<u>New Zealand’s Next Top Engineering Scientist</u>

<u>How much fuel is required for a manned mission to Mars</u>

<u>Group ID: 1084</u>

Summary

Our approach to the question detailed that we will take the International Space Station (ISS) and attach sufficiently fuelled rocket boosters to transport the ISS to Mars' orbit and back.

Introduction

This report will investigate the quantity of fuel required for a proposed manned mission to Mars. We will look into the effects of gravitational attraction of planets, mainly focusing on the most economical way to get to Mars. We will also examine possible fuel sources and the efficiency of these. We have taken into consideration the fact that this is a manned mission to Mars requiring a minimum of three persons and we intend our men to survive the return journey.

Mission Overview

The fact that this is a manned mission gives us many challenges. We must consider how it is that we will be able to keep people alive for a prolonged period of time in space, as the round trip between Earth and Mars, with current rocket technology, is likely to take years. Fortunately, we already have a spacecraft capable of supporting people in space for prolonged lengths, the International Space Station (ISS). It is already in orbit, so additional fuel won't have to be used to get our main payload into orbit, making it an ideal fuel saving. The astronauts we are sending to Mars will be able to survive easily for however long it takes for the spacecraft to reach the destination, therefore not too many extra provisions will need to be ferried onto the ISS, so there will not be a significant gain in weight of the station. If, in spite of the high efficiency of recycling on the station, a sufficiently large payload of extra provisions does need to be taken to the ISS, there is equipment on board for non-vital experiments that could be jettisoned if need be to counter this weight gain. We will also send only a 3 man team, as opposed to the usual team of 6 on the ISS, because the additional crew members will be unnecessary, considering that their task would normally be to carry out experiments that will not be required for this mission. This has also been done to save provisions.

The ISS will be propelled to Mars by the addition of boosters which will be transported to the space station from Earth.

The ISS will not land on Mars, but will rather go into a low orbit, similar to that which it occupies on earth, but adjusted to a lower radius to account for the lesser gravity of mars (Mars has about 38% of Earths gravity[1] so the ISS will occupy an orbit of around 150 km above mars, as opposed to around 350km above earth[2]) From this orbit, the ISS will deploy a Mars Lander module, comparable to the Lunar Lander used in the Apollo 11 landing on the moon. This Lander will carry two members of the three group team. These are the astronauts who will land on Mars. They will spend a relatively short amount of time on the surface (probably only a few hours) before getting back into the Lander and re-launching to dock with the ISS.

The Lander module will be primarily based on the Lunar Lander, but will be different in a few key aspects. It will have a heavier build than the Lunar Lander, as it needs to endure a greater weight force than on the moon, and it will have a more powerful rocket booster to escape the Martian gravity on its' return to the ISS. It will also need heat shielding, which the original Lunar Lander did not have as there is no atmosphere on the moon. The Martian atmosphere can also be a small advantage, in that it means a parachute can be deployed by the Lander to slow its descent to the surface.

Once the Crew has returned to the ISS, it will then use the recently attached boosters to return to its' former earth orbit. The astronauts can then return to Earth in the ordinary fashion of the ISS, and the ISS could even resume its' original role, assuming the rigors of interplanetary travel left it safe to operate.

Because we know the mass of the ISS, and we can make an assumption that the Mars Lander will have a mass somewhere between that of the Lunar Lander[3] and the Apollo 11 CSM[4], after adjusting slightly for additional mass that may be required for the repurposing of the ISS, we can make a guess that the total weight of our payload will be something like 450,000 kg.

We decided that our flight path for the mission will be via a Hohmann orbit.[5] This is where, through the input of a relatively small amount of energy, we can move one

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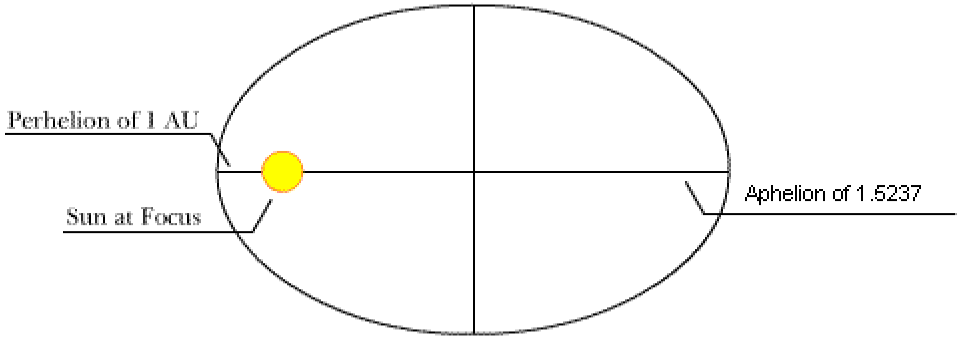
[1] http://www.space.com/scienceastronomy/mars_tape_030819.html
[2] http://en.wikipedia.org/wiki/International_Space_Station
[3] http://en.wikipedia.org/wiki/Lunar_Module
[4] http://en.wikipedia.org/wiki/Apollo_Command/Service_Module
[5] http://en.wikipedia.org/wiki/Hohmann_transfer_orbit

object (the ISS) from the orbit of another object (the Earth); into a new orbit about a central object (the Sun). This new orbit of the object, depending on how much energy you put in, can be set to coincide with the orbit of another object (Mars) about the central object. The advantage of this orbit is that, after the initial kick to clear the first object, no extra input of energy is required until it needs to break out of that orbit and occupy the orbit of the secondary object: For the bulk of the flight its' energy comes from being in orbit about the central object. This causes a significant saving in fuel. However the disadvantage is that it is not necessarily as fast as just using boosters for the entire flight, and it requires a rather long flight path (you must fly past the sun to get to mars, rather straight from earth to mars) However this is not a problem as the flight time can be calculated to be under 1.5 years for a round trip to mars: a perfectly sustainable time for astronauts on the ISS.

The following information has been adapted from the elliptical flight path a spacecraft takes when heading to another planet to fit our team's model of travelling from Earth to Mars.[6]



The period is therefore:

$P^2 = a^3$

$P^2 = (1.26185)^3$

Thus the time taken to complete this orbit is approximately 1.42 years, or about 520 days, which is consistent with the 'Russian Mars' program's predictions on how long the trip will take.[7]

Path to Mars

[6] http://www.polaris.iastate.edu/EveningStar/Unit6/unit6_sub3.htm

[7] http://www.3news.co.nz/Russia-launching-520-day-Mars-mission-simulation/tabid/1160/articleID/159001/Default.aspx

From the multiple sources researched, the most economical way of getting to Mars will be to follow Hohmann's transfer orbit[8], which follows an elliptical path. Most of the energy required will be from getting from 1 (ISS) to the elliptical path (2) due to the Sun's gravitational pull. This will be the most economical way as this will use less fuel and energy due to the fact that we won't be going against the gravitational pull of the Sun as a result of taking a direct path to Mars.

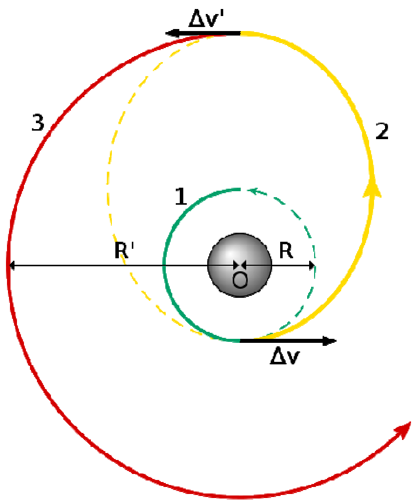


Diagram of Hohmann's Transfer Orbit.

Source: http://en.wikipedia.org/wiki/File:Hohmann_transfer_orbit.svg

From here, we need to calculate delta v for the jump from ISS to the Hohmann orbit, which the elliptical path is taken to get to Mars.

$$\mu = GM \qquad \Delta v = \sqrt{\frac{\mu}{r_1}}\left(\sqrt{\frac{2r_2}{r_1+r_2}} - 1\right)$$

G = 6.67 x 10^-11

M = 1.988 x 10^33

[8] http://en.wikipedia.org/wiki/Hohmann_transfer_orbit

R_1 = 149597870700

R_2 = 227939100000

$$\Delta v = \sqrt{6.67\text{x}10^{\wedge}\text{-}11 \text{ x } 1.988 \text{ x } 10^{\wedge}33 / 149597870700} \left(\sqrt{2\text{x}227939100000/3.778369707 \text{x}10^{\wedge}11} - 1 \right)$$ **= 93080 m/s**

This delta v value shows that there needs to be a 93080 m/s change for the spaceship to get into the Hohmann orbit in order to reach Mars

V (Hohmann) – V (earth)[9] = V (input)

Input velocity is therefore 63.28 Km/s

$$\Delta v' = \sqrt{6.67\text{x}10^{\wedge}\text{-}11 \text{ x } 1.988\text{x}10^{\wedge}37 / 227939100000} \left(1 - \sqrt{2\text{x}149597870700/3.7783697077\text{x}10^{\wedge}11} \right)$$ **= 83729 m/s**

1.25GJ is produced from 1kg of fuel.[11]

Return to earth orbit V

$\Delta v =$

83729-29800

$E_k = \frac{1}{2}mv^2$ = ½ x 450000x53929^2

= 654375.8342 GJ

= 523500.6674 kg

Exit from Mars

[9] http://www.windows2universe.org/kids_space/vel.html

$\Delta v =$

83729-24131

$E_k = \frac{1}{2}mv^2$ = ½ x 973500.6674x59598^2

= 1728899.026 GJ

= 1383119.221kg

m= 450000+523500.6674

Entry to Mars

$\Delta v =$ 93080-24131

$E_k = \frac{1}{2}mv^2$

= ½ x 2356619.888x68949^2

= 5601643763GJ

= 4481315kg

m= 973500.6674+1383119.221

Exit from Earth

$\Delta v =$ 93080-29800

$E_k = \frac{1}{2}mv^2$

$= ½ x6837934.898x63280^2$

= 13690771.02GJ

= 1095261682kg

m= 2356619.888+4481315.10

(10952616.82+6837934.898) – 450000

=17340551.72 kg of fuel

Fuel Choice

There have been multiple variations of rocket engines designed. All of them have their advantages and disadvantages. Many of the designs are still in their theoretical stages and need a lot of improvement before they can be put to practical use. This includes most Nuclear Powered engines (such as the nuclear fission).

To increase efficiency of the fuel, a high density propellant should be used so that smaller, lighter storage tanks can be used to propel the space craft. Storage temperature is also crucial. A propellant with low storage temperature will require insulation and sturdy material to maintain pressure. This can all add unnecessary weight to the space craft, thus requiring more fuel.

The most common type of engine that has been used in the past is a dual liquid bipropellant. This consisted if two separate highly pressurised tanks; one of liquid hydrogen (LH2) and the other with O2 (LOX). During combustion these are directed through series of plumbing systems where they are injected under pressure into the combustion chamber (either shower head, centrifugal, or cross impinging being most common) [10]. They are then ignited to produce a large amount of energy and therefore thrust. This process is reasonably efficient and relatively cheap. The thrust

[10] http://en.wikipedia.org/wiki/bipropellant_rocket

process is also easily controlled due to the fuel being a liquid and not a solid. This process, however, has many disadvantages. The fuel can 'slosh' as it is used up, resulting in decreased control over the space-craft. This process can also result in 'chugging'[10]- space craft oscillations which can resonate to dangerous amplitudes. Leaking and crystallization are also problems that are usually hard to detect.

The LH2/ LOX thrust engine is the most efficient known chemical rocket engine that has been used so far. It produces approximately 12.6MJ[11] of energy per kg combusted. This fuel is very light for the energy that it produces.

Despite all this, we settled upon using pulsed plasma thrusters (or a 'ion thrusters'). This engine, although producing less thrust per kg, it produces significantly more specific impulse (I_{sp}). We need the value of I_{sp} to be large because it is the change in impulse that will allow the ISS to be launched into Hohmann's Orbit. The plasma thrusters have and I_{sp} value of 5,000s[12] compared to a chemical engine's 500s. It is also about 15 times less dense than bipropellant thrusters. This deficit in mass for a bigger Isp will significantly increase efficiency such that much less fuel is needed. Modern ion thrusters can propel a spacecraft up to 90,000[13] meters per second. This is a lot faster than the chemical propellants that have been used. However, the sacrifice for this top speed is low thrust. These thrusters also produce much more energy per kg – approximately 1250MJ – ten times more than the liquid propellant.

The ion thrusters generally ionise gas Xenon[12] as the main propellant because of its high atomic number, low ionisation energy and because it has been successfully practically used in the past. Hydrogen propellant can also be used in the near future as it produces almost 20 times more thrust. Particularly we chose to use the electrostatic ion thrusters as it is more efficient and practical than the electromagnetic.

[11] http://en.wikipedia.org/wiki/Rocket_engine
[12] http://en.wikipedia.org/wiki/Ion_thruster
[13] http://www.nasa.gov/centers/glenn/about/fs21grc.html

Assumptions:

The Hohmann orbit would not be affected by the masses of our spacecraft or the gravity of Earth and Mars because our Hohmann equation that we have does not sufficiently compensate for these variables however we feel that compared to the gravitational pull of the sun, these effects would be fairly negligible considering how vague an approximation this is.

The mass of our propellant would eject itself while it is being used without leaving any trace products attached to the spacecraft.

We assumed that the weight of our modified ISS with it's Lander capsule would weigh 450,000kg.

We assumed that at our flight window (time we would leave), the distance between Earth and Mars at the end points of the flight would be their mean distance from the sun. This is possible but unlikely to happen due to their elliptical orbits.

Our equation assumes that the time taken to accelerate our rocket is very small which is a necessary assumption for our Hohmann equations.

Either way, even if the time taken for our rocket to accelerate was large, we could still manoeuvre the rocket into the Hohmann orbit and thus our equations should remain fairly accurate.

We have assumed that the weight of our boosters once they have released all of their energy, have a negligible mass.

Conclusion

In conclusion, given that our assumptions above hold true, the amount of fuel required for this manned mission to Mars would be approximately 17300000kg in our pulse plasma thrusters.

This return mission will take approximately 520 days.

We do not have a large amount of complete information/data and therefore we cannot be entirely sure that our mathematical models are accurate. We do feel however, that our estimate could provide a reasonable degree of accuracy when trying to assess how much fuel is required for a manned mission to Mars.

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