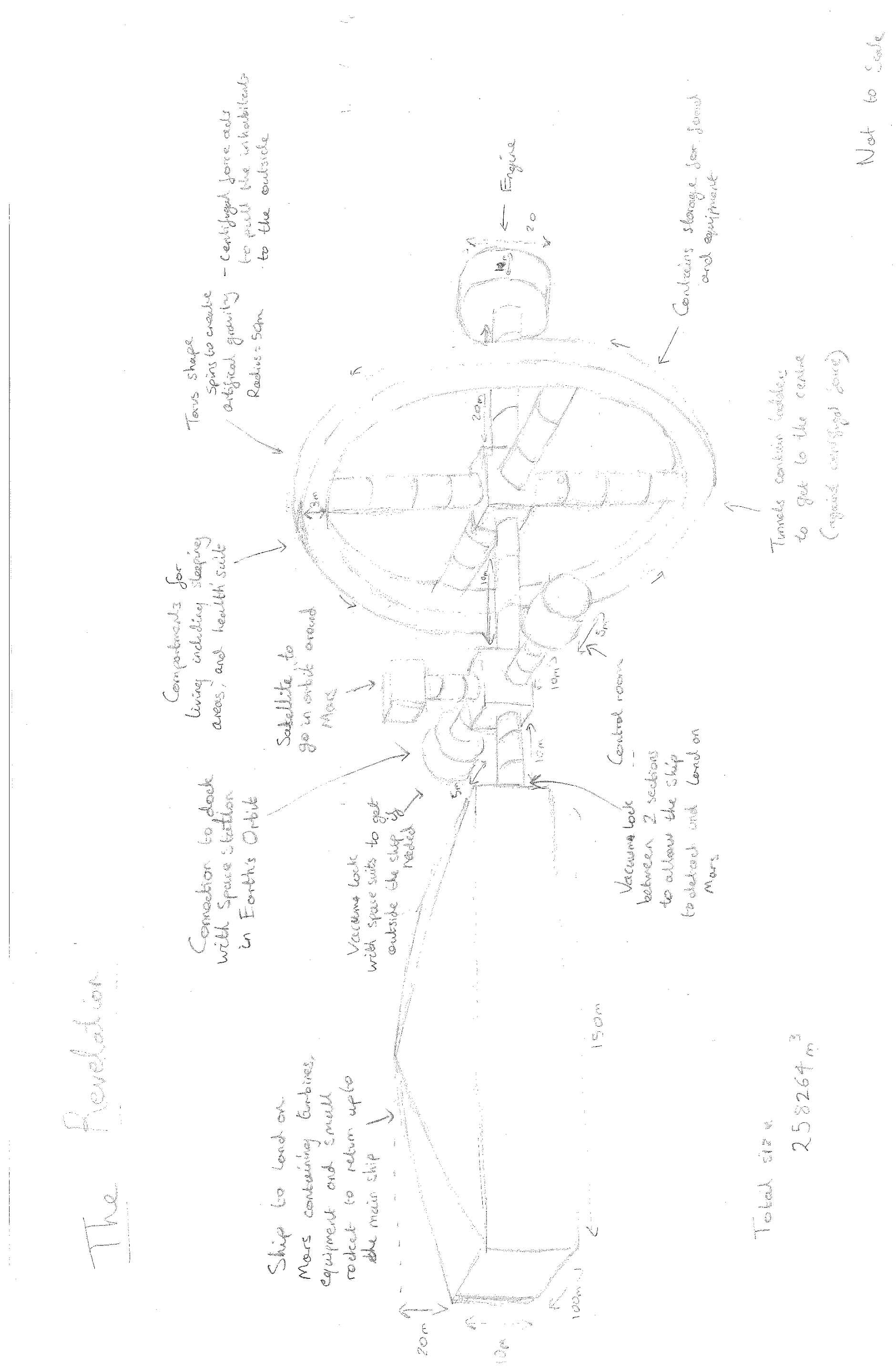
This section details the specific design of our spaceships and how the astronauts will live safely inside.

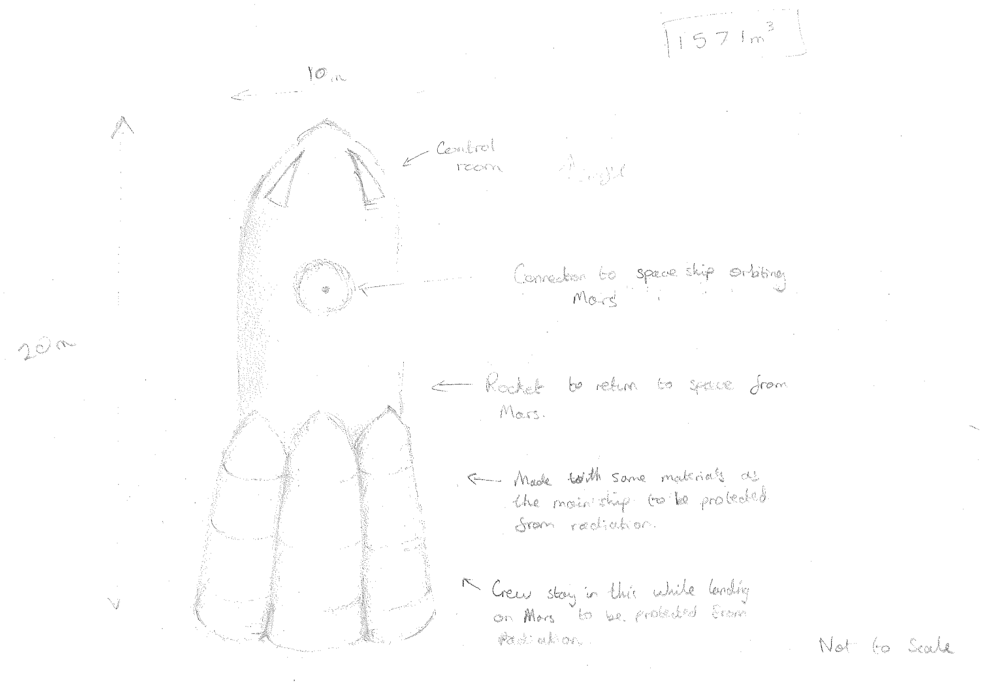
Spaceship Design

The spaceship will need to get to Mars and back while allowing the crew to carry out their mission. To allow this the design of the ship is in two parts. The main part of the ship is where the astronauts will live and stay during the trip and called the Revelation. This ship is designed to give enough space for the crew's living compartments and other necessities like a gym and storage for the food and equipment needed for the trip. This will stay in orbit around Mars while they go down to Mars and then take them back home. The other part is a ship that will contain the main equipment with everything needed on Mars including the turbines and cranes. This ship is attached to the other to get to Mars and will then detach and go down to Mars. This will stay on Mars as the equipment will not be needed to be brought back so allowing the crew to get back there will be a small rocket to return to the spaceship.

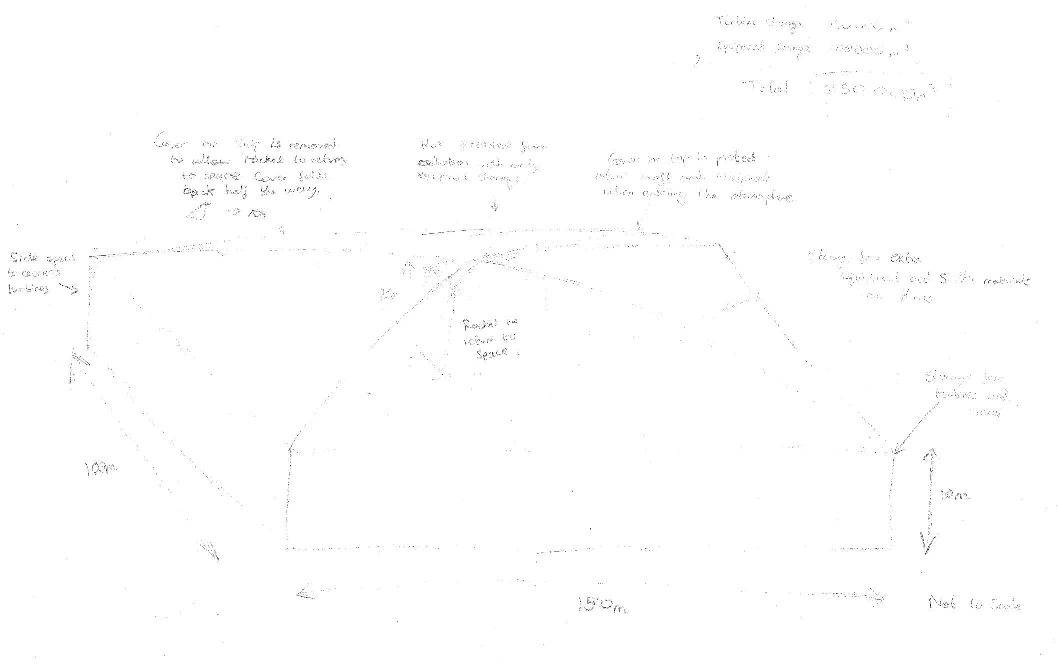
Scale drawing using CAD




The Revelation
Not to Scale
Engine
Torus shape spins to create artificial gravity – centrifugal force acts to pull the inhabitants to the outside
Radius: 50m
Contains storage for food and equipment
Tunnels contain ladders to get to the centre (against centrifugal force)
Compartments for living including sleeping areas, and health suite
Satellite to go in orbit around Mars
Control room
Connection to dock with Space station in Earth's Orbit
Vacuum lock with space suits to get outside the ship if needed
Vacuum lock between 2 sections to allow the ship to detach and land on Mars
Ship to land on Mars containing turbines, equipment and small rocket to return up to the main ship
150m
100m
20m
10m
Total size: 258264 m³



1571m³
10m
20m
Control room
Connection to space ship orbiting Mars
Rocket to return to space from Mars.
Made with same materials as the main ship to be protected from radiation.
Crew stay in this while landing on Mars to be protected from radiation.
Not to Scale



Equipment storage 100000 m³
Total 250000m³
Cover on Ship is removed to allow rocket to return to space. Cover folds back half the way.
Not protected from radiation with only equipment storage.
Cover on top to protect return craft and equipment when entering the atmosphere.
Side opens to access turbines
Storage for extra equipment and shelter materials on Mars
Rocket to return to space
20m
100m
10m
150m
Not to Scale

Rotation:

With the long journey to Mars the astronauts would be in a microgravity environment. This is not beneficial because it makes muscles and bones weaker. Therefore to help prevent this artificial gravity can be created to give a sense of gravity for the astronauts. This is why the design of the spaceship has a torus in the middle. This will spin round and with the centripetal forces acting on the far edge gravity can be created.

This could raise the issue that the junction between the rotating and non-rotating section would need to be properly sealed. By using ferrofluid seals this can be solved and are often used in vacuum areas and can be used for rotating objects. This is possible where rolling bearing with integrated magnetic-fluid seal. The bearings have built in permanent magnets, polarised to hold the ferrofluid in the gaps between the bearing ring and the moving section. [1]

The speed of the torus is also a major effect on the ship as it would change gravitational force. It has been researched to show that the human body typically can cope with a range of angular velocities but the most comfortable velocity for humans is below 2rpm. However it is possible that humans can adapt to more than this therefore the rotating section of the ship will be moving at 2.6rpm (0.272 rad/s) with a radius of 50m.

Where w = rad/s

$a = w^2 R$

$a = 0.272^2 \times 50 = 3.7ms^{-2}$

With this they will experience gravity at $3.7ms^{-2}$ which is the same as on Mars. This may be much less than on Earth but it will prepare the astronauts for when they land on Mars. [2] [3]

Materials:

The main frame of the ship will be made of a titanium-aluminium alloy which is resistant to corrosion and not conductive or magnetic allowing it to be constructed in space easily. The strength is needed to withstand the change in pressure and temperature where there will be Earth like conditions inside and very little pressure and freezing temperatures in space.

There will also need to be protection needed for the radiation in space from the sun and other background radiation. On other shuttles into space they have used material called Multi-Layer Insulation (MLI) made of Mylar and dacron. This could be used as radiation protection but for a mission to Mars the full radiation that the ship will be under would be too much for MLI however it has an important use to keep the ship insulated. The heat of the space ship needs to be contained in it and with the MLI is a good insulator of heat. [4] For radiation the main protection therefore will be a graded-Z style radiation shield. [5] This type of shield uses high atomic number materials in the outer layers to lighter materials towards the inside.

Polyethylene would be used to prevent most of the radiation although it is to light and flammable which is a risk to take with no replacements in space. Therefore instead of placing it directly on the outside of the spaceship a layer of aluminium on either side of it will increase the protection against radiation and protect the polyethylene. A thicker layer of titanium-aluminium alloy placed on the inner side of the ship wall as the main construction material to provide strength and structure on the ship.

The layers would therefore be:

- 0.5 mm tantalum
- 0.5 mm tin
- 0.5 mm copper
- 0.5 mm low-carbon steel
- 22 cm titanium-aluminium alloy
- 1.0 cm aluminium
- 2.0 mm polyethylene
- 1.0 mm MLI
- 2.0 mm aluminium

The outer layers stop protons, alpha and beta particles but produce secondary radiation in the form of gamma rays. The inner layers absorb gamma rays and neutrons causing the overall result to be that each layer helps remove the effects of the layer before it. Therefore the total width of the outer wall of the ship will be 236mm. [6] [7]

Size:

The size of the Revelation will be a total size of around 26000m^3. Where the ship landing on Mars takes up a volume of 250000m^3 and the ship in orbit is 8000m^3. Although with the outer wall of the ship at 236mm, the internal volume is a total of about 246000m^3. This gives enough room for all the equipment needed and living space for the crew.

Cost:

The cost for each material ranged from around £1000 per m^2 to £10 per m^2. Due to this the cost will be around £64,700,000 for the materials needed and to build it.

Conclusion:

The Revelation main features involve the rotating torus to experience gravity during the trip where the crew will mainly live and spend the majority of their time. It allows the crew to arrive on Mars better prepared than in microgravity. Plus with the graded-Z style radiation shielding it will fulfill its purpose to get to Mars and back while allowing the crew to fulfil their mission.

Space, Sizes and Living

The minimum space one person requires is 11 cubic meters (including 3 metres of height per person, according to Britain's health and safety chief. In the temporary conditions of the spaceship, we believe that we could minimise this to two metres of height if necessary. According to this, if we took up 6 people we would need a minimum of 66 cubic meters of internal space for the astronaut's living space.

There are permanently 3 people in the ISS but this figure is be usually higher and it can take up to 20 people. It is 109 meters wide and 73 meters tall and has an internal volume of 916 cubic meters. This gives 45.8 cubic meters per person at the point of which there was 20 occupants. According to the guidelines published by the 'Health and Safety Executive' the ISS could hold up to 82 people.

Sleeping in space: There is no 'up' or 'down' in space. Sleeping involves wrapping yourself in a sleeping bag attached to the wall. The astronauts use ear plugs to keep out the noise of the life-support systems that are continuously running, as well as sounds caused by the thermal expansion and contraction of the ISS itself. They try to secure their free-floating arms, which could end up blocking the air tubes that circulate the air in the ISS and cause a dangerous build-up of carbon dioxide in one place.

Conclusion:

The minimum space the astronauts would need is 11 cubic meters each just for their living space. On the journey to Mars, the astronauts' beds will need to be contained for both the safety of themselves and the ship.

Spacecraft Lighting

Lighting can affect a person's mood and when out in space and exposed to artificial light most of the time, the lighting on the ship can be very important. When exposed to dark lights, it can cause a greater chance of depression and vice versa, with bright lights, it can decrease the chance of depression due the levels of the hormone secretion of melatonin done by the light. This can help us, as we could install bright mood lights on the ship to subconsciously lighten people's mood and in turn increase productivity.

Cost:

To light the whole spaceship and pods with our selected mood lights will cost £2,000 as the lights will be relatively cheap but most of the ship will have to be covered as the astronauts use every available space.

Conclusion:

Due to the lack of natural light from the sun when out in space and Mars, mood lighting will be necessary as it will help prevent depression and increase productivity.

Heating solution

The spacecraft that we will use will need a thermal control system. Having this will sustain the crew with a suitable working/living environment. The TCS would allow the reduction or increase of absorbed environmental fluxes or can allow the reduction or increase of heat losses to the environment if needed. The generators of the equipment and machinery would produce a large amount of heat and in some case be too much so the TCS would be able to reduce the heat in order to maintain a suitable temperature for the crew.

In space there will be different levels of heat such as when the craft starts in Earth's orbit, the Earth would produce low levels of heat but as the craft travels further out into space there will be no atmosphere or heat so the TCS would be needed most to control the heat levels. Once the spacecraft enters Mars' orbit it would be produce a vast amount of heat combined with the generators so this would be an example of when the TCS would be to maintain the heat and help cool the engines.

A thermal control system would be needed when the crew has moved down to Mars' surface as there would not be many of the generators or engines to produce the heat needed as the average Mars temperature is around minus sixty degrees Celsius. This is why the TCS would be needed as this could raise the temperature in the pods to suitable living conditions.

Cost:

The thermal control system totals £10,000. We accept this price because we would want the best quality machines and we will need at least three systems to ensure that core body temperature is maintained. However, costs are lower due to the fact that the ship's machinery transfers a significant amount of heat when it is in operation.

Conclusion:

The Thermal control system will keep the temperatures stable in the spaceship and when the astronauts are down on Mars. This will be to keep the astronauts alive. The TCS will also be able to cool down the engines if they are going to overheat.

Food

Introduction:

Currently, we pre-process all food required in space in a mixture of tubes and full dehydrated meals; however, on a two-year mission, there is a clear requirement to grow some food on board when we consider that it costs £10000 to get an extra 1kg of food up into space.

Science:

Food will mainly be grown on board using aeroponics$_4$ techniques. Not only has this been proven to work in zero gravity (since 1960 on the Sputnik crafts, aeroponics has been part of missions to space) it also protects against disease. There are certain foods which grow more than others in zero gravity; based on this, we have devised the base diet of six staples to be grown in bulk. These are:

- Spirulina
- Soybeans
- Beets (beet greens and beets)
- Khorasan grain
- Potatoes
- Lettuce

These choices combine the whole range of vitamins and minerals with the specific balance of macro-nutrients required to sustain a unique lifestyle in space, when consumed in conjunction with vitamin supplements of calcium, manganese, iron, zinc and magnesium. These vitamins do not synthesise normally when grown in zero gravity. Carbohydrates are not required to feature prominently because energy is not used excessively- protein is instead required to sustain muscles. It is important to note that there will be no livestock on board; using vegetables removes a trophic level and makes energy transfer far more efficient.

The reference intakes from the NHS[1] give a basic guideline for the amounts of different macro nutrients the average person needs:

- Energy: 8,400 kJ/2,000kcal
- Total fat: 70g
- Saturates: 20g
- Carbohydrate: 260g
- Total sugars: 90g
- Protein: 50g
- Salt: 6g

RDAs[2]

Vitamins and Minerals	**Amount**
Vitamin A	800μg
Vitamin B1 (Thiamin)	1.1mg
Vitamin B2 (Riboflavin)	1.4mg
Vitamin B3 (Niacin)	16mg
Vitamin B5 (Pantothenic Acid)	6mg
Vitamin B6 (Pyridoxal Phosphate)	1.4mg
Vitamin B7 (Biotin)	50μg
Vitamin B9 (Folic Acid)	200μg
Vitamin B12 (Cobalamin)	2.5μg
Vitamin C	80mg
Vitamin D	5μg
Vitamin E	12mg
Vitamin K	75μg

NASA conducted further research on nutritional requirements in space and came up with these tentative guidelines (based on a panel discussion based on individual scientists' previous research[3])

Foodstuff	Amount
Fluid	1ml per kcal of energy consumed
Calories	3000kcal per day based on exercising to reduce muscle atrophy
Protein	50g (not more because it increases calcium loss and not less because it aids muscle growth)
Fat	80g (based on the fact that fat is dense in calories and does not increase calcium loss)
Complex carbohydrates	360g
Simple carbohydrates	40g
Calcium	1000mg per day to prevent bone density decreasing
Vitamin D	UV radiation exposure required
Fluoride	In water
Iron	Maximum 10mg because of increased serum ferritin levels in space

Aeroponics:

Aeroponics is the most sustainable and highest-yielding method of growing food in zero-gravity. The following conditions are necessary for aeroponics on board our ship[5]:

- A relatively small volume of water- which can be recycled from waste water- as aeroponics uses 60% less water than conventional growing methods
- Nutrient solution (can be recycled- see below)
- An inflatable aeroponics 'room' as created by Stoner et al which allows control of conditions to promote quicker growth and more crop cycles per year
- A hydro-atomiser to allow efficient nutrient and water transmission to the plant roots- it should be capable of producing droplets 5-50 micrometres in diameter
- Ion-exchange resins to maintain nutrient levels
- A clean air supply (using CO_2 from astronauts' breathing)
- UV light bulbs

Yields using aeroponics in microgravity can be up to seven crop cycles per year for fast-growing plants (like tomatoes as quoted in NASA's article); all of our chosen plants are considered to be relatively fast-growing. Spirulina especially would be grown constantly in its own aeroponics inflatable because of its unparalleled ability to convert carbon dioxide into oxygen.[6] The Russian BIOS-1 experiment on their space station demonstrated that only 0.02m^3 of spirulina was required to produce the oxygen needed for one person using hydroponics; the increased efficiency of aeroponics means that a complete oxygen supply for a crew of four would only require 0.04m^3 of spirulina growing at any one time. More growing would account for vital vitamins to eat, of course.

Cost:

- Specialised aeroponics environment= approximately £3 million (to include research and development to improve the current systems developed by NASA
- Nutrient solutions=£1000

- Methods to recycle nutrients and water= £6 million (as technology already exists)
- Seeds= £1000
- Emergency rations= £500000

Conclusion:

Aeroponics techniques are a steadily growing technology- currently, they are not reliable enough to risk starvation on the small chance every crop fails. Firstly, we will dedicate several rooms to aeroponics to further resist spread of disease, control conditions for the different crops and to use slightly different technologies. By the time the mission would theoretically take place, aeroponics would be reliable enough to use in the mission. However, we will also bring enough food to last each astronaut six months, to allow time for four crop cycles to fail and the astronauts still to survive.

Workout schedule

To keep fit in space the astronauts need a steady schedule to make sure that they do not let bone or muscle tissue from wasting away from disuse. The minimum time required to exercise is two and a half hours each day. There are three types of exercise they perform: the first is the Cycle Ergometer, this acts as a bicycle as it is easy to measure fitness in space. The second exercise machine is the treadmill which can help simulate walking as this keeps bones and muscles healthy. The last machine is the Resistance Exercise Device. This is very useful as it can give a full body workout allowing the astronaut to perform many different exercises such as squats, bending exercise for the legs, arm exercise and heel raises.

Once the astronauts are on mars there will be low level gravity which would allow the astronauts to perform basic exercise such as walking and give them some support for their weight from the gravity. However, the astronauts will still need to perform their two and a half hours exercise each day as the gravity is 62% less than Earth.

Cost:

Each exercise equipment will come to £2,000 as multiple pieces will be bought and each piece will be highly advanced.

Conclusion:

The gravity in space and Mars is much less than that of Earth and therefore the astronauts will need to perform daily exercises to keep fit, prevent muscle decay and keep bone density.

Living on Mars:

This section provides additional information to the 'Living on Board' section where we need to adapt our conditions to suit Martian life.

Martian Environment

Mars' atmosphere is very thin making it vulnerable to harmful radiation from the sun and other sources of radiation from outer space. Since Mars is smaller in diameter it has a lower force of gravity resulting in 1/3 of the gravity found on earth, reading at about $3.7m/s^2$.

The length of the Martian day (24 hours and 37 minutes) and the tilt of its axis (25 degrees) are similar to those on Earth (24 hours and 23.5 degrees, respectively). The orbit of Mars around the Sun takes almost twice as long as Earth. As a result, a Martian year is about twice as long as an Earth year and the seasons are each twice as long as those on Earth. The atmosphere is composed mainly of carbon dioxide (95.3%), nitrogen (2.7%), and argon (1.6%), with small amounts of other gases. Oxygen, which is so important to us on earth, makes up only 0.13% of the atmosphere at Mars and there is only one-fourth as much water vapour in the atmosphere.

Habitat:

1) First classification on habitat involves earth dependent techniques; such as modules, and structures.
2) The second is surface conditions such includes natural and man-made conditions. E.g. craters.
3) Finally we must look at how to utilize natural resources from the environment on mars.

1) The modules must consist of self-contained pressurized vessels. The material that the inflatable space structures are made from should consist of Kevlar 29, nicalon or Nextel.
2) Craters are usually considered as natural features but can be man-made from things like mining. If the diameter ratio is of a depth of 1:6 it should be suitable for surface habitation.
   Lave tubes are formed by lava flowing during the volcanic activity. These tubes carry the lava from the vent to the flows leading edge. The flow terminates and clearing of the lava occurs causing them to naturally produce underground caverns. The theory behind this proves that the inside these are 300ft in length and 30ft thick. They provide sheltered areas when pressurized habitats are placed

inside them and they can be pressurized chambers themselves with the use of airlock and seals.

3) A hybrid planetary habitats emerge when two or more construction methods are integrated. This includes an inflatable space structure used in combination with either a prefabricated space structure or lava tube or crater to produce a multi-use space structure could be used to produce airlock.

Advantage of using space structure	**Disadvantage of prefabricated modules**
- The ability to transport large habitats and other structures for use on the mars surface in a compact form. - It is launch-efficient and easy to deploy. - It is spacious. It can create habitable volume which exceed size constraints imposed by launch system. - The configuration and construction possibilities offer a high level of adaptability.	- Their mass and volume increase and thus more cargo space is required.
Advantage of lava tubes	**Disadvantage of lava tubes**
- Low costing in energy and manpower. - Provide radiation shielding.	- To find lava tubes extensive time is required.

Building pods on Mars

When the astronauts arrive on Mars they will need a place to live and a base to do research. The buildings can be done in the form of a pods in which can be flat packed to save space on the storage and can be inflated once on Mars. These pods will be made with a Strong flexible plastic such as nylon which would be 3D printed to make the required shape.

Once inflated we will use UV curing. Apply a coat to the outside of the pods and once it is introduced to electric powered UV lamps the glue/paint will harden to make the pods habitable. The formula can use different resins to provide very specific coating properties, such as abrasion resistance, hardness, chemical resistance, and flexibility (if required to resist Martian storms).

Cost:

The UV curing will be relatively cheap as only a few gallons of the adhesive glue will be needed and the lamps the dry it. The price of the materials and making the pods would be quite cheap as well as the total price of everything will come to £2,000.

Conclusion:

When the astronauts get to Mars they will live in inflatable pods which will be hardened by UV curing which can increase all resistances to environmental factors.

Radiation

How to protect from radiation:
There are two types of radiation on Mars. One type is from the solar winds. These mostly contain protons, with a few electrons and heavier elements mixed in.[1]
The second source of energetic particles is harder to shield. These particles come from galactic cosmic rays, often known as GCRs. They're particles accelerated to near the speed of light and are of the same atomic make-up as the first type of radiation stated above. These more energetic particles can knock apart atoms in the material they strike, such as in the astronaut, habitat, or vehicle, causing sub-atomic particles to shower into the structure. This secondary radiation, as it is known, can reach a dangerous level.[2]

We could, however, use a more efficient shielding material.

One technology that NASA has been investigating is hydrogenated boron nitride nanotubes—known as hydrogenated BNNTs—which are tiny nanotubes made of carbon, boron, and nitrogen, with hydrogen interspersed throughout the empty spaces left in between the tubes. Boron is also an excellent absorber of secondary neutrons, making hydrogenated BNNTs an ideal shielding material.[3] We will also use this to line the wash rooms where the astronauts will not be wearing their radiation suits. Medication and pills will also be taken to reinforce radiation protection.

It's flexible enough to be woven into the fabric of space suits, providing astronauts with significant radiation protection even while they're performing spacewalks in transit or out on the harsh Martian surface.

Conclusion:

Our strategy for managing radiation contains several layers of protection. Our spaceship contains yet more optimisation (using specialist materials) to ensure safety and we believe the combination we have developed will prevent long-term health issues.

Communication

Introduction:

This short section considers how our mission would approach the unique challenge of contacting Earth from the base on Mars and from the orbiting vessel. It also addresses the problem of astronaut-to-astronaut contact on walks outside of the ship or pods.

The Ideas:

To communicate between the Earth and Mars we can integrate the idea of an orbiting vessel that orbits Mars to relay communications between the station on the surface and Earth. We can do this by placing receivers on the mothership and the station on the surface and transmitters of course. There will of course be a delay between sending and receiving messages because of the rotations needing to line up.

To send the signals from Earth we can use the Deep Space Network (DSN) [1] which is comprised of 3 large dish antennas located in California's Mojave Desert; near Madrid, Spain; and near Canberra, Australia. This strategic placement permits constant observation of spacecraft as the Earth rotates on its own axis to have round the clock coverage. The DSN antennas are huge: 70 and 38 metres .The DSN antennas are equaly large: 34 meters and 70 meters. These enormous antennas enable humans to reach out to spacecraft millions of miles away. The larger the antenna, the stronger the signal and greater the amount of information the antenna can send and receive. We will use high frequency X-band waves to communicate.

When the astronauts want to communicate with each other they have a communications device set up in their helmets that is much more effective than the balaclava-esque design used previously (which could get dislodged and cause sweating within the helmet). In addition, the built-in microphone accounts for the shaking of the helmet and the equipment within it and cancels out the noise to provide clear communication.

Costs:

The Deep Space Network is already established, meaning that we will be able to use their facilities with little more than international cooperation and political maneuvering. The costs for our part of the system is integrated into our spaceship costs above.

Conclusion:

Our proposal for Mars-Earth communication presents an exciting new use for the Deep Space Network and we are confident that this technology will provide the level of accuracy we require to send information back to our Earth base.

Total Cost:

The complete mission will come to a cost of £843.6 million. However, including contingency cost as a safety net to cover any misconceptions and miscalculations, we estimate that it should cost roughly £1 billion. However, our project isn't simply 'spending money in the name of science,' and is instead an investment. As explained in the document, we are expecting £9 billion worth of electricity back from the project over 20 years, which more than justifies our mission. (Conversion rate used for $ to £ in the cost calculations is assuming conversion rate is 1$ = 0.66£ as on 21/11/15.)

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