Project: MH1505

Humanity and Space

An Interactive Qualifying Project

Submitted to the Faculty
of
WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the
Degree of Bachelor of Science
By

Justin Canas

George Pytlik

Samantha Monte

Submitted to Professor Mayer Humi

March 6, 2015

Abstract

Space exploration is motivated by our desire to ensure the survival of the human species and commercial enterprises. To avoid extinction and maintain quality of life of the human species, humanity has to experiment with colonization and manipulation of our Solar System. Commercial enterprise includes technological advancements, communications, and new sources of energy available throughout the Solar System and to the benefit of humanity. This project explores all of these possibilities, provides guidelines, and a vision for the future.

Authorship

Our project team consisted of Justin Canas, George Pytlik, and Samantha Monte. The contents of the paper were divided between the three project members. However, due to the collaborative nature of the IQP, all members were involved in the editing and revision of the project.

We certify this final report can be considered a group effort.

____

Justin Canas

____

George Pytlik

____

Samantha Monte

Table of Contents

Table of Figures

Executive Summary

We make up only a very small portion of our amazing Solar System. Space is still seen as the final frontier and has been fascinating humans since the dawn of time. There are still many aspects of our Solar System that have yet to be explored and many questions left unanswered. Not only are we looking to continue our exploration deeper into our Solar System but we are now looking to answer today's questions with space. This paper will explore the history of our understanding of space, new technology and today's endeavors, potential missions in space, and how space will benefit all of humanity.

In order to get a complete understanding of the current space technology and how we were able to have a presence in space, the history of astronomy and the space race had to be explained first. We can thank the Ancient Sumers and Greeks for our foundation in astronomy. The Ancient Sumers were the first to discover that five planets were visible from Earth; Mercury, Venus, Mars, Jupiter, and Saturn. The Ancient Greeks were the first to present the idea that the Earth is round and floats in a three dimensional space without support. Other famous astronomers' and scientists' work, such as Aristotle, Nicolaus Copernicus, Galileo, and Goddard lead to amazing technological advances in the space industry and lead us to where we are today.

Once we established how humanity entered space, we began to focus on how space can benefit humanity. Space is being seen as a new, vast source of resources for here on Earth. One resource is the infinite amount of solar energy that can be harvested for useable electricity to solve the energy crisis on Earth. Solar powered satellites (SPS) are being designed to be launched into space and beam down solar power in the form of a beam to receiving stations on Earth. Helium-3 (He-3) found on the Moon is another energy resource that we can use to solve the energy crisis. He-3 is thought to be the best helium isotope to be used in a fusion reactor to

create clean energy. New forms of energy are not the only way that space can benefit humanity; advancements in robotics will be advantageous for assisting astronauts in space but also for help with paraplegics on Earth. Humaniod robots, such as Robonaut 2, and exoskeletons will be able to assist astronauts in either dangerous environments or with combating microgravity. They will also be able to assist the elderly and be used for mobility assistance on Earth.

With these advancements happening today, we began to shift our focus on to the future and where we will go next. Colonization of outer space may be inevitable one day with global warming and the exponential growth of the world population. Being the closet celestial body to us, a blueprint for a colony on the Moon was drafted. With new interest on Mars, we also explored the best location for a colony on Mars and also teraforming the planet for our needs. Our celestial bodies, Venus and Mercury, were investigated for potential colonization, teraforming, or for new resources.

Expanding our world past Earth also brought about an interest in new forms of life. The question of whether we are the only life in the Solar System is examined. Fermi's paradox states how could we never been visited before if other life exists. There are many stars and star systems that are more ancient than ours. If another life form exists in these systems, are they not capable of visiting us just as we can't explore deep into our own Solar System. Has the reason we have not been in contact with other life form because there has been a catastrophe on their planet? Is that a premonition of how our Earth will end? These unknowns are all the more reason to be searching for new homes for humanity to be prepared for any catastrophe that may happen ot Earth. Extraterrestrials are not the only new life form that we discussed but also where bio-engineering will take us in the future.

There is no doubt that exploring space can bring endless benefits to life on Earth. Whether it is in the form of new technology, new energy, or a new place to call home, the need to continue research and missions into space is great.

Introduction

In the course of human events, it becomes necessary to look towards the future and ask "where do we go from here?" Technology on Earth has exploded into an exponential growth of innovation in the past few decades. It was but 60 years ago that we came to realize the dream of space exploration, motives aside. In recent years, many space programs have aimed towards the sky with much greater goals than simply landing on the Moon as an exhibition of power.

Slowly but surely, the safety of the world as we know it is unraveling before our eyes. Some say ignorance is bliss, and perhaps it is true; with the knowledge we have attained in these past decades, so too have we gained knowledge of all that can destroy us in the blink of an eye. Global problems such as climate change, unsustainable energy sources, and the possibility of an asteroid crushing our species has confirmed that we are not as untouchable at the center of the universe as we once thought a few centuries ago. We are running out of land for cultivation and our population is quickly growing out of proportion in terms of what the Earth can handle.

These issues encompass all of humanity, regardless of the divisions we presently draw. Unfortunately, these are not the musing of the common man. Only a very small subset of people think about these problems that face us; an even smaller subset has the ability to do something about. Indeed, the issues that have been presented are on the scale of governments to solve.

Currently, many projects involving space have a narrow scope with immediate returns. Humans regularly send probes and rovers for reconnaissance but plans to send actual human settlers have been far and few between, with very large time scales; none of which are currently in the stage of sending humans. There exists limited research in the area of human exploration and colonization of space, as well as in the area of manipulating the Solar System; our home for the near future.

This paper aims to bring to light applicable technology for the human exploration and eventual colonization of our Solar System. It also aims to apply these technologies to humanity as a whole on Earth. The research started by laying a basis by exploring the obstacles space presents to biological creatures, and identifying technologies as solutions to these obstacles. This is done with the intent to provide information to anyone wishing to attempt the grand effort involved with sending humans into space for an extended duration of time. It is the goal that such efforts will ensure the long-term survival of the human race, and help to maintain quality of life for the foreseeable future.

I. History

A. Ancient Philosophy

In this day and age, the everyday person living in a developed nation knows at least a little bit about space. The space race is over and now every country from India to Japan frequently sends missions into space. It was not always this way though; the technology we have is often taken for granted. Just sixty years ago, there was a monumental struggle to achieve space-flight. Fueled by the cold war, both the Unites States and Russia had a bitter race to be the first country to conquer the unknown frontiers of space. This is the recent future that most people know and discuss. Neil Armstrong's words as the first man on the Moon at the conclusion of this race are iconic and known by almost every household today. This was simply the last leg in a long journey however. In reality, these achievements were the culmination of thousands of years of scientific discoveries and theories. As with most human achievement, the knowledge that allowed us to achieve space-flight was built upon thousands of years of prior experience.

This experience was not by random chance. It was the trial and error of generations upon generations of scientists and philosophers. The people of Ancient Sumer were the first astronomers. They were aware of the five planets visible to the naked eye (Mercury, Venus, Mars, Jupiter, and Saturn). The Greeks preceding recognized this, but the Sumerians most important contribution. The Sumerian calendar featured a 29-30 day lunar month, with a month every four years to adjust that was similar to the Gregorian calendar, but the main thing is that it had 7 day weeks and 12 months just like we use today. Sumerians, and later Babylonians, also left primitive star chart engravings.

The next great era of cosmology came from the Greeks. The revolutionary idea that changed the way people thought about space, which is sometimes referred to as the first cosmological revolution and the starting point of scientific thinking [1] is the realization that the Earth is round and floats free in a three-dimensional without falling and does not need to be resting on something. This idea comes from the Greek philosopher Anaximander (611-547 B.C., Greek). While it may seem trivial there is never an end result without a starting point. Aristotle (384-322 B.C., Greek) later refined the idea to "the Earth is spherical" as opposed to round. Aristarchus of Samos (310-230 B.C, Greek) was the first to put forth the idea that the Sun is the center of the universe and that the Earth is not He also made inaccurate measurements on the

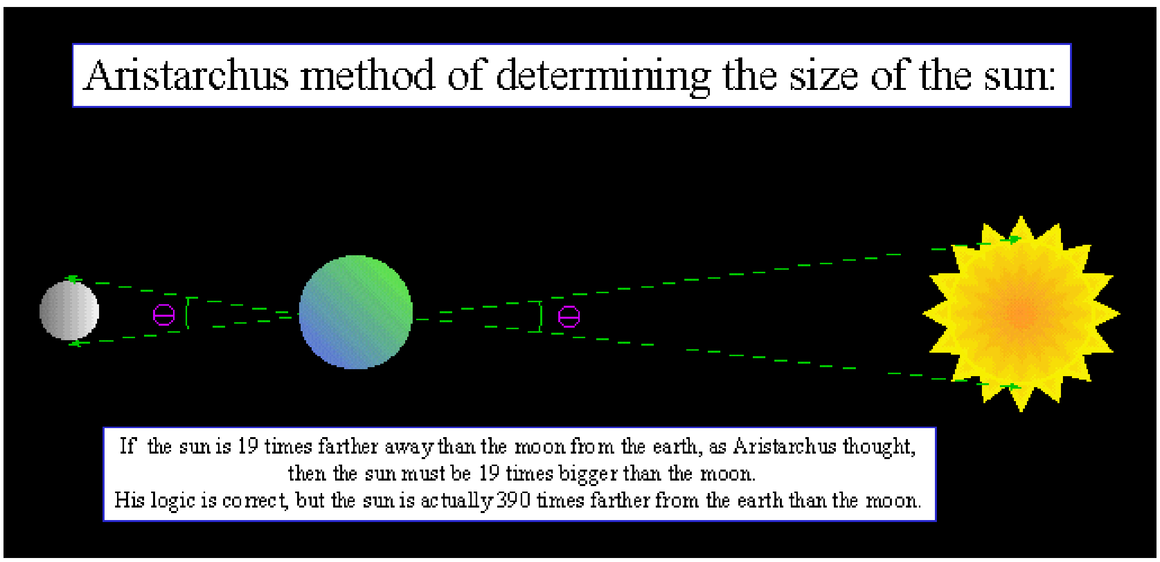

FIGURE 1: ARISTARCHUS METHOD OF DETERMINING SIZE OF THE SUN

[132]

distance between the Sun and Earth due to inadequate technology at the time. He deduced that when the Moon is half full the angle adjacent to the Moon will be a right angle with respect to the Earth and Sun. His incorrect calculation of the angle adjacent to the earth of 87 degrees led to the ratio of 1/19.

Eratosthenes (276-194 B.C.), on the other hand, was able to fairly accurately calculate the circumference of the Earth around the same time that Aristarchus lived. Heliocentricity was not accepted at the time and it was 1,750 years before the theory was again considered. Hipparchus (190-120 B.C, Greek) contributed a catalog of the skies and an accurate star map. Hipparchus's extensive work was used by Ptolemy (85-165 A.D., Greek) to create the Ptolemaic system which placed the Earth at the center of universe. This model overshadowed Aristarchus's and was upheld for 1,500 years as the cornerstone of astronomy mainly due to the church. At this point in time, orbits were still conceptualized as circles. If we had not experimented and found the exact

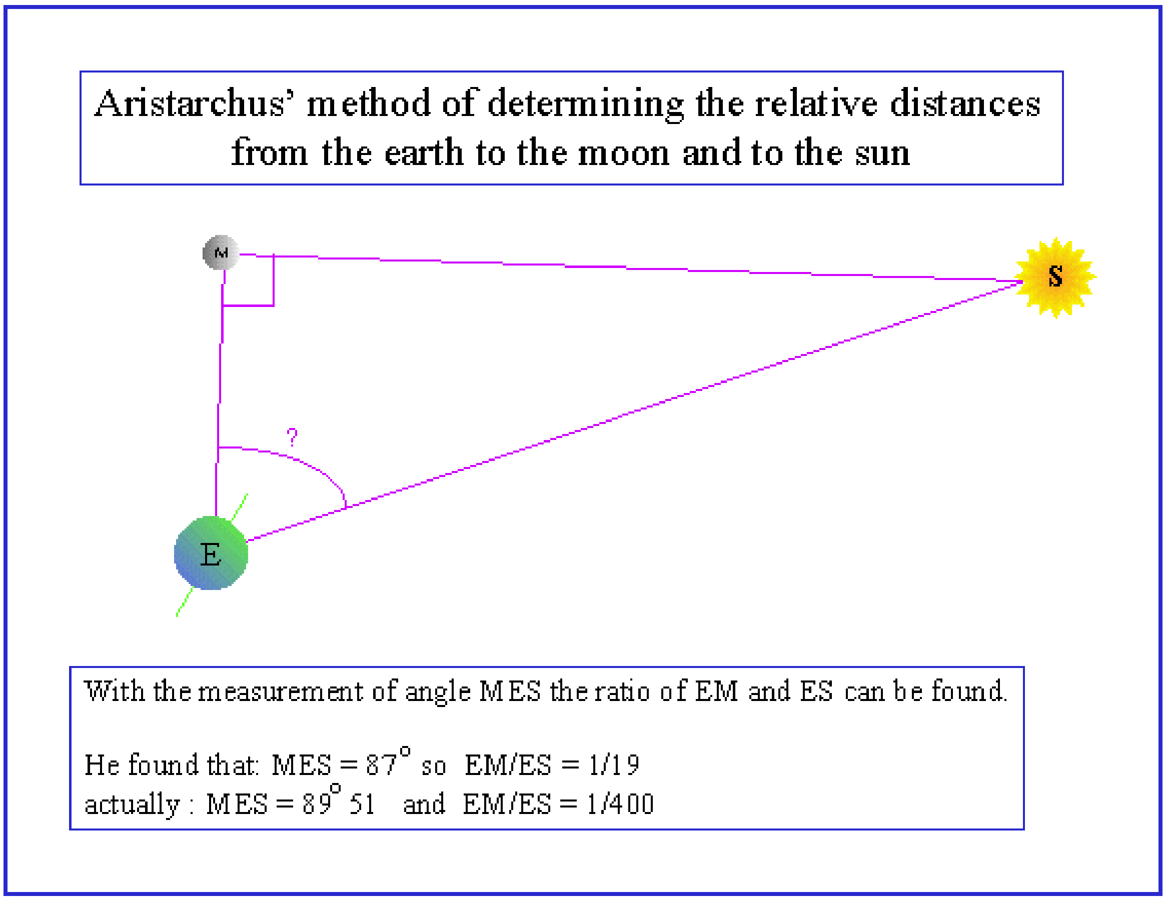

FIGURE 2: ARISTARCHUS' METHOD OF MEASURING THE DISTANCE FROM THE EARTH TO THE SUN AND MOON [132]

orbits, our calculations would have fallen short for many of our space endeavors. The Greek's made significant contributions to astronomy and science over the course of almost 1,000 years and many generations from 611 B.C to 165 A.D.

The Greeks also have numerous myths involving the cosmos that their daily lives revolved around. One myth in particular is the Sun being dragged across the sky. One that perhaps was not so every day, but stands out nonetheless is the myth of Icarus. Icarus is the son of the famed inventor Daedalus, inventor of the Labyrinth to imprison the Minotaur. Daedalus and Icarus were imprisoned in Daedalus' own Labyrinth and forced to work for King Minos. Daedalus was not one for captivity, so he built wings out of feathers and attached them with wax to the backs of him and his son. During the flight Icarus, enthralled by his new freedom and abilities, flew too close to the Sun. The wax melted, his wings fell off, and he fell into the ocean; a lesson for us all.

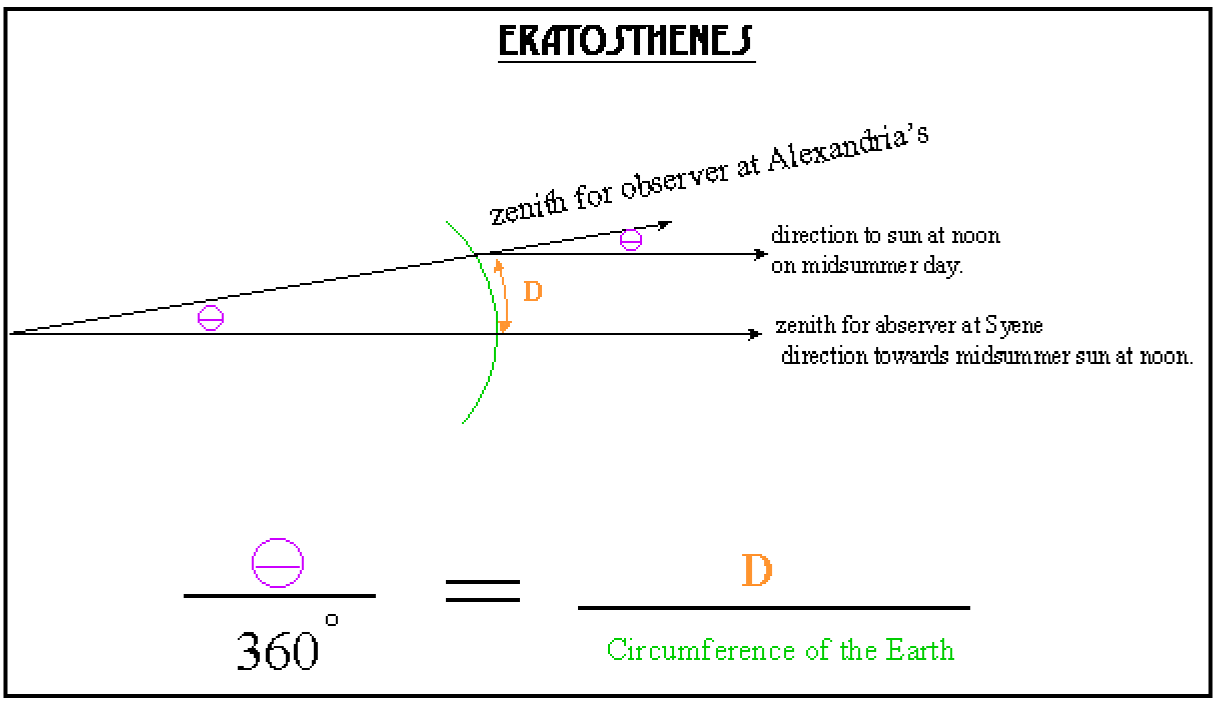

FIGURE 4: ERATOSTHENESE EQUATION FOR THE CIRCUMFERENCE OF THE EARTH [2]

The next great contribution is from al-Khwarizmi (780-850, Islamic). Al-Khwarizmi in hailed as the inventor of algebra, and when his work was translated into Latin hundreds of years later, the Europeans were introduced to the Indian number system (Arabic numerals) and the concept of zero. The medieval times were a dark time for humanity where science and progress grinded to a halt in much of Europe until the Renaissance. Despite this, there were still observatories built intermittently in the Middle East and Asia since the Arabs and Chinese continued with their observations. The earliest record of a supernova is in 1054, hence the name SN 1054 A.D, where it can be found in a Chinese record. In 1259 A.D., an observatory was built in Iran for Nasir al-Din Tusi (1201-1274 A.D, Iran). Nasir used the observatory to make accurate tables of planetary motion. Ulugh Beg (1394-1449 A.D, Persia) was another astronomer that had an observatory built. Ulugh Beg catalogued over 1,000 stars accurately and published them in a book. Stars were used for navigation on land and sea at the time; one could tell direction with stars and mapping them had practical uses.

It was not until around the 1500s, that Nicolaus Copernicus (1473-1543, Polish) began a new era of astronomy for Europe by proposing to a very church-centric world that the Sun is the center of the universe, not the Earth. Copernicus' ideas were not very popular due to the lack of separation of church and state and as a result Copernicus died without validation, but the idea was still in the air. Shortly after Copernicus's death, Galileo Galilei (1564-1642, Italian) heard talk of the Dutch invention of telescopes in 1608 and a year later in 1609 he put the telescope to use for astronomical purposes. Galileo has been called the father of observational astronomy. He was the first to make significant observations with respect to our Solar System and the four moons orbiting Jupiter that he discovered are still called the Galilean Moons. Galileo's support of Copernicus made him an enemy of the church as well, and in 1633 he was put on trial and forced to renounce his views and was subsequently put on house arrest. He had proof though, unlike Copernicus, so there was not much the church could do to stop the idea from spreading. Lastly, Galileo made contributions to kinematics, namely that gravity affects all objects uniformly which many believe is a precursor to modern physics. Johannes Kepler (1571-1630, German) was a student of a previous astronomer, Tycho Brahe (1546-1601, Danish). Brahe had built an observatory and made extensive observations. With the knowledge from Brahe's observations, Kepler created three laws to describe planetary motion. These laws modified circular orbits to elliptical orbits based on observations of Mars. Isaac Newton (1643-1727, British) built upon and proved the models put forth by Kepler and Copernicus with the Theory of Universal Gravitation, showing these laws applied on the surface of Earth as well. Newton invented calculus, which helped him develop the laws of motion as well. Space travel is possible with Newton's equations alone they are so complete. Without these people, none of our accomplishments in space would have been possible. Their work across generations laid the foundation for the technology we have today. As Isaac Newton said, "If I have seen further it is by standing on the shoulders of giants."

B. Space Race

The transition from stargazing to a concrete foundation for physical exploration did not happen for a few centuries after men such as Isaac Newton. When did the birth of the modern rocket age begin and who started it all? This is a tricky question because no one man accomplished all of the developments singularly; it was accomplished by three men. The conception of the modern rocket age began in 1903 with Konstantin Tsiolkovsky, a Russia then Soviet astronautic theorist. He envisioned a universe inhabited by man and its resources exploited. He studied the properties of rockets, which have existed since the 1200's in China and applied physics and mathematics to them. He created equations which related the type of propellant, the mass of the rocket, the speed of the rocket, and the speed of the exhaust gas. He proposed that humans could go to space with multi-stage liquid hydrogen/oxygen rockets.

The next man who gestated modern rocketry was Professor Hermann Oberth in 1922. For his doctoral degree, he created an extensive thesis on rocket development. Although it was initially rejected as being radical, he eventually evolved it into the book *The Rocket into Planetary Space.* This book tackled some of the problems with rocket based space flight such as how to increase fuel efficiency, how to handle fuels safely, the dangers of solid fuel and the effects rockets would have on the human body.

The last father of rocketry, the man who gave birth to the first liquid propellant rocket in 1926, was Robert Goddard. A Worcester native and graduate of Worcester Polytechnic Institute (WPI), he began exploring rocketry via mathematics in 1913. In 1914, he gained his first two patents; one for the idea of multi-stage rockets and the second for using liquid propellant. In the Clark Physics labs, he tested multiple rocket engines, calculated their efficiency, and then worked to improve them. He applied the de Laval nozzle to greatly increase the efficiency by raising the exhaust speed. He also determined he could achieve significantly greater performance with liquid propellants. Additionally, he tested and proved that rockets would work in a vacuum and would actually perform better than in our atmosphere. On March 16, 1926 in Auburn Ma, he launched the first liquid propellant rocket which achieved 70 MPH. Other accomplishments by Goddard include firing a rocket with scientific instruments on board, using vanes in the blast for control, using a gyroscope to control these vanes, creating pumps designed to pump rocket fuel, and launching rockets with all of these developments [3] [4].

After each of these men announced their work, organizations began to emerge in multiple developed countries around the world dedicated to either space exploration or rocketry improvement. Britain did research into radio controlled missiles for delivering payloads. Rockets were fitted to cars, trains, aircraft, and sleds for testing. From 1930 to 1937, Russian government-backed scientists tested many variations of rocket designs and fuel combinations. Their two largest accomplishments were a rocket called Aviavnito, which reached a maximum altitude of 3.5 miles in 1936 and GRID-X which reached an altitude of 3 miles in 1933.

Before World War 2 began, the largest yet unnamed contributor to the development of rocketry was Germany. The most prominent group was the Society for Space Travel (VFR), established in 1927. Wernher von Braun was a young rocket enthusiast who assisted Oberth in rocket testing after Goddard. They initially opened an office in Berlin and used an abandoned ammo dump in the city to launch the rockets from. Their first static test fire in 1930 was successful but subsequent tests ended in failure. They improved the design but tests during March and April ended in failure. By May 14, 1931, they designed and launched a new rocket called Repulsor 1 using the knowledge from previous test firings; it reached an altitude of 200 feet. Multiple other versions were created, eventually reaching an altitude of a mile. All designs used a combination of liquid oxygen and gasoline. In 1932, the Berlin police began to object and restrict rocket launches in the city. This coupled with Hitler's rising to power meant that VFR had a hard time proceeding with rocket launches. In 1933 and 1934, VFR was forced to disband and Wernher von Braun was officially employed by the German Army. He and a team of scientists were charged with creating the Aggregate-1 (A-1). It developed 650 pounds of thrust and ran on liquid oxygen and alcohol. While this design failed, its immediate replacement, the Aggregate-2 proved successful. Twin A-2's were launched in December 1934 and each reached approximately 6,500 feet. During April 1937, all rocket testing was moved to a top secret facility in addition to the original scientists from the ammo dump including von Braun. By the end of 1937, they had created the Aggregate-3 which produced 1,600 pounds of thrust [5]. As Hitler's war machine geared up, he requested a rocket that could travel 200 miles and deliver a one ton explosive device. This would be called the Aggregate-4 and later renamed the V-2. It was first launched on October 3, 1942 and reached an altitude of 50 miles while traveling 120 miles and producing 69,000 pounds of thrust. It used a gyroscope to control fins in the exhaust gas and on the exterior of the rocket to stabilize it. As the war progressed, von Braun's influence over the V-2 diminished as the German's trust in him waned. His original intentions for the A-4 were to eventually have men travel to space. As the war was coming to an end, he and the majority of rocket scientists decided to surrender to the United States bringing with them many of the German rocket documents, equipment, and experience. This effort was called Operation Paperclip in the United States [6].

During World War 2, all other countries that were involved, primarily including the USSR, the United States, Britain, and Japan, made some rocketry development. The United States ended up producing a rocket that reached an altitude of 43 miles. Japan, Britain, and the USSR's advancements were primarily for countering other rockets, aircraft, or naval units. In terms of after of the war, the United States was the most successful in recovering scientists and V-2 materials [7].

The United States immediately started using V-2 rockets for tests and to gain scientific data. The V-2 was fitted with an American designed second stage that became the first object to be put in space on February 24, 1949. The reasoning behind why multi-stage rockets are used it due to the law of conservation of momentum. This states that the total momentum = mass * velocity must stay the same. Since rockets work by burning fuel to create supersonic exhaust gas, the rocket wants to move forward to match the change in momentum.. The mass of the fuel times its exhaust speed is the momentum change in the negative direction. What this means, however, is that as the fuel is burned it leaves the structure that once contained it. This structure has mass and thus changes the momentum. If the mass of the rocket could decrease at a proportional rate to the fuel consumption, it could greatly increase the efficiency of the rocket and thus achieve higher speeds with the same amount of fuel. Additionally, at higher altitudes, it requires less energy to fight the Earth's gravity and atmosphere. To solve these problems, the multi-stage rocket is used. The first stage is used to leave the surface of the planet while later stages can propel different payloads at different speeds, all depending on the basic law of momentum. The first satellite, Explorer 1, was launched by the United States on February 1, 1958. The rocket that delivered this satellite was a modified Redstone army rocket called Juno 1. Another modified Redstone rocket called the Mercury-Redstone 3 launched on May 5, 1961, making Alan Shepard the first American to enter space. These Redstones were developed by a team of scientists that consisted mostly of German scientists lead by Wernher von Braun. While there is a great amount of development in rockets from this point on, much of the ground work had already been laid. From here, rockets mostly scaled up in size; the Redstone would eventually be developed into the Saturn 1 and then the Saturn 5 [8].

The path from the first revolutionary idea that celestial bodies were free-floating spheres in space to the rockets in which we would leave our own sphere and get a glimpse of how small we really are in the universe was long and marked with many great men. Now we must look towards the future.

II. Future Space Endeavors

A. Resources

1. Energy

With the depletion of natural resources, a large concern for the future of humanity is going to be the production of energy. People are starting to realize that the fossil fuels that we currently rely on are not going to last forever and are causing environmental damage to the planet we call home. Luckily, great strides have been made in the past few decades to increase the efficiency of everything around us from cars to appliances to packaging. Luckily, science has opened up many long term power solutions for the future. These solutions include anti-matter reactors, fusion reactors, fission reactors, fuel cells, wind energy, and solar energy. Each of these is in different stages of development and energy output.

Currently, the most efficient means we have to create work (mass to energy conversion) is with nuclear fission reactors. They use uranium and plutonium primarily as fuel. Nuclear fission is the process where the nuclear fuel's nucleus is broken apart by a neutron so that two smaller nucleus, being two new elements, are formed. This process also releases radiation and neutrons, which continue to cause more reactions. The problems with this method are that it creates a large amount of radiation and the fuel is not widely available. Additionally, once the fuel is used it remains radioactive for tens of thousands of years, which is dangerous to all living things. Plutonium, for example, has a half-life of 24,000 years [9]. Nuclear fission is responsible for 19% or 771 billion kilowatt hours of the electricity produced in the United States as of 2013.

Another available energy source is wind energy. Wind is the result primarily of uneven heating of the atmosphere of the Earth. This causes certain pockets to become hotter, which means it has higher pressure. Due to the fact that nature tries to establish equilibrium, hot air flows to try and balance the pressure. This kinetic energy can be harnessed with blades and is becoming more popular with time. As of 2013, the wind generates 4.13% of the total electricity produced or 168 billion kilowatt hours for the United States. The downside to wind energy is that it does not produce constant energy, which means other energy production methods must be used while the air is calm. Another popular, modern, renewable energy source is solar energy. This can be converted into usable energy through two processes; the photovoltaic process of directly converting the photons into electricity or by turning the solar thermal energy into mechanical energy via steam and turbines and then into electricity. The limitations of the photovoltaic process is that only a specific amount of energy can be used from a photon and that for max efficiency the panels must always be perpendicular to the photons. Due to the rotation of the planet, you can only produce usable energy when it is day time. This type of electrical generation results in only 9 billion kilowatt hours or 0.23% of the total electricity produced in the U.S. in 2013 [10].

An emerging energy manipulation technology is fuel cells. These produce electricity through the combination of elements to form new molecules. Generally, hydrogen is combined with oxygen to produce water and power as a byproduct. This form of electrical production is generally seen as a replacement to smaller engines such as in cars. The downside of this technology is that it requires large quantities of hydrogen. While it is the most abundant element in the universe, it is usually already bound to other elements. It is then necessary to separate it from these other elements, but that requires energy.

One of the most foreseeable answers to the worldwide problem of future energy production is the fusion reactor. These function under the principle of taking lighter elements and forcing them together to form new, heavier elements and energy as a byproduct. Fusion reactions have been created by humans before but they have never reached the threshold where it has created net power. This threshold is the point where the energy required maintaining the fusion reaction is equal to the energy output by the reaction. There are many locations working towards making fusion self-sufficient and controlled. The largest is a joint venture between China, India, Japan, Korea, Russia, the United States, and the European Union called ITER. It is being built in France and is expected to eventually reach a peak output of 500 megawatts of output for 50 megawatts of input power, achieving 1,000 percent efficiency. They are expecting to be able to make plasma by November of 2020 and start deuterium-tritium fusion in 2027 [11].

Another theorized energy production technique is matter-antimatter reactors. If we assume Einstein to be correct, then energy and matter are interchangeable due to $E = mc^2$. To get the most amount of energy out of the least amount of matter, it is necessary for there to be no matter at the end of the process. The leading theory on how to accomplish this is with anti-matter. Anti-matter is matter that has opposite electrical charges; instead of protons and electrons there are antiprotons and positrons. When these collide with conventional element matter, they will annihilate each other resulting in only pure energy. Anti-hydrogen has been created before in the CERN particle accelerator in 1995 [12].

These are the leading ideas on how to create usable energy in the future. All of them are in different phases of maturity; while antimatter is in its gestation phase, fission is in its midlife. How these can be used to travel to other celestial bodies is all still theoretical. Many of these are currently in use in space, such as photovoltaic solar panels that directly create electricity or fuel cells which were used on the Shuttles and Apollo capsules for power and water. Nuclear propulsion had been planned by the US government in the form of Project Orion, although it never produced anything due to fears of fallout. Some of these will probably fail but only the future will reveal how it plays out.

2. Solar Powered Satellites

Another source of energy being investigated is solar power beamed down from space. Many are looking to the stars for the answer to this pressing issue of energy; space is still widely considered the final frontier and scientists believe we can harvest enough energy in space to supply the world with power. One leading theory on how to harvest enormous amounts energy is to utilize the closest star we have, the Sun. The Sun is a constant source of energy and many have brainstormed ways to convert the Sunlight it emits into usable power. Solar power satellites (SPS) were once placed in the imaginary space concept category but with new technology and better designs we will soon see massive solar collectors among the stars when we gaze up. The basic concept of a SPS is the satellite will collect solar power and then beam the energy (either in the form of a laser or microwave) to a receiving station on Earth where it will then be converted into useable electricity.

FIGURE 5: SOLAR POWERED SATELLITES [122]

As with any new technology or energy source there are advantages and disadvantages. The most important advantage is that there is little limiting the amount of energy we can harvest. There is little in space to obstruct the photons such as an atmosphere or weather events so the collecting surface will receive more intense Sunlight than possible on Earth, allowing the satellite to be illuminated 99% of the time. This is more than a 3 fold increase compared to any

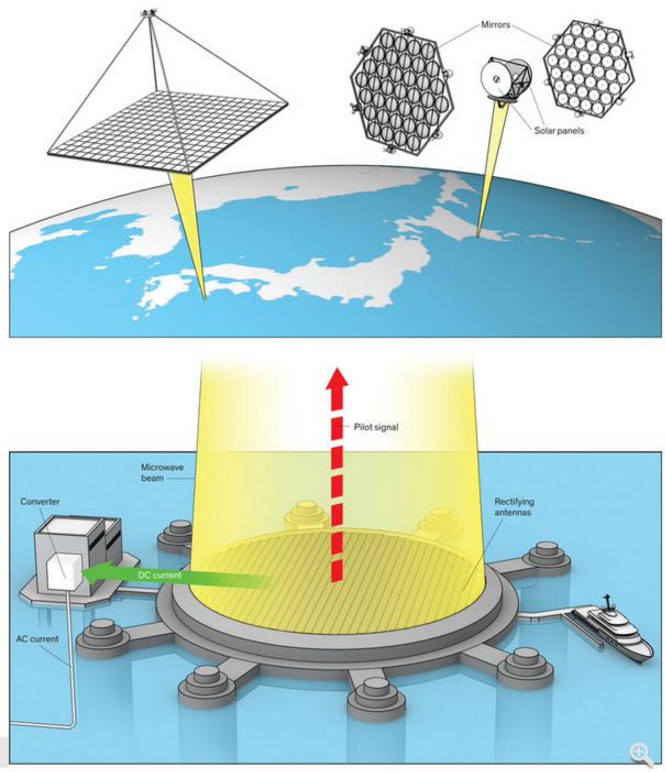

FIGURE 6: ILLUSTRATION OF BEAMING SOLAR POWER [15]

solar farms on Earth's surface which are only illuminated 29% of the time. Another advantage is the transmission of energy from space; since the energy is being beamed down to Earth it can be realistically sent anywhere where there is a receiving station. This ability to control where the energy is directed is important in emergencies and to supply energy to third world countries. The transmission beam also eliminates plant and wildlife interference. The disadvantages are mostly technical. Some examples of the disadvantages are the cost of launching a satellite, the issue of maintenance and degradation, the risk of becoming space debris and space debris being a threat to the SPS, frequency of microwave (if used) might interfere will other satellites in orbit, efficiency of the transmission from space to the receiving station and the large size and cost of receiving stations [13]. Technological breakthroughs and advances are happening every day and at leaps and bounds so many of these hurdles will be eventually overcome.

The United States began its research into SPS when Peter Glaser was granted a U.S. patent in 1973 for transmitting power over long distances using microwaves from one very large antenna on a satellite to a larger rectenna on the ground. This patent was the beginning of NASA's research into the feasibility of space based solar power system. In 1974, NASA signed a contract with Arthur D. Little Inc (ADL), with Peter Glaser as the Vice President, to lead a study involving four companies to assess the possibility of the space based solar power system. The findings of this study showed enough promise to continue research but also revealed the problems that will need to be addressed. From 1978-1986, Congress authorized the Department of Energy (DoE) and NASA to jointly continue this research in what is later called the Satellite Power System Concept Development and Evaluation Program. The program was not continued, however but in 1999 NASA created the Space Solar Power Exploratory Research and Technology Program (SERT). The responsibilities of this program were to perform design studies of flight demonstration concepts, study the feasibility, design, and requirements for SPSs. Additionally, SERT was responsible to design the subsystems that will benefit future space applications with use of SPS technology, formulate a preliminary plan of action for the U.S. for technology initiative that will involve international partners, construct roadmaps for critical SPS elements, and develop a full SPS concept for a gigawatt space power system. SERT were the first to propose an inflatable photovoltaic gossamer structure with either concentrator lenses or solar heat engines to convert the Sunlight into electricity. Lastly they suggested the SPS to be placed in a geostationary orbit. Conclusions of this study were that the increasing global energy demand is going to lead to new power plants and that renewable energy is the answer to this demand; therefore space solar power is ready to be looked at again especially for its environmental advantages. There are hurdles that will need to be overcome such as economic viability (launch costs especially) and the development of new technologies but this will be true of any other advanced power technologies [13].

NASA had concluded that SPSs are no longer a visionaries' dream but a concept that could be achieved. Technical and social factors have led to Japan and the Japan Aerospace Exploration Agency (JAXA) being the leaders in the development of solar power space systems.

The technical factors are helping to overcome the hurdles to building an efficient SPS. Newer technology and better materials have made the conversion of solar energy to electricity more precise; wireless power transmission will allow moving antennas to send precise beams of energy across vast distances with relatively minor losses of energy. Some social factors are shared around the world and others are specific to Japan. Our current forms of renewable energy, solar and wind farms, take up too much land for the amount of power that they produce whereas the SPS can ultimately generate power for twenty-four hours a day. Japan does not have the land needed for these wind or solar farms. Use of fossil fuels has created concern over the depleting amount available and the greenhouse gases that are produced as a byproduct. Additionally, Japan has to depend on other nations for their fossil fuels since they do not have any of their own. Nuclear power plants have always been a concern due to their radioactivity and potential accidents. With each accident, such as Fukushima, the public's desire to move farther away from nuclear power is stronger. These technical and social factors have led to increased research on SPS and the road map for building a commercial SPS that is 10000 metric tons and several km wide [14].

Commercial SPS will be a global effort once the road map leads to larger SPS since it will need joint space efforts and funding. The energy produced will be able to used around the globe and will be cleaner energy that our current sources. There are six factors that will need to be overcome to achieve a successful, commercial SPS: wireless power transmission, space transportation, construction of large structures in orbit, satellite attitude and orbit control, power generation, and power management [15]. JAXA is focusing on overcoming the wireless power transmission by establishing pros and cons for using either a laser or microwave beam. With a laser beam there are shorter wavelengths but the atmosphere (such as rain or clouds) will interfere with the beam so the conversion efficiency is lower. Microwave beams are between 5-10 centimeters and have a conversion efficiency of 80% but commercially available components are hard to get. With a microwave beam there have been concerns over safety of humans and wildlife alike. About 95% of microwave beam must fall on the rectenna so the remaining energy will be absorbed and dispersed within current standards for microwave emissions. Japan has built a man-made island to house their rectenna and communication station; the island is far enough way that the exposure to the microwave beam is minimized and not a threat to humans and it makes it much harder for unauthorized people to be near this powerful beam. There will need to be a constraint so that the beam is not so intense that it does not injure the surrounding wildlife (specifically birds). There have been experiments that show irradiation at reasonable levels did not show negative effects on health over generations [14]. One way to make the beam precise is to use retro directive phased array antennas and rectenna. A pilot microwave beam will be emitted from the rectenna which will establish phase front at transmitting antenna. In turn, each antenna's sub arrays will compare to the pilot beam's phase front and will adjust their outgoing signal with an internal clock phase. This will focus the beam more precisely and will also create a safety factor. If the pilot beam is lost then phase control on the transmitting antenna fails and the microwave power beam is defocused [15]. This factor is one of the first that need to be overcome to guarantee high efficiency conversion of the beam from the SPS.

JAXA's road map is to first build a simple design of an SPS and launch it in the next 50 years. The design will be sent into a geosynchronous equatorial orbit (GEO) about 36000 km about the Earth's surface. This orbit was chosen because the orbital period is about equal to Earths rotational period which would mean that satellite will appear stationary in the sky therefore the rectenna will be able to stay pointed at one location. There is permanent Sunshine since there is no atmosphere, dust, or cloud interference so the SPS will be converting Sunlight for about 99% of the time. The amount of energy falling on a 15 km wide band in GEO is about 2500 terawatts which is much greater than the world's current rate of energy use of 11 terawatts. If conversion efficiency of the SPS was 25% there would be enough to energy for the world's population in 2050. There are a few disadvantages of working in the GEO orbit. In order to not interfere with other radio-frequencies there are only limited amount of "slots" in the orbit [16]. There is also the problem of radiation; the amount of radiation in the GEO orbit is too much for humans to handle. There would need to be development of new protection for humans and also telerobotics to handle construction and maintenance.

FIGURE 7: ROBONAUT ABOARD ISS [123]

Advances in robotics are the key for the completion of the SPS project since the radiation levels are too high for humans to endure. Some challenges are the ultra-high vacuum in space prevents the use of most types of lubricants, the great difference in temperatures, and no gravity. Many robotic companies are continuing to make developments. The Robot Systems Technology Branch has designed Robonaut, a humanoid robot that has dexterity, a range of motion, and task capabilities that are close to that of an astronaut in a space suite. Robonaut has 2 five fingered hands and a human-scale arm. This design will be great for building the SPS in space since it will mimic that of a human. Engineers can "build" the parts here on Earth and capture the actions needed. Then once in space it will be easier to convert the actions to the Robonaut. Robonaut also has a thermal suit to protect it from temperature swings and a variety of sensors: thermal, position, tactile, force, and torque [17]. Advancements in robotics will greatly help not only SPS but other space endeavors which are further explained II.B.1.Robotics.

A two phase project has been developed to design the most successful SPS. A simple SPS will be launched in its GEO orbit while scientists will resolve any design problems for the second generation. The simple design will consist of a huge square panel covered with photovoltaic cells on top of the panel with transmission antennas on the bottom. A small bus housing the controls and communication systems will be tethered to the square panel suspending it. The design incorporates gravity gradient stabilization since the bus acts as a counterweight to the gravitational pull on the panel. The SPS will therefore be in a stable orbit so there is no need for fuel and making the design more energy efficient. The only negative of this design is the inconsistent rate of power generation; the power output depends on the Sun's position since the panel is fixed in orbit compared to the surface of the Earth.

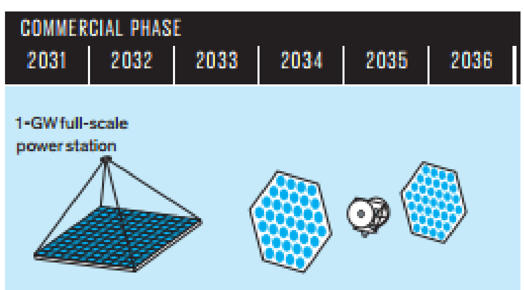

FIGURE 8: DESIGN 1 AND DESIGN 2 OF SPS [14]

The more advanced design eliminates the inconsistent rate of power because there will be two huge reflective mirrors that will direct the Sun light onto the 2 photovoltaic panels. With this design, the SPS will generate energy twenty-four hours a day since it will no longer depend on the position of the Sun. In order to achieve this design, a sophisticated kind of formation flying and docking procedure will need to be mastered so the mirrors are free flying and can reflect the

Sunlight at any angle. Another complication that must be overcome is material selections; very light materials are needed for the mirror structures and extremely high-voltage power transmission cable with minimal resistance losses [14].

There is still a lot of research and planning that JAXA needs to accomplish before the first SPS enters space and begins producing renewable energy. If Japan's first prototype is successful, they may want to consider cooperation with other countries to build larger receiving stations and help design the next generation of the SPS. JAXA has the potential for creating the next great energy source that could benefit all of society.

3. Mining the Moon

As our nearest celestial neighbor, the Moon has always been a fascination to us on Earth. Even with the cancellation of funding for the space program, the interest has never died to continue our research and further our knowledge. This responsibility has been shifted to private companies and there is a possibility of man returning to the Moon in the next 20 years. One reason for such a return is the possibility of mining the Moon for resources, such as helium-3 (He-3) and rare Earth resources (REE). Many countries, such as China and Russia, have made claims to returning to the Moon to begin mining for said resources. He-3 is an isotope of helium that is constructed of two protons and one neutron [18]. From the composition of He-3, it is a light nonradioactive element. Solar winds have been depositing vast amounts of He-3 on the Moon for billions of years with an estimated total of 1,100,000 metric tons on the Moon's surface. This is significantly higher than the total amount on Earth, which is about 161 kg [19]. He-3 is rare on Earth due to the atmosphere surrounding our planet; the atmosphere and magnetic field prevents the solar winds form depositing any He-3 on our surface. The Moon, however, has no atmosphere or magnetic field which allows He-3 to be absorbed into the lunar soil. Scientists believe that they can heat the lunar soil to about 600 ^{o}C to release the gas where it will then be captured in storage containers and transported to Earth. An economic value has been placed on He-3 of about $3 billion a ton, making it economically viable since it is estimated that 2 full space shuttle cargos (about 40 tons) could power the entire U.S. for a year [18].

Why the interest in He-3? By 2050 the world population is estimated to reach 9.6 billion people. With the exponential growth of the world's population will come three energy problems; achieving and balancing energy security, energy equality, and environmental sustainability? Due to the impending energy crisis, countries are looking to new energy sources and He-3 could be our answer [19]. He-3, which would be mined from the Moon, will be used in nuclear fusion reactors. While there is currently no successful fusion reactor, many counties are still moving ahead with their plans to return to the Moon for He-3. Our current form of nuclear power is from the nuclear fission reaction, which produces heat that turns water into steam which then drives a turbine to produce electricity. The reaction consists of uranium nuclei that will split apart and release energy. The negative side of this is that the reaction produces radioactivity and radioactive waste which will need to be stored properly for an indefinite amount of time. This reaction is a source of energy but it is not the ideal way to power the world due to its negative side effects. Fusion reactors are the next stage of nuclear energy; current attempts use the hydrogen isotopes tritium and deuterium that fuse together to create hydrogen and a neutron. This reaction is the same process that the Sun and other stars use to produce energy which is better than fission reactors since there is no radioactivity left over. Scientists, have not been able to develop a fusion reactor that produces more power than it consumes However, they are hopeful that this type of reactor will be the world's new energy source. The neutrons released in the tritium and deuterium reaction are extremely difficult to contain and lead to the significant energy loss. This is where He-3 comes into play. Scientists believe that if we replace tritium with He-3, the fusion reactor will be able to generate the power we need and be very efficient. The reaction will result in a balanced reaction that produces only hydrogen and a proton (which is easier to contain) [20]. At this moment, the He-3 fusion reactor is all speculative but many scientists are confident that He-3 reactor will be the solution to nuclear waste and the growing energy demand. Since He-3 is so rare on Earth, countries are looking to mine the Moon for its He-3 reservoirs and continue fusion testing to eventually produce continuous "clean" power [18].

One of the largest energy consumers in the world, China, has already released statements regarding the future of mining the Moon for He-3. China has already begun to limit the export of their rare earth elements so they can be used for wind turbines, solar panels, and defensive measures nationally. They have recognized that relying solely on fossil fuels and nuclear energy will result in the eventual collapse of economies and governments. The fight for energy, especially fossil fuels, will lead to fuel regional tensions, geopolitical frictions, and will result in armed conflicts. China has chosen to begin focusing on nuclear fusion for the answer to their energy crisis [21]. Professor Ouyang Ziyuan, the chief scientist of the Chinese Lunar Exploration Program, claims that the Moon is so rich in He-3 that the energy crisis will be solved for 10,000 years. China is not only interested in the He-3 but a country's lunar exploration is directly related to the country's national power. If China is the first country to begin mining of He-3, they could be become the world's first energy super power. Many are worried that China will set up a monopoly on He-3 mining and in turn nuclear fusion plants. Another space race will be sparked once scientists have made breakthroughs in fusion technology and excavating He-3. China is not waiting for that space race and plans to move forward now with mining the Moon [19]. Mercury has been predicted to also have abundant sources of He-3 due to the lack of atmosphere, which would allow the He-3 to be absorbed into the surface. However, some believe that Mercury's magnetic field could have prevented He-3 from being deposited on the surface. In section III.B.4.Mercury, Mercury's He-3 supply is further discussed.

Helium-3 is not the only resource that can be harvested from the Moon. NASA has developed a mapping device that orbits the Moon and identifies different minerals on the surface. The Moon Mineralogy Mapper (M3) was launched aboard India's Chandrayann-1 lunar orbiting spacecraft with the mission to characterize, assess, and map the mineral composition of the Moon. M3 searched for water molecules in the Polar Regions by measuring the light reflected off of the lunar surface by M3's spectrometer and the wavelengths absorbed by the soil. The signatures they received were consistent with water molecules and hydrogen. Other results found by M3 show that there is a new range of processes for mineral concentrations on the Moon, such as a new lunar rock that is a mix of plain old plagioclase and pink spinel (a precious gemstone on Earth). M3 created a three-color composite of the Moon, which is shown below, that illustrates the different materials that were mapped as well as water which is marked by blue [22].

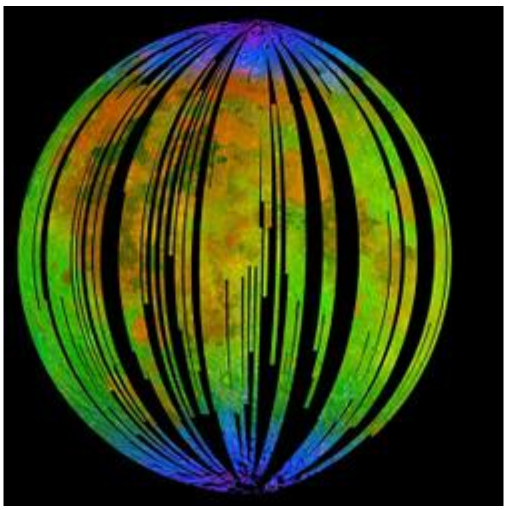

FIGURE 9: M3 THREE-COLOR COMPOSITE OF THE MOON [22]

The minerals found on the Moon can be categorized as KREEP, an acronym for potassium (K), rare earth elements (REE), phosphorus (P), thorium, and other incompatible elements. These elements are not found in common rock-forming minerals during magma crystallization so they become enriched in the residual magma and in the rocks that finally do form from it. KREEP is exposed on the lunar surface but REE are harder to discover alone. The technique for finding REE is to find thorium first and then to try and find REE because of their similar geochemical properties that cause them to crystallize under the same conditions. Scientists believe that it will be possible to mine these REE and ship them back to Earth. The only drawback is that current separation methods are not advanced enough to separate the specific REE from the lunar soil. Much like mining on Earth, there will also need to be drilling and sampling to determine the actual amount of REE found on the Moon [23]. If the amount of REE is abundant, it will be beneficial for Earth since these elements are depleting and countries are concerned about the future use of these elements. The Moon is not the only location that scientists have been searching for these REE. The University of Tokyo has sampled from 78 different locations in the mud floor of the Pacific Ocean and confirmed that there are vast expanses of the ocean floor that have REE. The fact that there are REE on the ocean floor is not new, but we are approaching the day that we will be able to mine these precious elements. Some researchers believe that mining for theses REE will not happen for at least another ten years due to the huge start up costs and the fact that there is only a 0.2 concentration of REE opposed to 5-10 percent on land [24]. The question is where will we mine first? Countries that do not have an advanced space program already in place may start to develop a mining operation for drilling on the ocean floor where as countries with plans to be back on the Moon may continue forward with their plans for mining the Moon.

Now that the M3 has determined there is water on the Moon, NASA's next step is to determine how to mine the Moon for this water. NASA will conduct two separate mission concepts to find and mine the water stored at the poles. The two concepts are the Lunar Flashlight (LF) and the Resource Prospector Mission (RPM) that will be launched in 2017 and 2018, respectively. These supplies are essential is we ever decided to build a Moon colony since it will be exponentially cheaper to live off the land then to ship water for drinking, breathing, and rocket fuel. LF will be launching in December 2017 with NASA's new Space Launch System megarocket on its first test flight. LF is a CubeSat that after it is deployed will release an 860 square foot solar sail which will allow LF to cruise toward the Moon on a circuitous route, being propelled by photons from the Sun. LF will orbit the Moon for about six months before it begins its year-long descent to about twelve miles above the lunar surface. LF will make a total of 80 passes around the Moon while it maps and measures the water ice deposits in permanently shadowed regions such as craters near the lunar poles. The solar sail will act as a mirror to reflect Sunlight into the permanently shadowed regions and use passive infrared spectrometer to collect the light. LF's spectrometer will measure the wavelengths much like M3 did to determine how much water is present [25].

RPM's mission differs in that it is sending a rover to the surface of the Moon to study the lunar poles. The rover, once on the surface, will map the surface and subsurface concentrations of hydrogen at two locations at that are approximately 0.6 miles apart. RPM will use a neutron spectrometer to measure water concentrations as far as 3.3 feet underground and near-infrared spectrometer to measure the surface. The objective of both of these projects is to find water that will be accessible by either humans or robots so they will focus on areas that are closer to the surface. The rover will be solar-powered but will have a back-up battery aboard for when the rover is operating in permanently shadowed regions. RPM's goal is to determine how the water ice is distributed in the soil, the best way to excavate this water supply and the cost in terms of energy to complete this project. Samples collected from the rover's drill will then be placed in an oven so volatile materials (water especially) will be released in this process. Water is not the only resource that RPM is looking into; oxygen will also be extracted from the lunar soil to showcase in-situ resource utilization (ISRU). A long term goal for the RPM project is to conduct similar experiments on Mars; the only difference is there will be an instrument that will generate oxygen from Mar's atmosphere which is mostly carbon-dioxide [25].

Some countries and private companies have already announced that they will begin mining missions within the next couple decades. Russia has announced that they will resume their Moon exploration program in 2016 with the first spacecraft to be launched in 2018. Their first manned Moon mission is currently slated for 2030. Their mission is to retrieve comet fragments and explore REE for green technology, defense systems, and consumer electronics to bring back to Earth. Sternberg Institute's Head of the Department of Lunar and Planetary Research Vladislav Shevchenko believes that the Moon's surface is very rich with these REE. It is predicted that if Russia succeeds with its mining mission then China's share of REE will drop from 97% to about 65% [26]. Of course that statistic is only factoring Russia into the REE market never mind the growing amount of private space companies that are popping up all over the U.S. NASA has set up the Lunar Cargo Transportation and Landing by Soft Touchdown program (CATALYST) which will award private companies contracts, but no money, to build prospecting robots. NASA has successfully worked with private companies before, such as work for the ISS, and is looking to do the same with mining since the budget is still sparse for the space program [27]. Even companies that are not a part of the CATALYST competition are still undertaking their own research and missions to be the first private companies to mine the Moon, such as Deep Space Industries and Moon Express. The Moon is expected to be an abundant source of wealth for Earth and many are hoping to be part of these emerging market.

B. Technology

1. Robotics

The next progression for space exploration is directly related to the advances in robotics and their integration into space programs. Two main robotics that are currently being developed are humanoid robots and advanced rovers. There are many advantages for each of these robots, including tasks that can be completed and work environments, but a robot that utilizes the best of both designs would be beneficiary and a universal solution. A humanoid has the ability to perform the same tasks that an astronaut in their suit can due to the design of its joints providing the dexterity to accomplish complex tasks. The new advanced rovers have upgraded wheels that will be able to navigate through rough terrain while simultaneously mapping and selecting sites for a potential colony. A robot that incorporates the design of the two would be able to travel anywhere on

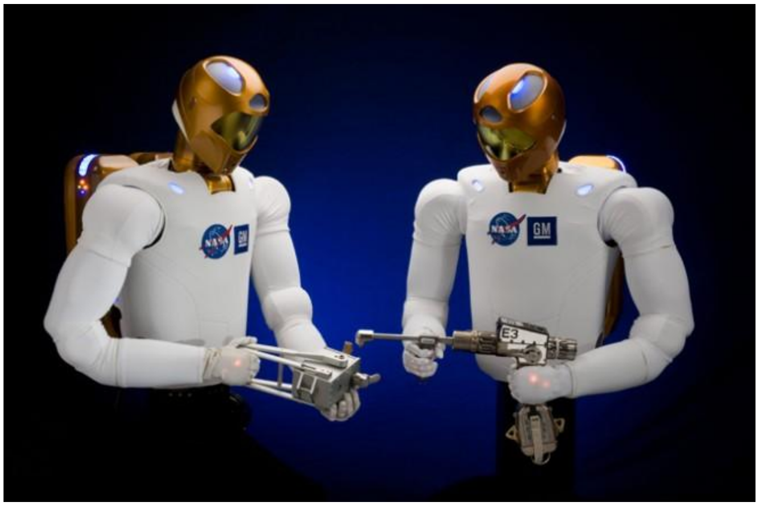

FIGURE 10: ROBONAUT WITH SPECIALLY DESIGNED TOOLS [17]

the surface of a planetary object while completing tasks that astronauts cannot easily accomplish due to the destinations.

In September of 2011, Robonaut 2 made the International Space Station its home where it, alongside astronauts, works to maintain the space station and perform different required tasks within the space station. Space stations and all tools aboard are designed for humans to use in astronaut suits so the installation of a humanoid robot is essential due to the high expense of building and sending a robot to the station, not including the extra cost to develop unique tools for the robot. Robonaut 2 will not only be able to use the tools already at the space station but can be outfitted with additional tools when the robot is deployed to space for the completion of certain tasks more efficiently. The Robonaut project started its journey in 1996 with Robonaut 1 being created in 2000. In 2006, General Motors (GM) partnered up with NASA's Dexterous Robotics Laboratory at Johnson Space Center to create the next generation of Robonaut. Robonaut's design mimics an astronaut in a space suit with two arms each with a five fingered hand. It is also equipped with multiple sensors that measure thermal, position, tactile, force, and torque that will enable Robonaut to operate autonomously on tasks. Robonaut 2 is currently in the programming stage to become an autonomous system; a task-based system will build up behaviors and once a task is programmed and a specific sensory inputted, Robonaut 2 will be able to make a decision on its own for the next course of action. The improvements to Robonaut at the ISS will give it the ability to move around inside the station and then to be allowed to do extravehicular activities as opposed to being in a fixed position inside the space station [17]. Robonaut will be evaluated at each progression on its ability to complete the tasks assigned and the integration with the astronauts. In 2012, it was reported that Robonaut 2 accomplished its first piece of productive work: checking air flow in the ship. Since 2011, it has been completing experiments to test its ability to operate the space shuttle technology. In 2014, Robonaut 2 will be receiving an upgrade: a new set of legs. The legs will have a nine-foot leg span and will be flexible like that of a human's due to its seven joints. Its feet will be pincer-like with small cameras so it will be able to grip handrails and sockets inside and outside the space station to make maneuvering easier [28]. The advancements in Robonaut's technology are allowing for better integration with astronauts onboard ISS. Robonaut will soon be able to take over dangerous tasks and maintenance issues that will allow more free time for the astronauts and increase safety.

FIGURE 12: ROBONAUT RECEIVES LEGS [28]

Rovers have already completed many successful missions on both the Moon and Mars. These initial rover missions have been for three months each but some have continued on for longer missions due to continued functionality, including NASA's Spirit Mars rover which has completed six years on Mars. NASA has designed the next generation of the Spirit Mars: Curiosity. It is a six-wheel system that is larger than Spirit which will give it more power and mobility. It can perform a 360-degree turn easily since each wheel has its own drive motor. Curiosity will be able to navigate the

FIGURE 11: NASA'S CURIOSITY ROVER [29]

rough terrain and will be equipped with a laser rock-vaporizer that it can use to remove any obstacles. It has the latest technology such as the ability to collect samples by drilling into the soil and use 3D cameras that can map the topography [29]. Another NASA rover is the All-Terrain Hex-Legged Extra-Terrestrial Explorer (ATHLETE). ATHLETE is equipped with 6 limbs that have a dual function of either using wheels to act as a rover or the limbs can act as legs to walk. ATHLETE will be able to navigate all types of terrain by either using its wheels or its limbs to walk over rough and steep terrain. The limbs will have attachment points for power tools or can be used as arms to perform tasks. ATHLETE will be built with a platform that it can use to load and transport payloads to any site. The new limbs are an attempt at a crossover between the humanoid robots and rovers [29]. The limbs, which can be used as wheels or as arms, will enable the rover to complete more missions and make great advances on Mars. ATHLETE will be able to use the limbs as arms to repair any malfunctioning rovers and once a site has been chosen for a potential colony it can aid in construction and transportation of materials.

FIGURE 13: NASA'S ATHLETE ROVER [29]

A crossover design that utilities both the humanoid and rover would be useful as an overall service robot. At this stage of the Robonaut 2, it is currently a torso attached to a rod but it could possibly be attached to the top of a rover which would enable it to navigate to any site for repairs or construction. This hybrid could be a service robot to large structures in orbit as well. A compartment on the rover portion could store tools necessary to perform maintenance to the satellite. The humanoid torso will be tele-operated to complete all repairs, refueling, and to deflect debris. The robot/rover could be powered by the solar power satellite or can have its own solar panels on board. Due to the expense of building and sending large structures into orbit, such as a solar power satellite, there will be a need for collaboration between countries. This collaboration could lead to the deployment and use of service robots. There should be approximately 3 or 4 service robots that service the GEO orbit so there is no more debris added to the orbits than necessary. These service robots can also be deployed to any planet or asteroid when needed and navigate with ease. The hybrid robot can be beneficial in many space related missions. The further into space that we plan to travel and the longer the missions, are the more dependent we will be become on robots.

Humanoids and rovers are not the only advancements in robotics that will be useful in space; construction robotics is making huge advances. It is costly to send materials to space to start construction on a lunar colony but recent technology and research have taken advantage of a cheaper and more abundant resource: lunar soil. In-situ-resource utilization (ISRU) will take advantage of resources found on either the Moon's surface, such as lunar regolith (a layer of loose, heterogeneous material that covers solid rock, dust, soil, or broken rock), or asteroids. NASA is proposing to use existing robotics for material excavation and transport such as the Lunar electric rover, the Chariot rover, versatile light-weight cranes, and Tri-athlete cargo transporters. These tools, coupled with new construction technologies, will be used to begin building and testing different methods of automated construction of important structures. Structures would include landing pads and aprons, roads, blast walls and shade walls, thermal and micrometeorite protection shields, and dust-free platforms. One major benefit of automated building is the increase safety factor for humans since they will now be delegated to supervisor roles. Another is the decreased cost of building intricate designs since the need to ship materials to space will be eliminated [30].

Contour Crafting (CC) is the leader of automated construction techniques that are being developed. Berok Khoshnevis, a professor at the University Of South Carolina Viterbi School Of Engineering, began working on CC in 2000 with the support of NASA Office of the Chief Technologist's Innovative Advanced Concepts (NIAC) program. He concluded that it is more cost effective to build structures from automated technology that is established on the Moon and

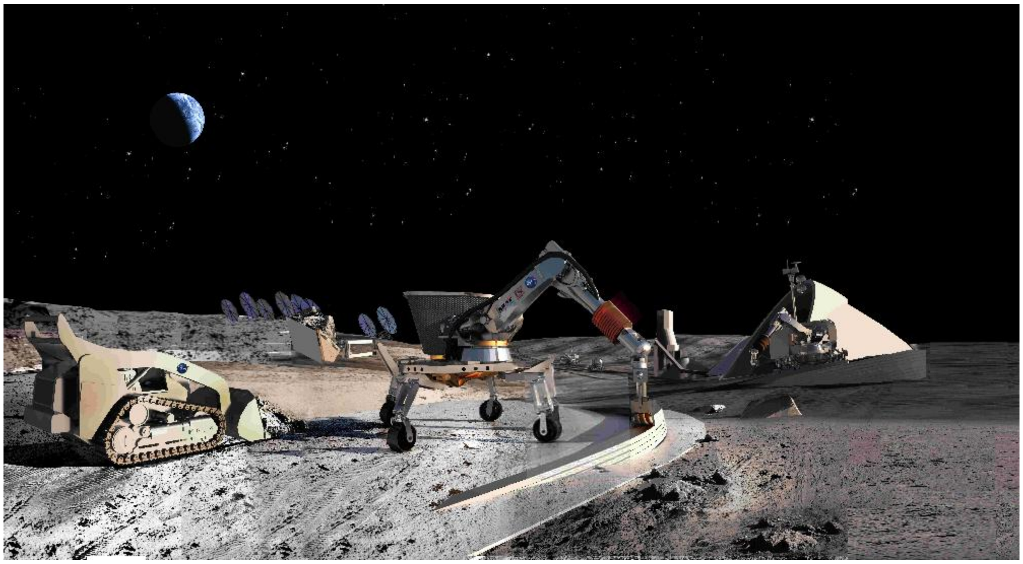

FIGURE 14: CONTOUR CRAFTING [32]

can build infrastructure layer by layer using lunar regolith [31]. CC is essentially a giant 3-D printer which means it is a "fabrication process where large scale parts are fabricated quickly in layer-by-layer format." CC has superior finish and incredible speeds, even going so far as to report it could build a house on Earth in twenty-four hours. CC will not only be able to build the frame of the infrastructures but also integrated radiation shielding, plumbing, electrical, and sensor networks throughout each structure [32]. The Phase-I final project report was completed in October 2012 by Khoshnevis which details the study of materials and processes, building of experimental machines, structural design and analysis studies, and possible architecture. The study of materials has shown that two options are the most feasible: sulfur concrete and regolith sintering. The CC creates sulfur concrete by combining about 80% regolith and 20% sulfur and then extrudes the dry mix through a nozzle. The CC nozzle will heat the mix to about 130 ˚C to make cement like paste to be used in construction which will have a higher compressive strength than most ordinary concrete. Sulfur concrete is 100% recyclable and CC will be able to build complex structures with the mix. Sulfur concrete structures will be sufficient unless they experience temperatures higher than the melting point of sulfur, such as at landing pads or under direct Sunlight. In these cases, molten regolith concrete is the optimal choose and is easily accessible since the only ingredient of lunar regolith is abundant. Molten or sintered regolith structures have a high compression strength and tensile strength especially if metal powders (copper and steel) are mixed before sintering. The mixture of metals and lunar regolith are compacted into graphite molds and then placed into a ceramic furnace where the sintering temperature ranges from 975 C to 1100 C. Both materials created in CC will consume less energy and time than standard materials for construction and allow astronauts to tele-operate and supervise from a lunar lander [33]. In order to build a colony or any other type of infrastructure in space, there will need to be construction robots. CC is one type of construction robot but there are many other ideas for robots that will construct our next habitat.

TERMES is a very different type of construction robot. The hive mentality and building habits of ants and termites are the inspiration for TERMES. TERMES does not require a master plan or even regular instructions from Earth, which will be beneficial for use on Mars because of the long travel time of communications. TERMES has autonomous decision making capabilities in respect to the needs of the project as well as environmental conditions. TERMES has been undergoing testing and can build bridges and towers from foam bricks and can even include stairs or ramps with any instructions before construction and will not deter construction on the main project. The robot knows where bricks have been attached only through direct inspections and can make a decision on where the next brick needs to be placed. This building strategy is adopted from ants and termites and will be useful when a single robot can no longer function properly. If one robot has stopped working for some reason, other robots will take its place and continue construction. If the environment changes, such as a wind storm, the robot will be able to sense this and either construct or find a shelter where it will then wait for a signal from Earth that it is safe to continue working. TERMES is still in the development and testing phase and is predicted to be sent to Mars in the next couple decades [34].

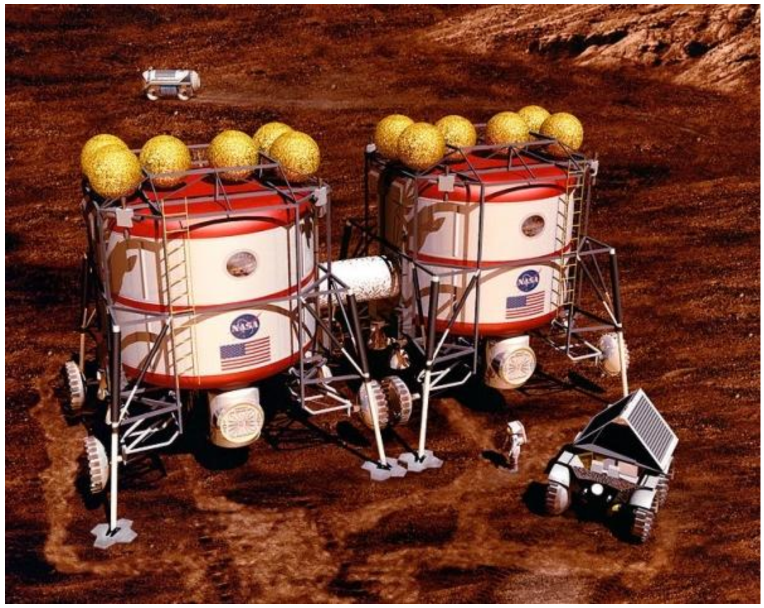

FIGURE 15: TERMES ROBOTS [34]

There is not only a need for construction robots but also mining robots to harvest the needed lunar regolith. Profits from the mining operations could potentially be enough to convince governments and corporations to invest in the future colonization of space. The projection for these mining robots is to not only mine the soil but to build structures as well as build more robots that are superior to themselves. The first equipment is projected to be launched in the next few years; the goal is to make water from extracted oxygen from the soil and combine it with hydrogen that was sent from Earth. The goal in 50 years is for these robots to tow drinking water from icy asteroids to astronauts in orbit. The Moon materials harvested will not only be able sintered for cement but also solar cells which can be constructed from purified silicon (which is 20% of the soil by weight). The oxygen found in the soil can be used (with either hydrogen sent from Earth or eventually from hydrogen found on the Moon) to fuel rockets or make water for radiation shielding. Scientists predict that there is enough ice in the Moon's North Pole to launch one space shuttle from the Moon every day for 2200 years.

RASSOR, created by NASA, is a rectangular shaped robot that has a pair of pivoting arms on each end with tracts across the body to maneuver the terrain. The arms hold a long, hollow, rotating drum with multiple shovel shaped opening. These drums will rotate in opposite directions to scoop up soil in the shovels. When the robot senses the shovels are filled, it can then transport the soil to a collection site where the drums will rotate in the opposite direction of collection to empty the shovels. RASSOR is not yet ready to be launched but NASA is preparing to launch a flight-ready version called the Regolith and Environment Science and Oxygen and Lunar Volatile Extraction (RESOLVE), which will hopefully be launched on a rover around 2019. Its main goal is to hunt for hydrogen but it will also attempt to make water by heating the soil to 900 C to release the oxygen and then combine it with hydrogen stored on RESOLVE. Tether Unlimited has created a project called SpiderFab, a free floating robot that consists of robotic arms that will build up and move around 3-D printed

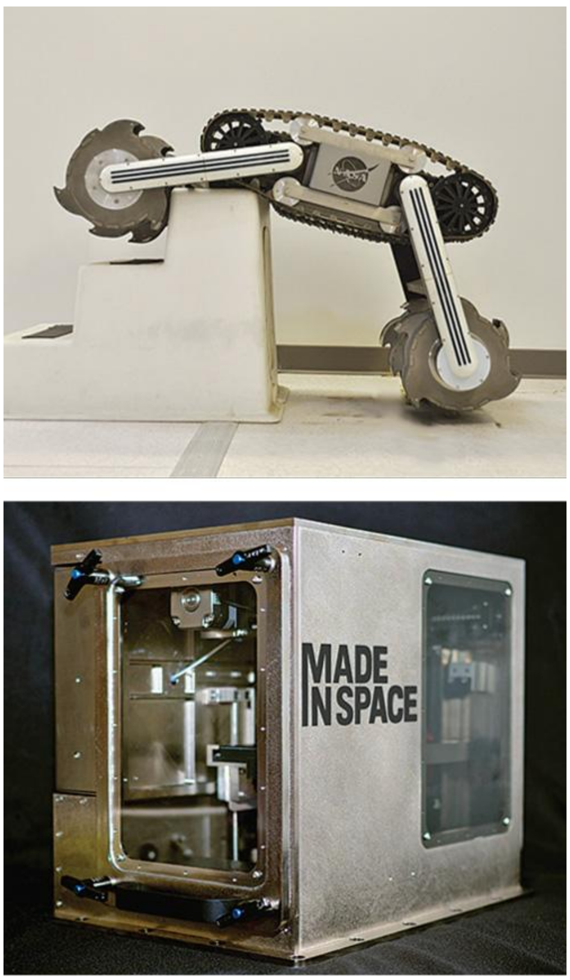

FIGURE 16: 1) RASSOR 2) MADE IN SPACE 3-D PRINTER [35]

structures. The goal is to build structures bigger than those that can be fitted into a rocket but one challenge that needs to be overcome is the large temperature gradient which could prevent the structure from cooling properly and causing deformations. Made in Space has sent the first 3-D printer to ISS in a climate-controlled glove box that can operate in microgravity. The 3-D printer fabricates structures from heated polymer filament sent from Earth. With all of these new construction robots, the idea of building lunar structures using lunar raw materials is advancing however there are no set plans to begin this type of construction [35].

Advancements in space robotics are not only reducing humans to supervisory roles but will also enable them to have super human strength. Many companies and organizations are creating exoskeletons to help astronauts, emergency personnel, and soldiers. NASA and the Florida Institute for Human and Machine Cognition (IHMC) have created X1 robotic exoskeleton as a spinoff of Robonaut 2. X1 is a 57 lb device that humans wear over their legs and harnesses across the back and shoulders. X1 has ten degrees of freedom due to four motorized joints at the hips and knees. There are also six passive joints that will allow different range of motions from sidestepping to turning and flexing. On Earth, X1 can be used to assist with leg motion for physical therapy or paraplegics. In space, X1 will replace the current exercise routines of astronauts while not taking up valuable space or weight. The exoskeleton can inhibit leg motion by applying resistance but it will also measure, record, and send data back to doctors on

FIGURE 17: NASA’S X1 EXOSKELETON [36]

Earth for analysis of their exercise regimen. In future applications, it can provide additional force to astronauts walking in low gravity environments as well as giving more strength to astronauts to carry larger loads [36].

NASA isn't the only organization that is developing exoskeleton technology. Perceptual Robotics Laboratory (PERCO), based in Italy, is saying they have the "most advanced" exoskeleton in the world. PERCO's Body Extender is a full body exoskeleton instead of just legs like NASA's. The Body Extender has four limbs that have a total of 22 degrees of freedom which can mimic fluid human motion and track the movement of the human operator. It can lift 110 lb in each hand and is designed to be rugged and maintain balance on rough terrain. The Body Extender, unfortunately, still needs to be tethered to an external power source [37]. The Human Assistive Limb Exoskeleton (HAL) built by CYBREDYNE Inc. can not only track human motion but can also predict it and move fractions of a second before the operator does. HAL uses electrical signals that are sent from the brain to the muscles to anticipate the motions and from there calculate how much power is intended for use [38]. ESA has an exoskeleton of their own that can be tele-manipulated by an astronaut when the robot is operating in harsh environments. This exoskeleton is operated by Haptic Telepresence, human/machine system where a human operator will receive enough information about the site environment and the tele-operator that the human operator will feel physically present at the robot's site. Haptic Telepresence is designed so that an untrained astronaut will be able to use the technology. The human operator will wear an exoskeleton arm that weighs less than 10 kg which does not need to be attached to an external source. The kinematics of the exoskeleton are different than that of a human arm but can still complete all range of motions including the shoulder, elbow, and wrist even though the system is carried by the thorax not the arm. The benefit of this is that there will not be a need for calibration and alignment to the human joints [39].

Robotics can only advance as far as an external source allows since many are limited to tethered power cords and will not be able to function for long in space. NASA recognizes that the robotic advances are directly related to energy storage, so they have created awards in three phases to provide funding for research and development of four new energy storage systems. Phase I awards about $250,000 that will provide funding for an eight month component analysis and testing. Phase II awards about $1 million for engineering development of the unit hardware for one year. Phase III awards about $2 million for prototype hardware development over 18 months. The four technology proposals are silicon anode based cells for high specific energy systems, high energy density and long-life Li-S batteries for aerospace applications, advanced high energy rechargeable lithium-sulfur batteries, and garnet electrolyte based lithium-sulfur energy storage. NASA intends to make many large investments within the next 18 months on energy storage [40].

Another form of an external energy source is microbial fuel cells (MFC). The U.S. Naval Research Laboratory (NRL) plans to use MFC in small devices to supply power while in space. MFC works by using bacteria that release ions while they eat which will then be captured and converted into useable electricity. There are many benefits to this form of power because the bacteria produce electrons automatically and will continue to reproduce over time which makes it a reliable source of power. The application of MFC is ideal for space since the bacteria does not need oxygen to survive and can even survive in low temperatures. Bacteria can also be packed tightly so MFC becomes more efficient than a standard lithium-ion battery. The negative is that MFC does not produce high enough power to supply a large robot but can still be used in simple task robots. MFC, however, can store the energy over time and release it all at once which would make it a great back up energy solution [41].

In 2013, NASA published its “A Roadmap of U.S. Robotics” which details different applications of robots and the areas where research and development is needed. NASA has indicated the following five topics need more attention in the application of robots in space: sensing and perception, mobility, manipulation technology, human-systems interaction, and autonomy. For sensing and perception, algorithms need to be created to convert sensors’ input into representations suitable for decision making. Sensing and perception include position, attitude, and velocity estimation in reference frames centered on Solar System bodies but future development will include these estimations relative to the local terrain. Advancements will greatly impact autonomous navigation, sampling and manipulation, and onboard science data analysis. Enhancements in mobility will enable robots to be able to navigate new sites of interest that were otherwise unobtainable. Extreme terrain mobility, free-space mobility, and landing/attachment equipment area are all factors that will need to be explored. NASA eventually wants to become able to use vehicles below-surface, above-surface, and on small bodies or similar microgravity situations. Manipulation technology will be dependent on a mission’s requirements but will likely include digging, handling objects, sampling, and positioning. Advancements will need to include robotic arms, dexterous manipulators, mobile manipulations, collaborative manipulations with different robotic machines, and drilling and sampling processing. Human-systems interactions are an important development to ensure that humans can operate interfaces safely when in close proximity. With the complexity of robots increasing, interfaces will also need to increase in complexity. Humans will need to quickly understand and operate the complex interface but in order for this to be, interfaces will need advancements in improving situational awareness of operator, being able to capture operator's intent, and control safe operation of robots in close proximity with humans or other fragile systems. Autonomy is a crucial advancement especially when robots are being used in far distances from Earth, like Mars. Complete autonomy of a robot would enable the robot to perform all tasks and decision making without an external source. Right now, robots have some automation which is the ability to perform only a certain function without input from the external source. The benefits of autonomy are the robot's operations capability is increased; it will save costs due to no need for human interfaces or communication links, and an increased mission completion rate in uncertain environments. Areas that will need additional research are integrated health management systems, dynamic planning and sequencing tools, autonomous guidance and control, adjustable autonomy, terrain relative navigation, path and motion planning with uncertainty, and autonomous onboard science data analysis. NASA has also created a 5, 10, and 15 year timetable of different milestones for these topics of research as well as advancements in existing technology which can be found in Appendix 1 [42].

NASA and many other countries' space programs are developing the new technologies that are needed to make the robotics that will enable further space travel. Humans will be able to transition to a supervisory role which will limit the dangers of humans being in space. These robots will be able to complete longer missions and travel to destinations once believe impossible. Constructions robots will be able to design and build colonies on the Moon and possibly further. Our knowledge and access to deep space is directly related to the advances in robotics. With NASA's timeline of milestones, exploring Mars and beyond may be achievable in the next 50 years thanks to robots.

2. Artificial Intelligence

Artificial intelligence is a fast-expanding field with very real application for space travel. Currently, artificial intelligence is used by the rovers on Mars for some of their tasks. Opportunity received an upgrade to its software in 2013, seven years after it arrived. Before this, it was nothing more than a fancy remote-controlled drivable drone. With the upgrade, NASA can give Opportunity a destination, and it will find the safest path between points A and B. The rover does this by analyzing geometric patterns, compiling a list of all possible paths, and then choosing the best one [43]. Curiosity, launched in 2012, can "choose" which samples to investigate as it roams the surface of Mars with pre-programmed criteria to look for.

In more sophisticated areas of Artificial Intelligence (AI), computers simulate a network of virtual neurons, mimicking the functionality of a human neocortex. A program maps out a set of virtual neurons and assigns random numerical weights (0 or 1) to the connections between them. The program then uses these weights to determine how a virtual neuron responds to stimuli. The idea was developed in the 1950s, around the dawn of AI research. It looked promising as mimicking nature had proved successful in many other areas of engineering. This technique is called Deep Learning [44].

While initial attempts at simulating a neural network were met with failure, recent attempts have proven they are fairly successful. Companies such as Google and Microsoft are able to use networks of computers to analyze troves of data and accomplish AI capable speech recognition. At first these were rudimentary, but they have since been refined to be somewhat consistent.

For the purpose of space exploration, it would be extremely beneficial to create AI capable of laying the framework for eventual human habitation, so humans do not have to worry about the inhospitableness of space. Robotic exploration lowers the risk associated with manned missions, and could be more profitable in the long run if they were also used to construct settlements for more complex work done by humans (or perhaps even a new generation of intelligent robots). A robot could wait indefinitely, as long as there is Sun shining and remains in good condition, for supplies to build a sufficient habitat for humans. Furthermore, if a habitation is established on a celestial body such as the Moon or Mars, a robot could perform repairs that require outdoor maneuvering, perhaps even controlled by a human inside the base if the AI aspect is too challenging or unfeasible due to the timeframe.

We are fairly distant from making AI perform similarly to a human, due in part to Moravec's paradox. Moravec states that "it is comparatively easy to make computers exhibit adult level performance on intelligence tests or playing checkers, and difficult or impossible to give them the skills of a one-year-old when it comes to perception and mobility." To give a computer the depth of human evolution and experience is a challenge that we have yet to overcome, though we are making leaps and bounds. Perhaps in the near future we will face the ethical questions that science fiction often presents us with AI, but we are not there yet.

3. Propulsion

Propulsion is another important topic to consider when talking about space exploration. Propulsion is an important topic to consider when talking about space exploration. In the past, our utilization of Newton's third law to escape the bounds of this Earth has been chemical. The biggest obstacle to rocket science has been the fact that to bring something into space, you need fuel. To bring fuel into space, you need more fuel ad infinitum. This is the reason behind the staging of rockets: they drop the mass of a stage as soon as possible on the way up once the fuel in that "stage" has been expended. This is an incredibly inefficient use of the already limited amount of mass one can bring into space. There are other options that humans have barely experimented with in comparison to the scale that we use chemical propulsion. The two metrics that we will judge by are specific impulse, force per unit of time, which is efficiency, and thrust, the amount of force actually generated in the moment.

Solar sailing is a method we have touched upon a few times in our space experience. The first solar sail was launched by the Cosmos Studios in 2005 [45]. It was not successful, but future plans were announced in 2009. Theoretically though, solar sails have high promise for fast long-distance probes. When Sunlight hits the surface of the sail, photons collide with the sail and transfer their kinetic energy while reflecting backwards at a lower energy. While it still requires other propulsion, like a multistage rocket, to get into space, once in the vacuum of space, constant acceleration should be conceptually possible. Even an acceleration of $5 * 10^{-4}$ m/s^2 away from the Sun accelerates you to 43.2 m/s^2 in a day and 45,000 m/s^2 in 2.74 years. At this rate, Pluto is reachable in less than five years.

Nuclear propulsion is another method that has been considered. There exist three methods with fission, nuclear pulse propulsion, thermal nuclear propulsion, and nuclear electric propulsion. Nuclear pulse propulsion was originally brought up in the 1960's with Project Orion by the U.S. [46]. This project suggested nothing more than exploding atomic bombs behind a spacecraft for propulsion. This makes up the basis for nuclear pulse propulsion. Even this very crude method can lift over four times the amount of traditional chemical propulsion due to the massive amounts of thrust produced. Many concerns were raised about the radiation fallout, and the program was quickly discontinued. Thermal nuclear propulsion creates thrust by passing a cooling agent over the fissioning fuel rods and exiting this now super-heated agent out of a nozzle. Nuclear Electric propulsion utilizes a fission reactor to generate electricity for propulsion. As of right now, we do not quite have the technology to harness nuclear energy efficiently in terms of scale and the waste produced. NASA still is holding onto high hopes for the potential of nuclear propulsion though, carrying on the work of Carl Sagan [47].

Lastly is ionic propulsion. Ionic propulsion works on the principle that charged particles (or ions) exert an equal and opposite force as they accelerate away from the spacecraft, propelling it forward. These ions are accelerated by an electric field. This method has a reversed pros and cons list when compared to the standard of chemical propulsion. The specific impulse of ionic propulsion is extremely high, with a ratio of 6 times higher than standard bipropellant chemical engine. Indeed, ion thrusters are capable of accelerating a space-craft over 200,000 mph [99]. The space shuttle is capable of max speed of about 18,000. This comes with the hitch that the acceleration for ion thrusters happens over time with relatively low thrust.

As mentioned above, each of these techniques has its own pros and cons. Solar sailing technology should be further investigated for its potential for exploration. Ionic propulsion is in wide use today for propulsion, but usually only once the craft has reached space. Nuclear propulsion, while the most promising in terms of mass to energy efficiency returns, is still a long way from being anything other than theoretically good.

Propulsion is an important topic to consider when talking about humans modifying the Solar System. Up to the present, our utilization of the conservation of momentum to escape the Earth has been with chemical means, primarily with liquid fueled rockets. The biggest obstacle to rocket development has been the fact that to bring some mass into space, you need thrust. To bring fuel to create thrust into space, you need more fuel ad infinitum. The most efficient means humans have to create energy at the moment is by manipulating the atom, either through fusion or fission. Fission is the process of breaking apart heavy elements, usually uranium or plutonium, into smaller ones. Fusion is the process of combining smaller elements, such as deutritium and tritium, into larger elements. Many of the methods discussed will revolve around these technologies. While fission is widely used to create electrical power, fusion is still 20 years from being able to break even. Currently, fusion has occurred but the energy required to create the process is larger than its output.

The first method of propulsion with nuclear energy was conceived in the late 1950's and further explored in the early 1960's. It was called as Project Orion and explored riding the shockwaves from nuclear explosions. Project Orion proposed building a rocket that would have fission explosions at the back of the craft to force it forward. This crude method, they proposed, could lift over four times the amount of traditional chemical propulsion due to the massive amounts of thrust produced. Conventional rockets create a high amount of thrust over a short amount of time. This method would create intense acceleration over very short periods of time. These explosions could be timed to provide many bursts of thrust. It could accomplish all this while using a small portion of the mass of liquid-fueled rockets. This is ideal for efficiency in travel, and thus would be very effective for moving large payloads. The sudden acceleration would be lethal to humans but they soon engineered a system of dampeners so the spacecraft could be manned. Many concerns were raised about the radiation, primarily fallout and radiation exposure for the crew. Engineers changed the proposed craft to include liquid and metal shielding to protect the humans but general fear of fallout cancelled Project Orion [48]. This technology could be applied to our idea of engineering the Solar System. If we wanted to change the course of an asteroid or other celestial body, we could simply set off a large amount of nuclear explosions on the opposite side. This acceleration will change the orbit of the celestial body which will allow us to control its course. Radiation in outer space is not as large of a concern due to the protection the Earth will have from distance and the magnetosphere.

A second application of nuclear energy is thermal nuclear propulsion. The engines that have been created that use this method are called solid core. They use liquid hydrogen to cool the reactor, drive the turbo pumps and then fuel the nuclear core. This would create a great amount of heat. The super-heated exhausting gases would then be put through a funnel to further increase the thrust. The Soviet Union worked on a nuclear thermal engine called RD-0410 from 1965 through the 1980's. The primary attempt by the United States was called Project Rover, which ran from 1955 to 1972. While the United States was ready to replace the upper stage of a Saturn 5 rocket with a nuclear powered equivalent for future Mars missions, funding was pulled after the Space Race was won [49].

The last form of harnessing nuclear energy is ionic propulsion. Ionic propulsion works on a number of different principles. The first is similar to the nuclear thermal energy in that the engine heats charged particles (or ions) that exert an equal and opposite force as they accelerate away from the spacecraft, propelling it forward. The difference is that electricity is used to create this heat. A second application of nuclear electric propulsion is using the Lorentz Force. This force states that a charged particle moving through an electric and magnetic field will experience a force. The last application of electrical propulsion is using Coulomb's law, which states that two charged particles will either repel or attract each other depending on the distance. The specific impulse of ionic propulsion is extremely high, with a ratio of 6 times higher than standard bipropellant chemical engine. Indeed, ion thrusters are capable of accelerating a space-craft over 200,000 mph. The space shuttle is capable of max speed of about 18,000. This comes with the hitch that the acceleration for ion thrusters happens over time with relatively low thrust. Additionally, all ionic propulsion methods have downfalls. The first of these is the need for a gas, usually xenon, to ionize and then effect with electricity. Secondly, thrust is ultimately limited by the amount of electricity that is produced. A fusion or fission reactor could be used but its power output is limited by size, weight, and fuel [47].

For the foreseeable future, nuclear power is the most efficient means we have to create energy from mass. Ionic propulsion is in wide use today for propulsion in satellites, but usually only once the craft has reached space. Direct nuclear propulsion has great promise for high energy outputs to change the path of celestial bodies but the human population must become comfortable with the technology before it can be applied to manned spacecraft. Ionic propulsion is the most promising for efficiency in the current state of events but it is not feasible for large payloads.

4. Rail Guns

In a similar vein to propulsion, if humans are going to have a presence in the Solar System we must discover a better way of travelling to other celestial bodies. Trying to use the Earth as the launch platform is a silly idea considering its gravitational pull and atmospheric drag. These forces, as well as others, make leaving the planet very difficult. One of the large advantages to colonizing the Moon is that it has significantly lower gravitational pull of 1.6249 m/s compared to the Earth. In addition to a thin atmosphere, this means that it would require significantly less energy to escape the Moon's surface than the Earth's. Due to this low friction, it has been suggested that instead of using fuel to escape the Moon's surface, they should use rail guns. These are devices that use electricity that can accelerate objects to incredible speeds. The most basic design involves a simple circuit with two long parallel pieces of wire and a supply. There is a moving wire that moves and connects these long wires which complete the circuit. This creates a magnetic field between the two wires that accelerates the bar. The United States Navy has recently built one of these devices that can accelerate normal warheads to over 5,000

MPH. To achieve this speed, a total of 25 MW of power is supplied. $P = V * I$ They operate under the Lorentz force which states that an electric charge moving through a magnetic field will experience a force in a specific direction [50]. $F = B * L * I$ where F is Force, B is the magnetic field density, L is the length of the conductor inside of the magnetic field, and I is the amount of current flowing through the wire. To find the magnetic field density B, $B = H * \mu_0$ where H = $\frac{I}{2\pi r}$. Using this information, it becomes clear that to operate a very powerful rail gun on the Moon, a large amount of current will be needed. The strength of the Lorentz force on whatever object being propelled by the rail gun is directionally proportional to the amount of current delivered to the gun. To simplify equations, DC power will be used to run the gun to keep all values constant over time. Since the principles of how a rail gun work are established, it is necessary to determine how much force the rail gun should produce if it is going to be used regularly on the Moon. After considering the options for existing rocket platforms, Saturn V rocket is used as a model for the equations. This rocket was a three-stage with the first stage producing 33,500,000 Newtons (N) for 150 seconds and the second stage at 4,500,000 N for 395 seconds. The third stage burned twice, once for 185 seconds to put it into an Earth orbit at 185 kilometer above the surface and once again after a few revolutions for 312 seconds to go into a lunar trajectory. It produced 1,000,000 N. When the Saturn V was fully loaded and fuelled on the launch pad, it weighed approximately 2,800,000 kg. [51] [52] [53]

As you can see, the majority of the power, fuel, and mass that the Saturn V possessed was needed to escape the gravitational pull of the Earth exerted on it, in addition to the friction through the air. Very little energy was needed to go from an Earth orbit to a trans-lunar trajectory. This suggests that if we could accelerate our space vehicles to similar speeds in the vacuum of space and with the little gravitational pull from the Moon, we could easily use the conventional means and technology already in the Saturn V to explore our close neighbors. Using this information, a fully loaded Saturn V will be the basis for the rail gun calculations and specifications. $F = m * a \quad 1.6249 * 2800000 = \ 4550000N$ If we are to assume that the rail gun will produce the same power as the first stage of the Saturn V, $B = \frac{I\mu}{2\pi r}$ Thus, $F = \frac{\mu}{2\pi r} * L * I^2$ 33500000 = $\frac{4\pi * 10^{-7}}{2\pi 5.3333} * 10.6667 * I^2$. To produce this much force using the size of the Saturn V and the magnetic permeability of a vacuum, it would require a current of 9,150,000 A. $P = V * I \quad 25000000 = 915000 * V \quad V = 2.73\, Volts.$ If our rail gun uses as much as the Navy's, it would require a very high current. There are other means that we could try to increase the strength of the magnetic field, B, such as increasing the number of wires. This would reduce the amount of current per wire which would make the rail gun more viable. This is assuming that the rail gun should produce the Saturn 5 first stage's maximum thrust the entire time. If we are only trying to get the Saturn 5 off of the surface of the Moon, it is only necessary to produce 4,550,000 N to cancel the force of gravity. To produce this much with the basic design, a current of 337,000 A is needed about 27 times less than the previous requirement.

5. Superconductors

The application of superconductor technology in space is also a very real possibility that must be examined. It is an established part of thermodynamics that there is resistance whenever anything moves. Electricity is the movement of electrons from one point to another through an electric and magnetic field. As with all moving things, there is resistance in the flow of these electrons from point A to B. Resistance increases with the temperature and length of standard, non-superconducting wire. For small circuits, the resistance of wire is generally considered negligible. When electricity is transmitted over long transmission lines, the resistance is very high due to the length. As the length increases, the voltage drops across the line, making the voltage at the end of the line lower than what is standard. To counteract this, AC power is used because the voltage can be easily changed via transformers. This energy is lost as heat. The US produced approximately 3,900,000,000 Mwh in 2005, yet sold 3,600,000,000 Mwh. The total loss from transmission and distribution was 239,000,000 Mwh. This was an efficiency of 93.9%. At room temperature, the best metal conductor is silver which has a resistivity of $1.6*10^{-8}$ Ω/m. The next best metal that conducts electricity is copper with a resistivity of $1.7*10^{-8}$ Ω/m. The reason that we use copper on Earth significantly more than silver is because it is much more readily available through mining. Aluminum, which costs approximately a third of copper, has a resistivity of $3.2*10^{-8}$ Ω/m. This is used for long transmission line and is a large cost that comes with distributing electricity. In truth, DC electricity is a better waveform to distribute if only the voltage drop problem could be addressed. If only there was a way that we could transmit electricity from one place to another without loss, we could increase the efficiency of our electrical circuits greatly. This is where superconductors come in. Superconductors have no resistance, thus in a parallel circuit, the voltage across all loads should be the same as the source, regardless of distance.

The dream of this was realized in 1911 when mercury was cooled to 4° Kelvin by Heike Kamerlingh Onnes of Leiden University (0° Kelvin being the point where there is no molecular thermal energy and thus the atoms will not move at all). When it reached this critical temperature, its resistance suddenly dropped to nothing. Electricity that enters one side of the superconductor will be transported to the other side with no loss. Later, it was found that classical superconductors repel all magnetic fields that get near them. When most materials respond to a magnetic field, they produce a field in the opposite direction to oppose the field and effectively reduce it to zero (which is how a motor works). In total, 22 elements have been found to have the same superconducting properties when they are cooled to near 0° Kelvin. These are called low temperature superconductors (LTS) and are classified as Type 1. Type 2 superconductors (high temperature superconductors, HTS) are alloys, the combination of other elements, and when cooled they have also shown to display the same zero resistance property. These Type 2 conductors are not as black and white as Type 1. While Type 1's have a critical temperature where they suddenly become superconductors, Type 2's are more gradual. As the Type 2 material approaches its critical temperature, it begins to exhibit Type 1 characteristics. Areas of the surface of the conductor become superconducting but other sections continue to exhibit normal conductor principles. There become pockets on the surface that continue to react to magnetic fields but other areas repel fields. The temperature at which these designed Type 2 superconductors reach their state is considerably higher than Type 1 superconductors. The highest temperature that materials act as a superconductor is 138° Kelvin at atmospheric pressure. Many materials have been found to be superconducting at higher pressures in addition to heat. Very little research has been conducted to determine what the resistance characteristics of these materials is at a lower pressure than atmosphere.

Is there a way that we could continually cool these semiconductors to below their critical temperature without the need for energy extraction through other means? To accomplish this, we must discover a location where the ambient temperature drops to below 138° Kelvin. It turns out that the Moon does a single full rotation on its axis every 27 days. On the surface of the light side of the Moon, the ambient temperature can reach 123° C or 396° K. This is obviously not ideal for superconductors. On the surface of the dark side of the Moon, however, the ambient temperature can drop to -153° C or 120° K. This is well within the range established by Type 2 superconductors at this moment. There will be some large problems with using superconductors on the Moon. The first problem is the availability of these materials and how much money it will cost to use it for wide scale purposes. A second problem is how to handle the heat the superconductors will absorb from being exposed to direct sunlight for 13.5 days when they are on the light side of the Moon. The South Pole of the Moon is perpetually dark and cold so this would most likely be the most obvious location to start using them. Superconductors will prove to be very useful in the future as long as their shortfalls are overcome and more research accomplished.

American Superconductor, based out of Devens, MA, is current using HTS to revolutionize the way we create motors and generators. They are building a 10 MW Off-Shore generator that uses HTS in its rotor. They claim it will be smaller, lighter, cheaper, more efficient, and less complex. This is possible because they are synchronous generators that use HTS in the rotor circuit. What they do is send a very large current through the HTS to create a magnetic field which is then turning due to the blades moving. This induces a current in the stator windings. There are many advantages to using HTS in motors and generators. Due to the zero resistance principle, the amount of current that a superconducting wire can carry per area is significantly higher than standard conductors thus you can use less material and less space. This also means that a much stronger magnetic field can be created. This also means that the air gap between the rotor and stator can be larger which allows for more slip, the term to describe how far from the sine wave of the grid the generator can operate. The amount of energy needed to cool the HTS is only 40 kW. Even though this is a loss, the system overall is much more efficient, around 40% more [54]. American Superconductor has also created a 49,000 horsepower electric motor that uses HTS for the US Navy to eventually be propulsion for ships.

Another area that superconductors are being used is in Magnetic Levitation trains, MagLevs. Due to superconductor's principle to match the pole of a nearby magnetic field, the two repel each other. Thus, a superconductor will float above a magnet due to the magnetic fields opposing force. This technology has been scaled up to make trains which run on this levitation. Since there is no resistance from contact with rails, the only resistance is air. While superconductors are used to suspend the train, electromagnets are timed to both attract the train on one end and oppose it on the other end, applying a magnetic force which accelerates the train. Trains in Japan have travelled up to 581 km/h using this technology.

How can superconductors be used in space? Their high current density means that rail guns will be much easier to build and much smaller due to the higher magnetic field created, $F = Bli$. Additionally, MagLev can be easily implemented on the Moon to achieve incredible speeds due to the very thin atmosphere and thus low air resistance which would be the only source resistance. Due to their lower weight, it will be cheaper to bring them to the Moon. All major electrical distribution could use it to greatly increase the efficiency and thus sustainability of a colony. Lastly, they could be implemented into common electrical generation devices and ones that consume it. [55]

C. Hazards

1. Space Debris

A very large threat to exiting satellites and future exploration is that of space debris. Space debris consists of decommissioned satellites, spent rocket stages, fragments from disintegration, erosion, and collision with existing debris. In 2009, there was recorded to be about 19,000 pieces of debris larger than five centimeters and about 300,000 pieces smaller than one centimeter below 200 kilometer altitude. It is important to track each piece to help prevent collisions in space or any large debris heading toward Earth's atmosphere, but it is becoming more difficult with the increased amount and the decreased size of the debris with each new collision. The Kessler syndrome explains the ever increasing amount of space debris as a domino effect that occurs when debris causes a collision that produces more debris which will in turn cause another collision. The velocities of these pieces are significantly high so the smallest piece

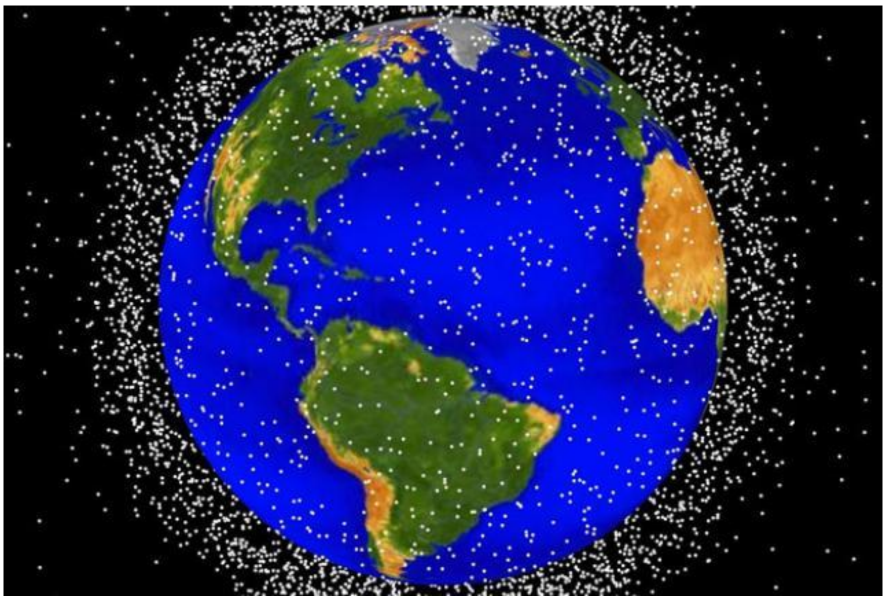

FIGURE 18: SPACE DEBRIS [59]

can cause massive damage; a paint chip at hypervelocity may cause a 0.025 cm hole in a satellite when it collides. According to this syndrome, the amount of orbital debris will triple by 2030 [56]. Many different agencies across the world are designing new ways to combat the war on space debris and many involve advances in robotics.

A key contributor for clearing up space debris is the advancement of robotics designed for use in space. The use of robotics has many advantages, including the ability to withstand greater temperature ranges and radiation than humans are able to. Without as many constraints as humans, robots allow for further travel into space and longer mission times. Robotics will also be beneficial in refueling satellites, fixing any hardware malfunctions, and canceled missions. A concept of a ‘service robot’ has been proposed; the main job functions will be to stabilize or repair any malfunctioning satellites and to deflect any threat of space debris to satellites or Earth’s atmosphere. The service robot will be small enough that it will be able to take advantage of a launch vehicle for transportation to the trajectory and orbit it has been assigned. With current tracking software, debris 10 cm or larger can be detected about three to four days before impact which will allow ample time for the service robot to be in position to deflect the threat [57]. Many companies have designed different types of robotics for space debris that utilize different techniques. Ideas such as a “catcher’s mitt”, harpoons, nets, robotic arms, and “kamikaze satellites” have all been proposed. A promising design is the KUKA arm, which is a robotic arm 1.5 meters in length with 7 joints. It has a functional hand with four fingers, and was originally intended for machine assembly but was later programmed to capture a moving object. The process of transition from machine assembly to capturing objects is done with teaching methods similar to those used with humans. The first step of the process would be for KUKA to learn how to predict the trajectory of the moving object. Once this is complete the second step is to determine the optimum catching posture of the arm. The third step is to generate said arm motion with different trajectories so the robot will learn from repetition. The Learning Algorithms and Systems Laboratory (LASA) reprogrammed the KUKA arm using programming

FIGURE 19: KUKA ARM [58]

by demonstration which is similar to human trial, error, and imitation. The robot was shown sample trajectories while the arm was moved manually to the projected target repeatedly. From this, the robot would learn the possible paths and the different arm motions associated with each one, as well as the corresponding catching position. Once the arm is ready for its mission it will be fitted on a satellite to catch the passing debris by tracking it and noting the rotation to determine the next translation velocity and the necessary catch position [58]. The KUKA arm will be manufactured by Simlab with funding from the European Union research commission project Firt-MM and AMARSI. The Swiss Space Center and EPFL are taking on the responsibility of developing this technology [59]. CleanSpaceOne is a space debris clearing satellite design that the KUKA arm could be fitted to.

The Swiss Space Center at the University of Lausanne has announced their designs of CleanSpaceOne and the plan to launch it with an experimental space plane. Swiss Space Systems (S3) is building an unmanned Suborbital Reusable Shuttle (SOAR) that will be released from an Airbus A-300 after the craft is about 10 km in altitude. SOAR will then use its own engines to reach an altitude of 80 km where it will then release the delivery vehicle. Once this delivery vehicle reaches an altitude of 700 km it will release CleanSpaceOne. The delivery vehicle will

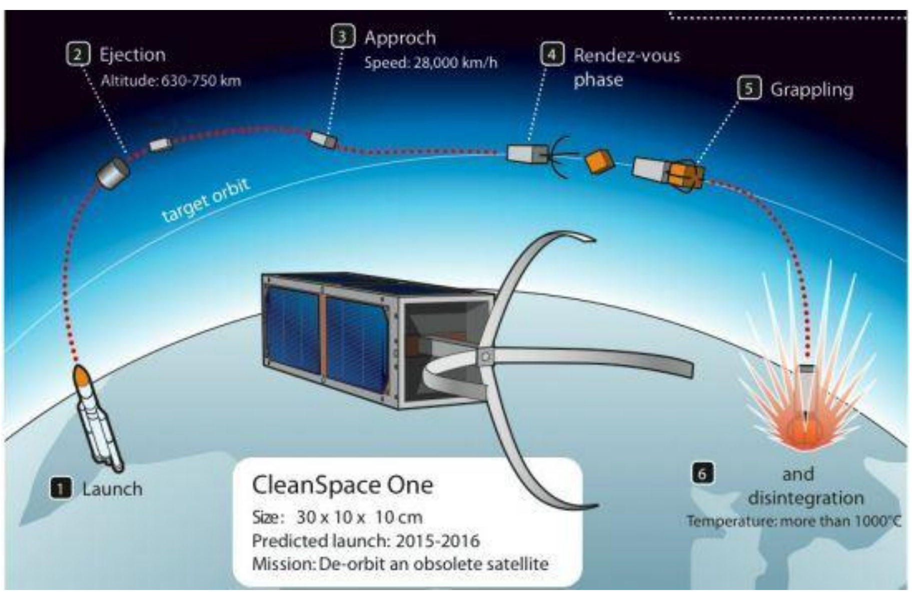

FIGURE 20: CLEANSPACEONE [59]

then de-orbit and SOAR will fly back to Earth for another launch. CleanSpaceOne is a 30 kg single-capture mission satellite, or a “kamikaze satellite”. Its mission is to grab a chunk of space debris and then propel both itself and the debris back towards Earth’s atmosphere where the satellite and space debris will burn up upon re-entry and the debris will no longer pose a threat. The Swiss Space Center cleanup plan will include the manufacturing of multiple CleanSpaceOne satellites that will be sent into different sections of Lower Earth Orbit (LEO). Although this design does eliminate pieces of debris, it is not the most cost effective option since the method involves multiple satellites that destroy themselves and as of now it will cost $10 million Swiss francs to build one. The Swiss Space Center has announced that the first flight of SOAR will occur in 2017 and CleanSpaceOne will be in orbit the following year. CleanSpaceOne may not be launched for another 3 years but the satellite has already been given its first mission: to retrieve SwissCube-1, Switzerland’s first satellite ever launched. CleanSpaceOne will use its four robotic pincers to grab onto SwissCube-1 and then launch toward Earth’s atmosphere [60]. Space debris has become one of the biggest issues concerning safety during space exploration and has been the focus of many companies.

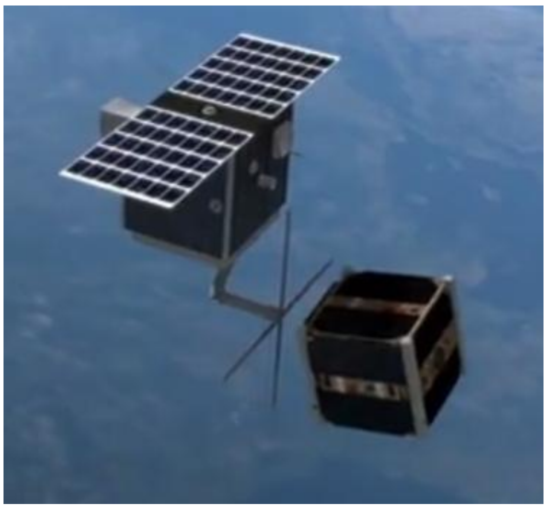

FIGURE 21: CLEANSPACEONE GRABBING SWISSCUBE-1 [60]

2. Effects of microgravity

Before man ever tried to leave the Earth, we were aware of the effects that space may have on our body. Many scientists did not even think that it was possible for a human to function at all and would die quickly in microgravity. Before human’s lives were risked, many different animals were sent into space such as monkeys, dogs, and fruit flies. Many of these flights ended in death for these animals due to impact with Earth. Before they crashed, however, it was found that animals, including mammals, could survive the increased gravitational pull during launch, the weightlessness of space, the radiation of LEO, and the force of reentry. Animals continued to be our medium for space testing until Yuri Gagarin took the first orbital flight of the Earth on April 12, 1961 which confirmed definitely that we could survive in space. Since this time, there have been many humans who have spent considerable amounts of time in space. The record holder for the most amount of time in space is Sergei Krikalev with over 800 days or approximately 2.2 years. The single longest uninterrupted time in space is held by Valeri Polyakov at 437 days.

While short flights seemed to have little impact on the astronauts and cosmonauts, scientists noticed that there were physical repercussions from microgravity (1×10^{-6} G) that affect the skeletal, muscular, cardiovascular, and other systems. First, there is a loss of 1 to 2 percent of skeletal density per month [61]. The loss primarily occurs in the weight bearing bones such as the legs and hips. Second, muscles that are used to support weight and posture are affected since they no longer have to fight gravity. These muscles are primarily located in the back and legs. The symptoms of microgravity on muscles include atrophy, strength, and mass loss [62]. Third, the heart no longer has to fight gravity when sending blood throughout the body. A large amount of blood is sent to the brain so it can function normally. Since the brain is located above the heart, it means that it has to fight gravity to raise the blood to the higher point. The effects of gravity also keep a large amount of blood flowing to the legs under the assistance of gravity. Without the pull of gravity, the heart doesn’t have to work as hard to supply the body with oxygenated blood [63]. Long duration flights in space stations cause the immune system to be weaker. This is caused by the closed, controlled environment of a space craft. Lastly, the body tends to lose its ability for coordination and balance. Research using centrifuges has shown that it takes approximately 0.15 G for the human body to determine which direction is up or down [64]. This is good news since the gravitational pull of the Moon is 0.16 G. The body needs to be strained by 1G of gravity to maintain its strength.

Due to the recent desire to send humans to Mars, it has been apparent that the effects of low gravity, such as the Moon's, should be explored. The first attempt to try and test the long term effects of low gravity on mammals was supposed to occur to 2010 although it was first conceived in the early 2000's. It was supported by a wide number of universities but was spearheaded by Massachusetts Institute of Technology (MIT). A satellite was to be launched with mice aboard and stay in orbit for 5 weeks where the satellite would spin to recreate the exact gravitational pull of Mars. After the five weeks, the mice would drop back to Earth and make a soft landing with a parachute. Unfortunately, the funding never formalized and the project died with no launch [65].

If astronauts are expecting to stay healthy according to Earth standards, they are going to have to work out while they are on the Moon or Mars. To fight the effects of microgravity, long-term mission astronauts and cosmonauts must exercise regularly in specially designed machines to stress their bodies to stay physically healthy. Abroad the ISS, astronauts must work out a total of 2.5 hours a day with a treadmill, bike, and weights. It is still unknown whether the human body could adjust to low gravity and function. While in flight to Mars, it is possible to have the spacecraft spin to replicate gravity by using centripetal force.

Besides Apollo, no other human space flights have had to be overly concerned about radiation. Due to the spinning molten iron core inside of the Earth, there is a magnetic field that blankets the planet in two primary belts. These are called the Van Allen Belts and they are part of the magnetosphere. The outer belt takes the brunt of the charged particles flying at the Earth, dispelled primarily from the Sun in the form of solar wind. This protects the Earth from a large deal of radiation from space. The ISS rests within the first belt and is also well protected while GPS satellites exist between the outer and inner Van Allen Belts. When Apollo astronauts were on their way the Moon, they must have passed through both Belts. During these missions, the average radiation received was around 2 Rads over six days. This number is so small since there were no solar flares or other masses of radiation around the Apollo crafts as they made their voyages [66].The United States Occupational Safety and Health Agency (OSHA) have stated that the average lethal dose of radiation for a human is 200 Rads in an hour. All crafts were equipped dosimeters which measure radiation in addition to shielding. Once past the Van Allen Belt's protection, it is up to the craft to protect the occupants. Traditional methods to shield humans from radiation involve sheets of material to absorb these charged particles. While this may be a viable option on Earth where transportation costs are low, the added weight of the shielding does not make long term space voyages feasible. The primary method that has been proposed for years to counter this problem is to create a strong enough magnetic field to cover the craft but not strong enough to interfere with the occupants or their equipment. Unfortunately, there has been little development in this field since there have been no planned missions since Apollo to leave the Van Allen Belts. More research and data is needed to make conclusions on the subject.

3. Radiation

Of the challenges that space travel poses, radiation is perhaps the most consistently dangerous to human life. Space radiation is different from the background radiation we

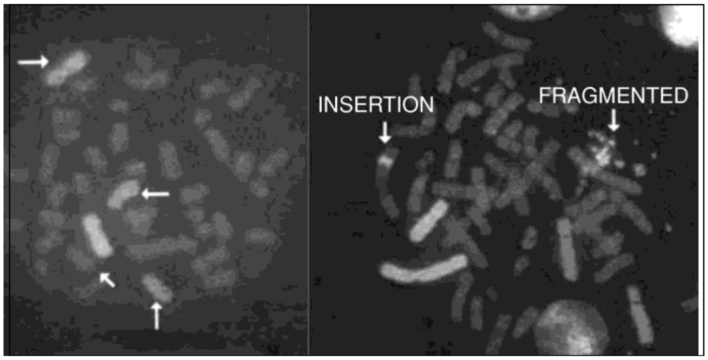

FIGURE 22: HEALTHY CROMOSOME (LEFT) AND CHROMOSOMES FRAGMENTED BY RADIATION (RIGHT) [147]

encounter on a day-to-day basis due to the fact that it is most often ionizing and at much higher energy potentials. At these levels, the radiation has serious potential to damage biological structures such as DNA which could potentially cause cancer or other undesirable ailments. There are three categories of space radiation to consider. One type is the particles trapped in Earth's own magnetic field. The second type often comes from our Sun in the form of solar particle events (SPE), characterized by a large volume of particles, namely protons. The third type consists of Galactic Cosmic Rays (GCRs), which are high energy protons and heavy ions with their electrons stripped away from outside our Solar System [67].

Radiation from space is often ionizing, meaning the particles themselves are the nucleus of an atom with their electrons stripped away and are accelerated to near the speed of light. Upon striking matter, this type of radiation can strip electrons away from the matter that it comes in contact with or ionize the matter [68]. Of the three types, GCRs pose the biggest consistent threat to travelers through the Solar System. It is the dominant form of radiation dealt with by the ISS, and makes up a significant portion of the radiation trapped between the Van Allen belts [69]. The ISS is still in LEO though, which receives a factor of 10 reductions in the radiation due to Earth's magnetic fields.

Due to this constant bombardment, which is variable based on a number of factors including but not limited to solar cycle and inclination, astronauts' suits need to keep the radiation levels within established safety limits. To put numbers in perspective on a round trip to Mars, a human astronaut would receive about 0.66 Sievert (Sv) of radiation whereas 1Sv of radiation is associated with a 5.5% increase in cancer [70]. A Sievert is a unit of measurement for how the radiation is normalized to the amount of damage done to humans or an equivalent biological dose measurement. The crew of the ISS undergoes continuous dosimeter monitoring to ensure their annual dose does not exceed safety standards. This may mean astronauts will need to be regularly switched out so their radiation levels do not exceed the limit. There exists preventative measures that will be detailed later, but there is also the issue of protection from space weather. More specifically, solar storms pose a significant immediate threat without proper detection and preparation. These are high energy storms which require a storm shelter to properly shield against. There were several of such solar storms which happened in close proximity to when the Apollo missions took place. If these happened during the missions the result could have been catastrophic and could have led to acute

TABLE 1. ORGAN SPECIFIC EXPOSURE LIMITS

EXPOSURE INTERVAL	DEPTH (5 CM)	EYE (0.3 CM)	SKIN (0.01 CM)
30 DAYS	25 REM	100 REM	150 REM
ANNUAL	50 REM	200	300
CAREER	100 TO 400	400	600

TABLE 2. CURRENT CAREER EXPOSURE LIMITS BY AGE AND SEX*

SEX	AGE			
	25	35	45	55
MALE	150 REM	250 REM	325 REM	400 REM
FEMALE	100	175	250	300

*** The career depth equivalent dose limit is based upon a maximum 3% lifetime excess risk of cancer mortality. The total equivalent dose yielding this risk depends on sex and age at the start of exposure. The career equivalent dose limit is approximately equal to:**

200 + 7.5 (age - 30) rem for males up to 400 rem maximum

200 + 7.5 (age - 38) rem for females up to 400 rem maximum.

FIGURE 23: RADIATION EXPOSURE LIMITS BY ORGAN (TOP); AGE AND SEX (BOTTOM) [148]

radiation poisoning. Based on data from these events, about $20 g/cm^2$ of water shielding or an equivalent would be able to effectively shield astronauts from such events [71].

Solar storms are the extreme. It is unlikely that spacecraft will be able to carry the proper material for shielding against these with current propulsion technology, so that will not be considered initially. What spacecraft do need, however, is sufficient protection against the constant bombardment of GCRs. Three materials stand out as good for radiation protection, with research in several areas such as plastics for even better materials. The below graph shows the protection various materials offer as shielding. The only issue with shielding is that a thicker shield does not necessarily offer more protection. This is due to the fact that not only is this inefficient in terms of weight, but also because as shield thickness increases beyond a threshold, shield effectiveness can drop or plateau. This is due to the splintering that occurs when ionizing radiation collides with shield nuclei, causing a large number of secondary products, including neutrons. In order to ensure that all astronauts are properly protected from radiation and solar weather, there will need to be many advances in protection.

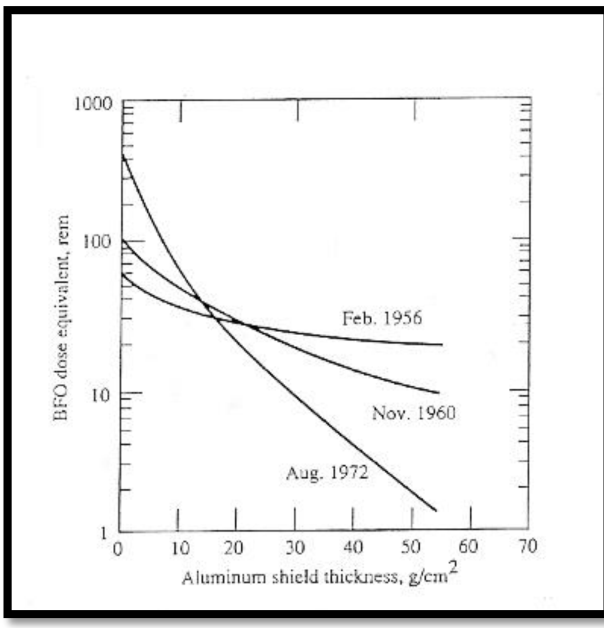

FIGURE 24: SHIELDING REQUIRED FOR SPE EVENT DURING TIME PERIOD OF APOLLO MISSION [149]

Radiation is an important factor to consider when sending biological life forms into space and one that past missions to the Moon have really not had to worry about. Even with some of the most effective shielding technologies used in the past, GCR radiation still has an effect over time. Aluminum is sufficient for approximately six months on the Moon, but could not protect individuals over long stretches of time within the safety threshold. It is also not sufficient against the annual dose for a trip to Mars, so alternatives are needed [72]. Therefore, we need to look for better materials to allow long trips into space or even to Mars as previously mentioned. Not only is aluminum insufficient for long-term shielding, it also fails to protect adequately against SPE, shown in figure 25. Figure 25 also shows that the Apollo timeline narrowly missed SPE. Both the massive dose associated with a solar storm, and the constant bombardment of GCRs must be taken into account when traveling through the Solar System. New materials will need to be investigated to ensure proper protection for all astronauts traveling in space.

A material compound with hydrogen is especially effective, so these are currently under research. Polyethylene and Boron Nitride Nanotubes (BNNT) also deserve discussion. BNNT is a lightweight nanomaterial that has a large neutron capture cross section, making it capable of stopping neutrons in the range of 10^{-5} to 10^{4} eV, while hydrogen can protect against more energetic bombardments. This substance is still theoretical and largely untested outside of simulations, but it looks promising [73]. In 2005, NASA also came up with a polyethylene based material that is stronger and lighter than aluminum, called RXF1. RXF1 is composed of three layers and the composition of each can be altered for different properties, such as micro meteoroid impacts. The upper layers would provide physical protection (layer 1 and 2), while the lower layers (layers 2 and 3) would provide radiation protection. Layer 3 can also provide structural support for the craft being protected. RXF1 is

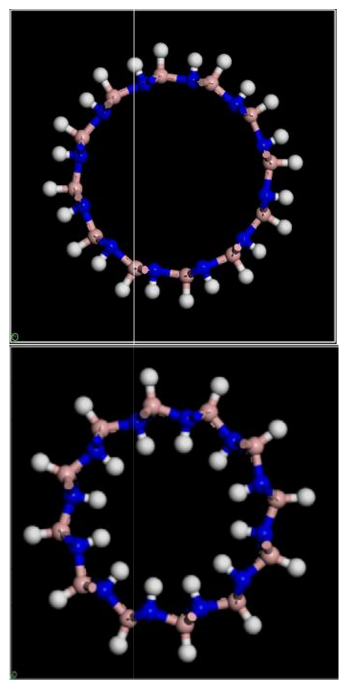

FIGURE 25: 1) BNNT WITH HYDROGEN EXTERNALLY BONDED 2) BNNT WITH HYDROGEN EXTERNALLY AND BORON AND NITROGEN INTERNALLY BONDED [73]

composed of mainly polyethylene interwoven with graphite fibers and an epoxy binding. The outer layer's composition is a bit different to provide micrometeoroid protection and is composed of Aluminum Oxide, Boron Carbide, and Silicon Carbide [74].

A material such as RXF1 that could protect against both micrometeoroids as well as radiation is ideal. Unfortunately, a large portion of the radiation data we possess dates back to the Apollo missions. Therefore projections of the performance of RXF1 are based off of past data as opposed to first-hand astronaut experience. As such, these materials will need experimentation against the brutal bombardment of radiation that occurs in space but it is optimistic for future long-term trips. As radiation protection technology and material science advances, more smart materials like RXF1will emerge. Material science often brings advances to the quality of protective structures which need to be lightweight or have specific properties, and this in turn advances the technology we have at our disposal for space travel. For leaps and bounds to occur, manned space missions need to resume.

D. Colonization

1. Teraforming Mars

Is teraforming Mars a long term option for the future of colonizing space? As our population swells past 7 billion, many have begun to question for how much longer we can continue on our current path without doing irreversible damage. If we cannot stop the current trend of environmental damage, the Earth could eventually no longer support the growing human population. If this becomes true, what will humans do to support themselves if the Earth is uninhabitable? Space is obviously the solution, but this raises another question, do you try and teraform an existing celestial body or do you build a base in or on a celestial body? Since this question has been originally raised, we have primarily focused on either building a base on the Moon or teraforming Mars. The primary method we should be focused on is building a base on the Moon whereas Mars is not an ideal body to be teraformed. The idea of teraforming a planet is to make it Earth-like so that Earth-based creatures can live easily and with relatively little adaptation. Initially then, Mars seems like a good idea due to their similarities. They are both inside of the Habitable Zone, a region of space in the Solar System where liquid water can form on the surface of bodies assuming the correct atmospheric pressure. They both have an iron core which is beneficial for a magnetosphere, a magnetic field that is created around the planet, shielding it from solar wind. Solar wind is charged particles that are flung from the Sun and the rest of space which can strip an atmosphere. In 2001, NASA sent a probe around Mars that was equipped with a Gamma Ray Spectrometer, which allows it to detect up to 20 elements. It has reported that there is a vast amount of hydrogen in the soil, especially in the South Pole. This means that it would be very easy to produce water while on Mars. Lastly, they both have had their landscape scarred by other celestial bodies. Unfortunately though, the two planets have more differences than similarities. The Earth's core is still very hot, causing a magnetosphere to form around the planet which effectively protects it from harmful solar winds. The mass of Mars is about a third of the Earth or Venus [75]. This fact combined with its far distance from the Sun means that its core cooled very quickly in comparison; there is a plate tectonics but it happens at a much slower rate. This lower mass and core temperature also caused its magnetosphere to stop producing a sufficient magnetic field to protect the planet early in its history, which indicates that charged particles in the form of solar wind was allowed to strip the planet of the majority of its atmosphere. This lack of core heat and atmosphere means that Mars is not beneficial for long-term teraforming. To make this possible, the core must be heated to a point where the magnetic field is strong enough to protect the atmosphere that would be created around the surface and maintained. If this is not accomplished, it is very likely for the same course of events to occur again, making the time, effort, and money invested effectively futile. The only lasting solution to teraforming Mars is to change significant factors about it. Some potential solutions could be to change its path around the Sun with an asteroid or other mass that will bring it closer. This would give it the benefit of being farther from the inner asteroid belt which poses a great threat to the planet's surface. Additionally, since the planet is closer to the Sun, it is effectively providing it more heat. If this cannot be done, mirrors can be put near the planet to redirect heat to it and thus simulate the same effect. This can only be done to a degree however, basically until the temperatures rise too greatly above what is relatively the same as Earth's. Another solution would be to increase the mass of the planet, allowing it to better retain heat. This would also give the benefit of Mars providing more gravitational pull, making it more Earth-like. This is not to be seen as a failure, but it means that there are many problems that need to be worked out. This means that we should further research into putting a base on the Moon since there are less problems that need to be solved.

2. Building a colony on Mars

Though the aforementioned obstacles surrounding colonizing Mars are great, it is one of the three sister planets. Due to the runaway greenhouse gas effect on Venus, Mars is the closest planet that humans have set their sights on for colonization. The challenges it poses are impressive, but surmountable with the correct technology and perseverance.

The most pressing challenge about colonizing Mars is its lack of radiation protection. The radiation on Mars is about three times as strong as that on Earth [98] due to the lack of a magnetic field and Van Allen belts, meaning damage to DNA is inevitable if precautions are not taken. It is rather grim, but the increased DNA mutation rate may aid natural selection on Mars, though this would occur over time. For this reason, the solar winds and cosmic rays necessitate a shelter capable of shielding from radiation; water is a possible solution to this problem. Water exists in the ground of Mars and in impact craters and the halving distance of water is 18cm. If Mars's radiation is three times stronger in comparison to Earth's, then 32cm of water is needed to reduce the radiation on Mars to 0.75 the levels on Earth. Another risk is the large temperature variation, ranging from -140° C to 20° C. This would also require some form of shelter to protect against. Mars, unlike the Moon, actually has an atmosphere though. However, it is so high in carbon dioxide (about 95% of the atmosphere) that it would be lethal to plants and animals. This atmosphere is so thin that Mars still gets about as much Sunlight as a moderately cloudy day on Earth though [96] meaning solar energy is viable. All of these factors combine to make an underground structure such as a cave or lava tube very attractive for early colonization.

There exists a plan by a private organization called "Mars One", funded by public interest, to put their first "crew" in successive waves on Mars, starting in 2024. They have 200,000 volunteers and they plan to begin a full-time training of selected candidates, full-time being from 2015 until their launch in 2024. They plan to send out communications satellites and rovers in 2018 and 2020 respectively, and then in 2022 they plan to launch six cargo missions. The following year will consist of the base being constructed from the cargo mission by the rover sent previously. This mission will be a one way trip for volunteers. It is apolitical and the only thing they need technically is "larger rockets" to send a pressurized robot capable of setting up the habitats. The life support unit generates energy with solar

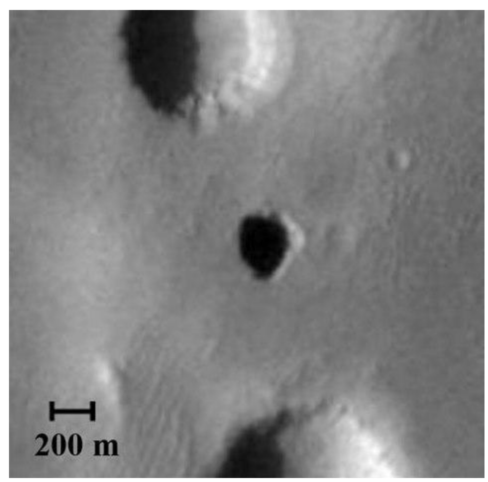

FIGURE 26: ONE OF THE SEVEN SISTERS CAVE SKYLIGHTS [121]

power and water is created and used for radiation shielding by harvesting it from soil. The Life Support Unit is able to collect 1,500 liters water and 120 kilograms oxygen in 500 days time [97].This looks like a fairly ambitious group that claims to have people who have already agreed to make the technology they need with a fairly detailed roadmap and already 200,000 volunteers. This is definitely something to keep an eye on, and the only major flaw is the fact that the mission is basically at your own risk and that the structures are inflatable, which make the colony vulnerable to even small rocks flying through space.

As previously mentioned, caves are a very attractive site of colonization on Mars. In 2007, NASA made the first discovery of a patchwork of what appears to be holes on Arsia Mons; they range from about 300 feet to 800 feet in diameter. In the same year, infrared images confirmed that the holes stay warmer at night than the surrounding air and stay colder during the day [76]. Due to these lessened temperature fluctuations, these must be fairly deep caves on the surface of Mars and they were dubbed the "Seven Sisters" [77]. Even their method of discovery shines light on the caves as a possible refuge for future humans. These holes were most likely formed from lava that is no longer flowing. There were later discoveries of more underground systems, not just holes. Many faults, of volcanic and tectonic origin, exist on the surface of Mars as well. These underground structures are ideal to protect against virtually everything that humans fear on Mars. The temperature extremes are lessened for one, and the caves provide a barrier to all of the radiation, (micro) meteoroids, and dust storms that plague Mars. Caves are also very attractive because water cannot stay long on the surface of Mars due to its lack of atmosphere. If water were to get trapped in a cave, it would be much harder for the harsh environment to remove it, especially if it seeps into the ground. Indeed, the Tharsis region is dotted with caves and water-ice clouds are observed to form there nearly every day of the year. [78]

Unfortunately, we do not currently have much knowledge about the interior of these subterranean systems. There is a need for robotic advancement before using a robot to explore the caves is an option. Hopefully the two probes that were recently sent can gather some more information. Further exploration is definitely warranted as caves could easily provide a temporary shelter for humans if bringing supplies for building a shelter is not feasible, especially since they are among the best places to find water on Mars.

3. Ceres

Ceres is the largest object in the asteroid belt with a diameter of approximately 950 km. Giuseppe Piazzi discovered Ceres on January 1, 1801 and was the first object to be considered an asteroid. In 2006, when Pluto was demoted to a dwarf planet, Ceres was simultaneously promoted to a dwarf planet. With a mass of $9.4 * 10^{20}$ kg, it accounts for slightly under one third of the mass of the asteroid belt and is estimated to be the same age as the rest of the Solar System, approximately 4.5 billion years old. Pictures from the Hubble telescope returned blurry pictures which showed a white spot on the surface. Recently, the Dawn spacecraft, an ion thruster powered probe, returned back the highest resolution pictures to date of the dwarf planet, confirming the white spot. As of March 6, 2015 at 07:39 Eastern Time, the Dawn spacecraft had entered orbit around Ceres at a distance of 61000 km. The Dawn spacecraft is the first man-made object to ever orbit Ceres. For the rest of Dawn's usable lifetime, it will orbit Ceres to gather data using its spectrometers and other instruments. This white spot was hoped to be water vapor being released

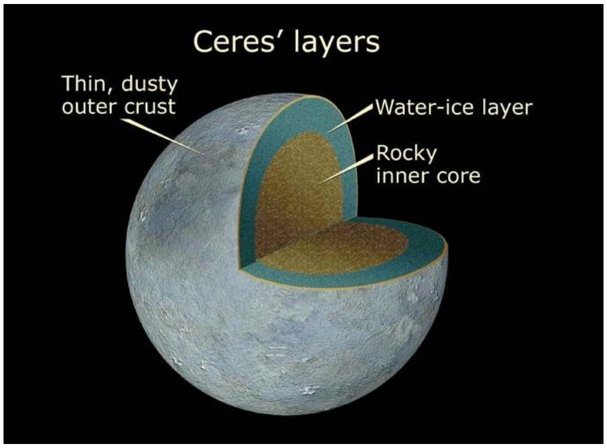

FIGURE 27: CERES' LAYERS [79]

from the surface which otherwise appeared to be solid. Multiple studies have tried to determine what this spot and the vapor is composed of. Using advanced telescopes capable of emitting and detecting ultraviolet light, the reflectivity of the surface of Ceres was tested painting the most detailed picture of Ceres to date. The most interesting response was in the 3μm range of radiation. High reflectivity in this wavelength is directly a result of high amounts of water. This result allows us to deduce that the white spot is probably a pole that releases approximately 10^{25} molecules per second of water vapor when it gets closer to the Sun. We now believe that Ceres has a solid, porous rock core that is surrounded by a layer of ice (Figure 27). There is not believed to be enough gravitational pull to force the water to occupy the pores in the rock. Much of the dust surface on top of the ice mantle, expected to be around 20m thick, is believed to be hydrated [79]. There is estimated to be more water locked in the mantle of Ceres than there is on Earth. This celestial body would not be helpful as a moon because it does not have enough gravitational pull to be effective, such as the Earth's Moon. It could be used to supply a planet with water, a stop towards teraforming. Due to the dwarf planet's location in the asteroid belt, it could be launched at Mars to bring it closer to the Sun and additionally increase the mass of the planet. This would be beneficial for restarting and maintain heat in the core and thus maintaining a magnet field to defend the surface and atmosphere from radiation. [80]

4. Colonization of the Moon

We have looked to the Moon in wonder since we got our first glimpse of the pale blue dot as a spectator instead of an inhabitant. It brings a sense of catharsis if our journey into the cosmos ends there. The first space race was fought over the Moon, and many nations (US, Russia, Japan, China) still cast a longing eye on it. Indeed, there exist numerous plans and methods to build bases and settlements, none with a definitive date or game plan. The challenges that are posed by colonizing the Moon are so great that the effort underscores the need for international cooperation to achieve the progress necessary to become a space-faring species.

Colonizing the Moon poses two main problems. The first and foremost are the resources, a massive amount of money and other resources (such as an oxygen supply and food) are needed to even go there in the first place. One solution is to get resources needed from the Moon itself and asteroids. Most of the oxygen and other volatiles on the Moon are trapped in compounds in the soil, so methods to extract this could be beneficial in producing oxygen producing plants for use in fuel and sustaining human populations [81]. Then hydrogen (a much lighter element) could either be brought in supply runs or obtained from volatiles. Agriculture on the Moon has been researched even though it has a half-month day, and the limitations on plants are slightly less than those on humans [82]. They don’t fear radiation for one, but they still need an atmosphere with carbon dioxide.

The second problem is the fact that humans are vulnerable creatures. We would need to take precautions against many things. Radiation comes to mind first. Cosmic rays and ultra-energetic bursts of protons are constantly bombarding the Moon, so a radiation shield of sorts is needed. Water or lunar regolith can shield from radiation fairly effectively. The halving distance of water is 18cm, and lunar regolith shields from gamma rays effectively at 18cm with a density of 1.9 g/cm^3. [83] There is also the issue of microasteroids, which can cause damage to non-fortified structures and humans alike. An overhead shield would be necessary to protect against this. Due to the Moon’s lack of atmosphere, there are massive temperature fluctuations between day and night (between about -250 F to about 250 F). We would need some kind of insulation to protect us against this as well. Due to these dangers, it would be beneficial for at least preliminary structures to be built inside the lava tubes that dot the Moon. This would protect from radiation, micrometeoroids, temperature variance, and things ejected from the surface from takeoff or landing. These lava tubes have never been entered though, so exploration is needed before settlement can occur.

An initial supply ship would most likely need to be sent out in order to ensure a suitable base that can be established in one trip without reinforcements. Robots would be ideal to construct the initial base, with engineers coming soon after as back-up or extra hands. The South Pole would be an ideal site for construction because of the effect that a perpendicular axis of rotation in relation to orbit has. The poles of the planet also have areas of almost constant sunlight. The South Pole is also in close proximity with the Shackleton crater, which has a high probability to contain preserved volatiles. This means the South Pole has easy access to energy in the form of solar power unhindered by an atmosphere, and quite possibly water. There is also Malapert Mountain that is always visible from Earth, which can be used for communications arrays.

There are additional advantages the Moon has over other celestial bodies as well. The Moon would be a great staging ground for future exploration. It has no atmosphere and therefore a view of space unimpeded by static or even human background radiation (radio waves). Its proximity to Earth (about 3 days by ship, 3 seconds for light) means that messages and supplies would not be too far behind if they were desperately needed on the Moon. Taking off from the Moon's gravity is also trivial in comparison, meaning if it were to become sustainable that launches from the Moon would be far more economical. In the end though, all governments are forbade to lay claim on any celestial resource "such as the Moon or a planet," but this may change once we are able to colonize the Moon.

5. Blueprint for Moon Colony

Arguments have been presented for the colonization of other bodies, but a case is presented below for setting our sights on the Moon as the first place for human colonization. Humans have a natural, insatiable, curiosity. This curiosity often leads to adventure and expansion. Throughout history there has been a constant drive for this. From the conquests of Alexander the Great to the first man on the Moon, humans have always strived to expand and better the cause of humanity.

It is for these reasons that it is only natural that many such explorers and adventurers of this age have set their sights on the Moon. It is a perfect staging ground for future exploration. It allows easy access to space due to its low gravity in comparison to Earth. This can pave the way for future explorations where the majority of the fuel payload can be used for acceleration instead of escaping atmosphere and gravity. It would also provide a safety net for humanity in the long run if something were to happen to Earth. It is only natural that humanity should continue to expand and make the massive leap it takes to become a space faring species. The Moon offers a place free of the numerous background radiations of Earth and a view of the cosmos unimpeded by an atmosphere, making it very convenient for astronomy and sensitive measurements as well.

Why not Mars

So why not choose Mars as the first location for setting up a base? One of the primary problems with Mars is its distance from the Earth. It would take a spacecraft of conventional chemical means between 8 and 12 months to reach the Red planet after launch. This means that there would be a significant amount of isolation and thus physiology wear will affect the crew. Additionally, due to the distance, there is approximately a 12 minute delay between when a message is sent from one planet and is received by the other. This is a significant enough of a delay that vital information that can spread in seconds on Earth to avoid catastrophes will be received too late if you consider the first possible time Mars will receive any word back is 24 minutes, assuming control has an immediate and full response.

Another reason not to consider Mars is that it offers very little solar radiation protection due to the lack of a magnetosphere. This means that it offers no atmosphere and thus is practically a vacuum, providing no sustainable environment for humans. Lastly, it is farther from the Sun so it will receive less collectable solar energy for power.

Why Choose the Moon

So we have given an argument as to why not choose Mars, but that doesn't directly answer the question of why choose the Moon. The answer is that the Moon is a familiar object for people. You look up at the sky every night and see the Moon shining back at you. Generations have been inspired by talks of humans setting foot on the Moon ever since the very first leap for mankind - the only celestial body we have yet to accomplish this feat on. Out of any other object in space we have the most knowledge and raw data on the Moon, save for the planet we call home of course.

This is in part due to the proximity of the Moon, which also has several desirable consequences. For one, it takes light three fourths of a second to travel from Earth to the Moon. This means that the delay is almost negligible in communications between the two if a satellite were to be established on the Moon. Regular trips for supplies and miscellaneous needs could be accomplished in about three days, making only the cost an issue. The plan of regular communication from Earth to a colony in space has a powerful psychological effect on the people living in space, and lets them know “you are not alone up in space”. It allows any Moon inhabitants to have dependable, regular, contact with people from back home.

Human Physiology

If humans were to not live permanently on the Earth, what would be the short and long term health effects? Firstly, we will address the short term effects. Initially, there will be minor changes in blood flow and there might be general disorientation. As time goes on however, the effects of low gravity will start to make noticeable effects. The amount of work the heart does decreases since it no longer has to fight gravity. This means that if a human that is adapted for the Moon or microgravity in general comes back to Earth, he will experience blackouts and other symptoms of lack of blood flow to the brain, while simultaneously making the lower extremities swell. In addition to these affects, bone strength and muscle degeneration will occur due to the lack of stress that allows us to maintain strength.

Is human reproduction affected by microgravity? tests with various animals including rats have shown that while it is possible for an egg and sperm to come together to form an egg, it was very unlikely for these cells formed in this microgravity to take hold and multiply. When in vitro fertilization was attempted, it was found that there was a lower survival rate for those rats born in unnatural conditions. Rats remember are relatively simple creatures compared to humans, thus our dependence on gravity is much higher for proper development.

Radiation Protection

Radiation is present in many forms in space. Energetic protons bursts from the Sun, gamma cosmic rays, and even some heavier nuclei solar plague anything left unprotected. Reliable radiation protection is needed to safeguard the delicate biological structures of any humans living on the surface. Experiments have been done on lunar regolith, and 100 MeV protons stop in approximately 5 cm of regolith at a density of 1.9g cm. 200MeV protons need 18 cm of regolith [83]. Water is also a viable shield, as the halving distance of water is 18 cm. This means successive 18 cm sheets of water can be layered to provide protection on the order of magnitude of 2 (# of sheets).

Energy and Location

One large benefit to the Moon is that there is a very thin atmosphere. This means that there is little to protect the surface from the Sun's rays. This means that photoelectric solar cells will be able to absorb much more energy per area. There also exist areas on the Moon with almost permanent Sunlight. This is because the Moon's axis is perpendicular to its path of orbit, so this results in the poles having almost constant Sunlight. This would make either pole an ideal location to settle.

The South Pole in particular stands out due to the proximity of Shackleton Crater. The crater is 20km in diameter, and there is evidence there may be a large amount of volatiles preserved in the crater, including Hydrogen, which is a possible indicator of water. This would be a valuable resource for human inhabitants. The rim of the crater has almost constant Sunlight due to the phenomenon mentioned above, making it ideal for collecting solar energy necessary to support human life. The question of where exactly to put the settlement is a little trickier. A lava tube would be ideal however a mapping of lunar lava tubes lists none near the South Pole [84].

We could perhaps manipulate the regolith and inhabit an area or slightly inside the crater. Going underground would provide the benefit of protecting against radiation, asteroids, and temperature extremes that fluctuates between 100 degrees C during the day to 173 degrees C at night. This is why a lava tube would require the least amount of effort to turn into a settlement. A modular settlement could be built by robots before humans arrived as well. Automated construction techniques can be used to build structures on the Moon. A giant 3-D printer that can be attached to the top of a rover will take advantage of raw materials on the Moon. Not only will the 3-D be able to construct the basic structure but also integrated radiation shielding, plumbing, electrical, and sensor networks throughout the entire structure. The two most feasible options for materials are sulfur concrete and regolith sintering. Sulfur concrete is compiled of 80% regolith and 20% sulfur. The 3-D will be equipped with a nozzle that the dry mix of the two components is poured into. The nozzle will then heat the mix to 130 C to make a cement-like paste that will be layered to form the structure with a high compressive strength. Sulfur concrete cannot be used where temperatures exceed the melting point of sulfur but sintered regolith would be able to be used. Sintered regolith's only ingredient is the lunar regolith which has a high compression strength and tensile strength. If metal powders (copper and steel) are added to the mix both strengths are increased. The mixture will then be compacted into graphite molds and then placed into a ceramic furnace where the sintering temperature ranges from 975 to 1100 C. These materials consume less energy and time for construction and will allow astronauts to teleoperate and supervise from a different locations [33].

Water

As previously mentioned, volatiles are present in craters. These would require careful extraction and mapping, so a more reliable method of obtaining water would be needed until we have more physical exploration of these craters. A promising avenue is to use the high amounts of oxygen contained in the soil of the Moon, and obtained hydrogen elsewhere to make water.

Hydrogen is a lot more lightweight than oxygen so it would be a lot easier to bring as a small payload if needed in a pinch.

Agriculture

Agriculture is possible on the Moon, and should be considered for a sustainable colony. Plants do not mind radiation as much, and simply need the proper concentration of CO, light, and water. This would require room specifically dedicated to growing crops.

Payload

If we are going to effectively build a lunar base, we need to know initially how much mass we can get to the Moon from the Earth with rockets. If we only look at rockets that have been built, the Saturn 5 is the most powerful, with a Trans-Lunar Injection payload of 45,000 kg. A proposed NASA rocket, the SLS Block 2 will eventually have a TLI payload of 40,000 kg. The Falcon Heavy, built by Space-X, will have a TLI of 10,000 kg.

Communication satellites

A communication relay system will need to be implemented for 24/7 coverage of the Moon to ensure constant inter-lunar communication with the station as well as a global positioning system (GPS) for astronauts. There are “dead spots” across the Moon that are hard to reach without a relay system like the Moon’s poles and the far side since it does not face the Earth. The relay satellites will have to overcome constant gravitational pulls from the Earth, Moon, and Sun. A “frozen orbit” has been proposed for the lunar communication satellite (com-sat). The frozen orbit will allow the lunar com-sat orbital characteristics to be constant even with pull from the Moon’s uneven gravity field. If the orbital path is carefully chosen the pulls from the uneven gravity field will cancel each other out so the com-sat will remain in orbit. Another potential orbit is a halo orbit which is a periodic three-dimensional orbit around five Lagrange points which is the position in an orbital configuration where the com-sat is affected by gravity only and can maintain a stable orbit in the Earth-Moon system. A halo orbit at the L2 point (Lagrange point above the lunar far side) would be the best option since this orbit will have a view of the far side of the Moon. Since these com-sats would be in a delicate obit which will make it easier to correct its orbit or be sent back to either Earth or the Moon with small amounts of fuel. It also takes less fuel to place a satellite in a L2 halo orbit than to place a satellite in a GEO orbit. Another cost reduction is the use of Liaison Navigation between com-sats in L1 and L2 halo orbits. The com-sat will be able to send a pulse to another com-sat and time how long it takes to return. This will allow the com-sats to be located in orbit and a constellation of com-sats can navigate as one reducing the cost of operating the constellation [85]. For communications to Earth from the lunar station, a radio relay system could be built on the Malapert Mountain. The Malapert Mountain is about 5 km tall and is located about 120 km from the aforementioned Shackleton Crater on the South Pole. The Malapert Mountain peak is constantly visible to the Earth which will guarantee constant communications between the Earth and the lunar station.

The Crew

The Moon station will need a mixture of both robotics and skilled people to guarantee the successful operations of the station. There are different occupations that are needed; doctors, engineers, astronauts, chefs/nutritionals, and biologists. The initial Moon station would employ about 25 people but with expanding there would be a need for more employees. Each profession is staffed with enough employees in case of any emergencies that would danger a staff member.

The average time for a shuttle to reach the Moon is three days so worst case scenarios will need to be taken into account to guarantee the safety of all aboard the station. The medical ward would employee three doctors with a variation of specialties to cover any medical needs of the astronauts. Robonaut 2 would be beneficially to the medical ward. With advances in teleoperations, doctors will be able to perform operations and other medical procedures. Robots will be able to make sure all staff members will be properly checked out and all medical procedures are performed. A department of engineering will be established. Robotics, computer science, and electrical engineering are three disciplines that would be beneficial to the station. A department of engineers will consist of four people with one appointed as head engineer for robot supervision. These engineers will need to maintain a network, establish a power system, and supervise construction. A leadership structure will need to be established with the astronauts as the leaders. A department of three astronauts will observe Near Earth Objects (NEO), survey the Moon, and maintain the Moon station equipment. The food department will consist of three chefs and two biologists. These chefs will also posses the knowledge of nutrition and health. It is essential that the station staff is kept healthy in space so the chef will guarantee everyone is fed properly and getting the necessary exercise. A space farm would create a sustainable environment and an artificial ecosystem on the space station.

Two farmers/biologists would be needed to maintain the space farm. Ten “laborers” will be staffed to help with each department and maintenance. The laborers will need to be educated with at least a Bachelor’s degree. These laborers will be needed to assist where it is needed and simultaneously be trained in different roles to help with relief and in case of emergencies. About 5 Robonauts will be used across the station to help any staff members perform routine tasks.

Game Plan

An initial payload of tools and survival supplies will be needed to start the space station. A wide variety of tools will be needed for construction and maintenance. Computers and other technology will need to be shipped. Initial survival supplies will be sent until a space farm can be established and a reliable water source. Water will need to be supplied until we can find a way to harvest hydrogen. Hydrogen can either be sent from Earth or gathered from solar wind. Oxygen can be harvested from the lunar soil by heating it up and extracting the oxygen. A regular supply trip will be scheduled to bring fresh supplies and bring relief for the staff. Depending on funding, the scheduled trips could be every month or quarterly.

What's the plan

Once the perfect location is selected, construction on an underground structure will begin for the initial habitation. Various robots will be used in the construction phase. A 3-D printer, that takes advantage of lunar soil and regolith to build the infrastructure of the station, will be used to construct the large structures. Rovers and humanoid robots will be able to transport materials and construct the more intricate details of the station. The entire space station will have a modular architecture so that once the initial station is stable and can satisfy all basic human needs successfully other buildings can be built that have specific function. Tunnels will connect each building for easy access throughout the whole station. Expansion can include an observatory with a telescope, laboratories, "hotels" for destination vacations, and a staging ground to aid with future exploration.

Physical Structure of Base

The main characteristic of the base is that it needs to be modular. If this is not taken into account future additions if the base were to ever grow in size would be unpleasant. Initially, the ideal base would be build inside of a lava tube with the opening sealed with an airlock. The interior of the lava tube will then be sealed so that it can be pressurized. This would allow the people to function regularly in terms of respiration, giving a much more Earth-like environment. On the other hand, a modular connected structure above the surface or inside a crater near the South Pole may be more viable after further exploration is done. Basic buildings will need to be prioritized such as sleeping quarters, communications, mess hall, waste management medical stations, food and water supply and lastly an energy source such as electricity. Once these are accomplished, less critical buildings can be built.

Conclusion

A lasting colony on the Moon would certainly be a great achievement for humanity. It would allow for future exploration and advancement in science we have not yet imagined. Obstacles still exist, such as the need for human (or robot) exploration of the lunar surface and the monumental effort in robotics and human ingenuity to set up of the initial base, but they are surmountable with perseverance, as is needed in all pilgrimages. This past section has aimed to take a comprehensive look at all that is required for consideration for an organization desiring to settle a celestial body than Earth.

E. Space Policy

The future of space endeavors are centered on the colonization of celestial bodies. With the fact that different countries will want to colonize the same celestial body (such as the Moon) there will need to be clear policy and laws to govern this new frontier. The 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space (1967 Outer Space Treaty) specifies many conditions regarding the use of outer space: (1) outer space is not a sovereign territory, (2) It is governed by international laws including those listed in the United Nations charter, (3) States will bear international responsibility for national activities in outer space, (4) States are obligated to supervise activities of their non-government organizations in outer space, (5) States will retain jurisdiction over the objects that they launch into outer space, and (6) Ownership rights will not change by their existence in outer space. Many operating guidelines were discussed and adopted by the United Nations (UN) General Assembly such as the sovereignty of individual states, international cooperation with other states, technical assistance for developing countries, and environmental protection. This treaty outlines many issues that will arise when colonization begins to take place. Construction of a base on the Moon, for example, is legal under the 1967 Outer Space Treaty. However, any country claiming sovereignty for use or occupation is illegal. The country that builds the Moon base will have jurisdiction over its base but will also have to obey international and UN laws. With the US government contracting many of its space related missions to private companies, a committee must be created that will be responsible for supervising all private endeavors to ensure that all laws are being upheld and proper responsibility is taken for anything that goes wrong on a mission.

After the 1967 Treaty, there have been additional documents added for the protection of space for all states. The 1972 Convention on International Liability for Damage Caused by Space Objects places liability on each launching state for any damaged caused by space objects that are launched. This is beneficial since there is never a guarantee for a successful mission. The 1975

Convention on Registration of Objects Launched into Outer Space mandates that each launching state must first register any object that is planned to be launched into space. Only then will the state have jurisdiction over its space objects. With this standard set in place, there is no confusion over which object belongs to which state, establishes “space territories” for each object and makes it known to all other states. The International Telecommunication Union (ITU) coordinates all radio frequencies used in space so all states will operate on their own frequency and there will not be any interference on other established frequencies.

With the road map for SPS to supply most of the world’s energy in the future, the 1967 Outer Space Treaty has been used to outline the potential legal issues that could arise. SPS’s will be governed by international law and national laws but will also have various legal relationships with other countries depending on competition requirements, collaboration on technology or construction, supply and demand for the electricity, national security, and liability. A project of this scale would most likely need collaboration between various countries for the funding and construction. Another important relationship is between different countries that each has their own SPS. The GEO orbit has limited locations that can house these massive structures, especially since they will need to be above the ground station. Cooperation between these countries will be essential to ensure that there will be no interference of the energy being sent to Earth. A potential “space energy” committee may need to be formed in the UN to place restrictions on the number of SPS’s as well as the competition to ensure that less fortunate countries will be able to take advantage of this new energy source. Space energy will be an international commercial entity and will most likely operate as a public-private partnership (PPP) similar to the GPS system or the International Atomic Energy Agency.

The growing trend in the US has been to keep difficult and deep space missions within NASA but to outsource other missions (like transporting cargo or crews) to private industry. Even though the government is not directly funding or working on these projects, it will still need to supervise and be held liable for any damage or failures that happen in space from these private endeavors. This will simultaneously make choosing which private companies are awarded these contracts a stricter process and construct guidelines for the companies. As long as each state still keeps a close eye on private endeavors, there will be no difference in government launched objects opposed to private launched objects [86].

The UN has created a committee on peaceful utilizations of outer space (UNCOPUOS) whose main responsibility is enforcing international space law. This committee has negotiated five treaties (most of which have been discussed in previous paragraphs) with only four ratified by countries with active space programs, such as the United States and Russia. The treaties cover many areas of outer space but new gaps have arisen due to the advancement in technology since the treaties were written. Many projects that are soon going to become a reality will further widen this gap. Some aspects that are missing from the treaty are the issues of mining celestial bodies, colonization, robotics, and floating habitats. Many of these issues have not been addressed and the science is advancing so quickly that many countries will be competing in these areas. International space law has been very vague and now is the time to draft a treaty that will be effective for future developments. This will need to be ratified by all countries that have an active or soon to begin space program. If every nation signs this treaty then we will have a basis for any future problems in space and a format to work off of. This treaty will need to be revisited throughout the years with each new breakthrough in science and technology or any major accomplishment in space [87].

The next few sections will outline recommendations for additions to the Moon Treaty. Before any mission should occur into space, there should be a payload review and documentation of the goals and logistics of the mission. The payload review will acknowledge ownership of any resources that are extracted from space by the company or nation. With the documentation of the goals and logistics of the mission, there will be no interference from other nations or companies during the mission. The safety of all those who enter space is still vital and ensuring that each mission can be accomplished with minimal risk of encountering another spacecraft is one way we can try and guarantee safety.

In regards to mining, there should be a subcommittee within UNCOPUOS that deals specifically with space resources. Any nation that is making plans to mine a certain location, on the Moon or other celestial body, must first do a reconnaissance mission and draft a report with an estimate of the amount of the resource that is to be extracted in addition to the exact location. We are unsure of the quantities of different resources and, since outer space should be used for the advancement of all mankind, one nation should not have exclusive access to a certain resource. The main responsibility of this subcommittee would be to prevent the exploitation of these resources by a single state. Once this subcommittee approves of the mining mission, the nation or company will still not have ownership rights over the location of the mine but will have ownership of the resources that are extracted. Each nation or company will have to undergo a payload review of the resources that are mined and report the findings of the mine, such as the amount found versus the amount mined and other resources that were found in that area. If a mining expedition comes across a single source of a resource, it must report it to the subcommittee and any nation who wishes to mine the resource. The nation must then present the use of the resource and the subcommittee will be responsible for the allotment of the resource.

The issue of mining near Earth objects (NEO) has been brought up since a nation cannot have sovereignty over any celestial body. If the nation mines the entire existence of a NEO, does that mean it owns the NEO? There should be a reclassification of the celestial bodies especially where mining and colonization are concerned. NEO and other asteroids should be in their own classification and nations would be allowed to claim them as their own. Again they will need to present their mission to the mining subcommittee to ensure that nations are not fighting over the same NEO and it is documented which nation claims which NEO. Since NEO and other asteroids are a threat to Earth, having a nation responsible for them will lessen their threat since it is in the best interest of the nation to either harvest the entire NEO or plan a colony that is successful.

In regards to international cooperation, it should be expressed that it is encouraged and essential for international cooperation in developments in mining and energy sources. International cooperation will lessen the competition and focus more on the need for the resources from mining and providing energy throughout the world. The mining and energy subcommittees will be more favorable to missions that involve more countries since the liability will be spread throughout all nations involved and more of the world will be gaining from these space endeavors.

In regards to colonization, the Moon Treaty clearly expressed that no nation will have sovereignty over a celestial body but does over any object they bring to outer space. If there is a plan for constructing a colony in outer space, whether it is on a celestial body or floating in space, there needs to be a written proposal outlining the number of habitants, the location, the square footage used, and the purpose of the colony. It must be approved by UNCOPUOS as long as it does not interfere with any ongoing mission previously approved or with another nation's proposal. Outer space is to be utilized by all nations and one nation cannot monopolize on a location. Approval from UNCOPUOS will ensure that each nation is getting a fair chance at the location of their choice

Current space programs are aiming to continue research in space but the future will bring many obstacles to the forefront when it comes to countries utilizing space. The Moon is not the only celestial body that will be the focus of countries' space programs. There will be many commercialization opportunities that space has to offer and space policy will play a major role in establishing common law.

F. Commercialization

The new frontier for commercialization has become space with the transition from a government dependent industry to a self-sufficient private industry. There has been increased private investment into rockets, equipment, and experiments in space. NASA has begun to focus more on difficult, riskier missions such as those involving deep space which will lead to the more established missions to be handed over to private enterprises. The missions in the LEO and the ISS have already been passed over to the private sector. NASA has awarded contracts to both SpaceX and Boeing to transport NASA crews to and from the ISS [88]. NASA also has a new program, Commercial Crew Integrated Capability program (CCiCap), which aims to foster design and development of new private spaceships. This program will begin to fill the gap in US human spaceflight capabilities since the cancellation of the space shuttle program. Currently the US has had to use other countries' rockets to deliver cargo and crews to ISS, namely the Russia Soyuz. With the development of this program, three companies (Sierra Nevada Corp, SpaceX, and Boeing) will be able to design efficient and reliable spacecraft so the U.S. will no longer need to outsource missions to other states [89].

50 years ago, the idea of taking a vacation in space was science fiction. With the private industry taking over space travel, it is becoming a very real, yet expensive, possibility. Virgin Galactic already has a waiting list of 700 people to be the first few hundred to fly in space. A $250,000 tickets will get you one of six seats aboard SpaceShipTwo (a combination of a rocket and glider which is attached to a powerful airplane called WhiteKnightTwo). WhiteKnightTwo will fly the rocket to 50,000 feet where the two pilots will separate the space ship from the airplane and ignite the rocket's engine. The passengers will experience 2,500 mph acceleration until the engines turn off and passengers will be allowed to feel the weightlessness of space for six minutes. After those six minutes, passengers will return to their seats just as gravity begins to pull the glider back towards Earth. Virgin Galactic is still in its testing phase of the SpaceShipTwo and originally projected passengers will board at the end of this year. Recently there was a failed test flight with the ejection of the pilot so further testing will be done before any civilian space travelers board [90].

Not only is a tour of space a possibility, but there is a potential to book a weekend at a space hotel. Bigelow Aerospace has designed the Bigelow Expandable Activity Module that will attach to the ISS in 2015. The Module is 13 by 10 ft of inflatable material that will be used as laboratories or hotels. If this Module is successful, there could be two Modules attached to the ISS: one could serve as the laboratory and one as a hotel. Commercialization of the ISS is what will lead to additional funding that is needed to continue research aboard the ISS or to help minimize the costs of transporting cargo and crew. Since there is already a waiting list for Virgin Galactic, it is a relatively safe assumption that a space hotel will have the same draw. Advances in propulsion and materials are lowering launch costs which will make it a destination that can be accessed by more people [88].

Another way to utilize the ISS as well as any cargo flights is to use the vessel as a laboratory to grow perfect crystals. Perfect crystals are important because they will be used in an X-ray diffraction laser to determine the internal structure of the crystal. An experiment of this type was sent to the International Space Station: Protein Crystals for Neutron Crystallography (PC4NC) which focuses on the study of an enzyme inorganic pyrophosphatase (IPPase). IPPase is a major component in many biological reactions such as DNA replication, gene expression processes, and fatty acid synthesis. The thesis of this experiment is that microgravity is the ideal environment for crystallizing large molecules, such as proteins, and will enable the neutron diffraction study of these large molecules. On Earth, crystals always have some imperfections due to gravity since their molecule structures do not always form the correct structure. This makes the study of these crystals incomplete since there is not a uniform structure for all the crystals of the same protein. In microgravity however that is no longer an issue and large "near-perfect crystals" can be formed. Neutron Crystallography is the still shots captured of the enzyme reactions at certain stages and requires a large protein crystal. The researchers for the PC4NC project will then be able to locate the positions of the hydrogen bonds in the enzyme from these still shots which will be beneficial in determining how the molecules work in a cell. This research will lead to a new design of antibiotics or other drugs that will interact with those enzymes. Eventually they would like to bring the research and crystals back from the ISS with the Dragon spacecraft, constructed and operated by SpaceX, which is the only spacecraft currently able to deliver and return cargo from space [91].

Commercial protein crystal growth-high density (CPCG-H) is another experiment that is taking advantage of microgravity to research perfect crystals. CPCG-H is a protein crystal growth experiment flight hardware that is outfitted with High-Density Protein Crystal Growth

(HDPCG), which is a vapor-diffusion facility that could process up to 1008 individual protein samples. The experiment consists of 4 independent trays that hold 252 individual protein crystal growth experiments each. The chambers have components (a protein reservoir, a precipitant reservoir, and optically-clear access cap) that ensure reduction in sedimentation problems and will produce highly uniform singly crystals. CPCG-H flight system can fly aboard a typical Dragon spacecraft or can be transferred over to the ISS Expedite the Processing of Experiments to Space Station (EXPRESS) for an extended mission. Experiments that are onboard a spacecraft have a limited timetable to complete the experiment where as if it is transferred to ISS, the experiment timetable is exponentially longer with the only complication being if the samples need to be returned to Earth at a certain time. The goal of this experiment is to grow high-quality protein crystals of specific proteins so that the molecular structures of each can be studied. Once the model of structure is determined, the model can be used to accurately determine which compounds will bind to the protein which will benefit pharmaceutical companies so they can improve current or develop new drugs. The protein is like a key hole and the drug is the key; currently we are guessing to determine the key size but now with the accurate model they can develop the exact key. The final results of this study were that 65% of the macromolecules that were flown in the experiment produced diffraction-sized crystals. Those crystals were able to be compared to X-ray diffraction data that was created on Earth which proved that the HDPCG worked well and produced the high-quality crystals that are needed for accurate X-ray diffraction models [92].

Another form of commercialization is in the medical industry. Many medicines or devices used for astronauts have found applications back on Earth as well; measuring the nitric oxide in a person's breath is one example to help with asthma on Earth. The effect of microgravity plays an important role in the advancement of biotechnology research. One example of this is in cell and tissue engineering experiments with the goal to grow cells on a tissue in microgravity. These experiments will lead to new research in the field and the development of new tissues that can be used in transplant operations [93]. The cells grown in space can also be used to research the growth of tumors. The cells grown in space can also be used to research the growth of tumors. Space cells produce longer-lived cultures which will enable researchers to document the growth of the tumors and test different methods to control the growth. Microgravity also allows scientists to develop ways to isolate different mechanisms in the evolution of tissue structures as well as study fundamental life processes down to the cellular level. This research will lead to improved artificial organs and new designs of bioreactors. Being able to study the cell cultures for longer amounts of time or growing new cells on tissues improves many areas of the medical field and without these experiments performed in microgravity and we may never have the information [94]. Microgravity also shows the key changes in microbial cells and these are directly related to infections and diseases. Some key changes are alterations of microbial growth rates, antibiotic resistance, microbial invasion of host tissue, organism virulence, and genetic changes within the microbe. Now that these key changes can be studied, experiments will be conducted to identify which of these changes and their components facilitate increased virulence (relative ability of microorganism to cause disease). This research will then be relayed to Earth where new anti-microbial therapeutics (such as vaccines) will be reengineered to cause fewer symptoms and treat the disease or infection with more success [95].

For the past few decades, man has expected science-fiction technology and many of these technologies have come to realization. One that is still very much considered science fiction, however, is the concept of living among the stars. A few scientists have created a blueprint for what a city in space will look like and how to construct such a city. Dr. Globus, a contract scientist at NASA Ames research center, is a huge proponent for living in space and has proposed a city of huge habitats orbiting around our planet.. He believes that by the end of this century, humans will be traveling from these habitats in the LEO as they do now from New York to London. Dr. Globus says that the purpose of these orbiting habitats is the same as any other town or city on Earth: to provide a habitat for humans to expand and to survive off of the Earth in case of any disasters. People that live on these habitats will be vacationing on Earth instead of taking the Virgin Galactic flight into space.

FIGURE 28: SPACE CITY [96]

The design he has proposed is a habitat that rotates around a cylinder. The rotating habitat will provide artificial gravity due to the centripetal force and will make moving around the habitat similar to Earth. Since the inhabitants will be experiencing gravity similar to the Earth's, moving between locations will not cause acclimation problems for those from space as well as other microgravity biological issues that will not arise like they do on the ISS. The center of the structure would have no gravity but this will be the location for laboratories, recreation areas, and experiments. Agriculture will be designed into the habitat with solar energy being harvested from solar panels that will line the outside of the habitat. Dr. Globus also believed that retirement homes will be constructed in space. Retirees will no longer need wheelchairs or walkers in space and there will be no issue of returning back to Earth since most people that are checked into a retirement home are there until their termination. Dr. Globus recognizes that we are not ready yet to start construction on this city in space due to financial, technological, and infrastructure restraints. He did however propose different ways to overcome the financial restraint by increasing space tourism as well as possibly conducting a “Space Olympics” [96].

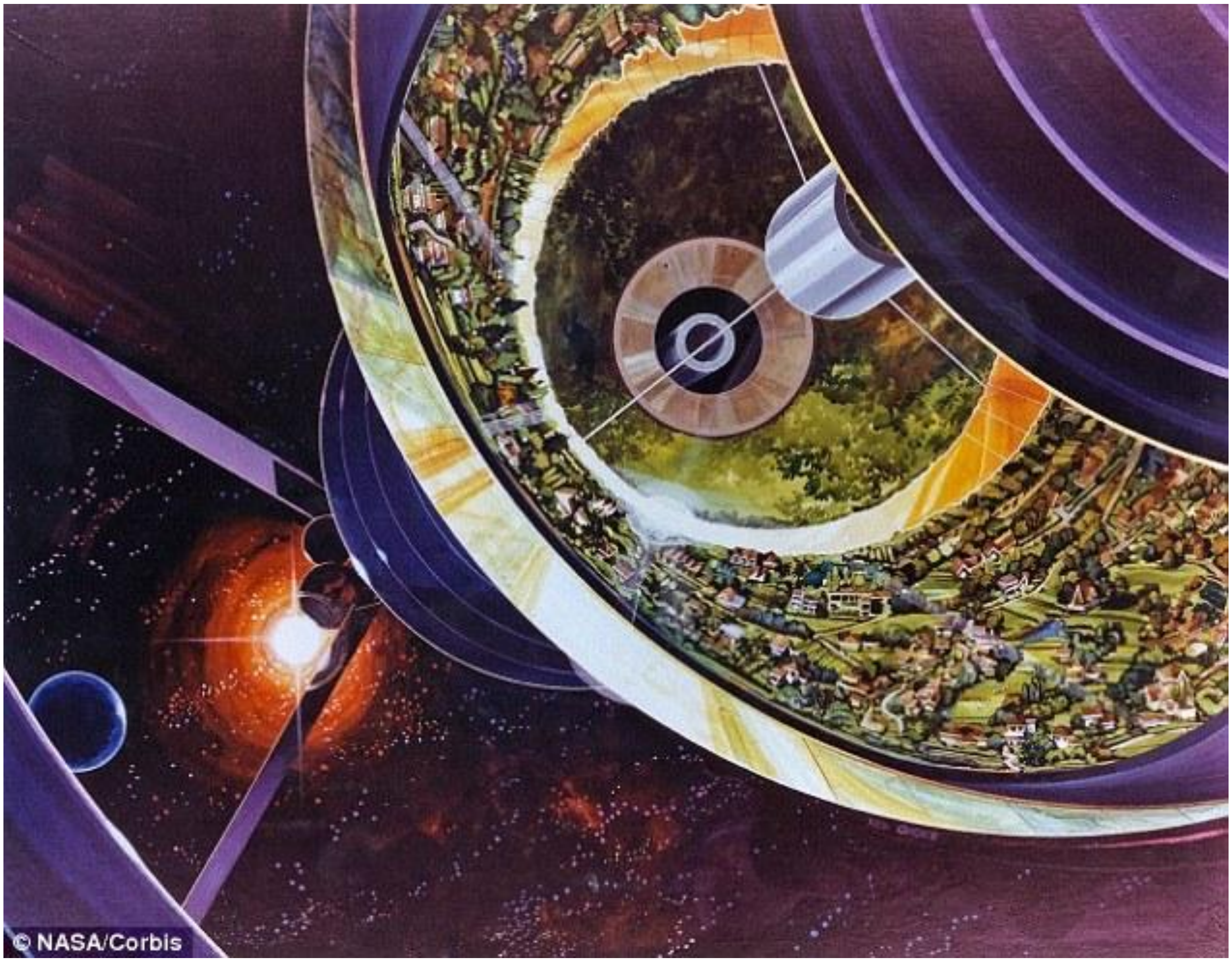

FIGURE 29: ORBITING HABITAT [96]

Other scientists have stated that there are three methods to build a space colony: teraform a nearby Earth-like object, a LEO orbit model, and a free space model. With teraforming a celestial body, there will need to be massive geo-engineering projects or the creation of bio-domes. A LEO orbit model would be comparable to the one proposed by Dr. Globus. A free space model would be similar to the LEO model but would survive by using natural resources found in outer space. Gerald O'Neill, a Princeton physicist in the 1970's, proposed a free space model at the L5 point between the Moon and Earth, where the model will stay located in the same spot due to equal and opposite gravitational pulls. O'Neill envisioned many habitats that were each 200 km apart and attached by cable cars. The habitats would be rotating just as Dr.

Globus' and would use the sun as its energy source. With the close proximity of the Moon, aluminum and titanium would be mined and used on the habitat. Other resources obtained in space would be asteroids that contain water or other materials and would be towed behind the habitat for ready access. Another challenge for this type of habitat is creating a closed loop system of sustainability [97]. These habitats are only one solution for humans populating the Solar System.

III. Where will we go next?

A. New Forms of Life

1. Bio-engineering

Improving human life has been an interest for scientist for decades. Now that the technology has caught up to the science fiction theories there have been breakthroughs in the world of neuroscience, artificial organs, and "cyborgs". These new technologies will not only help humans here on Earth, but also enable deep space travel and colonization in space. Humans are not able to survive in space for longer than a few minutes without the help of technology, but it is very possible that one day humans will possess the technology equipment to survive long term in space. Somewhere in the future we may have enough bio-modifications that we do not need technological assistance to go into space.

Neuroscience has been able to develop small devices that are implanted in the human body that improve the health of the patient. A recent breakthrough has been with epilepsy treatment. There are three different types of epilepsy stimulators that send electric pulses through the body; neurostimulators, open-loop vagus nerve stimulate (VNS), and AspireSR. The neurostimulators consist of a small device with a microprocessor and a battery that fit into a small cavity of the brain. Leads are then inserted into the brain by a surgeon. Each lead has four electrodes that record electrical activity and send the electric pulses. Algorithms are developed to configure the device to detect certain electrical patterns that signal to indicate a seizure. Since the brain has no pain receptors, the patient does not feel the electric pulses that are then sent to prevent the seizure after detection. Neurostimulators can also be modified to help with other disorders such as movement or mood.

VNS is similar in that the device sends electric pulses, but to the vagus nerve instead of in the brain. A pulse generator is inserted in the chest and is led up to the vagus nerve where two spiral electrodes are wrapped around it. The electric pulse is sent to the vagus nerve and then passed to the brain. An advantage of the VNS is that it offers on-demand stimulation for those who have an aura, a premonition in the form of smell or visual clues, by passing a pager-like external magnet over the pulse generator.

AspireSR is a closed-loop nerostimulator that detects heart irregularities instead of brain waves. AspireSR uses an electrocardiogram (ECG) to monitor the quality of the heart rate and does numerous checks to determine if a hear beat is irregular and a pulse should be sent to the brain. The theory behind AspireSR is that before a seizure the heart will speed up; although the heart does speed up due to other instances, such as exercise, false positive pulses will not cause problems for the patient since they do not feel them.

There is also a pain stimulator called Medtronic that sends pulses to the brain to interfere with pain signals from the spine. There is a remote control to adjust the stimulation based on the amount of pain. This remote control is used to maintain the amount of pain relief desired. These stimulators will be able to enlighten scientists about the nervous system, diseases, and physiological signals. If astronauts are implanted with these devices it will be beneficial for payload and to maintain their health in space. Doctors on Earth will be able to monitor the physiological signals of the astronauts in space and regulate their diet and exercise appropriately. The benefits of these systems are as follows. The VNS system will already have an ECG implanted in each astronaut so there is one less piece of equipment that will be needed in a colony or long trip. There will also be no need to take pain medication since the body will be outfitted with Medtronic to help with the pain relief from any injuries [98].

It may not be an implant but there is a proposal for a diabetes wristwatch. This wristwatch will take advantage of space technology to deliver a constant supply of insulin to the patient without the use of a battery. The wristwatch will use piezo-electric transducer technology that absorbs energy from light movements the patient makes, and then causes a crystal (such as quartz) to change shapes which is converted into electricity. This electricity will then drive the pump to inject the patient with the correct does of insulin. Multiple transducers can be placed around the wrist to absorb energy from any movement and the watch will be able to store energy for use during dormant periods. This watch will help diabetes patients everywhere but the science could also be applied to astronauts [99]. Vitamins and other necessary nutrients can be liquefied and given to the astronauts the same way insulin is administered to patients. Astronauts will no longer have to worry about receiving proper nutrition from their food supply since they can get any nutrients they need for their wristwatch. It will also cut down on the cargo load since they will only need to package these tiny canisters instead of specific food or other vitamins. The future of food engineering is also growing and science fiction has always depicted the future of food to be a liquid. If food were to be liquefied, astronauts could consume their daily dose of food in the same way. Long expeditions on a planet will not be hampered by having to pack food or make sure they are close enough to the spacecraft to eat.

Artificial organs are being developed to help with the long list of waiting patients for implants, but improved organs can help maintain astronauts' health on long mission. Astrium, an aerospace company, and Professor Alain Carpentier, a cardiac surgeon, have partnered up to create the first artificial heart to be built using space technology. This artificial heart was made from biological tissue and miniature satellite equipment while Astrium engineers guaranteed absolute precision and durability for the artificial heart. The partnership worked well since both fields have to account for harsh and inaccessible environments; major heart surgery is a tricky and dangerous operations and there are many life-threatening factors to be considered when an astronaut is in space. Professor Carpentier was very impressed by the extensive space based testing to ensure that there were no issues with the system. Satellites and other space technologies have to undergo these extensive testing since it is almost impossible and also quite expensive to fix any problems once the satellite is in orbit. Just like with a heart, keeping a satellite operational at all times is critical.

Another example of satellite technology used in the heart was the ability to respond to exertion levels. Satellites need to respond to different cues such as pointing an antenna or facing toward the Sun just as a heart has to respond to the different levels of exertion such as exercise [100]. After the successful integration of the artificial heart into the human body, scientists can then work on modifying the heart to work better while in space. They can place sensors in the heart to determine the amount of gravity and pump blood accordingly. They can also develop other organs that are affected by gravity and create artificial ones that overcome those obstacles. Lungs, muscles, and any other body parts can be artificial made and created to work exactly as we need them to survive in the harsh environment of space. Lungs can be built with a greater lung capacity while muscles can be built stronger and denser.

When people hear the term cyborg, they usually think of the Terminator. On the other hand, some believe that those who live on a space colony will not just be human but cyborgs. Cyborgs are humans that rely on technology for assistance in living; many humans can already be considered cyborgs due to pacemakers and prosthetics. The Smithsonian has place the Bionic Man on display which is a combination of all the bionic body parts. The Bionic Man components surprisingly make up about 50% of the human body already and there are other functions that are going to be created “bionic” [101]. Cyborgs may be the answer to deep space travel and living on a space colony since we can then upgrade any body part to be able to resist the effects of microgravity, radiation, or any other side effect for being in space long term. Two technologies that would be great for space is Gordon a rat-brained robot and the Defense Advanced Research Projects Agency’s (DARPA) insect cyborgs. Kevin Warwick, a cybernetics at the University of Reading, has created these tiny robots that are controlled by the brain cells of a rat. Neurons were taken from a rat embryo and grown in a dish; within a week there was enough brain activity to control these robots. The robots main objective in life is to move forward without hitting anything. It does this by learning from its environment the best way to accomplish that. Warwick is very pleased with Gordon and expects to begin using human neurons soon which will need significantly more neurons than the rat which has about 30 million brain cells [102]. These cyborg bodies will be able to withstand the harsh space environment while still having the human brain’s capabilities. We will not be depending on artificial intelligence for robots, which could lead to ethical issues over robot civil rights, to venture into deep space. These cyborgs will have the brain power and personality of a human with all the capabilities of a robot. They will be able to live on these colonies for long periods of time and will not the amount of food and water that a purely human colony would need. The best cyborg will incorporate more human elements than just the brain since we know so much about how the body works already. These brain cyborgs are a great starting point for this science.

Another cyborg is the complete opposite technology of Gordon. DARPA has installed sensors and computers inside the heads of insects and they are completely able to control the movements of the insects. They are designed to be used in warzones to conduct either surveillance or a warning system for any poisons [103]. This technology has been used with rats as well. We don't know much about how microgravity will affect us long term since a human has not been endangered for science; however, humans have always used their technology and testing on animals before humans so why not test microgravity on animals first as well. If we can implant this technology into a primate when can send them to live in space for long durations or even to Mars and study the effects of microgravity. We will have complete control over the animal when need be to ensure as much safety as possible. The knowledge of what happens to the primate in space could be invaluable when it comes to protecting human life. New forms of bioengineering or even radiation protection can be developed.

Cryonics may also be an answer to deep space travel. Cryonics could be used to freeze the astronauts during the long, extensive flights and then awoke upon arriving at their destinations. Unfortunately, the science is not quite there with unfreezing a human and reawakening them. Molecular nanotechnology has to make advances first but the theory is the ice would slowly need to melt and then the metabolism would need to be kick-started with chemical reactions within the cells [104]. Robonauts could be essential on these flights to be the ones to unfreeze the astronauts and make sure they are awakening properly.

One day we will be able to completely engineer our children if we so wish or to change anything about ourselves to give us superhuman qualities. Many ethical questions have been raised concerning these new technologies but they would open many doors for space travel, and the precedence is already there. Humans are not able to travel very far and for very long, but with the help of science we can overcome these obstacles. In order for our species to survive and flourish past our atmosphere, bio-engineering will be a great asset to have for astronauts. Not only astronauts, but those who inhabit the colonies on our planets will be able to be reengineered to survive the harsh environments. A new species of humans will be born; a blend of humans and robotics that will be able to survive and spread expansively across space.

2. Extraterrestrial Life

The thought of extraterrestrial life has been prominent throughout science fiction and scientists minds alike. In the summer of 1950, Fermi posed the question “Where is everybody?” He and some colleagues bounced a few ideas off of each other, and then Fermi went off to do some probabilistic calculations involving the probability of earthlike planets, the probability of life given an earthlike planet, the probability of an intelligent species given life, and finally the probability of the emergence and long-term duration of technology as we know it. Based on these calculations, Fermi concluded we ought to have been visited long ago and many times over. Which then arises Fermi’s paradox, why if the probabilities are so high, have we not yet encountered extraterrestrial life? [105]

Scientists have been working to reconcile this paradox and are actively searching for signs of life within our own galaxy. As for efforts outside our galaxy, the Kepler Space telescope is searching and cataloging Earth-like planets; however, beyond this, not much can be done to confirm life on planets outside our Solar System. Within our galaxy, several objects are of interest. ExoMars is a joint effort from the ESA in collaboration with the Russian Federal Space Agency (Roscosmos) to search for biosignatures of Martian life. This will be a multi-craft mission, with preliminary observances in 2016, and the launching of a new generation ExoMars rover in 2018 [47].

Europa is also a subject of interest, which is about the size of Earth’s Moon [106]. Pictures of hundred mile high geysers of liquid water were discovered by comparing photos Hubble took in a time-lapse fashion. Scientists suspect that under a few miles under Europa’s ice crust, Europa possesses a giant churning ocean. These plumes apparently sprout when Europa is almost at its apocenter (furthest point from Jupiter), which suggests that Jupiter's massive gravitation pull could be the cause of tidal forces. Researchers discovered spikes of hydrogen and oxygen levels in two regions in Europa's southern hemisphere, giving further evidence to this hypothesis [107]. A subsurface liquid ocean could provide ideal conditions for microbial life. As such, NASA is studying for a mission called the Europa Clipper, which would perform detailed reconnaissance of Europa. It would perform 45 flybys of Europa while orbiting Jupiter. No time-frame for this mission is yet in place.

We as a species have yet to find significant evidence for other life, despite probabilistic predictions such as Fermi's. There exists the hypothesis of "the great filter". If we list the steps out from the correct initial planetary starting conditions (step 1) spanning through evolution to intelligent life and ending at step 9 space colonization explosion (there are 9 steps postulated by Robin Hanson), it becomes evident that three logical answers exist. One is that the list is not complete nor is our understanding. The other two are that either a step before us (we are currently at step 8) is improbable, or a future step is improbable. This is merely a hypothesis though, and we must first become masters of Solar Systems while not destroying each other before interstellar travel can come on our radar.

B. Manipulating the Solar System

1. Re-engineering the Solar System

Humanity could very well expand and become engineers of our Solar System in the future. Many valuable resources exist in space, and these could be used to sustain bases for further expansion. Teraforming planets or Moons by moving them into the habitable zone around the Sun where the Earth resides is a possibility. Water and organic materials could be delivered to planets via collisions with asteroids or various bodies in space that are made of water. While these are the dreams of the future, how are we going to make these happen? Current rocket technology does not have the ability to move massive celestial objects in a relatively short amount of time. To accomplish this dream, then, we must employ different propulsion means. They must be able to operate for long periods of time, potentially multiple lifetimes, without servicing or refueling.

2. Teraforming Venus

Venus is often referred to as Earth's sister planet. It was known long ago, and named after the Roman equivalent of Aphrodite, the Goddess of love. This is due to the fact that Venus is the brightest object in the sky, other than the Sun and Moon; it is brighter than any stars. Until recently, Venus was an object of mystery for most of the rationally thinking world due to its cloud cover. In 1918, a Swedish astronomer conjectured that the clouds were of water vapor and thus Venus must be extremely damp. It wasn't until the 60's that the truth was found out; that Venus's clouds are sulfuric acid and that the atmosphere is 100 times denser than Earth. So the question then is why would some of the scientific community even consider teraforming such a hostile environment?

TABLE 7.3 VENUS - TERRAFORMING REQUIREMENTS

Parameter	Present value	Modification required for: Minimal ecopoiesis	Modification required for: Terraforming
Surface Gravity:	0.88g	Not possible	
Solar Day:	117 days	Unnecessary?	Substantial reduction
Axial Inclination:	2.6°	Unnecessary	
Insolation:	2620 W/m^2	Reduce to 1507 W/m^2	Reduce to 1370 W/m^2
Albedo:	0.77	High as possible	
Mean Surface Temperature:	737 K	~370 K reduction	~440 K reduction
Surface atmospheric pressure:	~ 95 bars	< several bars	380 - 3700 mbar
CO_2 Partial Pressure:	~ 91 bars	< several bars	< 10 mbar
O_2 Partial Pressure:	< 9.5 mbar	Unnecessary	95 - 500 mbar
N_2 Partial Pressure:	~ 3.3 bars	Unnecessary	Unnecessary?
Hydrosphere:	0%	> 0%	>> 0%
UV Flux 0.2-0.3 μm:	~ 27 W/m^2	Reduction	Zero

FIGURE 30: PROPOSED VENUS TERAFORMING VECTORS [108]

Venus shows promise as one of the three planets, the others being Mars and Earth, that have similar compositions, size, and location relative to the Sun. Therefore it seems logical that Mars or Venus would be the first sites for human colonization eventually. Venus is closer in proximity to Earth than Mars, has a radius of 95% of Earth's, and has a gravity of 88% of terrestrial gravity [108].

Unfortunately for hopeful human colonists, that is where the similarities end. Venus takes the equivalent of 243 Earth days to make a full rotation. That is longer than the 225 Earth-days that it takes to make a full revolution, resulting in 117 Earth-days for a complete Venusian solar day. The temperature of Venus is 464 C with little variation due to the clouds. This temperature is higher than the critical temperature of 374 C at which liquid can exist. This extreme temperature is due to a run-away greenhouse effect caused by the atmospheric composition of 93.6% carbon dioxide (CO_2) by volume. As a result, Venus has about a 5cm global layer of water, which is less than that of even Mars. Finally, 85% of Venus is covered in volcanic plains.

Below is a suggested modification chart for teraforming; a checklist of the necessary things for human life, provided by the above academic journal. Broadly speaking, habitability can be described as followed:

1. Global Average Temperature between 273K and 303K
2. Total Atmospheric Pressure between 0.5 bar and 5 bar
3. Less than 10 mbar of Carbon Dioxide (toxic above this level)
4. Greater than 300 mbar of inert buffer gas (such as Nitrogen or Argon)
5. Oxygen Partial Pressure between 130mbar and 300 mbar [109]

To summarize, the main problems are the temperature and the massive pressures of the atmosphere. The composition of the atmosphere, namely the CO_2 toxicity, as well as the sulfuric acid, and lack of oxygen all pose issues. Finally, the severe length of the night could pose stress on a biosphere.

The solutions offered are as widely varied as the scale of the problem is large. The main focus is on removing excess CO_2 and removing the run-away greenhouse effect. This is very applicable to Earth, as global warming due to CO_2 is becoming more prevalent, so solutions to the problem could be employed in either place and be useful to the other planet's cause. One interesting idea posed by Carl Sagan is the use of a biological (or mechanical) self-replicating unit that feeds upon the atmosphere until it has expended it as fuel and dies off. There are no known organisms that do this, but it is a tantalizing idea. Another idea involves hitting Venus with a large amount of hydrogen, either through a gas giant or an ice moon. If Venus were to encounter about 4×10^{19} kg of hydrogen, it would convert the abundance of CO_2 to elemental carbon (graphite) and water. This would get rid of the excess atmosphere and convert the mostly-flat planet to 80% of the surface being covered by water [109]. A final solution involves using a giant sunshade (most likely out of similar material as a solar sail) to reflect the energy from the Sun back into space, and allows convection currents to carry the cooled air through the atmosphere, causing the CO_2 to be removed as the temperature lowers past its critical point. The time scale of this is on the order of 200 to 1,000 years if done correctly [110].

In the end, Mars is likely a more feasible endeavor. We should not limit our thinking just because one option is easier though; Venus is still closer in proximity and size to Earth. If the aforementioned problems could be solved more easily than Mars's, it could be a better future-home in our Solar System.

3. Teraforming Mars with Ceres

To teraform Mars would require changing its distance from the Sun. This is required for any teraforming efforts to be stable and permanent. Earlier in its life, Mars was an active planet with a hot, churning iron core, an atmosphere, and potentially flowing water. However, this all came to an end as the core cooled. This cooling caused the magnetosphere surrounding the planet to collapse. This caused solar wind to sweep away the atmosphere, effectively killing the planet.

To prevent this from happening again, Mars' core must be hot enough to produce a strong enough magnetic field to protect itself and an atmosphere. This temperature must then be maintained so that the planet does not die again. The best way to do this is to bring it closer to the Sun. Preferably Mars should rest between the Earth and the Sun. This minimizes our chance of accidental impact. Another goal that would need to be accomplished by teraforming is for there to be water available or easy to produce. While there has been evidence of ice existing at the poles and trapped in the soil, this is not a sustainable source.

There is an asteroid/dwarf planet in the asteroid belt that might solve this problem. Ceres is composed of a rock core with an ice mantle and a 20m thick dust crust. If Ceres collided with Mars, it has the advantage of adding mass which, even if negligible, will increase the gravitational pull, and thermal insulation for the core. According to Kepler's Third Law, the average distance from the Sun for an object is related to its orbital speed and mass. $P^2 = \frac{4\pi^2}{G(M1+M2)} * a^3$ Where P is its rotational period in seconds around the Sun, M1 is the mass of the Sun, M2 is the mass of Mars, G is the gravitational constant and is the average distance in meters [111]. The mass of the Sun is $1.989*10^{30}$ kg. The mass of Ceres is $895.8*10^{18}$ kg. The mass of Mars is $639*10^{21}$ kg with an orbital period of approximately 687 days *24 * 60 * 60 = 59356800 seconds and an average distance of $227.92*10^{6}$ km from the Sun [112]. If we wanted to change the position of Mars in the Solar System so that it was closer to the Sun, we would need to reduce its orbital period. If we wanted Mars to orbit between Venus and the Earth, we need to calculate its mass after impact and the distance. The distance from the Earth to the Sun is on average 149,600,000,000 m, while Venus rests 108,200,000,000 m. The average distance between Venus and Earth compared to the Sun is 128,900,000,000 m. To find the mass of Mars after impact, Mt = M1 + M2. $639*10^{21}$ kg + ($895.8*10^{18}$ kg*.9) (for efficiency of mass transfer)

= 6.398958*10^{23} kg. $P^2 = \frac{4\pi^2}{G(M1+M2)} * a^3$ $P^2 = \frac{4(3.14)^2}{(6.673*10^{-11})(1.989*10^{30} + 6.39806*10^{23})} * 128900000000^3$ = 6.37*1014 seconds^2. P = 25,240,000 seconds. This compares to its current orbital period of 59,356,800 seconds showing that the planet would need to slow its period by a factor of approximately two.

To achieve this, Ceres should collide with the planet in such a way to reduce its orbit but not its angular momentum. The length of a day on Mars is approximately 24.66 Earth hours. Changing the rotational speed to match the Earth's would be ideal for a celestial body if we were going to teraform it. However, Mars rotational period closely matches the Earth so it would not be a big change for astronauts and future inhabitants. They would still see the Sun rise close to every Earth day. To reduce the change of angular momentum, the impact with the planet will have to be precisely at its axis. If it is off-centered, some of the momentum of Ceres will be transferred to angular momentum. This impact must also be timed so that Mars "falls into place" without hitting Earth or passing right by.

If we decide to proceed with Ceres' impact into Mars, we would first need to calculate the speed and energy Ceres must have the moment before impact to cause such a large change. To move the planet in a short time span, conventional, chemical propulsion methods must be used to apply acceleration to Ceres. Since we are greatly concerned about fuel efficiency in rockets, Ceres should be guided into place with a Hohmann transfer orbit. This would provide the best energy efficiency while also helping solve alignment of how Ceres will hit, either directly in front or behind Mars. Ceres must move Mars on average (227,920,000,000 m - 128,900,000,000 m) = 99,020,000,000*(.5*π) = 155,540,000,000 m. The estimated distance from Ceres to Mars is (414,000,000,000m - 227,920,000,000m)*π = 584,587,561,000 m. Since the mean orbital speed is 24.07 km/s, the new speed would have to be 24.07

km/s*$(\frac{25240000}{59356800})(ratio\ of\ old\ vs\ new\ period),=$ 10.235 km/s, representing a decrease in kinetic energy [112]. Since kinetic energy is $Ke = (1/2)mv^2$, Mars currently has $\left(\frac{1}{2}\right) * (6.39 * 10^{23}\text{kg}) * \left(24070\,\frac{\text{m}}{\text{s}}\right)^2 = 1.8510709 * 10^{32}\text{kg} * (\text{m}/s)^2$ kinetic energy. The total kinetic energy required to enter the appropriate orbit, accounting for an increase in mass due to Ceres, would need to be $\left(\frac{1}{2}\right) * (6.398958 * 10^{23}\text{kg}) * \left(10235\,\frac{\text{m}}{\text{s}}\right)^2 = 3.35162 * 10^{31}\text{kg} * (\text{m}/s)^2$. To accomplish this large decrease, Ceres must impact with high kinetic energy, $1.8510709 * 10^{32} - 3.35162 * 10^{31} = 1.51591 * 10^{32}\text{kg}(\frac{\text{m}}{\text{s}})^2$. To achieve this kinetic energy, $\left(\frac{1}{2}\right) * ((895.8 * 10^{18}\text{kg}) * \left(\frac{\text{m}}{\text{s}}\right)^2 = 1.51591 * 10^{32}\text{kg}(\frac{\text{m}}{\text{s}})^2,$ (m/s) = 5.81763*10^5 m/s or 581.763 km/s. While it currently has an average orbital velocity of 17.882 km/s, this is still an increase of over 30 fold [113]. If we assume that it has constant acceleration, using average velocity and distance, we can calculate the time until impact. $\frac{Vf+Vi}{2} = \frac{d}{t} = \frac{2*584{,}587{,}561\text{ km}}{581.763\,\frac{km}{s}+17.882\frac{km}{s}} = t = 1{,}949{,}778 seconds$ or approximately 22.5 days. This does not take into account the time it will take Mars to reach its new stable orbit after impact. This is ludicrously fast compared to the current orbital speed of the planets. Further research and calculation must be completed to determine how to make Ceres move that fast and thus have the required energy to collide with Mars to change its orbit so significantly. The mass of a rocket is miniscule compared to an asteroid, so this is not the best option.

Another option for Ceres is to make it a moon of Mars so that its gravitational effects will restart the core and thus the magnetosphere. To accomplish this, Ceres must pass close to Mars and be moving slower than Mars' escape velocity yet fast enough to put Ceres into orbit, called the orbital speed. If the speed is higher than Mar's escape velocity, when it passes by, it will not be captured and will simply sail by. The relationship between minimum escape velocity and minimum orbital velocity is $\frac{escape\ velocity}{\sqrt{2}} = orbital\ velocity$. Since Mars has an escape velocity of 5.03 km/s, the minimum speed required for Ceres to be captured is 3.55675 km/s and maximum is just under the escape velocity. To accomplish this, Ceres can continue at its current speed and then simply slow down when it nears Mars. 17.882 km/s - 5.03 km/s = 12.852km/s must be lost. While this is still a significant amount of kinetic energy to scrub off, $\left(\frac{1}{2}\right) * ((895.8 * 10^{18}\ \text{kg}) * (12852)^2 = 7.39814 * 10^{28}\text{kg}(\frac{\text{m}}{\text{s}})^2$. This change in kinetic energy is 2,049 times less then that required to collide Ceres with Mars and alter its orbit as desired, making it a much more viable option. The time required for Ceres to move under these new conditions uses the same formula, $\frac{Vf+Vi}{2} = \frac{d}{t} = \frac{2*584{,}587{,}561\ \text{km}}{17.882\frac{km}{s}+5.03\ \frac{km}{s}} = t = 5102942\ seconds$ or approximately 590.5 days. While the time required to put Ceres into orbit is significantly higher, it is still a relatively short time period. Unfortunately, the technology does not exist for constant acceleration on this scale, so both concepts are currently nothing more than optimistic dreams.

4. Mercury

For centuries our solar system has been a mystery to those who gazed up in wonder. As technology advances, we are slowly discovering many of the secrets of our Solar System. Human curiosity has set its sights on Mercury. As the closest planet to the Sun, many challenges had to be overcome in order to investigate Mercury including the extreme temperature range of 427 ^{o}C to -183 ^{o}C. There have been two successful missions to this planet, Mariner 10 and MESSENGER, and there are plans for another mission. Mariner 10 was the first spacecraft to get an up close view of Mercury. It was launched in November 1973 by NASA as part of the Mariner program which aimed to learn about Mercury and Venus. The Mariner 10's objectives were to measure Mercury's atmosphere, environment, surface and body characteristics. Mariner 10 successfully completely three fly-bys of the planet and concluded that hydrogen, oxygen, and helium were found in the atmosphere. A global magnetic field was also discovered and samples were taken of the magnetic field and energetic charged particles in Mercury's magnetosphere. The magnetosphere is the area of space near an astronomical object where charged particles are controlled by the object's magnetic field. [114]

NASA's Mercury surface, space environment, geochemistry, and ranging mission or commonly known as MESSENGER was the next spacecraft to investigate Mercury in August of 2004. The spacecraft complete three fly-bys of the planet in 2008 before settling into orbit for the next years. MESSENGER has captured 100,000 images of the planet and has used its onboard equipment to collect data on the topography, structure of the core, and the areas of permanent shadow that are near both the North and South Poles. [115]. Learning about Mercury is very important because it will lead to answers about how the planets and solar system was created. Through studying the topography and the composition of the crust and core, we gain knowledge that let us develop different hypothesis that are used to explain the potential creation of the planets. Since the bulk density of the planet is high, about 5.3 Mg/m^3 after the internal compression, scientists have assumed that the planet has an unusually large amount of iron. This large amount of iron is common in meteorites and the Sun which makes Mercury unusual compared to the other planets [116]. There have been three different explanations put forth for this large amount of metal with the first explanation during the planetary formation phase and the second and third in the later stages of planetary formation after Mercury protoplanet's mantle, crust, and metal core were formed. The first explanation is the difference in aerodynamic drag of iron and silicate particles by nebular gas at the beginning of the planetary formation process. The second explanation is that the high metal content is from the vaporization of silicates. These silicates are vaporized by the radiation from hot nebula gas and then the removal by strong solar winds. The third explanation is that the silicates were selectively removed as a result of giant impacts by objects about the same size as Mercury protoplanet. Silicate contains an anionic silicon compound and silicate materials are rock-forming minerals. These make up about 90% of Earth's crust and are found on Mercury's crust as well. As for a proto-planet, they are large planetary embryos that originate within protoplanetary discs and have undergone internal melting to produce differentiated interiors such as the mantle, crust, and core. Protoplanets are suspected to be formed from planetesimals (solids objects formed from dust, rock, and other materials) that are attracted to each other, collide, and accumulate mass from such collisions over time [114].

There are also predications for the chemistry of the silicate fraction on Mercury that are based on the iron fraction explanations. The aerodynamic model predicts that the core and silicate sections of Mercury are built by nebular condensation models that are weighted by solar distance. The second prediction is from the vaporization explanation which predicts a strong enrichment of refractory elements and the depletion of alkaline and oxidized iron. Based off the third explanations for the iron fraction, silicate minerals would be mostly part of the mantle, and there would be a depletion of calcium, aluminum, and alkaline metals. Determining the precise chemistry of Mercury will help to narrow down the theories on how the solar system, the inner planets in particular, was formed and the most important influence on the composition of the planet [114].

The MESSENGER mission also learned important new information on the magnetic field, poles, atmosphere, potential water ice supple, the core composition, and the surface of

Mercury. Mercury has a very peculiar orbit; it is the only planet to have a 3-2 spin-orbit resonance which means that the planet rotates three times on its axis for every two orbits around the sun. Mercury was found to have an internal magnetic field that is strongly dipolar and its axis is closely aligned with the planet's spin axis which means it is the only other planet besides Earth to have an internal magnetic field. Mercury's magnetic field however is 1000 times weaker than Earth's but it is still able to protect the planet from cosmic rays and solar storms except at the poles. The magnetic field concentrates and deflects solar wind to the poles and the field is 3.5 times weaker at the South Pole than the North Pole due to its offset to the North of the planet's center by about 20% of Mercury's radius. This leads to asymmetries in sources of atoms, ions, and molecules; Helium-3 would be more prominent in the South Pole than the North Pole due to a large hole that allows charged particles to bombard the surface. There is also a prediction that space weathering and erosion may be different at the poles as well as less of an extreme variation in temperatures [115].

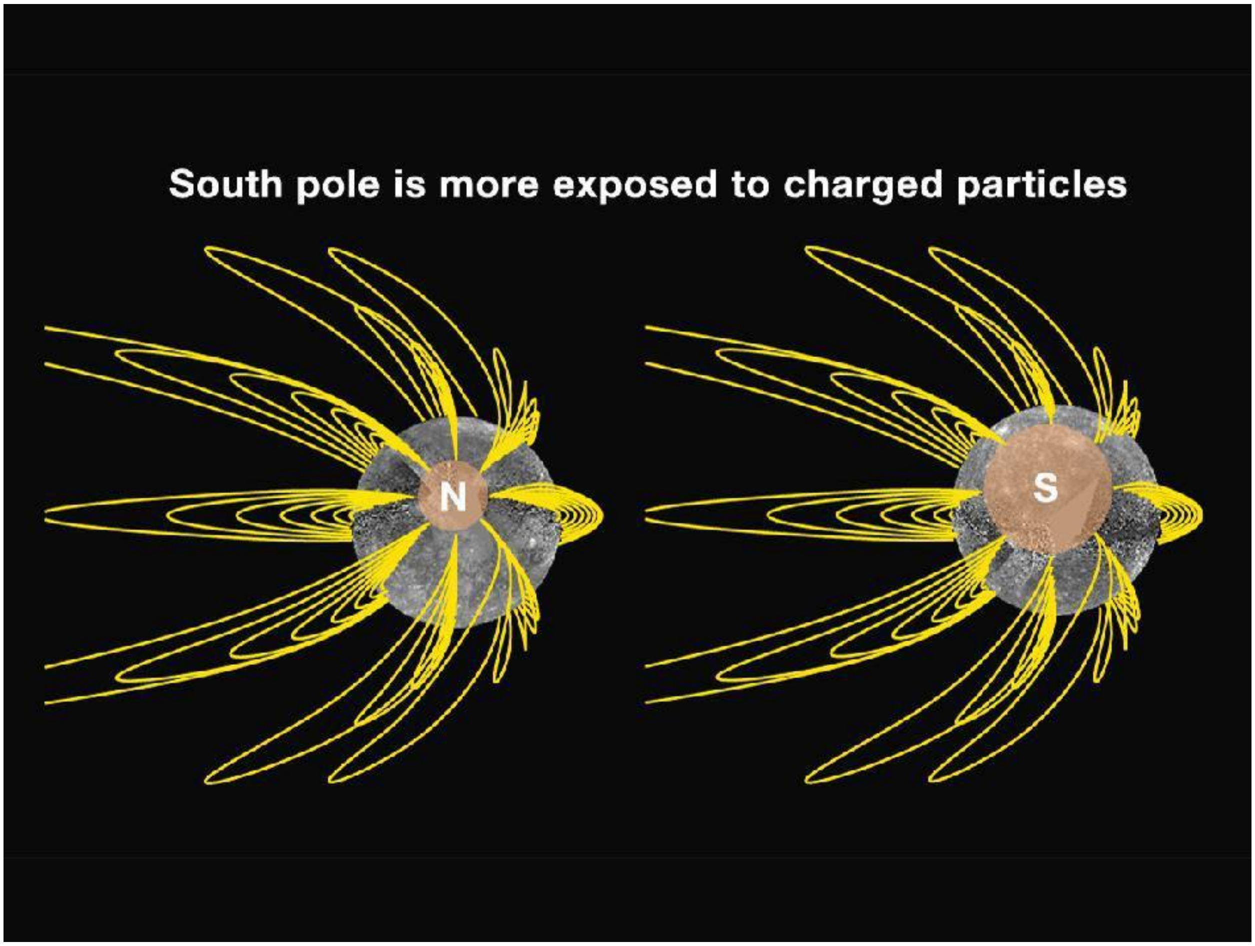

FIGURE 31: MAGNETIC FIELD OF MERCURY [117]

The atmosphere of Mercury is a tenuous exosphere; an exosphere is a thin, atmosphere-like volume surrounding a planetary body where the molecules are gravitationally bound to the body and the density is too low for them to behave like gas and collide with each other. The atmosphere has been found to be dependent on the season and the elemental composition. The composition has a varying level of calcium, magnesium, and sodium that depends on the planet's relation to the Sun. Learning more about Mercury's atmosphere composition will provide new information on how the space environment changes the outermost layers of the planet's surface materials.

In the 1990's, "radar bright" images were spotted on Mercury that could potentially be explained by ice and other organic materials. The "radar bright" spots were found to be near the poles and the MESSENGER was able to confirm that there is water ice in permanently shadowed regions in the poles. Scientists estimated that there is about 100 billion to 1 trillion tons of water ice on Mercury and could be as deep at 20 meters from the surface.

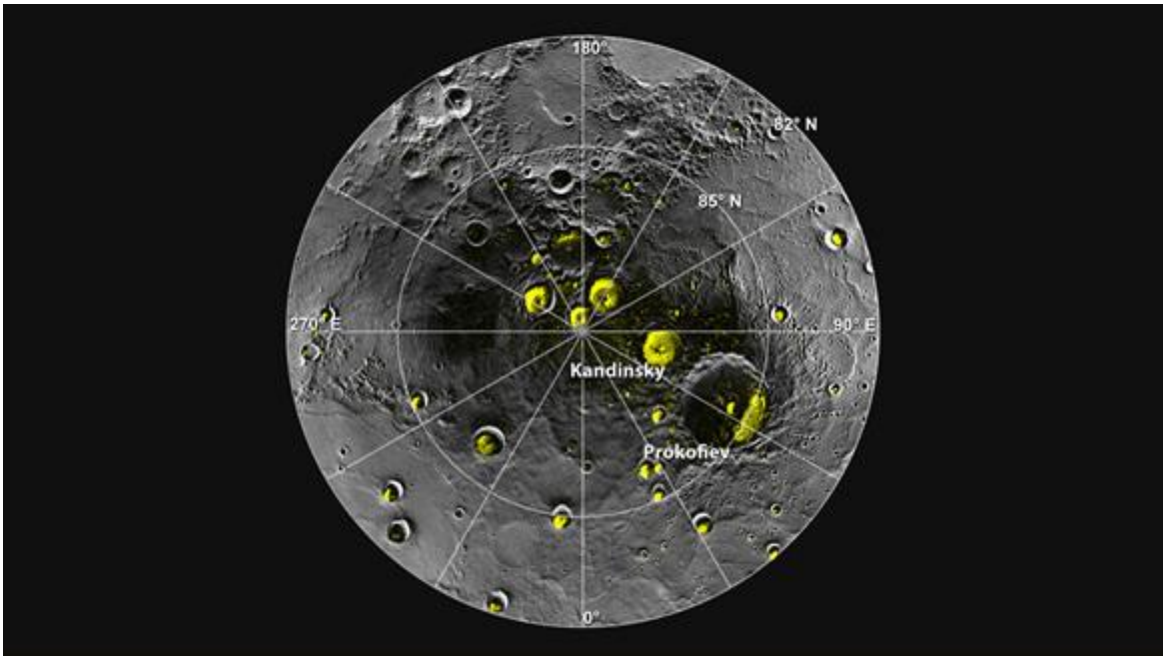

FIGURE 32: RADAR BRIGHT SPOTS FOUND ON MERCURY [117]

MESSENGER was also able to more accurately depict the core of Mercury; it determined that the core makes up about 85% of the planet which is significantly higher than what was previously suspected. Scientists also believed that due to the small size of the planet (Mercury is about 5% of Earth's mass and 40% of its diameter) the core would be mostly solid but after measuring Mercury's gravity, MESSENGER showed that Mercury has an active core dynamo which concludes that the core is partially liquid. It is believed to have a solid silicate crust and mantle, a solid iron sulfide outer core layer, a deeper liquid core layer, and then an assumed solid inner core. MESSENGER was also able to conclude that the surface is sulfur-rich and has the highest levels of sulfur; about 10 time more than Earth and Mars [115].

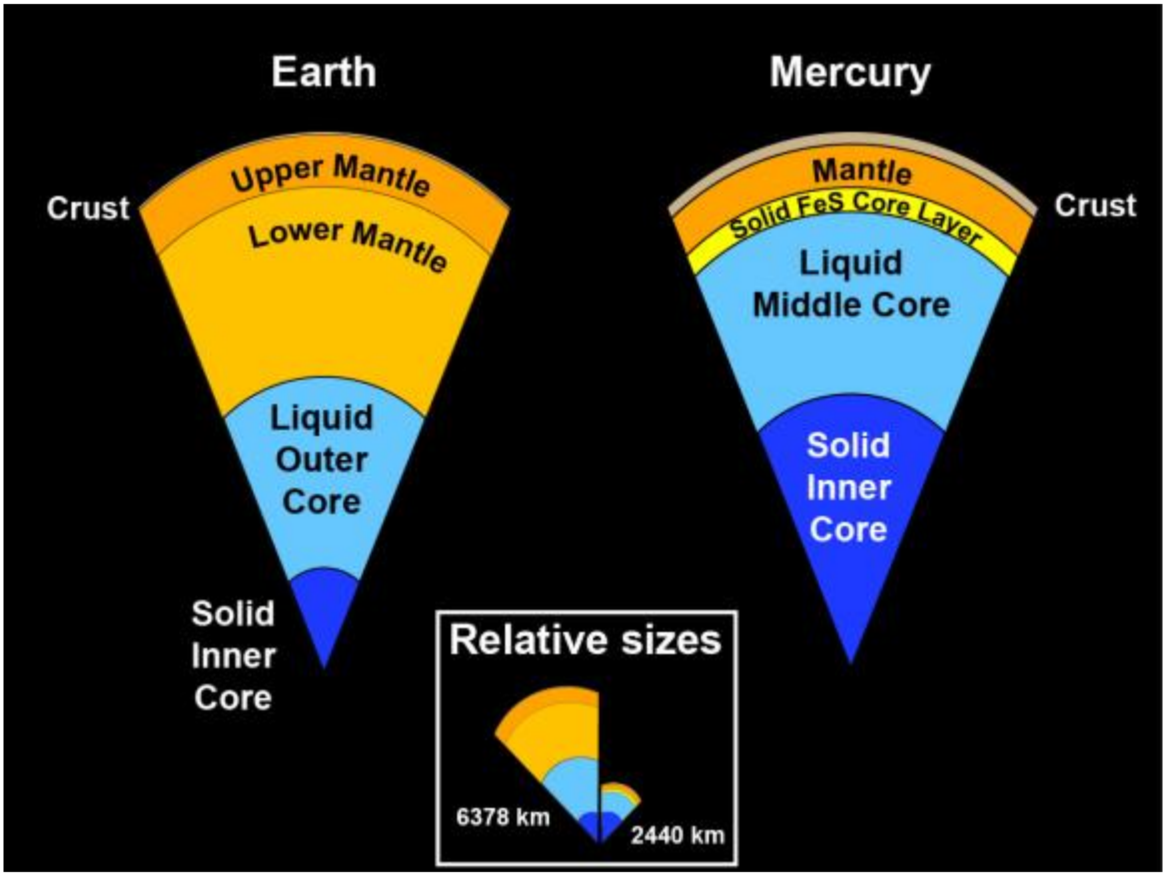

FIGURE 33: MERCURY'S CORE COMPOSITION VERSUS EARTH'S CORE [117]

NASA is not the only agency to be interested in learning more about Mercury; ESA and JAXA have partnered up for a joint mission called BepiColombo. BepiColombo consists of two spacecrafts that will orbit Mercury for at least one Earth year. Mercury Planetary Orbiter (MPO) and Mercury Magnetsopheric Orbiter (MMO) will hopefully be launched in July of 2016. MPO's main mission will be to study the surface and internal composition of Mercury while MMO's main mission will be to study the magnetosphere (which is the region of space around the planet that is influenced by the magnetic field). Mercury's Composite Spacecraft (MCS) will hold MPO and MMO along with the Mercury Transfer Module (MTM), which will provide solar-electric propulsion. This is in conjunction with MMO Sunshield and Interface Structure (MOSIF), which will provide thermal protection and mechanical-electrical interfaces for MMO. MCS will be launched into an Earth-escape orbit where it will then undergo a near-Earth commissioning phase. Traveling to Mercury creates a new challenge for spacecrafts since it will need to decelerate against the Sun's gravitational pull which increases the closer it travels to the Sun. This is the opposite for spacecraft that travel away from the Sun. In order to compensate for this occurrence, MCS will have to change its orbital plane to match Mercury's and will use Solar-Electric Propulsion (SEP) and the gravity of Earth, Venus, and Mercury to decelerate and change planes. Once it approaches Mercury it will use Mercury's gravity and conventional bipropellant thrusters to enter a polar orbit using a 'weak stability boundary' capture technique. From here, MMO will be released into orbit and then MOSIF will separate and use a chemical propulsion system to bring MPO to a lower orbit [118].

SMART-1 was the first ESA mission to leave Earth orbit solely by using SEP to reach the Moon in 13 months. SEP will be a more cost-effective propulsion technique to travel into our solar system. SEP is energized by electric power that is gathered from on-board solar arrays which will power the electrically propelled system. This system will use about 10 times less propellant than the traditional chemical propulsion system. The SEP program develops large, flexible, radiation-resistant solar arrays that can be stowed into small, lightweight packages for launch and then deployed to capture enough solar energy to propel the system. The SEP system will use lightweight structures and flexible blanket technology that will outlast long missions and harsh space environments such as the Van Allen radiation belt. SEP will also use electrostatic Hall Thrusters that will replace a rocket engine; Hall Thrusters use propellant that is accelerated by electric fields and then thrusters trap the electrons in magnetic field and use them to ionize onboard propellant (such as inert xenon gas). This onboard propellant is expelled into an exhaust plume of plasma that will push the spacecraft forward. Hall Thrusters can accelerate xenon ions to more than 65,000 mph, and durable Hall Thrusters have been created with an advanced magnetic shielding so several thrusters can be onboard and increase the power [119].

If the BepiColombo mission is successful there will be a more comprehensive knowledge of Mercury's surface and core, but there will also be a more cost effective method of propulsion. SEP could eventually replace current chemical propulsion, which will make trips to Mercury, Mars, and other missions more achievable. Mercury could also be our next planet to colonize. Mercury has twice the gravity of the Moon and has a gravity most similar to Mars. Long term colonization may be better on Mercury or Mars due to the increased gravity and less effects on the human body. There are several potential sites for a colony on Mercury. A colony underground in the North Pole would be best since the magnetic field is stronger in the North and will protect from the cosmic rays. The poles are also the source of the potential ice water reserves that can be used for human consumption and the oxygen and hydrogen could be extracted for rocket fuel. Mining in the South Pole would be best done by robots searching for He-3 and other important materials. Since the magnetic field is weaker in the South Pole, there will higher deposits of He-3 here than anywhere else on the planet. Mercury is also a great starting point for colonizing Mars since the gravity strength is very similar. Mercury would also be a great location for a solar farm since it receives about 6.5 times more solar energy than either Earth or the Moon. We can learn a lot about the formation of planets and a good way to learn more about building a colony on Mars is by studying and sending rovers to Mercury.

IV. Conclusion

Since the world's first astronomers, the Ancient Sumers, humanity has been looking to skies. With the exponentially growing population and depletion of natural resources, scientists have been aiming their research on how space can benefit all of humanity. The final frontier coupled with newer technology will enable us to take advantage of all space has to offer us.

Our research has allowed us to investigate new sources of energy, technology that will be able to benefit not only astronauts but humans on Earth, and the potential locations for colonization. In the next decade or so, the energy problem will be only worsening so we need to start finding solutions today. SPS's will one day be orbiting our Earth and beaming electricity to receiving stations around the world. SPS will take advantage of the infinite amount of solar energy we can harvest from the Sun and convert into useable energy. Harvesting solar energy is not the only energy resource space has to offer; He-3 found on the Moon may be the missing puzzle piece for a fusion reactor. Fusion reactors in theory will be able to produce clean nuclear energy with He-3 which is found in the lunar regolith from solar winds depositing He-3 for billions of years. He-3 and fusion reactor and SPS will be able to support the growing demand for energy across the globe.

Since SPS will be a massive satellite in orbit that needs to be operational 24/7, the question of how to solve the space debris problem arose. Space debris is an extremely dangerous hazard to existing satellites as well as rockets traveling through LEO and GEO. Every year, space debris collides with spent rocket stages and de-commissioned satellites that result in smaller pieces of space debris. Solutions were brainstormed to solve this ever growing problem. Robotics will allow us to be able to capture individual pieces of space debris. The KUKA arm will be able to predict the trajectory and react so the space debris will be 'caught'.

CleanSpaceOnce, created by Switzerland, will be able to capture and destroy the space debris by hurtling itself and the debris toward the atmosphere.

Robotics advancements are directly related to many other space missions, not only space debris and SPS. Humanoid robotics, such as Robonaut, will be able to assist astronauts aboard the ISS as well on any dangerous missions. New rovers and construction robots, such as CC, will be able to construct colonies on the Moon and other celestial bodies. This new technology will allow astronauts to be delegated to a more supervisory role. This will decrease the amount of danger these astronauts will encounter in space.

With CC, we will be able to build a colony on the Moon. After researching the best location for said colony, a blueprint for a Moon colony was drafted. The South Pole near the Shackleton Crater will be the ideal location for our colony. Depending on radiation protection that is available, an underground colony would be the best choice but it would also be possible to inhabit the crater as well. The blueprint discusses all the factors that must be thought of before a colony will be successful; we have given our recommendations on radiation protection, human physiology, food and water, the crew, and communication.

The Moon is not the only location that has been researched. Venus, Mars, and Mercury all have potential resources and locations that would be valuable for humanity. Each celestial body would need a different type of colony or even teraforming to ensure the safety of any occupants. Mars and Venus are sister planets with Earth so they have similar characteristics which make them a logical location for a colony. Mercury's close relation to the Sun and lack of a strong magnetic field and atmosphere have led scientists to believe the South Pole is rich in He-3. Water ice is also thought to be in the North Pole which would make that the ideal location for a colony.

Solar System re-engineering was only discussed in a small scale way. The technology we have available today is not advanced enough to consider large scale manipulation of the Solar System. Suggestions for future research will be with the technological advances that will allow humanity to construct the Solar System to their benefit. Not only can planets or asteroids be rearranged to teraform but also to create more Lagrange points. Taking advantage of gravity resources the Solar System already provides we will be able further create our own Solar System. Asteroid capture is another topic that can be further investigated. Asteroids can hold a wealth of resources or can be used as another habitat. In order to have a full understanding of the possible materials or minerals, asteroids and celestial bodies will need to be mapped for their potential use.

Many of these topics are dependent on improved propulsion techniques. Humans cannot safely travel deep into our Solar System and we heavily depend on robotics to conduct our research. New propulsion ideas and techniques are needed to further our presence in space. Interstellar travel is also a sci-fi concept that will become a reality in the next century.

In the coming millennium, our vision of the future includes humans inhabiting other celestial bodies than just Earth. Colonies will be developed to both continue the survival of the species and perform advanced research. Hopefully within 500 years, living on other planets will be as established as living on other continents today. This vision will be fulfilled with continued advancements in technology and the ingenuity of the human condition.

Works Cited

[1] D. W. Graham, Explaining the Cosmos: The Iorian Tradition of Scientific Philosophy, Princeton: Princeton University Press, 2006.

[2] "Eratosthenes (276-195 B.C.)," Cornell, [Online]. Available: http://www.astro.cornell.edu/academics/courses/astro201/eratosthenes.htm.

[3] C. Lethbridge, "Robert Hutchings Goddard," Spaceline, 2001. [Online]. Available: http://www.spaceline.org/history/22.html. [Accessed 15 January 2015].

[4] T. Benson, "History of Rockets," NASA, 12 June 2014. [Online]. Available: http://www.grc.nasa.gov/WWW/k-12/TRC/Rockets/history_of_rockets.html. [Accessed 15 January 2015].

[5] C. Lethbridge, "History of Rocketry Early 20th Century," Spaceline, 2000. [Online]. Available: http://www.spaceline.org/history/3.html. [Accessed 15 January 2015].

[6] C. Lethbridge, "History of Rocketry World War 2 Germany," Spaceline, 2000. [Online]. Available: http://www.spaceline.org/history/4.html. [Accessed 15 January 2015].

[7] C. Lethbridge, "History of Rocketry World War 2 Other Nations," Spaceline, 2000. [Online]. Available: http://www.spaceline.org/history/5.html. [Accessed 15 January 2015].

[8] C. Lethbridge, "History of Rocketry 1945 to NASA," Spaceline, 2000. [Online]. Available: http://www.spaceline.org/history/6.html. [Accessed 15 January 2015].

[9] U. F. Government, "Background on Radioactive waste," United States Nuclear Regulatory Commission, 1 September 2014. [Online]. Available: http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/radwaste.html. [Accessed 2 September 2014].

[10] US Energy Information Administration, "What is US electricity generation by source?," US Department of Energy, 13 June 2014. [Online]. Available: http://www.eia.gov/tools/faqs/faq.cfm?id=427&t=3. [Accessed 5 December 2014].

[11] ITER, "ITER Facts and Figures," ITER, 2015. [Online]. Available: http://www.iter.org/factsfigures. [Accessed 5 December 2014].

[12] M. Barnett and H. Quinn, "What is antimatter?," Scientific American, 24 January 2002. [Online]. Available: http://www.scientificamerican.com/article/what-is-antimatter-2002-01-24. [Accessed 2 September 2014].

[13] "Space-based solar power," Wikipedia, 2014. [Online]. Available: http://en.wikipedia.org/wiki/Space-based_solar_power. [Accessed 8 September 2014].

[14] S. Sasaki, "It’s Always Sunny in Space," *North American,* pp. 46-51, May 2014.

[15] S. Sasaki, "How Japan plans to build an orbital solar farm," IEEE Spectrum, 24 April 2014. [Online]. Available: http://spectrum.ieee.org/green-tech/solar/how-japan-plans-to-build-an-orbital-solar-farm. [Accessed 8 September 2014].

[16] L. Valentine, "A space roadmap: Mine the sky, Defend the Earth, Settle the universe," Space Studies Institute, 2002. [Online]. Available: http://ssi.org/reading/papers/space-studies-institute-roadmap. [Accessed 8 September 2014].

[17] A. Madrigal, "Why NASA is sending a robot to space that looks like you," Wired, 15

April 2010. [Online]. Available: http://www.wired.com/2010/04/robonaut-rides-the-shuttle. [Accessed 4 September 2014].

[18] E. Zolfagharifard, "Could the moon fuel Earth for 10,000 years? China says mining helium from our satellite may help solve the world's energy crisis," Daily Mail.com, 5 August 2014. [Online]. Available: http://www.dailymail.co.uk/sciencetech/article-2716417/Could-moon-fuel-Earth-10-000-years-China-says-mining-helium-satellite-help-solve-worlds-energy-crisis.html. [Accessed 20 January 2015].

[19] F. Bozzato, "Moon Power: China's Lunar Helium 3 Vision," World Security Network, 2 June 2014. [Online]. Available: http://www.worldsecuritynetwork.com/China/fabrizio-bozzato-1/Moon-Power-Chinas-Lunar-Helium-3-Vision. [Accessed 20 January 2015].

[20] C. Barnatt, "Helium-3 Power Generation," Explaining the future.com, 14 August 2014. [Online]. Available: http://www.explainingthefuture.com/helium3.html. [Accessed 25 January 2015].

[21] L. David, "Is mining rare minerals on the moon vital to national security?," Space.com, 4 October 2010. [Online]. Available: http://www.space.com/9250-mining-rare-minerals-moon-vital-national-security.html. [Accessed 20 January 2015].

[22] C. Pieters, "Moon Mineralogy Mapper," Discovery Program NASA, [Online]. Available: http://discovery.nasa.gov/m3.cfml. [Accessed 26 January 2015].

[23] L. David, "Is Mining Rare Minerals on the Moon Vital to National Security?," Space.com, 4 October 2010. [Online]. Available: http://www.space.com/9250-mining-rare-minerals-moon-vital-national-security.html. [Accessed 27 January 2015].

[24] R. Goodier, "Why Deep-Sea Rare-Earth Metals Will Stay Right Where They Are - For Now," Popular Mechanics, 8 July 2011. [Online]. Available: http://www.popularmechanics.com/science/environment/why-deep-sea-rare-earth-metals-will-stay-right-where-they-are-for-now. [Accessed 29 January 2015].

[25] M. Wall, "NASA is Studying How to Mine the Moon for Water," Space.com, 9 October 2014. [Online]. Available: http://www.space.com/27388-nasa-moon-mining-missions-water.html. [Accessed 28 January 2015].

[26] C. Jamasmie, "Russia pushes forward plans to mine the moon," Mining.com, 28 October 2014. [Online]. Available: http://www.mining.com/russia-pushes-forward-plans-to-mine-the-moon-13769/. [Accessed 28 January 2015].

[27] A. Jeffries, "NASA is now accepting applications form companies that want to mine the moon," The Verge, 9 February 2014. [Online]. Available: http://www.theverge.com/2014/2/9/5395684/nasa-begins-hunt-for-private-companies-to-mine-the-moon-catalyst. [Accessed 28 January 2015].

[28] F. Diep, "Big Pic: Robonaut is getting legs," Popular Science, 14 April 2014. [Online]. Available: http://www.popsci.com/article/technology/big-pic-robonaut-getting-legs?dom=PSC&loc=recent&lnk=1&con=big-pic-robonaut-is-getting-legs. [Accessed 22 September 2014].

[29] "Posts tagged space robotics," Robotics Zeitgeist, 2007. [Online]. Available: http://robotzeitgeist.com/tag/space-robotics. [Accessed 22 September 2014].

[30] B. Khoshnevis, "ISRU-based robotic construction technologies for lunar and martian infrastructures," NASA, 14 May 2014. [Online]. Available:

http://www.nasa.gov/directorates/spacetech/niac/2012_phaseII_fellows_khoshnevis.html#.VC3HBfldXnh. . [Accessed 30 September 2014].

[31] "Lunar Settlement: Piecing together a full moon picture," NASA, 31 October 2012. [Online]. Available: http://www.nasa.gov/offices/oct/home/niac_countour_crafting.html. [Accessed 30 September 2014].

[32] "Space Colonies," Contour Crafting, 2014. [Online]. Available: http://www.contourcrafting.org/space-colonies. [Accessed 30 September 2014].

[33] B. Khoshnevis, A. Carlson, N. Leach and M. Thangavelu, "Contour crafting simulation plan for lunar settlement infrastructure build-up," NIAC, October 2012. [Online]. Available: http://www.nasa.gov/pdf/716069main_Khoshnevis_2011_PhI_Contour_Crafting.pdf. [Accessed 30 September 2014].

[34] J. Maynard, "Will robot termite 'TERMES' be used one day to build Martian colonies possible," Tech Times, 15 February 2014. [Online]. Available: http://www.techtimes.com/articles/3467/20140215/will-robot-termite-termes-be-used-one-day-to-build-martian-colonies.htm. [Accessed 30 September 2014].

[35] R. Courtland, "Robots will pave the way to Mars," IEEE Spectrum, 27 May 2014. [Online]. Available: http://spectrum.ieee.org/aerospace/space-flight/robots-will-pave-the-way-to-mars. [Accessed 30 September 2014].

[36] "NASA's X1 robotic exoskeleton to help astronauts in space," SciTechDaily, 15 October 2012. [Online]. Available: http://scitechdaily.com/nasas-x1-robotic-exoskeleton-to-help-astronauts-in-space. [Accessed 30 September 2014].

[37] L. Winter, "Robotic exoskeleton lifts 50 kilos per hand," IFL Science, 7 March 2014. [Online]. Available: http://www.iflscience.com/technology/robotic-exoskeleton-lifts-50-kilos-hand. [Accessed 30 September 2014].

[38] D. Goldstein, "I am Iron Man: Top 5 exoskeletons," Discovery Communications LLC, 27 Novemeber 2012. [Online]. Available: http://news.discovery.com/tech/robotics/exoskeleton-robots-top-5.htm. [Accessed 30 September 2014].

[39] "The ESA Exoskeleton," European Space Agency, 25 September 2006. [Online]. Available: http://www.esa.int/TEC/Robotics/SEMA9EVHESE_0.html. [Accessed 30 September 2014].

[40] D. Steitz and C. Rink, "NASA selcts proposals for advanced energy storage systems," NASA, 7 August 2014. [Online]. Available: http://www.nasa.gov/press/2014/august/nasa-selects-proposals-for-advanced-energy-storage-systems/#.VC7Fh_ldXni. [Accessed 30 September 2014].

[41] "Bacteria power may be key energy source for space robotics," Huffington Post, 4 January 2012. [Online]. Available: http://www.huffingtonpost.com/2012/01/04/bacteria-robots_n_1183683.html. [Accessed 30 September 2014].

[42] "A roadmap for U.S. robotics: From internet to robotics 2013 edition," Robotics-VO, 20 March 2013. [Online]. Available: https://robotics-vo.us/sites/default/files/2013%20Robotics%20Roadmap-rs.pdf. [Accessed 30 September 2014].

[43] E. Guizzo, "Planetary Rovers: Are We Alone?," IEEE Spectrum, 30 December 2010. [Online]. Available: http://spectrum.ieee.org/aerospace/robotic-exploration/planetary-rovers-are-we-alone. [Accessed January 2015].

[44] R. Hof, "Deep Learning," MIT Technology Review, 23 April 2013. [Online]. Available: http://www.technologyreview.com/featuredstory/513696/deep-learning/. [Accessed January 2015].

[45] K. Howell and A. McInnes, "Strategies for Solar Sail Mission Design in the Circular Restricted Three-body Problem," Purdue University, Indiana, 2000.

[46] "Nuclear Space Propulsion: Overcoming the Chemical Barrier," University of Wisconsin-Madison, Madison, WI.

[47] NASA, "Status of Exomars Mission Analysis And Design - Entry, Descent, and Landing," pp. 1-9.

[48] R. Hollingham, "Will nuclear-powered spaceships take us to the stars?," BBC, 23 April 2014. [Online]. Available: http://www.bbc.com/future/story/20140423-return-of-the-nuclear-spaceship.

[49] M. Babula, "Nuclear Thermal Rocket Propulsion," NASA, 09 July 2008. [Online]. Available: http://trajectory.grc.nasa.gov/projects/ntp/. [Accessed 9 February 2015].

[50] W. Harris, "How Rail Guns Work," HowStuffWorks.com, 11 October 2005. [Online]. Available: http://science.howstuffworks.com/rail-gun1.htm. [Accessed 4 January 2015].

[51] NASA, "NASA," 1968. [Online]. Available: http://history.msfc.nasa.gov/saturn_apollo/documents/First_Stage.pdf. [Accessed September 2014].

[52] NASA, "NASA," 1968. [Online]. Available: http://history.msfc.nasa.gov/saturn_apollo/documents/Third_Stage.pdf. [Accessed September 2014].

[53] NASA, "NASA," 1968. [Online]. Available: http://history.msfc.nasa.gov/saturn_apollo/documents/Second_Stage.pdf. [Accessed September 2014].

[54] M. Fischer, "Superconducting SeaTitan opens up a new path to 10 MW," Renewable Energy World, 12 October 2010. [Online]. Available: http://www.renewableenergyworld.com/rea/news/article/2010/10/superconducting-seatitan-opens-path-to-10-mw. [Accessed October 2014].

[55] "Superconductors.org," 2 July 1999. [Online]. Available: http://www.superconductors.org/. [Accessed September 2014].

[56] B. Dugan, "5 Bold Proposals for cleaning up sapce junk," Mental Floss Inc., 29 January 2013. [Online]. Available: http://mentalfloss.com/article/48606/5-bold-proposals-cleaning-space-junk. [Accessed 19 September 2014].

[57] H. Ueno, S. Dubowsky, C. Lee, Y. Ohkami and S. Matsumoto, "Space Robotic Mission Concepts for Capturing Stray Objects," Asia Science and Technology Portal, 1 January 2014. [Online]. Available: https://www.jstage.jst.go.jp/article/jsts/18/2/18_2_1/_pdf. [Accessed 14 September 2014].

[58] "Could this catching robot be the answer to space debris?," Telegraph Media Group Limited, 12 May 2014. [Online]. Available: http://www.telegraph.co.uk/science/science-

video/10826231/Could-this-catching-robot-be-the-answer-to-space-debris.html. [Accessed 13 September 2014].

[59] J. Dumlao, "Robots to clean space debris," Maker Market, INC, 7 June 2014. [Online]. Available: https://maker.co/tag/space-debris-cleaning. [Accessed 13 September 2014].

[60] I. Thomson, "Swiss space plane to launch robotic orbital debris destroyer," The Register, 10 September 2013. [Online]. Available: http://www.theregister.co.uk/2013/09/10/swiss_space_plane_to_launch_robotic_orbital_debris_cleaner. [Accessed 10 September 2014].

[61] [Online]. Available: http://www.cubesatshop.com/index.php?option=com_virtuemart&Itemid=67.

[62] National Space Biomedical Research Institute, "Musculoskeletal Alterations," 2010. [Online]. Available: http://www.nsbri.org/SCIENCE-and-TECHNOLOGY/Musculoskeletal-Alterations/. [Accessed 27 January 2015].

[63] National Space Biomedical Research Institute, "Cardiovascular Alterations," 2010. [Online]. Available: http://www.nsbri.org/SCIENCE-and-TECHNOLOGY/Cardiovascular-Alterations/. [Accessed 28 January 2015].

[64] L. R. Harris, R. Herpers, T. Hofhammer and M. Jenkin, "How Much Gravity Is Needed to Establish the Perceptual Upright?," 3 September 2014. [Online]. Available: http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0106207#pone.0106207-DeWinkel1. [Accessed 20 January 2015].

[65] K. Erickson, "Mars Mice," 6 April 2011. [Online]. Available: http://science.nasa.gov/science-news/science-at-nasa/2004/20jan_marsmice/. [Accessed 20 January 2015].

[66] NASA, "The Deadly Van Allen Belts?," [Online]. Available: http://spacemath.gsfc.nasa.gov/Algebra1/3Page7.pdf. [Accessed 6 October 2014].

[67] T. Bevill, "What is space radiation?," NASA, 5 March 2014. [Online]. Available: http://srag-nt.jsc.nasa.gov/spaceradiation/what/what.cfm. [Accessed January 2014].

[68] "Understanding Space Radiation," NASA Facts, October 2002. [Online]. Available: http://spaceflight.nasa.gov/spacenews/factsheets/pdfs/radiation.pdf. [Accessed January 2015].

[69] J. Brief, "Space Radiation Program Element," NASA, 26 September 2013. [Online]. Available: http://www.nasa.gov/exploration/humanresearch/elements/research_info_element-srpe.html#.VOTPuvnF_nh. [Accessed January 2015].

[70] K. Tate, "Space Radiation Threat to Astronauts Explained (Infographic)," Space.com, 30 May 2013. [Online]. Available: http://www.space.com/21353-space-radiation-mars-mission-threat.html. [Accessed January 2015].

[71] "Spaceflight Radiation Health Program at JSC," NASA, [Online]. Available: http://srag.jsc.nasa.gov/Publications/TM104782/techmemo.htm. [Accessed January 2015].

[72] D. Rapp, "Mars 2," *Mars Informatics,* pp. 46-71, 2006.

[73] J. Estevez, "Nanotube's Mechanical Properties for Radiation Shielding Applications," *International Journal of Chemical Nuclear, Metallurgical and Materials Engineering,*

vol. 8, no. 1, pp. 1-5, 2014.

[74] NASA, "Radiation Shielding for a Lunar Base," 2011.

[75] D. R. Williams, "Mars Facts Sheet," NASA, 25 April 2014. [Online]. Available: http://nssdc.gsfc.nasa.gov/planetary/factsheet/marsfact.html. [Accessed 17 October 2014].

[76] D. T. Phillips, "Cave Skylights Spotted on Mars," NASA, 2007. [Online]. Available: http://science.nasa.gov/science-news/science-at-nasa/2007/21sep_caves/. [Accessed 2014].

[77] G. Cushing, "Thermis Observed Possible Cave Skylights on Mars," Lunar and Planetary Science, 2007.

[78] G. E. Cushing, "Candidate Cave Entrances on Mars," *Journal of Cave and Karst Studies*, vol. 74, no. 1, pp. 33-47, 2010.

[79] M. Y. Zolotov, "On the composition and differentiation of Ceres," *Icarus*, pp. 183-193, 11 November 2009.

[80] P. Rousselot, E. Jehin, J. Manfroid, O. Mousis, C. Dumas, B. Carry and U. Marboeuf, "A Search for Water Vaporizations on Ceres," *The Astronomical Journal*, 14 September 2011.

[81] J. Lewis, D. McKay and B. Clark, "Using resources from near-Earth space".

[82] P. Conerly, "The New Moon Race: Lunar Agriculture," Worcester Polytechnic Institute, Worcester, 2009.

[83] J. Miller, "Radiation Shielding Properties of Lunar Regolith and Regolith Simulant," *NSLI Lunar Science Conference*, pp. 1-2, 2008.

[84] C. Coombs and B. Hawke, "A Search for Intact Lava Tubes on the Moon: Possible Lunar Base Habitats," NSS, [Online]. Available: http://www.nss.org/settlement/moon/library/LB2-208-LavaTubes.pdf. [Accessed January 2015].

[85] D. Powell, "Lunar explorers will need MoonSat system," Space.com, 30 April 2008. [Online]. Available: http://www.space.com/5297-lunar-explorers-moonsat-system.html. [Accessed 8 October 2014].

[86] P. Larsen, "Current legal issues pertaining to space solar systems," *Space Policy*, vol. 16, pp. 139-144, 2000.

[87] P. Harris, "Space law and space resources," NSS, 1992. [Online]. Available: http://www.nss.org/settlement/nasa/spaceresvol4/toc.html. [Accessed 1 December 2014].

[88] G. Christ, "The Commercialization of Space: selling the final frontier," Industry Week, 13 October 2014. [Online]. Available: http://www.industryweek.com/transportation/commercialization-space-selling-final-frontier?page=3. [Accessed 11 November 2014].

[89] T. Malik and D. Chow, "NASA Awards $1.1 billion in suport for 3 private space taxis," Space.com, 3 August 2012. [Online]. Available: http://www.space.com/16890-nasa-private-space-taxis-funding.html. [Accessed 11 November 2014].

[90] R. Crane, "Inside Virgin Galactic's newest passenger spaceship," CNN, 13 June 2014. [Online]. Available: http://www.cnn.com/2014/06/13/tech/virgin-galactic-space-tourism-update. [Accessed 11 November 2014].

[91] Huntsville, "Protein Crystal experiment set to fly to International Space Station," Science Daily, 14 April 2014. [Online]. Available: http://www.sciencedaily.com/releases/2014/04/140414091739.htm. [Accessed 19 November 2014].

[92] "Commercial Protein Crystal Growth - High Density (CPCG-H)," NASA, 18 September 2014. [Online]. Available: http://www.nasa.gov/mission_pages/station/research/experiments/252.html#top.

[93] "Microgravity Research Program," 12 April 2008. [Online]. Available: http://www.nasa.gov/centers/marshall/news/background/facts/microgravity.html.

[94] "The weightlessness environment:what are the advantages?," 4 August 2008. [Online]. Available: http://www.esa.int/Our_Activities/Human_Spaceflight/European_ISS_Business_Club/The_weightlessness_environment_what_are_the_advantages.

[95] T. Ruttley, "International Space Station plays role in vaccine development," 3 March 2012. [Online]. Available: http://www.asc-csa.gc.ca/eng/iss/benefits_06_vaccine.asp.

[96] J. O'Callaghan, "Humans could live in 'space cities' that orbit Earth -and beyone-by 2100, claims experts," 18 September 2014. [Online]. Available: http://www.dailymail.co.uk/sciencetech/article-2760587/Humans-live-space-cities-orbit-Earth-2100-claims-expert.html.

[97] J. Gamble, "How do you build a city in space?," 16 May 2014. [Online]. Available: http://www.theguardian.com/cities/2014/may/16/how-build-city-in-space-nasa-elon-musk-spacex.

[98] T. Denison, M. Morris and F. Sun, "Building a Bionic Nervous System: Smart Neural stimulators sense and resond to the body's fluctuation," *Spectrum IEEE,* pp. 33-39, Feb 2015.

[99] "Space-tech could make life easier for diabetics," ESA, 13 December 2007. [Online]. Available: http://www.esa.int/Our_Activities/Space_Engineering_Technology/TTP2/Space-tech_could_make_life_easier_for_diabetics. [Accessed 11 February 2015].

[100] "Space in your heart," ESA, 5 December 2013. [Online]. Available: http://www.esa.int/Our_Activities/Space_Engineering_Technology/TTP2/Space_in_your_heart. [Accessed 11 February 2015].

[101] E. Ackerman, "Bionic man is the future of humans not robots," Spectrum IEEE, 7 February 2013. [Online]. Available: http://spectrum.ieee.org/automaton/robotics/medical-robots/bionic-man-is-the-future-of-humans-not-robots. [Accessed 11 February 2015].

[102] B. Ferreira, "Be Your Own Spaceship: How we can adapt human bodies for alien worlds," Motherboard, 29 July 2013. [Online]. Available: http://motherboard.vice.com/blog/be-your-own-spaceship-how-we-can-adapt-human-bodies-for-alien-worlds. [Accessed 10 February 2015].

[103] E. Anthes, "The race to create 'insect cyborgs'," The Guardian, 16 February 2013. [Online]. Available: http://www.theguardian.com/science/2013/feb/17/race-to-create-insect-cyborgs. [Accessed 10 Februay 2015].

[104] M. Anissmov, "Top 10 Transhumanist Technologies," Life Boat, [Online]. Available: http://lifeboat.com/ex/transhumanist.technologies. [Accessed 10 February 2015].

[105] E. M. Jones, ""Where is Everybody" An Accont of Fermi's Question," Los Alamos National Laboratory, Los Alamos, 1985.

[106] T. Greicius, "Hubble Space Telescope Sees Evidence of Water Vapor Venting off Jupiter Moon," NASA, 12 December 2013. [Online]. Available: http://www.nasa.gov/content/goddard/hubble-europa-water-vapor/#.VOTauPnF_ng. [Accessed January 2015].

[107] C. Choi, "Jupiter Moon Europa May Have Water Geysers Taller Than Everest," Space.com, 12 December 2013. [Online]. Available: http://www.space.com/23923-europa-water-geyers-taller-than-everest.html. [Accessed February 2015].

[108] M. Fogg, "Chapter 7. The Terraforming of Venus," academia.edu, [Online]. Available: http://www.academia.edu/4198039/Chapter_7._The_Terraforming_of_Venus. [Accessed February 2015].

[109] J. Moores, "Radiative Processes in Terraforming," Melo, Stela, Arizona, 2003.

[110] Birch, "Interstellar Studies Issue," *Journal of the Bristish Interplanetary Society*, vol. 44, pp. 157-167, 191.

[111] "Kepler's Third Law," Imaging the Universe, 2014. [Online]. Available: http://astro.physics.uiowa.edu/ITU/glossary/keplers-third-law. [Accessed 12 February 2015].

[112] D. R. Williams, "Mars Fact Sheet," 25 April 2014. [Online]. [Accessed 12 Februrary 2015].

[113] C. Mihos, "Ceres facts," 14 September 2006. [Online]. [Accessed 26 February 2015].

[114] S. Solomon, "A New look at the planet Mercury," Physics Today, January 2011. [Online]. Available: http://scitation.aip.org/content/aip/magazine/physicstoday/article/64/1/10.1063/1.3541945.

[115] P. Campbell, "MESSENGER: Mission To Mercury," NASA, 5 October 2011. [Online]. Available: http://www.nasa.gov/mission_pages/messenger/media/PlanetConf20111005.html.

[116] B. Dunbar, "MESSENGER Provides New Look at Mercury's suprising core and landscape curiosities," NASA, 21 March 2012. [Online]. Available: http://www.nasa.gov/mission_pages/messenger/media/PressConf20120321.html#.VPitXvnF_ni.

[117] E. Howell, "5 Mercury Secrets Revealed by MESSENGER," University Today, 18 March 2013. [Online]. Available: http://www.universetoday.com/100461/5-mercury-secrets-revealed-by-messenger/.

[118] "Bepicolombo," ESA Science and Technology, 5 March 2015. [Online]. Available: http://sci.esa.int/bepicolombo/.

[119] B. Boen, "Solar Electric Propulsion (SEP)," NASA, 7 February 2014. [Online]. Available: http://www.nasa.gov/mission_pages/tdm/green/sep_overview.html#.VPivt_nF_nh.

[120] A. Pierce, "Japan to Build an Orbiting Electricity-Generating Station," *Tech Directions,*

pp. 8-9, 2014.

[121] G. E. Cushing, "Thermis Observed Possible Cave Skylights on Mars," *Lunar and Planetary Science*, pp. 1-2, 2007.

[122] "Solar Powered Satellites," GStriatum, 2014. [Online]. Available: http://www.gstriatum.com/solarenergy/2012/04/solar-powered-satellites. [Accessed 4 September 2014].

[123] B. Draxier, "Look at this: Robonaut 2 put to work abroad the ISS," Discover Magazine, 8 January 2013. [Online]. Available: http://blogs.discovermagazine.com/80beats/2013/01/08/look-at-this-robonaut-2-put-to-work-aboard-the-iss/#.VEAwJfldXng. [Accessed 4 September 2014].

[124] U. F. Gov, "What causes wind?," MetOffice, 20 May 2014. [Online]. Available: http://www.metoffice.gov.uk/learning/wind/what-causes-wind. [Accessed 1 September 2014].

[125] D. Hitt, "What was Saturn V?," NASA, 17 September 2010. [Online]. Available: http://www.nasa.gov/audience/foreducators/rocketry/home/what-was-the-saturn-v-58.html#.VAkmwPmwLwk. [Accessed 6 September 2014].

[126] A. McDuffee, "Navy's new railgun can hurl a shell over 5,000 MPH," Wired, 9 April 2014. [Online]. Available: http://www.wired.com/2014/04/electromagnetic-railgun-launcher/. [Accessed 6 September 2014].

[127] "Third stage fact sheet," NASA, 1968. [Online]. Available: http://history.msfc.nasa.gov/saturn_apollo/documents/Third_Stage.pdf. [Accessed 8 September 2014].

[128] "Second stage fact sheet," NASA, 1968. [Online]. Available: http://history.msfc.nasa.gov/saturn_apollo/documents/Second_Stage.pdf. [Accessed 8 September 2014].

[129] "First stage fact sheet," NASA, 1968. [Online]. Available: http://history.msfc.nasa.gov/saturn_apollo/documents/Second_Stage.pdf. [Accessed 8 September 2014].

[130] T. Sharp, "What is the temperature of the Moon?," Space.com, 22 October 2012. [Online]. Available: http://www.space.com/18175-moon-temperature.html. [Accessed 12 September 2012].

[131] K. Zona and B. Dunbar, "Ion Propulsion," NASA, 21 May 2008. [Online]. Available: http://www.nasa.gov/centers/glenn/about/fs21grc.html.

[132] "Aristarchus (310-230 B.C.)," Cornell, [Online]. Available: http://www.astro.cornell.edu/academics/courses/astro201/aristarchus.htm.

[133] R. Netting, "Found It! Ice on Mars," NASA, 28 May 2002. [Online]. Available: http://science.nasa.gov/science-news/science-at-nasa/2002/28may_marsice. [Accessed 5 September 2014].

[134] "Energy efficiency in the power grid," ABB Inc, 2007. [Online]. Available: https://www.nema.org/Products/Documents/TDEnergyEff.pdf. [Accessed October 2014].

[135] W. Post, "A more realistic cost of wind energy," The Energy Collective, 29 November 2013. [Online]. Available: http://theenergycollective.com/willem-post/310631/more-

realistic-cost-wind-energy. [Accessed 30 April 2014].

[136] "Spacecraft shielding," Thayer school of engineering at Dartmouth College, [Online]. Available: https://engineering.dartmouth.edu/~d76205x/research/Shielding. [Accessed 6 October 2014].

[137] R. English, "Apollo Experience Report- Protection Against Radiation," NASA, March 1973. [Online]. Available: https://www.hq.nasa.gov/alsj/tnD7080RadProtect.pdf. [Accessed 6 October 2014].

[138] K. Lee, "What is space radiation?," NASA, 5 March 2014. [Online]. Available: srag-nt.jsc.nasa.gov/spaceradiation/what/what.cfm. [Accessed 6 October 2014].

[139] "The Deadly Van Allen Belts?," Space Math NASA, [Online]. Available: http://spacemath.gsfc.nasa.gov/Algebra1/3Page7.pdf. [Accessed 6 October 2014].

[140] "Clouds, Pollution, and Solar Radiation," FT Exploring Science and Technology, 2011. [Online]. Available: http://www.ftexploring.com/solar-energy/clouds-and-pollution.htm. [Accessed 2014].

[141] "Life Support Unit," Mars One, [Online]. Available: http://www.mars-one.com/technology/life-support-unit#sthash.SUQXvWYR.dpuf. [Accessed 2014].

[142] C. Cockell, P. Osinski, G. Horneck and P. Broady, "Impact-induced Microbial endolithic habitats," *Meteoritics and Planetary Science,* vol. 37, no. 10, pp. 1287-1298, October 2002.

[143] J. Slough, "The Fusion Driven Rocket: Nuclear Propulsion through Direct Conversion of Fusion Energy," NASA, 24 August 2012. [Online]. Available: http://www.nasa.gov/offices/oct/early_stage_innovation/niac/2012_phaseII_fellows_slough.html. [Accessed 2014].

[144] NASA, "Understanding Space Radiation," *NASA Facts,* pp. 1-3, 2002.

[145] University of Iowa, "Kepler's Third Law," 2014. [Online]. [Accessed 12 February 2015].

[146] K. Erickson, "Space Bones," 6 April 2011. [Online]. Available: http://science.nasa.gov/science-news/science-at-nasa/2001/ast01oct_1/. [Accessed 20 January 2015].

[147] "Understanding Space Radiation," NASA Facts, October 2002. [Online]. Available: http://spaceflight.nasa.gov/spacenews/factsheets/pdfs/radiation.pdf.

[148] D. Rapp, "Radiation effects and shielding requirements in human missions to the Moon and Mars," *The International Journal of Mars Science and Exploration,* vol. Mars 2, pp. 46-71, 2006.

[149] L. Simonsen and J. Nealy, "Radiation protection for human missions to the Moon and Mars," NASA Technical Paper 3079, 1991.

Appendices

Appendix 1: NASA 5, 10, 15 year Milestones for Robotics [42]

	5 Years	***10 Years***	***15 Years***
Object Recognition and Pose Estimation	An embedded system onboard a free-flyer capable of distinguishing humans and tracking their full body (head, torso, arms, legs) in a fully unconstrained 3D environment (including microgravity), and onboard a moving platform (i.e. segmenting a moving human from background motion induced by the moving platform).	An embedded system onboard a free-flyer capable of deriving a 3D object model (geometric) from multiple partial observations of a new/novel object from unknown poses (i.e., rather than relying on a priori CAD models) and using that learned model to recognize objects and estimate their pose.	An embedded system onboard a free-flyer capable of identifying (detecting, segmenting, and recognizing) 1,000s of objects in a fully unconstrained 3D environment in real-time and able to estimate object properties (material, functions, etc.).
Fusing Vision, Tactile, and Force Control for Manipulation	Tactile only manipulation of known objects placed in the compliant manipulator.	Integrated use of vision, force, and other sensors to recognize and grasp known objects for manipulation.	Visual and tactile exploration of unknown objects and estimation of task-appropriate usage.
Achieving Human-like Performance for Piloting Vehicles	An on-board machine system for piloting a vehicle in a safeguarded teleoperation mode, where short term operator intent (e.g., movement direction and speed) is communicated to the machine system and the system closes the loop on-board to carry out the intent.	An on-board machine system for piloting a vehicle in a supervisory control mode, where medium term operator intent (land the spacecraft at this location on the Moon, hold station above this point on an asteroid, dock with the Space Station, etc.) and the machine system carries out terminal guidance.	A fully autonomous unpiloted system capable of carrying out complex, multi-part procedures or plans to achieve multiple objectives without requiring remote operator input.

Access to Extreme Terrain in Zero, Micro, and Reduced Gravity	Perception systems capable of the resolution, range, and field of view required for sufficient situational awareness; and environmental conditions of extreme terrains, e.g. rough unstructured terrain, dusty environments, etc.	Perception systems that function in extreme lighting conditions, e.g. deep shadows and direct sunlight; and on materials with challenging surface properties, e.g. transparent or reflective materials such as glass, paint, mylar, kapton, etc.	Perception systems capable of determining material properties of extreme terrains, including unconsolidated or friable materials, and reasoning about how to move across delicate structures or surfaces.
Grappling and Anchoring to Asteroids and Non-cooperating Objects	TRL-6 grappling and/or anchoring device for 5-10 m asteroid.	Flight experiment of grappling and/or anchoring device for 5-10 m asteroid and/or large orbital debris (e.g. upper stage) capture in uncontrolled tumbling state.	Routine capture and de-orbit of large orbital debris and operational system for returning small asteroids to cislunar space with anchoring and human exploration/ISRU.
Exceeding Human-like Dexterous Manipulation	Human-density tactile sensing for "laboratory" level applications; aggregation and conditioning/filtering of sensor input at the manipulator level. Distributed sensor processing and motor control within the manipulator. Force-torque sensor for deep space applications. On-chip sensor processing, e.g. range maps.	Physically robust tactile sensing for "field applications;" grasp modification reflex control at manipulator level. Actuators and sensors that do not require heating and can work in deep space radiation environments. Sensor skin to detect distance to collisions at any point on the manipulator.	Human level DoF and better than human range of motion per joint through breakthrough improvement in actuator technology. Automated planning, plan decomposition, and execution state.
Full immersion, Telepresence with Haptic and Multimodal Sensor Feedback	Immersive theatre-like visualization systems allow groups of mission controllers to gain superior understanding of a distant environment and apply that knowledge in the creation of safer and more effective operational plans. Wearable peripheral-vision displays provide contextually relevant information for operational tasks and full-immersion head-mounted displays are used for some limited-duration activities. Exoskeletons are used to provide tactile feedback for precision tasks while vibrotactile gloves offer basic tactile feedback in other scenarios.	Glasses based on flexible transparent LCDs provide a low-latency, high-resolution, wide field-of-view partial and full immersive visualization solution that can be comfortably used by controllers and crew during many longer-duration activities. Flexible and non-rectangular displays and real-time rendering advances allow the conversion of any room into an immersive display space. Controllable-stiffness gloves integrated with fingertip tactile displays can simulate a variety of objects and textures. Input is naturally provided through speech and gestures.	Lightweight wearable retinal projectors provide comfortable partial and fully immersive visualization of any environment and are comfortably used as continuously as ordinary computer displays today. Thin and flexible tactile displays integrated into gloves and body suits can simulate most relevant touch sensations while accurately capturing all motion.

	5 Years	*10 Years*	*15 Years*
Understanding and Expressing Intent Between Humans and Robots	Software systems that enable robots to succinctly express their current state (health, perception of environment, task progress, etc.) and history (summarization of activities, problems, etc.) to humans via different modes (graphical displays, messaging, gesturing, etc.) depending on proximity and time delay.	Software systems that enable robots to identify and track planned human activity (steps in a pre-defined process, including contingency handling branches) using active and/or passive sensors.	Software systems that enable robots to identify human activity (pre-defined and novel), predict next steps, and offer task support. This includes recognition of user-specific characteristics and needs.
Verification & Validation of Autonomous Systems	V&V of an on-board machine system for piloting a vehicle in a safeguarded teleoperation mode. Achieve code quality and defect rate required for human rated systems.	V&V of an on-board machine system for piloting a vehicle in a supervisory control mode. Achieve code quality and defect rate required for human rated systems.	V&V of a fully autonomous system capable of carrying out complex, multi-part procedures or plans to achieve multiple objectives without requiring remote operator input. Achieve code quality and defect rate required for human rated systems.
Supervised Autonomy of Force/Contact Tasks Across Time Delay	Telerobots are capable of performing most tasks using intuitive "shop-foreman-style" instructions similar to what would be given on a shop floor to a trainee. Each command would be formed from macros of "mechanical primitive" behaviors that provide for stable and reliable transitions between N-constraints and N-1 or N+1 constraints on 6-DOF motions. For example, a move-to-contact in free space to put a tool into contact with a planar surface is a transition from 6 to 5 unconstrained DOFs. Sliding that tool-tip to drop into a hole in the surface would transition from 5 to 3 unconstrained DOFs.	Expanded dictionary of well-tuned and ultra-reliable shop-foreman-style commands such as might be given to a journeyman allow almost any task to be performed over time delay.	Dialog between operator and telerobot will be akin to that between a Factory Manager and Shop Foreman.

Rendezvous, Proximity Operations and Docking in Extreme Conditions	Autonomous control of spacecraft with proximity down to 3 meters about a small body (option to explore without landing, e.g. Touch-And-Go (TAG)); precision of TAG footprint <5m; repeated TAG capability (as opposed to TAG-sampling only once on a fly-by basis); autonomous hazard detection and avoidance; ground-based surveillance and characterization of the small body prior to close proximity ops.	Autonomous control of spacecraft with proximity down to 2 meters about a small body (option to explore without landing, e.g. TAG); precision of TAG footprint <5m; repeated TAG capability (as opposed to TAG-sampling only once on a fly-by basis); autonomous hazard detection and avoidance; autonomous surveillance and characterization of the small body prior to close proximity ops.	Agile exploration about small bodies, i.e. as opposed to above approach of extensive surveillance, characterization, approach and proximity ops, arrive, approach and explore with fast reaction to terrain and environment (e.g. comet ejecta), in an adroit manner agile closed sensing and control.
Mobile Manipulation that Is Safe for Working with and Near Humans	Structurally compliant mobile manipulator that dynamically alters its stiffness.	Demonstration of a "safe" compliant collision with a human while moving.	Demonstration of a "safe" compliant collision with a human while transporting a heavy payload.

Appendix 2: Key Terms

- SPS: Solar Powered Satellites
- He-3: Helium-3
- WPI: Worcester Polytechnic Institute
- VFR: Society for Space Travel
- A-1: Aggregate-1
- A-2: Aggregate-2
- A-4: Aggregate-4
- ITER: Joint venture for a fusion reactor between China, India, Japan, Korea, Russia, the United States, and European Union
- ADL: Arthur D. Little Inc.
- DoE: Department of Energy
- NASA: National Aeronautical Space Association
- SERT: Space Solar Power Exploratory Research and Technology Program
- JAXA: Japan Aerospace Exploration Agency
- GEO: geosynchronous equatorial orbit
- REE: rare Earth resources
- M3: Moon Mineralogy Mapper
- KREEP: Potassium, rare earth elements, phosphorus, thorium, and other incompatible elements
- LF: Lunar Flashlight
- RPM: Resource Prospector Mission
- ISRU: in-situ resource utilization

- CATALYST: Lunar Cargo Transportation and Landing by Soft Touchdown program
- ISS: International Space Station
- GM: General Motors
- ATHLETE: All-Terrain Hex-Legged Extra-Terrestrial Explorer
- CC: Contour Crafting
- NIAC: NASA Office of the Chief Technologist's Innovative Advanced Concepts program
- RESOLVE: Regolith and Environment Science and Oxygen and Lunar Volatile Extraction
- IHMC: Florida Institute for Human and Machine Cognition
- PERCO: Perceptual Robotics Laboratory
- HAL: Human Assistive Limb Exoskeleton
- ESA: European Space Agency
- MFC: microbial fuel cells
- NRL: U.S. Naval Research Laboratory
- AI: Artificial Intelligence
- N: Newtons
- LTS: Low Temperature Superconductors
- HTS: High Temperature Superconductors
- MagLevs: Magnetic Levitation trains
- LASA: Learning Algorithms and Systems Laboratory
- S3: Swiss Space Systems
- SOAR: Suborbital Reusable Shuttle

- LEO: Lower Earth Orbit
- MIT: Massachusetts Institute of Technology
- OSHA: Occupational Safety and Health Agency
- SPE: solar particle events
- GCR: Galactic Cosmic Rays
- Sv: Sievert
- BNNT: Boron Nitride Nanotubes
- GPS: Global positioning system
- Com-sat: Communication satellite
- L1 or L2: Lagrange points
- UN: United Nations
- ITU: International Telecommunication Union
- PPP: Public-private partnership
- UNCOPUOS: UN Committee on Peaceful Uses of Outer Space
- NEO: Near Earth Objects
- CCiCap: Commercial Crew Integrated Capability program
- PC4NC: Protein Crystals for Neutron Crystallography
- IPPase: inorganic pyrophosphatase
- CPCG-H: commercial protein crystal growth-high density
- HGPCG: High-Density Protein Crystal Growth
- EXPRESSS: ISS Expedite the Processing of Experiments to Space Station
- VNS: vagus nerve stimulate
- ECG: electrocardiogram

- DARPA: Defense Advanced Research Projects Agency
- Roscosmos: Russian Federal Space Agency
- CO_2: carbon dioxide
- MESSENGER: NASA's Mercury Surface, Space Environment, Geochemistry, and Ranging Mission
- MPO: Mercury Planetary Orbiter
- MMO: Mercury Magnetsopheric Orbiter
- MCS: Mercury's Composite Spacecraft
- MTM: Mercury Transfer Module
- SEP: Solar-Electric Propulsion