Part Two

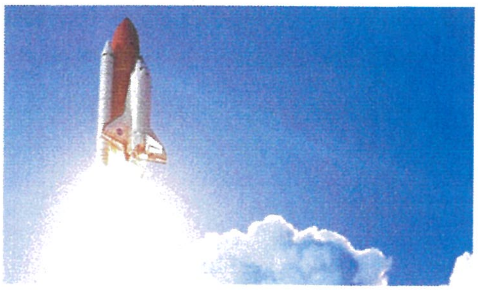
How Might We Get to Another Planet?

Traditional Rocket Propulsion and Space Travel

When colonising another planet the first issue you will encounter is how to actually get there. Although technology continues to advance, the basic systems of space travel have undergone little change since 1957 when the Sputnik satellite became the first object we sent through space. Over time, rockets have become more reliable, powerful, and precise but still follow the same fundamentals used 61 years ago. A chemical rocket is used to launch an object, perhaps a communications satellite, past the Earth's atmosphere where it will then deposit it into its final trajectory. Given this is the method of space travel that is used now and probably for many years to come it is worth taking an extensive look at exactly how it works.

Types of Rockets

So what is a chemical rocket? A chemical rocket is a rocket that uses the chemical energy of its fuel to produce thrust. This energy is usually produced via the burning of the fuel: the matter that remains takes this energy and is expelled from the rocket causing it to accelerate in the opposite direction. There are some thrusters that don't use combustion for propulsion: these are called cold gas thrusters. These are pretty much just pressurised gas which is released to produce thrust. Cold gas thrusters are only ever used outside of the atmosphere and are maneuvering thrusters used to point rockets in the right direction. This is because they have a very low specific impulse.



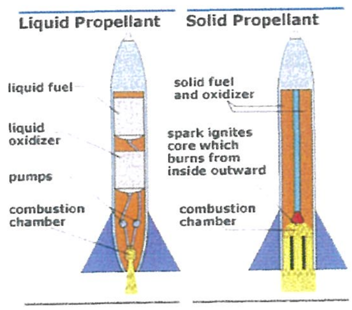
The space shuttle's rockets firing.

Specific impulse is a measure of how efficient a rocket engine is. A rocket's specific impulse is the change in momentum per unit of fuel consumed. An object's momentum is equal to its mass multiplied by its velocity. This is often presented in the equation $p=mv$ where p is an object's momentum, m is mass, and v is velocity. So if an engine uses 1 kg of fuel to increase the velocity of an object with a mass of three kilograms by three metres per second, it would have a higher specific impulse than an engine which increases the velocity of an object with a mass of 1 kg by six metres per second. (In this example, the mass for each object is its mass after its 1kg of fuel has been used.)

There are two main types of chemical combustion rockets: solid rocket boosters or SRBs, and liquid propellent rockets. Solid rocket boosters are not used very often nowadays and for good reason. Solid rocket boosters have one main advantage: they provide a lot of thrust and follow a simple design. They do, however, have some pretty major disadvantages. First of all, once activated they will continue to burn through their fuel until exhaustion, giving you very little control over what happens after they are activated. They are also susceptible to catastrophic failure because the slightest flaw in the exhaust nozzle or fuel mix could lead to a buildup of pressure and an explosion. Solid rocket boosters have only ever been used as a first stage booster, most notably on the NASA space shuttle missions.

Unlike SRBs, liquid fuel rockets use, well, liquid fuel. There are many types of liquid fuel rockets. The most common form of liquid rockets are bipropellant rockets which use two fuels. These two fuels are kept in separate tanks and pumped into a combustion chamber where the fuel is burned. This design allows the pilot to control the thrust the engine produces by burning propellant faster or slower. Also, unlike solid rocket boosters, they can be test fired prior to launch, making it easier to identify potential problems which could endanger the launch. Because of this, liquid rockets are replacing solid rocket boosters and I believe solid rocket boosters will be completely out of service in a couple of decades.

Rocket Fuels



So what fuels are used on rockets? On top of a flammable element to produce the energy, rockets also require an oxidiser. The oxidiser is simply there to make sure that the flammable element burns. Everything requires oxygen to burn so spacecraft have to take it with them since there is none in space, and due to the way rockets travel they are unable to take from the atmosphere during ascent.

An example of the way fuel is burnt in both a liquid rocket and SRB.

Most SRBs use a mixture of aluminium powder which is the fuel and ammonium perchlorate as the oxidiser. Because it is used in so many things integral to our everyday lives it may surprise you to hear that aluminium is one of the most reactive elements there is. Because of this it is often used in alloys and when it isn't it is covered in a thin layer of oxide which stops it from reacting with everything around it. Aluminium is so reactive that if pure aluminium is exposed to air it will begin to burn with a bright white flame. Ammonium perchlorate is the product of a reaction between ammonia and perchloric acid. Ammonium perchlorate is highly unstable and has been responsible for many disasters including an explosion at a chemical plant in 1988. Looking past its dangers it is one of, if not the most, effective oxidisers for SRBs.

Liquid rockets use a few different types of fuel. One of these types of rockets are monopropellant rockets. Monopropellant rockets use just one substance as fuel and are a rare exception to the 'everything needs an oxidiser' rule. Instead the energy is stored in the chemical bonds of the compound. Hydrazine is often used in monopropellant thrusters. The hydrazine is run over a catalyst which is a special compound which splits the atomic bond in the hydrazine. The gases produced in this process are heated to over 1000 degrees Celsius and are then shot out through an exhaust nozzle.

Another common monopropellant fuel is hydrogen peroxide. Monopropellant engines have low specific impulse and are used in much the same way as cold gas thrusters.

Bipropellant rocket engines use a variety of fuels along with liquid oxygen as an oxidiser. Bipropellant rockets often use liquid hydrogen or nitrogen tetroxide as their main fuel. Currently SpaceX use the Merlin engine on all of their spacecraft and it uses kerosene as its fuel. The upcoming BFR will use liquid methane as its fuel and if everything goes to plan it will be the most efficient rocket engine ever made. Because rocket fuel is unstable and sometimes corrosive it is only ever loaded onto the rocket just before launch.

Although rocket engines produce a large amount of thrust they are very fuel-inefficient compared to other forms of engines and a rocket must carry everything used for its propulsion. Because of this, the rocket's payload is often much lighter than the fuel needed to lift it. The amount of space needed to store that much rocket fuel also leads to a conundrum. As a rocket burns its fuel it becomes lighter and accelerates faster; however, as this fuel is burned the space used to store it becomes deadweight. As a solution to this rockets have multiple stages. Each stage will have its own set of engines and fuel tanks, and when it expends all of its fuel it detaches from the rest of the spacecraft and is usually left to follow its own trajectory. Most rockets used for sending objects into orbit have two stages. SpaceX are now landing and reusing their first stage boosters, as I cover later in Part Two.

Flight Through Space

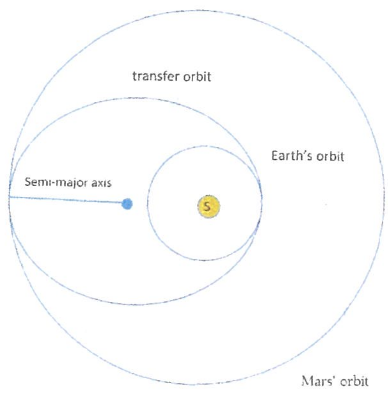
Now it is time to talk about the actual flight through space. When it comes to space travel, as long as time is not part of the equation distance is almost immaterial. You see when travelling through space all that matters is velocity. We're getting ahead of ourselves here. First it is important that I talk about the way objects travel through space. If you put one object in a completely empty version of space, and gave that object some velocity, it would continue to move forever unless it threw off some of its own mass (like the way a rocket engine shoots out its propellent). Since there is nothing for the object to collide with it will continue to move at the same rate under Isaac Newton's *First Law of Motion*. Newton's first law of motion, sometimes referred to as the law of inertia, states that objects will 'keep on doing what they are doing' if all forces are balanced (in this case the object is moving forward with nothing else present to provide another force).

It is now time to introduce you to another of Newton's laws, the law of gravity. Everyone knows about gravity: some in the flat Earth society may deny it, but it is known to be a fact and is generally accepted as such. Newton's law states that every particle in the universe attracts every other particle with a force proportional to its mass and which gets weaker the further you are from its centre. The gravitational force of an object decreases significantly as you move away from its centre. To find the decrease in force from the centre of an object you divide the gravitational force of an object by the distance from its centre squared (the distance from the center is squared, not the result of the previous mathematical operations).

Gravitational force is usually measured in gravitational acceleration. For example at Earth's surface the gravitational acceleration is 9.8 metres a second, meaning if there was no air resistance and you weren't touching the ground you would accelerate towards the centre of the Earth at a rate of 9.8 metres per second. When an object orbits the Earth, both the law of gravity and inertia come into play. For a stable orbit to be established the object in question needs a velocity away from the Earth strong enough for inertia to keep it from falling to Earth but not too strong or it will break free of Earth's gravitational forces. The result of this balancing act of forces is a curve in the object's trajectory which will form the continuous orbit. The altitude of the craft will influence the required velocity because of the weakening of Earth's gravitational force over the longer distance. One aspect of gravity is that it never entirely finishes, the force just becomes completely unnoticeable at a certain point.

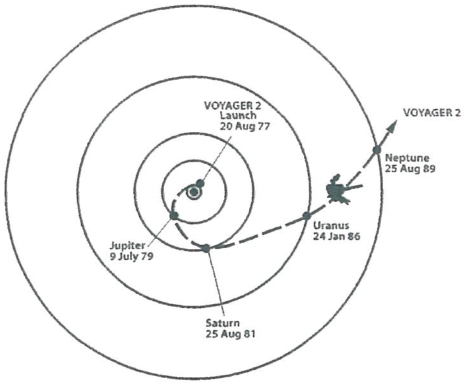
So why doesn't distance matter? Well when it comes to travelling between planets all that is required is for the spacecraft to break orbit of whichever planet it's currently orbiting, or to extend its orbit to intercept another planet. Without anything to stop it, it will continue traveling. If it does this at the right time its trajectory will intercept its target where it can then decelerate to fall into orbit or land on the surface.

It is finally time to introduce delta-v. Delta-v literally means change in velocity. So delta-v is the total required change in a spacecraft's velocity to reach its destination. With all factors considered, a delta-v of about 9.4 km per second is required to reach low Earth orbit with a final velocity of 7.8 km per second. From this point you are already over halfway there as it takes just another 4.3 km per second of delta-v to reach a Mars transfer orbit and a further 0.9 km per second of delta-v to transfer from that into Mars capture orbit where you are captured in Mars's gravity. A quick reminder: delta-v is the total change in velocity required for a maneuver, all acceleration and deceleration for the entire thing. A transfer orbit is an orbit which can transfer a spacecraft into another planet's orbit, and a capture orbit is a trajectory which causes a spacecraft to be snagged into orbit of a planet by the planet's gravity. From the launch pad a spacecraft wanting to complete this maneuver would need to be capable of producing 14.6 km per second of delta-v. Despite the massive distance between Earth and Mars it takes just over half the delta-v required to reach Earth's orbit to go from that Earth orbit to an orbit of Mars.



An Earth-Mars transfer orbit.

While usually a spacecraft has to rely on its own propulsion to travel, as is the case when travelling to Mars, depending on the positioning of other planets in relation to the target location a spacecraft can use a 'gravity assist' to gain some free velocity. If the spacecraft intercepts the planet's gravitational field at the right time and travelling in the right direction it could experience an increase in momentum; however, the energy required to accelerate the spacecraft will be equal to that lost by the planet during this maneuver. While the planet will experience a decrease in orbital speed, due to its enormous mass compared to the spacecraft the loss of speed is so small we can ignore it entirely. Both of the Voyager probes used gravity assists in achieving the velocity necessary to escape our solar system. Trips through space can take months or even years depending on the destination but in the end the main thing that matters is being able to achieve the necessary delta-v to reach a location.



The gravity assists used by the Voyager 2 probe.

I would quickly like to mention the number of extra variables and other forces that could influence a rocket's trajectory, all of which must be taken into account when calculating it. One of the greatest challenges comes from the basic operation of a rocket engine. Since the rocket shoots out mass to propel itself forward, the mass of the rocket is constantly changing. This means that when calculating a rocket's acceleration you have to take into account its constantly changing mass and perform a series of calculations instead of just one. Another of these variables is the distance of planets from a rocket's flight path and the effect that their gravity may have.

The Human Aspect

Of course when transporting humans time becomes part of the equation because the longer you spend in space the more food and water is needed to be carried on board to sustain those humans. This can become a very significant factor if they spend a long time in transit. It also means more time in zero gravity which, if it goes on too long, could cause problems, namely people's bone and muscle density decreases in zero gravity leaving them physically weak until their bodies readjust.[2] A trip to Mars lasts about 6-9 months which should be manageable in terms of food and water requirements and shouldn't be long enough for too many adverse health effects to manifest. On longer trips to the further reaches of the solar system spacecraft may require a place to restock supplies and a way to minimise the effects of a long time spent in low gravity. Or we could just aim to travel faster than we currently do, that would work too.

Hopefully you now have an understanding of the technical side of rocket propulsion and spaceflight. I also hope you now have a greater understanding of why the technical side of travelling to another planet is much easier than it may initially seem.

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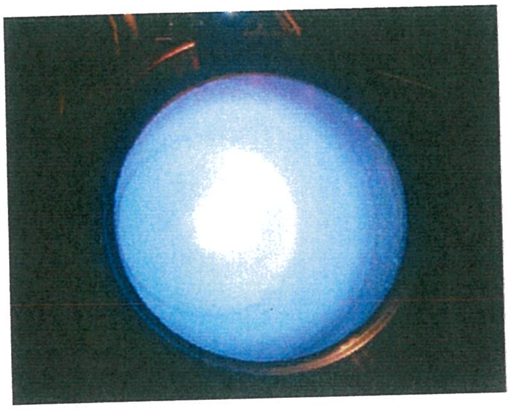
[2] I will cover the health effects of zero and low gravity in more detail in Part Three.

Future Forms of Propulsion

After covering current rocket propulsion and the fundamentals of space travel it is time to look into the future and take a look at what spacecraft might use to reach their destination.

Ion Engines

Ion engines aren't actually a future form of propulsion. They do exist today and they have great potential, but so far they have mainly been used as an experiment and have seen very little practical application. So how do they work? Inside an ion engine, atoms from a propellent gas are stripped an of electron making them a positive ion. Ions are reactive to magnetic fields. These negative ions are accelerated through the engine using magnetic fields. Using this method the atoms can be accelerated to incredibly high speed giving ion engines a higher specific impulse than any chemical rocket. On average ion engines are nearly three times as efficient as chemical rockets.



Ion thruster built by NASA.

While that sounds like it would make them the greatest engine ever, they have a few downsides. Because of the processes used inside an ion engine only a small amount of propellent is able to be used at any one time. This gives ion engines very low acceleration which completely rules them out when it comes to reaching orbit. Even so ion engines can achieve a lot of delta-v once in a stable orbit using just a small amount of gas propellent and some electricity. Current designs for ion engines use between one and seven kilowatts during operation. This is a lot of power but it can be managed by solar panels or RTGs (RTGs, or Radioactive Thermal Generators, use the heat released by the natural degradation of radioactive material to produce electricity[3]). Ion engines have massive potential for space travel and could be a great way to lower the cost of travel between planets. Eventually they may be the go-to method for all travel between planets.

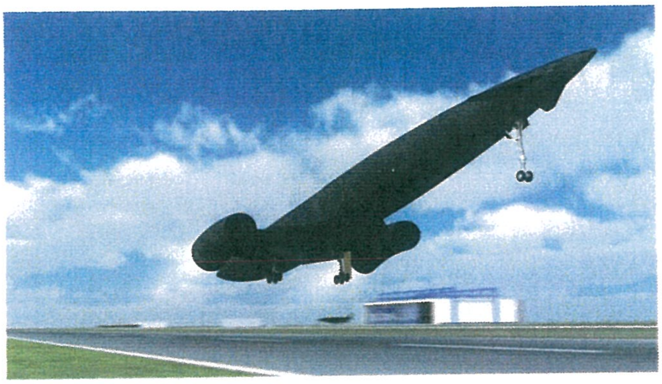
SABRE

SABRE is a new form of propulsion being developed by a startup company called Reaction Engines. SABRE is basically a hybrid between a jet and rocket engine. It will use a similar combustion chamber system as seen on rocket engines but the front of the engine is made to capture air while in the atmosphere, which is used to both cool the systems and as the oxidiser

[3] More on these when I cover power systems in Part Three.

in the combustion chamber. This air capture system would be impossible on a traditional rocket but SABRE is being designed for use on a spaceplane which will be called Skylon. A spaceplane is a spacecraft which is also able to operate as an aircraft while within Earth's atmosphere.

To date just five different space planes have successfully completed missions, all of which were launched to space by a rocket before gliding down. Unlike other space planes Skylon will take off from a runway and fly to the top of Earth's atmosphere using its air capture systems and aerodynamics (wings passing through air provide lift or upwards force) for greatly improved efficiency. Once the air is too thin to sustain the engine it will use some prestocked liquid oxygen as an oxidiser alongside its liquid hydrogen fuel. After dropping off a payload or smaller spaceship Skylon will glide down and land back on Earth. SABRE will be a great system for launching one-stage to orbit on a reusable system. The Skylon system will not be outfitted to travel to another planet; however, it could still be used to bring people and cargo to a larger ship in orbit.



Early concept for the Skylon design.

Nuclear Thermal Engine

NASA have recently decided to start up a program working on developing a nuclear thermal engine. Inside the engine, uranium reactions are used to heat liquid hydrogen and make it expand into a gas at extreme speed. This gas is then funnelled out through the exhaust nozzle. Nuclear thermal engines are expected to be about twice as fuel efficient as chemical rockets but still maintain decent acceleration (unlike ion engines).

These nuclear thermal rockets don't come without their risks. Any humans on board a ship like this would need protection from the passive radiation from uranium. If a rocket transporting nuclear material was destroyed in the atmosphere or Earth orbit everyone would enjoy their normal weather with a chance of falling uranium. Nuclear thermal rockets definitely have their benefits and their dangers. Personally I don't believe these are ideal for crewed ships where ion engines could do the job more efficiently even if it means an extra few days spent in space accelerating. But just to put the risk of radioactive material in context, as I have mentioned, RTGs use radioactive material, and they have been used many times on deep space probes.

Antimatter Drive

This will be the first of two more speculative methods of propulsion that I will cover. To talk about the antimatter drive it is important to first cover antimatter. Antimatter is like normal matter except instead of electrons and protons it has positrons and antiprotons. Positrons take the same space in an atom as electrons but have a positive charge, unlike electrons which have negative charge. Antiprotons take the same space as protons but have a negative charge, the opposite of a normal proton. If antimatter comes into contact with normal matter it will 'annihilate' and the matter and antimatter will disappear and the matter becomes energy, lots of it. It has been calculated that just 10 thousandths of a gram would contain enough energy to get a spacecraft to Mars in 45 days. As a reminder this trip currently takes 6-9 months.

Although this all sounds great, in total we have only ever produced 18 nanograms of antimatter. Also it has to be stored in special magnetic fields to keep it from contacting normal matter. A lot of the antimatter produced never makes it to its holding area and annihilates with something along the way. Just to show how tiny a nanogram is, a nanogram is one thousandth of a microgram which is one thousandth of a milligram which is one thousandth of a gram. In 1999 NASA made a prediction that to produce one gram of antimatter it would cost 62.5 trillion dollars. So while antimatter drives would undoubtedly have the highest specific impulse of any engine, until we can find a much, much cheaper and faster way of producing antimatter, antimatter drives will remain a thing of the future.

Warp Drive

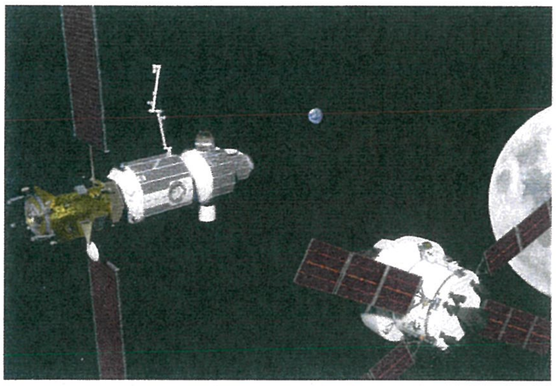
Warp drives are a staple of many sci-fi universes and NASA has a plan to make one. The problem with long distance space travel is that according to Einstein's theories it may not be possible to travel faster than the speed of light. This is a problem when we want to travel between solar systems which is most definitely the purpose of this drive (the closest solar system to our own is about 4.2 light years away which means it would take 4.2 years traveling at the speed of light to get there). The idea presented by NASA would circumvent this issue entirely. The premise of the plan is that instead of propelling a spacecraft to high speed they can instead contract and expand spacetime and move their destination to the spacecraft while also moving the spacecraft forward. This is highly speculative and could possibly require an amount of energy many times that of our sun. It would just require too much energy to ever work so it seems to me to be unlikely this will ever be used, even if we do manage to travel to another solar system.

Plans for Planet Colonisation

NASA

NASA is a government agency and they do not really have plans for planet colonisation because they are more focused on the scientific benefits of space *exploration*. They do, however, have some plans which have big implications.

NASA's plan is called the Deep Space Gate. The Deep Space Gate is intended to be a space station in orbit of the Moon. It is actually intended to be a replacement for the International Space Station which is intended be flown into Earth's atmosphere and destroyed in 2024. The Deep Space Gate will be launched into orbit of the Moon by a rocket called the SLS or Space Launch System. The SLS is being developed by Boeing and it is basically just a slightly downsized version of the Saturn V rocket, which interestingly was also built by Boeing (the Saturn V was used for the Moon landings). The SLS will have a launch capacity of about 140 tons but a launch cost of around 1.5 billion dollars. This gives it a cost to mass ratio of about 10.7 million dollars a ton. Compared to other rockets being developed at this time that is a pretty bad cost to mass ratio, but it will cater to NASA's needs.



A concept for the Deep Space Gate.

The Deep Space Gate will have multiple uses. It will take over the scientific duties of the ISS and be used to help the future exploration of the Moon. The most revolutionary thing about it, however, is that it will be used as a hub for future deep space exploration. It will both act as a refueling station and a shipyard. The Deep Space Gate will be the first place where we build a ship in space. Yeah that's right, our first shipyard in space: bring on the future. This is good for many reasons. The spacecraft can be specialised for use in space and it can be much larger because it will never travel to the surface of any planet. It will also use ion engines which are a great form of propulsion once a ship is outside the atmosphere.

The Deep Space Gate is important because it is the beginning of an interplanetary infrastructure. This is important because it will lower the cost of transport. It could be much cheaper to use ion engine craft between planets and then a separate craft to go between the planets' surfaces and a space station where everything can dock. Although launching space stations to all of the planets would have a large initial cost, over time it will pay itself back with cheaper transport costs.

When I first heard of this plan I dismissed it because I didn't think NASA would be able to fund it; however, Donald Trump has proposed a new NASA budget for 2019, raising their funding from about 10 billion dollars to around 20 billion dollars. This might be one of Donald Trump's only good decisions and NASA's plan could have a great, great effect on planet colonisation.

Mars One

One of the lesser known groups trying to achieve a settlement on another planet, Mars One has an ambitious goal and an interesting way of achieving it. Mars One consists of two groups. The Dutch Mars One Foundation does all of the mission planning, research, and pretty much everything to do with the challenges of getting humans on Mars. The other group is the Swiss organisation, Mars One Ventures, who are in charge of publicity.

Mars One aim to establish a permanent human settlement on Mars. From 2031 onwards Mars One aims to launch a crew of four people to Mars every two years. All astronauts who go will live the rest of their lives on Mars. The initial settlement will involve four pressurised living spaces (one per person), two life support pods, two larger farming areas, a solar array, and two rovers. The Mars One crew would draw water from the Martian soil and oxygen from that water. That is the purpose of the life support pods, they are built to process the water from the soil and then extract some oxygen from that water. The farming will either be hydroponic (see Threats to Human Life on Earth, Resource Shortage) or use Martian soil. The farms will use intense artificial lights to act as sunlight. This is to avoid exposing the plants to the intense radiation which would probably kill them.

Concept for Mars One settlement after the arrival of the second mission.

At the beginning there will be very little indoor space and only a few other people to talk to. The strategy Mars One is employing will be very costly and the settlement would grow very slowly. And this is just one of the crippling weaknesses in the Mars One plan. Mars One is funded entirely through private investors and donations. Mars One does not produce its own income nor is it supported by a large company. These failings in their plan reduces their progress to a crawl and they will be hard pressed to meet any of their goals.

SpaceX

Owned by one of the most vocal supporters of planet colonisation, SpaceX are currently at the head of the race to the red planet. For years Elon Musk has talked about the necessity of planet colonisation. Elon Musk's dream is for humans to be an interplanetary race with self sustaining colonies throughout the solar system. Everything SpaceX does is just preparation for their Mars missions.

Unlike Mars One, SpaceX is not focusing on the living side of things. Instead they are developing a transport system to get large amounts of cargo and people to Mars. So far I have been unable to find any information from SpaceX on the technology they will use to keep humans alive and well. It seems like Elon Musk views the details of living to be an easy problem to solve and will address it only when the he needs to. Or maybe he just hasn't given it enough thought.

The launch system in development is called the BFR. This politely stands for Big Falcon Rocket, but the meaning of the F has been debated. According to SpaceX the BFR has been in development since 2012 when they began work on its rocket engines. While SpaceX have now finalised the plans for the BFR it is not the rocket that was being envisioned in 2012. Originally what is now the BFR was called the Interplanetary Transport System. It was to be 116 metres tall with a diameter of 12 metres. Since then the design has been scaled both down and up multiple times, and the BFR currently under development will be 118 metres tall and nine metres wide.

The BFR will be a two stage rocket with a maximum payload of 100 tons to Earth orbit and Mars. The first stage booster for the BFR will be 58 metres tall. It will use 31 raptor engines designed and built by SpaceX to produce 52,700 kilonewtons of force.[4] Both the first stage booster and second stage space ship will require an impressive fuel tank but Elon Musk has that covered. In 2016 SpaceX released a video in which they stress-tested a giant carbon fibre fuel tank which was actually designed for the Interplanetary Transport System, the predecessor for the BFR. The giant fuel tank was able to take a considerable amount of mistreatment before failing which is good especially considering a downsized version is likely to be even stronger.

The second stage of the BFR will be 55 metres high and will carry its payload of up to 100 tons to its final destination. The top stage has seven raptor engines for propulsion. It will have three main configurations: crew, cargo, and tanker. The crewed design will be used primarily for Mars but will also do crew missions for the International Space Station. The cargo variant will also go to Mars but it will take over all satellite delivery and other uncrewed missions. The tanker will only be used in the Mars mission to refuel the BFR for its trip to the red planet. SpaceX claim that when it is completed the BFR will be able to transport 100 people to Mars.

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[4] A newton is the force required to accelerate an object with the mass of 1 kilogram by 1 metre per second squared. A kilonewton = 1000 newtons.

From what I've outlined it would seem that the BFR would be an extremely costly spacecraft and unsustainable for use on all missions. But Elon Musk has this all sorted out: the most revolutionary part of the BFR will be its 100 percent reusability. That's right, every part of the BFR will be landed and reused. The ship will still be extremely expensive to construct but by using one booster and spaceship over and over again, the price per launch can be massively reduced. The price per launch to Mars is estimated by SpaceX to be about seven million US dollars. This would be an astoundingly cheap 70,000 dollars per ton. I think this is far too ambitious, but the launch cost could certainly be very small, say in the low tens of millions. The BFR will almost definitely have a dramatically cheaper mass to cost ratio than any rocket built before.

SpaceX are looking to run a full test of the BFR in 2020, so where are they with the development? Recently there has been a large amount of activity around the Raptor engine test facilities with signs of large improvement. SpaceX has also begun construction of a new factory which is almost definitely for the construction of the BFR. To cap it all off, many people inside SpaceX who have previously been sceptical of Elon Musk's timelines have supported his statement.

So far SpaceX have only released detailed plans of the BFR and have not detailed their plans for how they will keep people alive on Mars; however, they have released a timeline for their mission. In 2022 Elon Musk wants to launch two of the cargo configuration BFRs to Mars which will be carrying the base infrastructure for an early Martian settlement. In 2024 two cargo and two crewed BFRs will be launched. These people will build the beginnings of a Martian colony and a fuel processor and depot before returning to Earth. From here Elon Musk will send a few more crewed missions to Mars which will also return. From here the Martian city will rely on governments, companies, and people buying themselves tickets to Mars for the continued expansion of the settlement and profit of SpaceX.

In my opinion SpaceX have a very smart plan for planet colonisation. Transport is currently the biggest cost difficulty in establishing any colony. By providing the transport system SpaceX will remove the main blocker stopping other groups from trying to get to Mars. I do think their timelines are unrealistic and it will take them many more years to be ready to send the first people to Mars (I estimate 2026 at the absolute earliest, and probably not to stay).

Rocket Lab

Rocket Lab is an American-owned company which operates primarily in New Zealand. Rocket Lab has recently finished the development of their very first rocket, the Electron. This Rocket stands at 17 metres tall and 1.2 metres wide. It's a two stage rocket capable of launching up to 225 kg into low Earth orbit for a cost 7.5 million NZ dollars. The first stage is powered by nine Rutherford engines made by Rocket Lab and the second stage uses a Rutherford vacuum variant. These engines burn kerosene and liquid oxygen just like the Falcon 9 and Falcon Heavy. While the power and size of the electron is nothing new there is something to be said about how it's made and what it's made out of.

Rocket Lab build the entire structure of the Electron out of a special carbon composite, with not a scrap of metal involved. This is a revolutionary form of rocket construction as this carbon composite is much lighter and cheaper than metals. It doesn't end there. Rocket Lab also 3D prints the central structure of its rockets using the carbon composite. Even with relatively small facilities Rocket Lab produce nearly all of their hardware to make sure it is reliable and perfect for their rockets; however, what impresses me most is that they also 3D print their rocket engines. To me this entire process feels like something of the future but it is happening right now right here in New Zealand. These construction techniques dramatically reduce the cost of launches. At the time of writing this, Rocket Lab have completed just four launches but I think these numbers will soon sky rocket (I'm sorry about the pun). Although Rocket Lab do not have any plans for planet colonisation their rocket technology could have big implications. A mix of reusable rocket technology along with Rockets Lab's cost saving construction methods would allow for much cheaper transport costs.

Electron on the NZ launchpad.

Rocket Lab are just a small group in a wider effort to get humans to other planets. While getting to other planets may currently seem the biggest technical and economic problem, with innovations such as ion engines, 3D printed rockets, reusable rocket technology, and transport systems such as the Deep Space Gate, it will not be long before we conquer the vast expanse of space.