Part Three

How Might We Live on Another Planet?

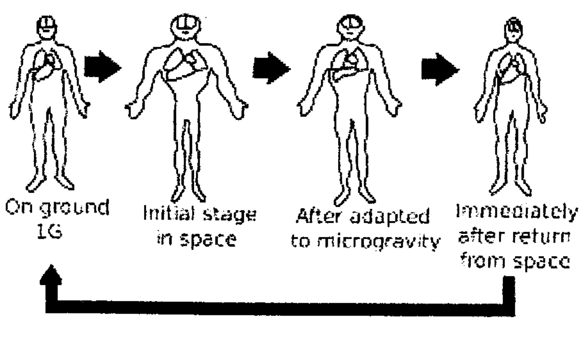
Health Effects of Living in Space

Now that we know how we might get to another planet, it is time to look at the technology we would need to live there. Before that happens, however, we need to take a look at the health effects of living in space. Some astronauts who have spent a long time in space have had a negative impact to their physical and mental health. In this section I will look at the impact on people's health and how a negative impact can be avoided.

Physical Effects of Low and Zero Gravity

On Earth your muscles and bones are constantly having to fight gravity to maintain your body posture and shape. In low gravity the constant pressure that they have to fight against is lightened. Without this constant use muscles, bones and even organs begin to deteriorate. If you are on another planet to stay this wouldn't matter as you will deteriorate or strengthen to that planet's gravity and you will be just as strong there as you would be on Earth (in low gravity everything has less weight, unless your body has already adapted to match that gravity). When it comes to planet colonisation the deterioration of muscle bones, and organs will mainly be a problem while in transit through space where the colonists' bodies could deteriorate too far and render the colonists far less mobile upon arrival. If the initial colonists are cycled on and off the colony location as they might be (I covered why in Part One), then they wouldn't be able to stay for too long and they would take months back on Earth to recover from the effects of their stay in space. These changes to the body do lead to a slightly increased cancer risk.

Our bodies contain many different fluids. On Earth they are drawn towards our feet and stay in the lower area of our body. In zero gravity there is no such pressure and your body fluids are distributed more evenly throughout your body. This makes the upper body slightly bloated and also has a few more harmful effects. These symptoms include blurry vision, loss of nasal function, and problems with balance. After a few days the human body will adapt to these conditions and the effects dramatically lessen. Even a slight presence of gravity goes a long way in reducing the effect of this issue so when on another planet or moon this shouldn't cause too much of an issue.



The effects of body fluid redistribution in the human body.

Both of these changes to the body will only pose a significant problem in transit to a colony location. The travel to another planet shouldn't be long enough for the zero gravity to be of critical concern. Still we should do something about it if we can, so I have a simple way to help mitigate the damage of the physical changes. This is to use ion engines in flight to another planet. Ion engines are efficient enough that it would be possible to carry enough fuel to be either accelerating or decelerating for most of the flight and remain economic. Just a reminder: if accelerating or decelerating an object will experience forces basically identical to that of gravity. Constant acceleration by ion engines will not make for very high force but it could significantly slow the changes to the human body.

Psychological Effects of Living in Space

Some astronauts who have spent a long period in space on the International Space Station have developed some adverse psychological effects. The most notable of these are anxiety, depression and anti-social behaviour. The causes and extent of this issue are still being studied but a limited number of people to interact with and confined spaces are thought to have a large effect. Tensions between crew members tend to rise throughout their time on the International Space Station. If two people have a dispute there just isn't space on board for them to avoid each other until they have got over it. These mental conditions don't just come out of the blue. If someone has a slight disposition towards anxiety and depression there is a chance that they will develop it in the conditions of the ISS.

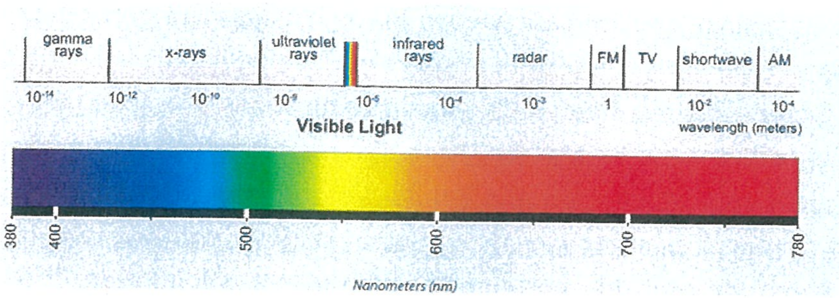
In a colony there will hopefully be much more space for everyone and each person could have a personal area. This would hopefully do a lot to keep tension levels down. Furthermore, in a colony there should be a much greater number of people around. Some variety in who you see and talk to every day could go a long way to help. Unfortunately the extent of this issue is still unknown. It is almost certain that going to another planet for a long time or even the rest of your life will certainly be harder than going to the space station. You would be leaving your family and all the great things we have on this planet. People could still live happily on other planets, it just wouldn't be the same. The implications of going to live on another planet isn't a deterrent to some people as was demonstrated by the Mars One program. Mars One isn't very well known, or a great example of how we could build a colony. On top of all this it was a one way ticket to Mars. Even so over 200,000 people expressed great interest in being an astronaut as of 2015 (I have been unable to find more recent data) and tens of thousands filled out full applications.

Radiation

On Earth we are protected from most damaging radiation by our planet's magnetic field. Most planets have no such protection. The Earth's magnetic field is generated by a spinning core of molten metal. Of the four terrestrial planets in our solar system (Mercury, Venus, Earth, and Mars), Earth is the only one to have a substantial magnetic field. Mercury has a weak magnetic field, Venus generates no magnetic field, and Mars has a weak magnetic field.

Because of this these planets' surfaces are constantly being bombarded with ionized particles and UV light.

These types of radiation cause damage to the human body in two ways. Ionised particles can kill living tissue and damage DNA, and the same goes for UV, X ray, and gamma radiation. The first of these types of damage isn't really of any great concern because your cells can replicate and replace damaged tissue. But unfortunately damage to DNA is a huge problem and could easily be fatal. Every cell holds DNA which allows those cells to perfectly replicate themselves. When this DNA is damaged the cells can no longer make perfect replicants of themselves and mutant cells are made. This can often lead to cancer. While the amount of UV and X rays received decreases with extra distance from the sun, some gamma rays and ionized particles come from other stars so radiation is still a danger anywhere in the solar system.



The light spectrum.

It is important that all colonists are constantly and effectively shielded from radiation. Many materials are very effective at stopping radiation and living spaces can have strong radiation shielding or even be built underground.[5] Time spent outdoors in a space suit should also be capped to a safe level. Even with our best efforts anyone living in a colony will receive much more daily radiation than anyone on Earth. It is important that all colonists are monitored should they need treatment. This way cancer tumors can be detected and removed while still in stage one when they are easily treatable. Still this is one of the larger issues that colonists would face and the dangers presented by radiation are definitely of great importance in any conversation about planet colonisation.

Childbirth in Space

I will keep this section brief but it is important that I go over the difficulties of human reproduction in space. For a colony to be truly sustainable it must have a population which can grow without immigrants from elsewhere. Currently the possibilities for human reproduction in space are highly speculative because it has never been done. Even so medical experts expect some difficulties. One test has been carried out on some rats aboard the ISS. The babies did surprisingly well in the environment, being just slightly smaller than their counterparts on Earth and slightly behind on mental development in which they eventually caught up. It was actually the mothers who suffered the most from the space environment,

[5] More on living spaces on page 53.

losing much more of their body weight than they would on Earth. It was also found that for healthy development of the fetus certain lights and noises were needed as stimuli at some crucial points.

Of course what happens with rats may not transfer to humans but it is thought that many of the same things will affect humans. Babies who develop in space will probably have much weaker bodies because most promising colony locations in the solar system are of lower gravity than Earth. These babies may also have slightly slower mental development but if they do they are likely to make up this gap later in life. It is also expected that babies who develop away from Earth will have a higher chance of developing significant physically impairing birth defects from early radiation damage which becomes part of a baby's early development. To this end it is important that pregnant women in a colony spend most of their time in areas with strong radiation shielding. Childbirth in space will probably be much more taxing and dangerous to the mother than on Earth. Abortions (terminations of a fetus) may need to be available should the mother's life be at risk. I have also seen it argued that it may be necessary to abort a damaged fetus which will be a liability to a colony. This is a very complex ethical problem and I am still forming my own opinion. While it will be difficult, problems with childbirth in space are probably not going to stop planet colonisation. It is expected that a colony would need a population of between 5,000 and 5,800 people to become self-sustaining.

Water, Oxygen, and Life Support

Before reading this section you should read my Appendix One on page 71 for more information on atoms, atomic bonds, and electricity.

Because of the wide range of equipment I have to cover I will be splitting it into smaller sections. I will start with systems for acquiring and recycling water and oxygen. Water is the basis for all life as we know it and every organism requires oxygen (some organisms can take this directly from water).

The different conditions of different planets will mean that oxygen and water will be found in different places and different states. On Earth water usually resides in its liquid state. In space, temperatures vary greatly, but in most locations in the solar system water is found in its solid state or ice. Luckily for us ice can easily succumb to its mortal enemy, heat. Heaters are nothing revolutionary and for the cost of energy we can melt ice into water. As long as enough water is available we should have no problem acquiring and using it.

Taking oxygen from water is a little more interesting. When separating oxygen from water a process called electrolysis is used. Electrolysis of water is where an electrical current is run through the water between two electrodes. The electrical energy passing through the water is enough to break the bonds between the hydrogen atoms and the oxygen. The nature of these bonds breaking leaves two compounds: oxygen, which is released with negative charge, and positively charged hydrogen. The oxygen is then attracted to the positive electrode and the hydrogen to the negative. When the oxygen and hydrogen reach their respective electrodes they exchange electrons and achieve a neutral charge. Hydrogen and oxygen atoms bond with one of their own. O_2 bubbles are released at the positive electrode and H_2 at the negative. Because the oxygen and hydrogen exit the water at different points it is easy to collect them separately. The oxygen can then be used for breathing air and oxidisers in rockets, and the hydrogen can be used to produce hydrogen fuel or for the recycling of air which I will explain in a second.

Sometimes the water we are trying to get might be buried beneath the surface of a planet, moon or asteroid. On Earth we are constantly boring deep into the ground to get at buried water sources. But while we do have the technology to get at buried water sources the equipment is very large and heavy. Launching this to another planet would come with a decent price tag. But as I have shown in Part Two, space travel is nowhere near as expensive as most people perceive so I am sure we can send this technology wherever it may be needed. After a colony has developed a system to obtain, refine, and process materials,[6] it can build these systems for itself.

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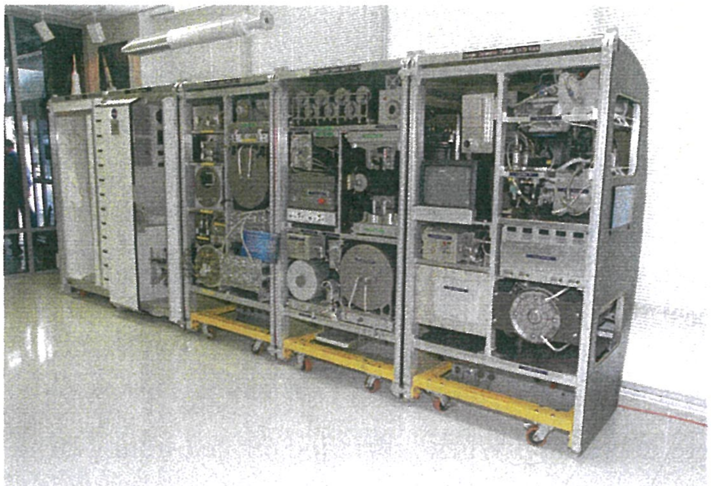
[6] More on this on page 56.

For a colony to be as efficient as possible, it is important we recycle all of our water and oxygen. On the international space station we are already recycling water for all purposes. All water is collected, cleansed, and recycled. When the water is cleaned for recycling it travels through two main processes. The first of these is a physical process where the water passes through specialised membranes filtering out unwanted contaminants mixed in with the water. These membranes are so fine that they let through water molecules while filtering out other things on the atomic scale, such as sodium. The second of these processes is chemical where specialised chemicals are used to kill bacteria and make sure no biological contaminants are left out. All water on the station is constantly recycled. On top of things like urine which produce a lot of recyclable water, this includes any extra moisture released through sweat, breathing, and other processes. While this may sound disgusting and unhygienic, the water recycled on the ISS is cleaner than most tap water on Earth.



The ECLSS is responsible for water and oxygen recycling on the ISS.

On the ISS they also recycle the air. When we breathe in oxygen we breathe out CO_2, which is a molecule made of one carbon atom and two oxygen atoms. If the concentration of CO_2 gets too high it will become toxic to humans, so the CO_2 must be removed. But we may have use of it yet. CO_2 can be collected from the air and be combined with hydrogen molecules to produce water and methane (H_2O and CH_4). The hydrogen for this reaction can come from the original electrolysis used to make the oxygen. The water made in this reclaiming can then be put through more electrolysis for more air if required. Not all of the hydrogen used to make water from the CO_2 is put back in the water because four hydrogen atoms bond with one carbon atom to make methane. The methane can also be put to use, probably in rocket fuels. While the air may not be able to be recycled infinitely it can help to save a large amount of fresh water and air that would have to have been acquired in the absence of this recycling.

There is also another way to process CO_2 and it is much easier but less consistent. A colony will need to grow food and therefore plants. Plants require CO_2 and absorb it from the atmosphere around them. They then remove the carbon and release oxygen. Humans and plants are symbiotic: we produce CO_2 for them, they produce oxygen for us. Plant CO_2 absorption is not a super consistent process so other extraction methods should constantly be monitoring and ready to spring into action.

So essentially as long as enough water is present we can take advantage of it and sustain a colony. The technology for water and oxygen extraction and recycling is already available to us and will pose no barrier for establishing a colony.

Food

It is absolutely essential that humans have food to survive. It is important that a colony is able to produce its own food and make sure that the colonists get all the nutrients they need.

Hydroponic and Aeroponic Farming

Hydroponic and aeroponic farming are two methods of growing food that may be crucial to a colony's success. They aren't new either and are tried and true methods here on Earth. I have mentioned hydroponic and aeroponic farming earlier in this Independent Study when I looked at threats to human life on earth and some solutions; however, I will cover them in detail now. Hydroponic farming is where plants are grown in water with a special nutrients solution. Aeroponic farming involves a similar nutrient solution but here the plants are held by a special structure and their roots are sprayed with the solution or it is turned into a mist and absorbed through the roots.

A hydroponic farm.

Both of these farming methods are very labor-intensive processes as plants require over a dozen essential nutrients and the ideal concentration of each varies from plant to plant. In all there are seventeen essential plant nutrients, and the most important of these nutrients include: nitrogen, phosphorus, sulfur. I will cover the locations that have these nutrients in Resource Gathering and Processing on page 56. Plants also require CO_2 which is provided by us breathing, as I have already covered. You may be wondering why we would use hydroponic or aeroponic farming and not just grow food like we do on Earth. This is because most places in our solar system (all but Mars actually) do not have all of the nutrients in their soil necessary to grow plants. It is much easier to put the nutrients in the solution than it is to mix them into previously unusable soil.

Surprisingly these types of farming actually tend to use less water than traditional methods. This is because excess water can be easily reclaimed and reused when it would normally just be absorbed by the soil. For this reason they are already being used in the UAE (United Arab Emirates) to great success. Also if enough attention is given to hydroponic and aeroponic crops they have a great yield to area ratio. In a properly maintained hydroponic farm, plants are always in the right conditions and they can achieve maximum growth. Also, because of the controlled nature of hydroponic farming, crops do not need to contend with weeds or other plants for growing space, sunlight, and nutrients. Because of all these factors they can produce many times more food than traditional farming. This is probably the biggest benefit of these two types of farming because the space within a colony will be very limited.

I have found one source claiming that using hydroponic and aeroponic farming, we could feed up to 10,000 people on sixty acres. Another says we could feed 100 people on an acre of land if enough attention is given to the crops and special growing methods are used. An acre is around 4,046 square metres, but if put into a square area, that square would only have sides of 64 meters. This kind of space could definitely be built in a colony with 100 or more people (it may need to be broken into smaller spaces though). There are many other sources with similar suggestions of yield to area. Some say we would need even less area, others slightly more.

In a colony, plants in hydroponic farms are going to need to be grown under the light of strong LEDs because if exposed to the sun, its radiation may cause significant damage to the plant and anyone tending to it. (The sun's radiation is much stronger in space: Earth's magnetic field blocks much of harmful radiation but most planets do not have the same qualities, as I have explained.)

Overall, hydroponics and aeroponics are reliable methods of plant growth, and an all around great solution for a colony's food problems.

Growing in Martian Soil

Studies of Martian soil have left it looking surprisingly hospitable to plants as it contains the right nutrients for plant growth. The amount of nutrients in the Martian soil varies between different areas of the planet's surface and it does lack any organic compounds or bacteria, of which at least some are needed for plants to germinate and grow. However, both of these problems can be solved: a colony can pick a landing site with nutrient-rich soil, and soil from Earth which will be full of bacteria can be brought to the colony. From there the bacteria can spread to any Martian soil it is brought into contact with, and from there it can spread from that Martian soil to more Martian soil. The harsh environment of Mars would kill any bacteria or plant growth, so as with hydroponics all plants would need to be grown and all bacteria transferred inside a pressurised room. Despite the potential of Martian soil, a colony on Mars is probably better off using hydroponic and aeroponic farming due to their higher yield. The soil on Mars could still be of great use because it is a confirmed presence of the essential plant nutrients, which, with not all that great difficulty, can be transferred into a water solution.

Cultured Meat

The food production I have just described does leave a little bit to be desired. It brings no element of meat to the table. Sustaining animals for food in space or on another planet is an extraordinarily difficult task. There are so many different problems that would need to be addressed. Animal farming is much less efficient than crop farming. Just a fraction of the water and food needed to sustain an animal is returned in edible form. On top of this special enclosures for animals will need to be designed and built and many other technical challenges will need to be resolved. A colony may keep some animals for scientific purposes; however, colonists may have to go vegetarian until the colony has enough excess resources to facilitate animal farming.

This would leave one way for colonists could get some meat in their diet without having it imported. Meet cultured meat. Cultured meat is a form of meat production where cells are taken from an animal and kept alive under special conditions where they replicate themselves and eventually form a larger piece of muscle tissue. This way a single animal can produce enough meat for many people without needing to be killed, and it can continue to provide food over a long period of time. The first burger patty of cultured meat was produced in 2013, costing hundreds of thousands of dollars. Since then the cost has dropped dramatically and the same patty might cost 10-15 dollars today. I personally see this as the best way for colonists to add some meat to their diet because it greatly reduces the number of animals needed. I would like to mention that I have found no one else connecting cultured meat to planet colonisation, so it is possible that there is a problem with this idea that I am not aware of. Also this has only ever been done with cells from cattle and the cultured meat is slightly lacking in iron and fat content. There is currently a lot of research being done to find solutions to both of these problems.

Conclusion

Overall we have all the technology we need to grow food in space. Even so, limited usable area will mean that, at first, a colony will only grow a small proportion of its food (the rest would need to be provided from Earth). Over time, the aim would be for that proportion to grow to full self sustainability. This limited space also means that meals are not going to be anything to get excited about. Food production will be kept to the most efficient and essential foods. As a colony grows so could the variety of the food, but it will be a very long time before meals become anything special.

Living Spaces

There are many ideas for how the buildings in a colony might look. I would like to provide my own ideas about how best to build a colony and the best ways to utilise available space. In this section I will also provide an idea of how some of the technologies I have already covered could be implemented in the structures.

I think it is first necessary to look at the way a colony, or more specifically the structures within it, would develop over time. The first structures on a colony will need to be built on Earth and sent with the colonists. For cost reasons these are unlikely to have all the features that they may need for the long term safety and happiness of the astronauts and longevity of the buildings. It will be up to the first colonists to develop the base upon which a colony could thrive. Their job will first be to build a system where resources can be acquired and then processed into whatever the colonists need (I will cover how this might be done in the next section). After this these colonists can begin the construction of permanent living areas. So what will they look like?

Every structure in a colony would need to: be air tight and retain stable pressure, monitor the colonists' air to extract CO_2 and excess water (in the form of humidity) for recycling and safety, and protect the colonists from harmful radiation.

Air-tight structures are relatively easy to build and we have been constructing them for quite a long time. They are important for colonists because if they are not air tight the air within them will be sucked into the cold vacuum of space and the colonists will die from lack of oxygen and pressure. Sounds important right? Even though we can build them reliably every structure in the colony could have a double outer hull. If one hull breaches for any reason it would not be fatal for anyone inside the building. If the gap between hulls is kept at a different air pressure to the planet and the inside of the building it would be easy to determine which hull has been breached. When this happens anyone within that area could move out of that space while the hull is repaired. This double hull system would definitely be of value. In September this year there was a hull breach on the International Space Station. It was tiny, too small to be of great danger to the astronauts, but it shows that hull breaches do happen. Each room within the colony should also be independently sealable for general safety. If these safety measures are followed fatalities from hull breaches should be extraordinarily rare.

I have already covered the recycling process of CO_2 and water but I would quickly like to go over some of the practicalities of this system. Each room would have to be outfitted with vents, some of which to pump in new air, and others to extract it. The amount of air flowing through the different vents would depend on the state of the room, but the vents would need to constantly take at least some air which can then be tested for CO_2 and water content and any other gases that may have found their way into the air. All spaces where water is used (for washing, drinking, etc) would need to contain that water and collect it for recycling.

Protection from radiation is definitely a major focus when it comes to building structures because it is not easy to provide effective protection. As I have previously explained exposure to radiation is the biggest threat to the astronauts and it is important that their exposure is kept as low as possible. Unfortunately due to the different types of radiation that will be harmful to astronauts and colonists (light rays on the UV side of the spectrum and charged particles) the materials used to protect against them will need a number of different properties to be effective.

When it comes to stopping UV, X ray, and gamma radiation which are all parts of the light spectrum, it is mainly about catching the rays because they do not have the strength to push away any matter that may be in their path. When they do strike matter, the energy they impart into the electrons can cause them to break free of whatever atom they are attached to, making it an ion in the process (ionising them). Stopping these types of radiation effectively is all about having a high density and atomic number. Denser materials have more molecules in a smaller space and are more likely to catch all of the rays. Likewise a high atomic number means a material has more electrons per atom and will stop more of these rays. Some of the best materials for stopping these rays include water, lead, steel, concrete, and stone.

When it comes to protecting against the charged particles, the density of the protective materials again makes the biggest difference. These charged particles can split matter they collide with, sending out a barrage of subatomic particles and harmful light rays. The dense materials are less likely to be split and are better at stopping any subatomic particles released in these collisions. When these charged particles impact materials, they also erode them. This means that the outer hull of any colony or reusable transport ship would need replacing every once and awhile. Steel or concrete would be great materials with which to build the outer walls of the living spaces. This is because they are both strong enough to build the hull out of, are pretty common, and are good at stopping radiation. When it comes to blocking just one type of radiation some materials are much better, but steel and concrete will be effective against all. Some of the materials which are good at stopping specific forms of radiation could be added as a coating to the outer hull.

There is one other way to protect colonists from radiation, and that is to live in structures below the surface. Soil and rock is a surprisingly good form of radiation protection and several meters of it would stop most of the radiation from reaching the colony. It also saves the resources required to repair the outer hull of structures. To do this, digging and tunneling equipment would be needed, so this development would likely come later down the line. On Earth's Moon, however, there are ancient lava tunnels beneath the surface which were made when it was first formed. These could be used to place a colony underground without much special equipment being needed.

Overall there are many things that buildings must do for the colonists and we know how to build structures that do them; however, the construction of the living spaces I have suggested would be extremely difficult in the environments that colonists will be in. To that end it is important to maximise the available area. So how might colonists best use the space available to them?

To maximise the use of all pressurised areas each individual should have a relatively small place to themselves. Enough for a bed, some storage space, a desk and not much else. Each personal space might be the size of a bedroom. Of course this wouldn't make for very comfortable living so larger public areas should be built for entertainment or exercise (exercise areas would take the form of gyms) were colonists can spend most of their spare time. Were each colonist to have their own larger entertainment area it would waste a lot of pressurized space as these will not see that much use compared to larger social areas. If most of the colony was underground social areas could be located above ground. Putting these above ground would allow for windows giving the colonists a view of their surroundings. The ability to view the world around them would go a long way in reducing the psychological strain on colonists and make the potentially tight indoor spaces seem less claustrophobic.

To stop colonists having to spend time moving between structures in bulky space suits, personal areas, social areas, and some work spaces could all be connected in a complex via underground tunnels (even in an above ground colony). I say some work spaces because areas where heat and fire are used like in the processing of metals and places where reactive chemicals are used and stored should be kept separate from everything else for safety purposes. Once enough space is available for a colony to become fully self-sustaining and produce all of its own food and other resources, colonists could begin to have a larger area to themselves and spread themselves over a larger area. Throughout this section I have bounced around the idea of both an above ground and underground colony. In the end I think it is likely that a lot of a colony may end up being above ground but sleeping areas in particular will be built below the surface.

Of course what I have suggested assumes that everyone has the exactly the same property built in the same way. If this was the case it would make for a poor economy within a colony which could hinder its expansion and development, but the economy and government are much longer term concerns. Overall, I hope this section has given you a better idea of what the buildings within a colony may look like and what they require to be successful.

Resource Gathering and Processing

To build any of the living spaces I have talked about, or just about anything, a colony will need many non-water resources. Metals are extremely useful for construction, especially of pressurised spaces, and are essential in electronics and most things that may be built in a colony. There are also a few other things like silicone which would be essential to the success of a colony. Much of the resource gathering would depend on the target for the colony and what is available there. In this section I will look at which targets for a colony have the minerals that will be needed and how they would be acquired and processed.

So what types of minerals might a colony need? The first obvious one is iron because it is the main ingredient of steel, which is probably the best material for the construction of living spaces and important in many pieces of equipment. A colony would also need copper and a small amount of gold for electronics. Aluminium and nickel would also be important because they form a number of important alloys with other metals and aluminium is used in electrical transmission lines. Other elements such as lead and titanium may not be essential but could be extremely useful. Silicon is used in a huge variety of things in day to day life, one important use being solar panels. There are also many elements that plants need for nutrition. When covering planets and moons I will group these as the nutritionals. There are other obscure minerals that would be of great use or even essential, but these are the ones that are more definitely known as essential. When I talk about which places have these minerals I will not talk about resources outside of what I have stated here unless it is something very valuable.

Which places have these resources?

So now it is time to look at which places have the resources that are needed.

First of all I will take a look at some of the moons of Jupiter. Jupiter has 67 identified moons. The vast majority of them are very small, too small to host a colony, but may still be of great use. Many of these smaller moons are rich in mineral resources such as iron, copper, aluminium, nickel, and much more. A spacecraft could travel between these moons using very little fuel and it would be relatively easy to set up a mining operation which could sustain a colony on one of the larger moons. The main challenge here is being able to cart enough resources back to the main colony to be sustainable. So this system may not be viable until space transport technologies improve and even with this system we should try to target a place which could provide at least most of its own resources. Especially minerals such as iron and aluminium which are needed in large quantities. Rarer minerals such as gold may be essential but are not needed in great amounts and could be mined away from the colony.

Io is the innermost of the four major moons of Jupiter and has the most mineral resources. Io has a massive amount of intense volcanic activity due partially to internal heat and pressure but also the massive gravitational pull of Jupiter mixed with the lighter pull of some of the other moons. Io has many large deposits of pretty much all of the most important resources for a colony and new minerals are constantly being brought to the surface through its volcanic activity. Silicon is a key component of pretty much all rocks and soil. Basically everywhere that we might colonise will have silicon including Io. Despite this Io is not a good place to colonise as it is unsafe due to its volcanic activity, lacks a large presence of water, and sits in a radiation belt of Jupiter's magnetic field.

Callisto is another of Jupiter's moons. It has a crust made of about equal parts of rock and ice. It doesn't contain many of its own resources but its rocks are known to contain some lighter elements including iron and aluminium and silicon, of course. It would provide these elements but rely on the mining of Io or one of the smaller moons for heavy elements and some of the nutritionals.

It is time to look at Earth's moon. The Moon is known to have iron, magnesium, aluminium, nickel, and titanium in abundance. It is also known to have gold in slightly lesser amounts. As I talked about in Part One it has been suggested that a mining operation on the Moon could be profitable for Earth-based businesses. If there are enough resources on the Moon to make a profit sending them to Earth then there are certainly enough to support a lunar colony. One bonus on the Moon is that it is covered in a layer of powdery soil called regolith. NASA has found a way to turn the regolith from both the Moon and Mars into a strong concrete-like material. This material is extremely valuable due to its uses in the construction of habitats and its great abundance. the Moon also has all of the nutritionals.

Now it is time to see what Mars has to offer. Over our time exploring Mars we have found many different minerals. Iron, aluminium, magnesium, and titanium have all been found on the surface of Mars and are abundant in many places. Lithium, zinc, copper, and gold have also been found but in much smaller amounts. It is possible that there are large deposits of these in some unexplored parts of the planet. Mars is a particularly good location when it comes to resources. Many of the mineral deposits on Mars have been deposited there by previous volcanic activity. While this volcanic activity is the main producer of mineral deposits some deposits are pieces of meteor which have impacted on Mars. Mars has an abundance of the nutritionals: they are even present in its soil. Also, as I just said before, Mars has regolith which can be turned into a strong concrete-like material.

Finally I would like to mention the main asteroid belt, which is located between Mars and Jupiter. Although it may not be the best place for a colony, the main asteroid belt has an immense amount of mineral resources, including just about every mineral you could think of. A colony could definitely find every mineral it would need in the main asteroid belt;

however, economically transporting these resources to another planet would require much better transport systems than we have today.

Collecting and Processing Resources

Collecting resources on a planet shouldn't be too difficult because collection devices do not necessarily have to be that precise in their work. If they detect a concentration of a certain mineral they can simply collect all of the soil and rocks around them and leave the separation of metal and rock to a processing plant. Initial collection devices could potentially be large rovers equipped with mineral detection and identification systems, a digging and drilling device for collecting soil, and a large basin to store it while it carries the soil and rocks back to base. One way to detect and identify minerals is to use X rays. Different minerals will reflect, absorb, scatter, and influence the wavelength of X ray light in certain ways which allows these systems to identify minerals in the soil and rocks around them. The digging tool would be essential to pick up minerals and deposit them in the carrying area of the rover. The drilling tool could be used to break up particularly hard surfaces so the digging tool can do its job. A mobile collection system like the one I have described would allow a colony to exploit all resources close to the surface within a large area around the colony. I am aware, however, that it may be a bit different when it comes to mining an asteroid or small moon away from a colony. When it comes to mining off world (mining on a different planet or moon from the location of the colony) I expressed my concerns earlier when I talked about a mining operation in the moons of Jupiter.

When collecting minerals, they don't just come in a ready to use form. These minerals will often have an atomic bond with oxygen, carbon, or a similar element, and are mixed in with rock and soil. Because of this they need to be processed into the pure mineral before they are put to use.

Processing minerals involves many steps to make the minerals ready for use. First of all they are crushed and then ground into a fine powder. This is mainly to facilitate later processes. Next this powder undergoes separation where the minerals and rocks are, well, separated. Depending on the mineral you are working with different processes are used. For some, gravity and water are used. In one of these methods the powder, produced by the crushing and grinding, is simply suspended in water where heavy mineral elements will float and unwanted and lighter rock will float. Other processes include magnetic and electrostatic separation, where the different magnetic and electrical properties of minerals are used to separate them from the unwanted rock and soil. After the particles containing the minerals have been separated from the useless rock they can be melted to separate the pure mineral from everything else. Away from Earth some of these processes would need to be modified to work but these modifications shouldn't be a major issue. The biggest issue is likely to be generating enough electricity to process these minerals, a problem I explore in the next section. It is worth noting that the processing of these minerals not only produces the mineral itself but also anything it was bonded with. For example, the process may release oxygen which could supplement other sources of breathing air.

Production of Items

Even when a colony has produced a raw material it may have trouble using it. With potentially limited area within a colony it is unlikely that there will be enough space for factories to produce individual parts. For this reason I think that 3D printing will be the best way for a colony to produce what it needs. 3D printing allows for great adaptability, an important quality when the available space is limited.

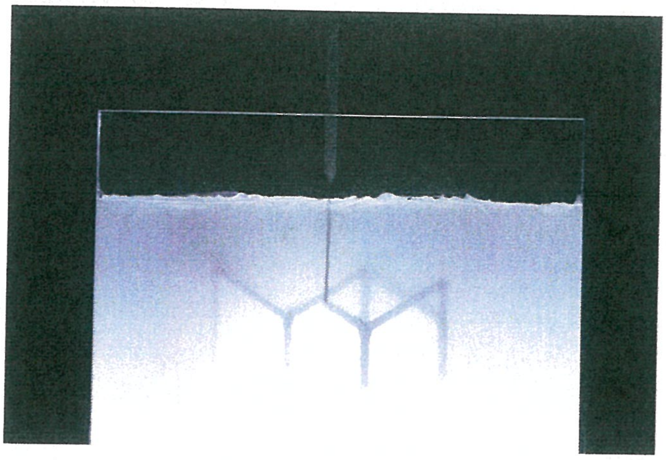
You may be wondering how a 3D printer could produce anything to the quality needed in space: most 3D printers you see print relatively low quality plastic. Well recently 3D printer technology has made some big advances and it is now possible to 3D print in both metal, high quality carbon composite, and even concrete. Let's take a look at some of this technology.

When it comes to printing in carbon composite there are a few different methods that can be used. One is to run a line of flexible plastic like nylon alongside a thread of carbon fibre. This produces an extremely strong material, probably not space grade though. Another method is to print in layers of fibreglass and carbon fibre. And remember the concrete that can be made of lunar or Martian regolith? Well NASA also made a 3D printer for this material. The concrete is kept from setting while it is printed, and later it hardens into a extremely strong construction material. This printer design is made to print large pieces and could print an entire habitat if attached to a large enough robotic arm.

Currently there are two main ways of 3D printing metal. The first is SLS or Selective Laser Sintering. In this 3D printing method the 3D printed part is printed from a bed of powdered metal. A high energy laser is used to heat small areas of the powder just getting them to the point where they bind to form a single solid. Any of the powder that does not get used in the part can be refined and reused. The other method of metal 3D printing is actually pretty similar in the way the metal is used. In this other method, called FDM or Fused Deposition Modelling, the part is printed in metal powder infused plastic. Once the part has been printed it is placed in a furnace where the plastic melts off and the metal is heated to the point where it binds to form a solid object.

Of the two methods, FDM is a cheaper system but SLS printing produces better parts and does not need to build in layers or build a support structure for the item. For that reason SLS is better for use on colony. Even so 3D printing has its downsides. Both of these systems are still relatively slow and have trouble when upscaling to print bigger products faster. In comes Rapid Liquid Printing.

Rapid Liquid Printing uses a special gel to negate the effects of gravity while printing. A brilliant new design from MIT, this system allows the print nozzle to print in 3D without need for supports. This new printing system can print in foam, plastic, and molten metal, all of which are held in place by the gel while they cure. When a part is finished printing it can simply be pulled out of the gel and be ready for use. This system can also be used to print very large parts. Only the size of the vat of gel limits the size of the object printed. This system has great potential and would be perfect for application in space as the effect of low gravity would be nothing but an improvement on this system.



A Rapid Liquid Printer in action.

I do recognise that there are some things 3D printers simply can't do like printing advanced electronics. This technology is currently being developed, though, and I think that we will find ways to make things that 3D printers can't and they can still make the bulk of what a colony may need.

Overall I think that we nearly have all the technology to identify, collect, refine, and use resources in space. At the same time I think that the issue of resources could do with some development. This is because it is probably one of the biggest problems for a colony. Even so I think that this technology could be ready for basic application very soon, though it will be much longer until it could cater for all of a colony's needs.

Power Generation

Over the previous sections I have done on survival in a colony I have mentioned many things that would require a great amount of electricity. Whether it be heating water, powering LED lights to grow plants, or electric smelting, a colony is going to need a lot of electricity. In this section I will explore methods of generating electricity, including ones that I have previously mentioned, and which ones will be most effective on different planets.[7]

Solar Power

Solar energy is great source of renewable energy and could potentially be one of the best sources of electricity for a colony. Solar panels are made up of smaller photovoltaic cells which are just cells that generate electricity from rays of light. The photovoltaic cells are made up of two pieces of a semiconductor of which silicon is most commonly used. One of these panels has a negative charge and one has a positive charge. When enough energy in the form of light strikes the negatively charged silicon the extra electron is knocked loose. The electrical field generated by the positive and negative sides is used to move the electrons to a point where they are intercepted by metal plates. The electrical power of the collected electrons can then be used as we humans please. You may wonder why the solar panels don't run out of electrons and stop working. Well the entire circuit is a loop and the lost electrons are eventually returned to the solar cells.

Solar panels are great for use on a colony. Due to the way they work, solar panels come with minimal complications for the colonists and require minimal effort to be kept running. Unfortunately the further you get from the sun the less light the solar panels receive and the less effective they become. Because of this solar panels will not be at all effective beyond Mars which cuts out a lot of the potential targets which are in orbit of Jupiter and Saturn. Even on Mars, they would need some help from other sources and should eventually be replaced or supplemented with a different source. Also, solar panels are unable to operate during the night so if a colony only used solar panels they would need enough battery storage to last the entire night. Solar energy is likely to be a colony's first energy source but will need help from other sources as the colony expands and energy-hungry systems like mineral processing are built.

Wind Power

Since there is no wind in space you may be wondering how this has anything to do with planet colonisation. Well actually there is one place they are useful: Mars. Mars does not usually have high wind speeds but during a sand storm the winds can get right up in to the

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[7] This section requires you to know much of the information in Appendix One on atoms and electricity (pg 71) so I suggest you read it if you haven't or even just to refresh your memory.

triple digits. During these wind storms solar power is not an option because they block out the sun, and since these can last for days or even weeks, this could be a serious problem. Wind power offers a perfect solution to this problem. Think about it. When a sandstorm is present wind turbines can power a colony and solar panels can operate the rest of the time. (Thank me later Elon Musk.) So how do they work? There are different designs of wind turbines but they all use the same principle to generate electricity: induction. Electromagnetic induction is using changing magnetic fields to generate an electric current inside a conductive wire. Inside wind turbines there are two sets of magnets and a coil of copper wire. One set of magnets is attached to the rotating part of the turbine and the other to the stationary shell. When the turbine rotates the magnetic field generated by the magnet constantly changes influencing the electrons on the copper coil, causing them move and generate an electric current. Like solar panels, wind power will need to be supplemented with more productive systems after a while.

Geothermal Energy

Geothermal energy works in much the same way as fuel burning power plants, and uses steam to turn large turbines. In the case of geothermal energy the heat to do this comes from the planet itself. The pressure that builds deep within a planet also generates a lot of heat which, if you drill down far enough (which isn't necessarily that far), you can use the heat to boil water into steam and generate electricity. Sometimes water isn't needed because steam is released directly from the heat point and can go straight to the turbines. Geothermal energy is only really viable on Mars and Venus because they are the only bodies big enough to produce enough heat for a geothermal energy plant. You may have noticed I am paying a lot of attention to Mars but I can assure you this is justified, as I show in my conclusion on the best targets for planet colonisation later in Part Three. Geothermal energy is a potential replacement or supplement for solar and wind power and could certainly be effective in the long term.

Fuel Burning Generators

Most of our electricity on Earth comes from large fuel-burning generators so it would make sense to use them on a colony right? Well when it comes down to it there aren't many places in our solar system that have the oil, coal, and gas that we use to power these generators; however, I may have an alternative. Earlier when I talked about oxygen and water I mentioned how hydrogen is produced in the electrolysis of water and could be used for rocket fuel. Well instead it could be burned to generate electricity.

Like wind turbines, fuel generators use induction to convert mechanical energy to electrical energy. The mechanical energy is also produced by a rotating turbine; however, this time the rotor is spun by water steam which is turned to steam via the burning of fossil fuels. Despite my previous statement about the burning of hydrogen these generators are unlikely to be a major power source for a colony. This is partially to do with the availability and potential of other more efficient energy sources and the fact that a lot of electricity is required just to get the hydrogen through electrolysis. I do, however, feel that it was necessary to address fuel burning generators given how much of Earth's electricity needs they provide.

RTGs

Earlier on I mentioned RTGs so I think I'd better cover them now. RTG stands for Radioisotope Thermoelectric Generator (it's a bit of a mouthful). Radioactive materials like uranium are constantly degrading, letting off radiation and more importantly heat. RTGs are able to convert the heat of the degrading material into electrical energy. To do this RTGs use a device called a thermocouple. A thermocouple basically consists of two different conductive materials joined together. When different temperatures are applied to the joints it generates a magnetic field which moves electrons and generates current.

RTGs have been used on many deep space probes because unlike other forms of nuclear generators they do not burn their fuel quickly and can continue to produce power for years as the radioactive material slowly degrades. Although they provide a reliable power source they are probably not suitable for a colony as their overall power output is too low and so is their overall efficiency (a high percentage of the heat energy is not converted to electricity). On top of this it is unknown whether enough of the radioactive materials needed to make more of these generators are available on other planets.

Nuclear Fusion

Nuclear fusion is a lesser known kind of nuclear reaction but it has the potential to form an extremely effective power source. Nuclear fusion is the fusing of atoms to form a heavier element. This reaction will only occur at extreme temperature and pressure like in the sun. That's right: we're trying to harness the power of the sun. When two atoms fuse it releases a massive amount of heat energy which can be harnessed to produce electricity (probably by producing steam for a turbine). This technology isn't fanciful: scientists have already built working fusion reactors and we have completed many nuclear fusion tests. Fusion reactors are not yet ready for generating electricity because they have a negative power balance (it still takes more energy to achieve fusion than is released in the reaction), but the technology is developing quickly.

Fusion reactors currently fuse hydrogen to produce energy and will likely do so in future, although it has been suggested that certain isotopes of helium could be used. There are two ways fusion has been achieved in the past. The first of them is to ionize the gases and use electromagnets to compress the ionized gas to the point of fusion. The second is to use lasers to heat and compress the hydrogen until fusion is achieved. Although it is not viable now it is probably just a matter of time until fusion energy is ready for use on the power grid. Scientists are constantly making small improvements to their systems and slowly getting closer and closer to achieving a positive power balance. Just recently MIT and a private company have agreed to work together to test a new technology combining special super conductive tape with magnets to lower the energy cost of achieving fusion. I have found many companies and scientific institutes which predict fusion energy will be viable within twenty years.

So what is the big fuss about fusion energy anyway? Well, if we succeed fusion energy may be the perfect energy source. First off fusion energy uses only a small amount of hydrogen which will be available on any colony due to the presence of water. Fusion energy also has the potential to be super efficient with most predictions of its success suggesting that it will eventually reach the point where it will produce up to ten times the energy used to achieve fusion. It also has no long lasting radioactive byproducts. I have heard a few suggestions that fusion energy may never be economically viable on Earth and while it may reach a positive power balance it will not catch up with other technologies; however, an overwhelming majority of other sources think otherwise. In any case this doesn't reduce its place in planet colonisation as the main methods of energy production on Earth are completely useless or much less viable.

Conclusion

Overall, energy production is much more of an issue than I previously thought, potentially even the biggest of all. The generation of electricity is certainly a limiting factor to the location, size, and success of a colony. After my research on this section I don't believe we will be able to colonise the outer moons of the solar system until fusion power is available because there is simply no other way to generate the vast amounts of electricity a colony would need. Electricity generation will not stop planet colonisation but will prove a significant issue and limiting factor.

Terraforming

So far I have been covering ways in which we might live in pressurized buildings, but there may be another way. We could try to make a second Earth. Terraforming is the idea that we would change features of another planet, mainly its atmosphere, to create an Earth-like environment and dismiss the need for other survival equipment. Terraforming would be a massive project requiring an immense amount of time and resources but it could have brilliant results. If terraforming succeeded, humans could live on another planet in larger numbers just like they do on Earth.

The terraforming process would vary greatly from planet to planet, making use of the different features of each planet. To give you an idea I will quickly go over a method that has been suggested for terraforming Mars. Mars has frozen CO_2 layered over water ice at its north and south poles. This could be melted using nuclear weapons or large mirrors in space reflecting light onto the poles. When this ice melts it would release CO_2 into the atmosphere and cause a greenhouse effect. This greenhouse effect and thickened atmosphere would raise the temperature and pressure to levels where humans could survive. At this point the atmosphere would mainly be made of CO_2 and we would need oxygen to breathe. To produce that oxygen plant life can be introduced to the planet's surface processing the CO_2 and releasing oxygen. This entire process would be extremely difficult and costly to complete and it could take a thousand years for the atmosphere to settle. With our current technology we are unable to complete a project such as this.

There are even more problems with terraforming another planet. Ignoring the immense effort and difficulty of terraforming, there would in fact be no point terraforming any of the planets or moons in our solar system. Other than Earth all of the planets and moons lack a magnetic field which keeps away a lot of the radiation that would normally reach the planet's surface. This is important for a few reasons. One, any place with an atmosphere the equivalent of Earth's wouldn't be able to stop that much radiation without a magnetic field and a lot of it would still reach the surface. Two, one of the types of radiation our sun releases is in the form of charged particles and is called solar wind. Earth's magnetic field completely deflects the solar wind around our planet so we don't have to deal with it; however, if solar wind strikes a planet, the particles from the sun collide with particles in the atmosphere and remove them from that atmosphere. This doesn't mean that they can't have any atmosphere; they just can't have one like Earth's.

Mars is at a point where the atmosphere is thin enough and held tightly enough that it can just retain what it has and no more. Venus is able to hold its thick atmosphere through an interesting interaction between the atmosphere and solar wind. This interaction causes the higher reaches of its atmosphere to be ionized and produce its own magnetic field. If the atmosphere was thinned to survivable levels it would lose this interaction and whatever atmosphere it was left with. Previously I stated that Callisto and Ganymede are protected by Jupiter's magnetic field but they still can't benefit from an atmosphere. This is partially because they are too far from the sun to capture enough heat for humans to survive on the surface and also because their gravity is too low to hold a full atmosphere.

So even if we could terraform, which is currently a long way off, it would have no point within our solar system because it is an expensive time consuming task that doesn't work properly and the results of which will eventually be taken away by the Sun's solar wind. Outside of our solar system terraforming could see use depending on what targets we found. Despite the huge scale of terraforming projects, by the time we can transport humans between solar systems we will definitely have the capability to terraform some planets with favorable features. In conclusion it is very unlikely that we will use terraforming within our solar system but we could potentially in others, in the more distant future of planet colonisation.

A concept for a terraformed Mars.

So Where is the Technology at?

So where are we at in terms of the technology of living on other planets?

When it comes to water and oxygen systems my overall conclusion is that the technology is ready and available and will not be a problem going forward. For food I conclude that we have the technology we need but it takes up a lot of space and it will take a while to build the required area for food production. We will be able to build the living spaces we need although the construction techniques would need to be adapted for operation in different environments. I have also concluded that we have most of the technology we need for the extraction and processing of a planet's resources but these will still need some development. Finally it is clear that some time and money needs to be put into the development systems for the generation of electricity because currently it is actually one of the biggest technical problems. All in all, while we already have the basis of most of the technology we would need to build a colony on another planet, it could all use some refinement.

I predict that if we continue at our current rate of development, all of the technology could be ready in some shape or form within a few decades. That is not to say the beginnings of a colony couldn't be built before then or that the colony would become self sustaining at that point. It is simply a timeframe that I think is realistic for when the technology for a self sustaining colony could be ready for use.

Of the possibilities for colonisation, the most viable location is probably Mars. As I covered in Part One, Mars has plenty of water and as I have looked at in Part Three, it also has lots of mineral resources. There are plenty viable ways of generating power on Mars and it is the second closest planet to Earth, offering a short transport time and a slightly lower cost. For these reasons I think that Mars is the place with the least technological problems when building a self-sustaining colony.

The only other place I think we have the technology for colonising is the Moon. Further exploration of the Moon's water ice is necessary but it is much the same as Mars when it comes to its supplies of ice and other resources. Furthermore it is much easier to get to than anywhere else in the solar system, reducing the cost of building a colony. In all the Moon is probably the cheapest location to build a colony but will require greater development of survival technology than Mars.

Currently all the other planets and moons would require technology we aren't so near to having to be successful. Were we to colonise the outer moons of the solar system we would need much better transport techniques to collect resources from places near the colony as well as fusion electricity. Also these moons lack a lot of features like the essential plant nutrients and some important minerals. We are very unlikely ever to colonise Mercury and Venus due to the various attributes of both planets (mainly related to heat).

On an undefined timeline it is obvious that planet colonisation will be well within our technological ability but, as I said before, we may be ready much sooner than that. For the economic reasons I covered in Part One, human presence on another planet may not be self sustaining for decades after the technology is available. The technology of planet colonisation is not something of the fanciful future and the next few generations will be the ones who begin our expansion into space.

Part Four

Big 'So What' Question Answered and Appencies

Big 'So What?' Question Answered

So what are the chances of humans colonising other planets? In answering this question I looked at whether or not we should colonise other planets, what is happening now, and where we are at with the technology, to get a sense of whether we might actually colonise other planets any time soon.

When it comes to whether or not we *should* colonise other planets I found that the main benefits were the increased chances of survival of the human race, from threats such as climate change and nuclear war. In addition to an increased chance of survival, planet colonisation offers economic potential, with access to large amounts of titanium and other rare minerals. The main downside to planet colonisation is the immense cost. Once planet colonisation becomes profitable, however, this will no longer be a problem.

There are potentially ethical, political, and legal problems involved with building a colony in space. These, however, are not inherent to planet colonisation and are problems that can be solved. Past UN treaties have made it illegal for people to claim sovereignty over anything in space. Recently though we have seen a careful adjustment of these laws, with people and companies being allowed to use and sell resources, as long as they do not claim any territory. In coming years it is likely we will see more action of this kind, but it needs to be careful because the subject of claiming land has been very contentious over recent decades. Agreements around the use of Antarctica are a very good example of this.

When it comes to technology I found that we are surprisingly close to being able to get to other planets, and to being able to live there. This is mainly thanks to the great work of NASA. Although they are not pushing for planet colonisation (and they aren't making headlines like Elon Musk), over the years they have been responsible for the development of many technologies we would need in space. Most of the technology we would need is ready now or only requires slight development of what we have before it can be used. Technology for propulsion is already available but it could do with significant improvement to bring down costs, the technology for water and food needs very minimal development, the technology for resource extraction and processing needs a bit of development, and the technology for habitat construction probably needs the most work. In the end I concluded that it will only be a matter of decades until the technology is ready.

One thing I have noticed while researching this topic is that some people such as Elon Musk are especially drawn to planet colonisation. I think this is because planet colonisation appeals to two of our most basic instincts: our instinct as a living species to survive and to spread our species, and our instinct as humans to push the boundaries of what is possible and to be drawn to the new and revolutionary. These are not instincts I think we should distance ourselves from. In fact I would say that these instincts are part of what makes us human.

These instincts have driven people to achievements such as the colonisation of New Zealand, both by Polynesians and Pakeha, and other feats, such as the conquering of Mount Everest and Ernest Shackleton's exploration of Antarctica. Planet colonisation is the next frontier.

One interesting argument I have heard against planet colonisation is the idea that staying on Earth despite problems with survival would be a noble end for the human race. Some people argue that this would be better than using up the resources of the solar system for our own benefit, especially given our selfish, destructive tendencies. I personally do not agree with this argument. First and foremost could we not do more good to the universe and other life by surviving and helping other species to survive, be sustainable, and coexist peacefully? Also, why should other possible life, life that we don't even know exists, have its survival and prosperity take precedence over our own?

Based on my investigations, I think that within the next 20-30 years we will see increased activity working towards planet colonisation but we are unlikely to 'colonise' as such in this timeframe. It is likely that we will only set up temporary or maybe permanent research bases on other planets. This is because planet colonisation will not yet be profitable (the cost to transport materials between planets is still too high) and because, as I said earlier, the technology will not be ready for about this period of time. After that point we may see some people exploring in the economic direction, looking at their options and sizing up their competition. I think this is likely to come with the proliferation of new transport systems like the BFR and the Deep Space Gate, plus the completion of most of the technologies we will need. It is very hard to predict the future, but based on what I have found throughout my Independent Study, I think it will be about 50-80 years until we see obvious economic opportunity in space. This will come as mineral reserves on Earth begin to run out, and transport through space is taken over by cheaper systems, maybe the step up from the BFR or a system like the Deep Space Gate. On top of this the technology for living there should be more than ready by this point. Once planet colonisation is profitable, I believe we will build self-sustaining colonies on other planets.

So, will the dreams of Elon Musk and Stephen Hawking come true? Will the topic that has captured the imagination of so many become a reality? Will humans build self sustaining colonies on other planets? In conclusion, we almost certainly will. The benefits are too good to ignore and people will be trying to do it as soon as they can make a profit.

I'll see you all on the red planet.

Appendix One: Atoms and Electricity

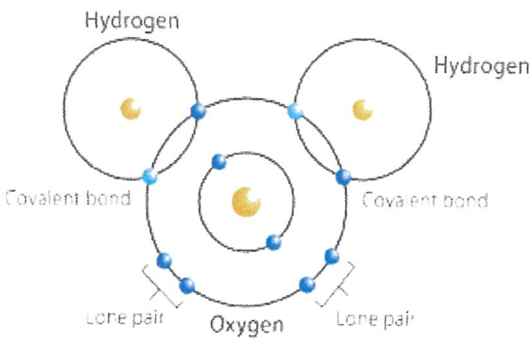
Some of the people reading this Independent Study will already have an understanding of how the world works at an atomic level. Others of you won't so hopefully I can explain to you here.

Atoms are made up of three different particles. Electrons, protons and neutrons. Protons and neutrons clump together at the center of an atom to form a nucleus while electrons form shells around it. Protons hold a positive electric charge and electrons hold a negative one. In keeping with their name, neutrons are neutral. The number of protons in an atom determines what element it is (different elements are different types of atoms) and will not change under most circumstances. On the other hand electrons can be transferred and shared by bonded atoms. An atom is considered to be in its natural state when it holds a neutral charge. For an atom to hold neutral electric charge it must have one electron for every proton. If an atom has one more proton than electron it has a positive charge. An extra electron gives it a negative charge. If it has a charge it becomes an ion. Opposite electric charges attract and the same charges repel. This means that electrons and protons can react individually to charges. Atoms are represented on the periodic table at neutral charge. Each atom's atomic number is the number of protons it has and subsequently the number of electrons.

Atoms always try to achieve a full valence shell of electrons. Let's speak English. The electrons around an atom form layers or shells. The inner shells must be full before another one can form. The valence shell is the outermost shell of electrons. Having a full valence shell of electrons is the most stable state of an atom, even if it leaves it with an electric charge. The number of atoms in the valence shell depends on what layer it is from the nucleus. The first layer can hold two, the second eight, and so on. This valence shell can be achieved through atomic bonding which is most commonly ionic or covalent.

In ionic bonding, electrons are transferred between the atoms. An atom which needs to get rid of electrons gives them to an atom which wants to gain them. One of the best examples of this transfer is the interaction between a natural sodium and chlorine atom. In its natural state sodium has one electron in its valence shell which it wants to get rid of, chlorine has seven in its valence shell and needs one to make a full valence shell of eight. When they interact the electron from sodium's valence shell is transferred to the chlorine giving it a full valence shell. When sodium sheds the one electron of its outermost shell the next layer down becomes its valence shell, which is full. It is important to remember that both atoms are trying to achieve a full valence shell; this interaction would not be the same if they didn't both finish with a full valence shell. After they transfer electrons they are bound together to form a compound.

The other most common form of atomic bonding is called covalent bonds. Covalent bonds are where atoms which need more electrons share their electrons with each other. One extremely common example is water. Water is comprised of one oxygen atom and two hydrogen atoms.



In its natural state oxygen needs two electrons to fill its valence shell. Hydrogen needs one electron to fill its valence shell. In this bond each hydrogen atom shares its electron with the oxygen, giving the oxygen a full valence shell. At the same time the oxygen shares one electron with each of the hydrogen atoms giving each of them a full valence shell.

A diagram of a water molecule.

Covalent and ionic bonds aren't the only way atoms bond: there are also metallic and hydrogen bonds. Metallic and hydrogen bonds apply to a very limited number of situations so I will ignore them in this section.

Although atoms always strive to achieve a full valence shell sometimes they can be forced to lose or gain electrons without bonding. If enough energy is applied to the atom electrons can break loose of the nucleus. If an atom does not wish to lose an electron it is harder to make it do so. One example of forced electron loss is in solar panels. In solar panels there are pieces of silicon. One has extra electrons and is negatively charged, the other has one less and is positively charged. When light strikes the negatively charged silicon it transfers energy into that ion and causes extra electrons to break loose.

Electricity takes advantage of the attracting and repelling forces of atoms. When a current runs through a wire it is actually a transferring of electrons through a conductive material. A conductive material has something called a low band gap. A low band gap means that very little energy is required to make it lose an electron. If an electron flies into an atom with a low band gap it may attach to that atom but another one will get forced out. That electron then flies to the next atom in the wire and knocks an electron off that one, and so on. We can make these electrons pass through special contraptions where their energy can be converted into other forms such as heat or light.

In electric circuits there does need to be some electric difference. At one end there needs to be a positively charged material and at the other a negative. This means that the electrons being bounced off atoms will move to the positive end. This keeps the electrons moving predictably so we can enslave them and drain their energy to produce our heat and light.

So I hope this has given you a better idea of how atoms interact and that it will help you understand the rest of my Independent Study.

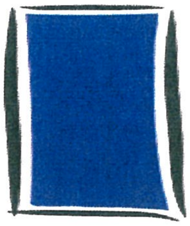
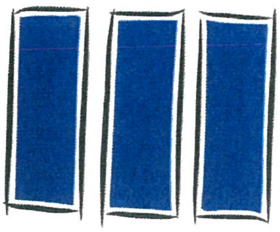
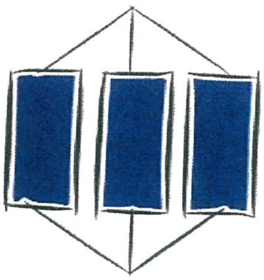
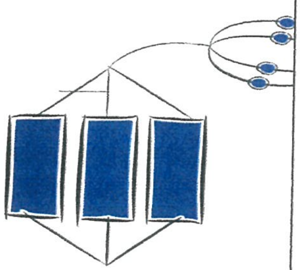
Appendix Two: Peer Questions

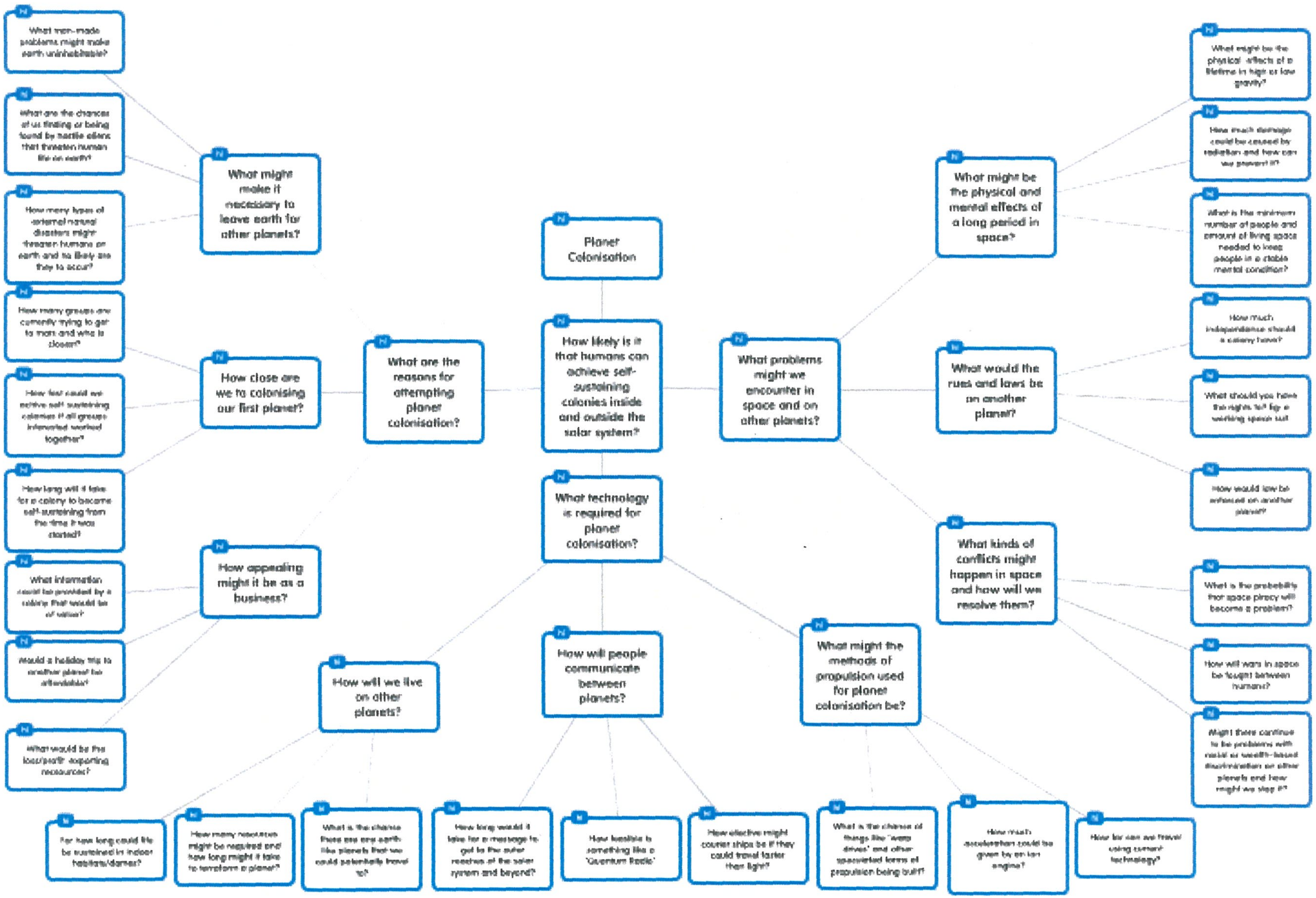
- Peer Questions 2018	
Benji Allcock	Q: What planet do you think will be colonised first? A: Mars if you are talking about planets, but the Moon may come first.
Ashan Bernau	Q: Which two planets do you think we will colonise first? A: Mars and the Moon.
Ben Brunner	Q: What is the biggest planet? A: Jupiter
Gatsby Cohen	Q: Will humans stay, or fund planet colonisation? A: It is very likely that we will eventually fund it.
Nikhil Cox	Q: How important is planet colonisation? A: In the short term it may not be of immediate importance but in future it has benefits that can not be ignored.
Arthur Fell	Q: How long do you think it will be before we do it? A: See Big 'So What?' Question answered
Malachy Holborow	Q: What are the risks behind planet colonisation? A: There are economic risks for any company looking to profit in space and some safety risks, although those aren't super big.
Oscar Horne	Q: How close are we to colonising a planet? A: See Big 'So What?' Question answered
Rishi Kharkar	Q: How many people could we put on Mars? A: If you are talking about transport, right now we could put a few people on Mars for 90 million dollars with the Falcon Heavy. That would only be getting them there and not sustaining them. If you are asking how many people Mars could sustain it would be a few hundred million, if not a billion.
Max MacLachlan	Q: How do you think it's going to happen? A: See Independent Study 2018, Planet Colonisation, by Henry Isac.
Ben McLanahan	Q: Do you think SpaceX will help planet colonisation? A: The SpaceX BFR will be essential to any big colonisation or settlement attempt within the next couple of decades, due to its launch costs.
Miles Moir	Q: Is planet colonisation a likely future? A: See Big 'So What?' Question answered.
William Adams	Q: Is *The Martian* an accurate representation of what planet colonisation could be like? A: In *The Martian* Mark Watney is there for a temporary scientific mission so it is not quite the same, although it does represent some of the risks (if slightly exaggerated).
Daniel Andrews	A: Will Breakthrough Starshot kickstart planet colonisation?

	Q: It will be the first step to planet colonisation outside of the solar system but we will likely colonise planets within our solar system first.
Hugo Cohen	Q: Why is it needed? A: See Benefits of Planet Colonisation in Part One
Xandi Cooke	Q: How long until we colonise our first planet? A: See Big 'So What?' Question answered.
James Hargreaves	Q: Which planet is the best candidate for colonisation? A: Mars.
Henry Isac	[redacted]
Joshua Langford	Q: When will planet colonisation become vital to stop extinction? A: This is an unknown but Stephen Hawking said it would be within 100 years.
Eddie Lethbridge	Q: How many planets are candidates for planet colonisation? A: Realistically Mars is the only planet we have a chance on in the forseeable future but there are many moons, including our own, which we could colonise.
Jack Pettit	Q: Are Elon Musk's ambitions realistic? A:His timeline for getting people on Mars by 2022 is certainly not but I think he probably will achieve his goals eventually.
Jack Riley	Q: When is planet colonisation going to happen? A: See Big 'So What' Question answered
Barnaby Stevens	Q: How could planet colonisation impact the chance of humans surviving? A: It gives us a chance of survival, especially against sudden events such as nuclear war or an asteroid impact.
Aarnav Tonpay	Q: What is the effect of SpaceX? A: SpaceX are building a transport system which could bring the costs of planet colonisation down massively and really make it something to consider.

Appendix Three: SOLO Taxonomy

Topic: Planet Colonisation

Unistructural 	• Define a sustainable colony. • Identify the essentials to human life and the quantity of each. • Find the price per kilogram of cargo launched to Mars. • Find the percentage of planets/moons that have water or the means to make it. • Find the specifications of the SpaceX BFR and how much it might cost. • List the different stages of colonising a planet.
Multistructural 	• Compare the different companies/agencies looking at planet colonisation. • Outline what we know about the physical and mental effects of being in space and what the effects might be living your entire life on another planet. • Make an educated guess/decision on how fast we could achieve our first colony if people worked together. • Analyse data and form an opinion about whether if it might be viable to grow food or a spacecraft. • Interview someone from NZ Rocket Lab. • Interview an someone knowledgeable about quantum physics. • Identify reasons for attempting planet colonisation.
Relational 	• Perform a case study of SpaceX's plan for planet colonisation. • Compare the different forms of propulsion that might be used to reach other planets. • Compare the different ways humans could live on a planet eg: Habitats, terraforming. • Debate whether it is worth attempting planet colonisation. • Argue on whether or not we will find intelligent alien life on other planets. • Highlight the reasons why people will not unite to tackle planet colonisation together. • Compare the potential profits of exporting rare metals to earth and the probable cost o transport. • Compare SpaceX, NASA, and Mars One's plans to get to Mars.
Extended Abstract 	• Formulate my own plan for colonising Mars. • Make a feasible concept design for a 'quantum radio'. • Suggest a long-term plan for colonising planets balanced against problems on earth. • Form a detailed, informed idea of what laws should be made about space travel and planet colonisation. • Give my own ideas on how pressurised area, and resources should be used to balance efficiency and comfort.


Planet Colonisation
How likely is it that humans can achieve self-sustaining colonies inside and outside the solar system?
What are the reasons for attempting planet colonisation?
What problems might we encounter in space and on other planets?
What technology is required for planet colonisation?
What might make it necessary to leave earth for other planets?
How close are we to colonising our first planet?
How appealing might it be as a business?
What might be the physical and mental effects of a long period in space?
What would the rues and laws be on another planet?
What kinds of conflicts might happen in space and how will we resolve them?
How will we live on other planets?
How will people communicate between planets?
What might the methods of propulsion used for planet colonisation be?
What man-made problems might make earth uninhabitable?
How many types of external natural disasters might threaten humans on earth and how likely are they to occur?
How many groups are currently trying to get to mars and who is closest?
How long will it take for a colony to become self-sustaining from the time it was started?
What would be the loss/profit supporting resources?
What might be the physical effects of a lifetime in high or low gravity?
What is the minimum number of people and amount of living space needed to keep people in a stable mental condition?
What is the probability that space piracy will become a problem?
How will wars in space be fought between humans?
How many resources might be required and how long might it take to terraform a planet?
How long would it take for a message to get to the outer reaches of the solar system and beyond?
How feasible is something like a 'Quantum Radio'
How effective might courier ships be if they could travel faster than light?
How far can we travel using current technology?

Independent Study Topic Selection Matrix 2018

Catagory	Topic	Focus	Interest	Challenge	Info available	Relevance	Sustainability	Total
Science/Exploration	Planet colonisation	Self Sustaining Colonies	11	10	8	10	10	49
Psychology	Sharks	Mr Tait's examples	10	10	1	10	10	41
War	WW1-WW2	Perception of War	10	10	9	9	9	47
Technology	The Internet	Information Online	5	8	10	10	6	39
Civilisations	Myths and Legends	Multipule Myths on one Event	8	7	8	8	7	38
History	Romans	Carthiginian Campaign	9	8	8	7	9	41
People	Language	Evolution of Speech	6	5	7	6	6	30
History	England	English Civil War	9	8	9	9	9	44
History	Napoleon	Penisular Campaign	8	8	8	7	7	38
Science/ Engineering	Transport	Future of Electric Transport	8	7	6	8	7	36

Key

First Place

Second Place

Third place

Rated From 1-10 **Henry Isac**

Appendix Six: Key References

Interviews:

Ken Keith - Thank you to Professor Sir Kenneth Keith for an interview surrounding law in space.

Yvette Perrott - Thank you to Dr Yvette Perrott for an interview about some of the planets in our solar system, terraforming, and a range of other topics.

Books:

***Destination Mars* (2017) by Andrew May** - This book helped me greatly when it came to understanding rockets and travel through space. It also provided some information on the technology for living on another planet.

***The Future of Humanity: Terraforming Mars, Insterstellar Travel, Immortality and Our Destiny Beyond Earth* (2018) by Michio Kaku** - Although most of this book is fixed on the distant future of humanity, it held a lot of great information on current plans for planet colonisation, details about some of the planets of our solar system, and why we should colonise other planets.

***Elon Musk* (2016) by Ashlee Vance** - This book did not help as much as I would have hoped but it did provide some information about Elon Musk's plans to colonise other planets.

***Controls for Outer Space and the Antarctic Analogy* (1959) by Philip Jessup** - This book was very helpful when it came to law in space. The entire thing is actually comparing the legal intricacies of Antarctica with those of outer space.

Noteworthy Key Websites:

The NASA Website: https://www.nasa.gov/ - The NASA website has hundreds of pages that have been of great help all through the year with information on Planets, Rockets, and other technologies.

Wikipedia - Who could forget Wikipedia? Although it may require some fact checking it holds vast amounts of information on just about any topic.

Other Key Websites:

These are not by any means all of the websites I have used, but are instead the ones that were most crucial to my study.

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Websites Providing Information About Other Planets:

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Websites Providing Information About Treaties, Law, and Ethics in Space (with thanks to Sir Kenneth Keith):

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Websites Providing Information on Rockets and Space Travel:

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