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Humanity and Space

An Interactive Qualifying Project

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by

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Abstract

This IQP was about the exploration of ancient culture's beliefs and traditions about space, the continued existence of humanity, how humans fare in extra-terrestrial environments, what can be done to improve our survival there, and lastly the commercialization of space. This group suggests that we take our energy search into space, with the mining of Helium-3 from a colony on Mercury and the collection of solar energy via solar panels orbiting around Earth.

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Executive Summary

This project delves thoroughly into the examination of the relationship humanity has with space. Ever since we have had the ability to imagine, humanity has been fascinated by the cosmos. When humanity was just starting to visualize outside our realm, space was believed to be a spherical shell around our planet. Once we developed the proper technology, we came to realize how vast space is, and how much we still had to learn about our place in the universe.

Humanity could not begin to imagine what extinction is like, what it means to be an endangered. However, there are very real threats to our existence; and in the scope of the universe we are merely ants to be stepped on. Whether it is a natural disaster, such as a biological outbreak from some unstoppable pathogen to an asteroid the size of Rhode Island, or perhaps our doom lays in our own hands with an all out nuclear war that would most certainly destroy us. Because of these threats, humanity must have a contingency plan. We need to be able to survive outside our current environment.

When the time comes for us to venture beyond Earth, whether to explore, to find new resources, or to put more efficient communication systems into space; we will need a way to do so. Mankind has used rockets up until now, and continues to do so; but these methods are beginning to become outdated. We need to find more efficient methods of transportation from Earth to space and beyond. In the meantime, while we continue our search for a perfect combustion system, we can apply our knowledge and put a base on the moon, so we can launch ourselves deeper into space from a lower gravity environment, thus lessening our fuel consumption and possibly enabling the colonization of our solar system.

While many argue that Mars is the next logical place for humanity to populate, it is imperfect. In its current stage, its days are too hot, its nights are too cold, and it has very little atmosphere; which means no air to breathe and no protection form solar radiation. While we could live within a biodome or similar structure, humans have proven far too often that they cannot be contained. In every experiment, the safety of the biodome is eventually compromised by our need to get out, to not be confined. In response to this, this IQP group initially proposed that we move Mars to a more suitable location in the solar system, merely a

fraction of its original orbit closer to the sun. It is a simple enough proposition; just hit Mars with asteroids and comets until its velocity is lowered enough to where it can be closer to the sun. We considered the simplest case, where we would collide a single, yet large enough, asteroid into the planet, effectively bringing it into a more habitable zone in one fell swoop. However, just moving the asteroid into position would take an immense amount of time, not to mention the high cost of the materials. Even then, it could possibly do irreparable harm to the Martian climate, rendering it uninhabitable for hundreds of years. While using more, but smaller, asteroids and comets would be safer, it would take far more time and energy to accomplish. Thus we shall leave the idea for future generations to ponder once they have more advanced technology. We next considered Mercury as a suitable location to settle down. Much like Mars, the temperatures and atmosphere pose the same problem. Unlike Mars, however, Mercury has resources which we can use in our search for more efficient sources of energy. One example is Helium-3, which is the main component in future fusion reactors. Therefore, this group proposes a mining colony on Mercury, comprised mainly of robots, to harvest the Helium-3, and return it to Earth. While the temperatures can pose problems over most of the planet, locations nearer the poles are safer, and water exists as ice deep within the craters marking the surface. Because the days on Mercury are equal to nearly two Mercury years, expeditions can be sent out on the dark side of the planet to explore and find new sources of Helium-3.

We have seen in the past how our initial foray into space has left us with many new and useful inventions that come directly from our space research, from smoke detectors to fire-retardant clothing. Who knows what will come to be in the future, when we are looking for ways to settle down in some other worldly environment. Space, like war, is an inventor’s dream. We can find uses for many new applications which will then be improved and changed and will eventually exist in a purely commercial setting. While there is always room for manufacturers to prosper, there is one area in particular which has always been hotly debated, but may soon be necessary for our success in space travel: genetic engineering. Biomedical engineers are looking for ways where we could genetically improve as space travelers. One such manifestation is in radiation protection. Once scientists can figure out how to incorporate our

DNA with radiation resistance, we will no longer need to fear long voyages in space where we come in contact with massive amounts of solar radiation.

Lastly, our group explored how we might acquire new energy sources while in space. One already discussed, is Helium-3. While these fusion reactors are only theoretical, this is the most efficient particle to fuse, for it requires the least amount of energy input for a He_3-He_3 reaction to occur. This may very well prove to be the energy source of the future, provided we can make the technology viable and get enough from the Moon and Mercury to power our grid for many years to come. Another form of energy comes from solar radiation, more specifically solar panels set up in Earth's orbit to capture sunlight continuously. By converting the sunlight to radio waves, the solar farm in orbit can send the waves down to a receiving station, which will convert the radio waves into electricity to be used in our power grid. There may certainly be other forms or sources of energy which we have not yet discovered, but our search and exploration into space is only just beginning.

Introduction

"Somewhere, something incredible is waiting to be known."

- Carl Sagan

Humanity's curiosity with space has existed since the earliest periods of recorded history. As far back as 5000 BC, cultures have looked toward the sky with a fascination that has been passed along each subsequent generation and persists even today. In ancient times, the sky was a place of gods and higher powers, a place where stars gave people a sense of time and scale of the universe. Today, with all of our technological innovations, we are not constrained to solely the role of observer, but we are now participants in the exploration of outer space. We can see the stars and planets with a clear view, and we possess the technology to travel to these distant planets and discover what lies beyond our small blue world.

Space is the final frontier in the truest sense of the phrase. We have explored every corner of the Earth, and are utilizing every resource that is available to us that the Earth has to offer. Space offers us many opportunities to learn about the universe and to further ourselves as a civilization. These opportunities will benefit us scientifically and economically. Our technology is constantly evolving to adapt to new challenges and will only grow more advanced with further exploration of space. Economically, we can benefit from the acquisition of resources that may be plentiful on other planets, but may be rare on Earth. Space provides an opportunity for more advanced satellite communication to be developed making information more easily accessible which will lead to an increase in global education.

This project's main goal is to explore the connection between technology and society. Space is the future for humanity. We explored some major reasons why we want to go to space. These reasons include the advancement of technology, the survival of our species, and economic opportunities. In this report, we examine the science behind space exploration and its impact on human society.

Samuel Daley

My original interest in this project stemmed from my enthusiasm for astronomy and the development of space technologies as well as my experience in my classes as an aerospace engineering major here at WPI. Through my classes and general habit of looking through current space-related events, I have learned a lot about space and space policy and have continued to develop my own opinions regarding humanity's advancement into space. For example, I always thought that humanity should make a combined effort to make human space exploration a reality as well as eventually colonizing the rest of our solar system. Therefore, when I saw that there was an opportunity to do a project on space policy and all the aspects surrounding human space flight, I knew it was something I would want to do as it is a field I am very interested in.

For this project, I am hoping to research space technologies and policies that would help further the advancement of humanity's presence in space as well as incorporate design aspects our team could undertake to include in the report.

Geoffrey Hong

I chose this IQP because Space is the final frontier which has not been fully explored yet. The far reaches of space are still a mystery to us. Alien life (in the most literal sense) has yet to be discovered. As our race continues to develop we begin to question if there are others out there, or if they are at all like ourselves. Are there even other planets out there which are habitable? Currently we lack the technology to make space travel a viable method. We can only use telescopes and satellites to see the stars so far. This IQP may allow us to explore in-depth new methods of space travel.

I also chose this IQP because I am an aspiring aerospace engineer. My first two years of study have been basics of math and science, but this year is my first chance to delve deeper into the mechanics of flight. I believe that my curiosity about space and thirst for knowledge will lend itself to this project.

By working on this project I will gain a more in-depth knowledge of the technology that I will be encountering in my field of work. I think that the team aspect is also very important and learning how to work with others and how to apply a 'division of labor' approach will be key. This project will also help educate us on how to research and how to write a better research paper. This IQP is an opportunity to prepare for our MQP which will take all of our skills and roll them up into one project.

Amanpreet Singh

As technology has advanced through the ages, it has allowed mankind to continuously expand its horizons. We were once very limited in terms of our understanding of the world and our mobility, but we now have technology that can take us around the world and even away from it. As time goes on, I feel that space travel will be more and more important. We have been advancing the sciences very quickly and people have become very specialized in their respective fields. Travelling to (and eventually colonizing) space is one thing that can unite all this knowledge into something truly great. It will incorporate the sum of knowledge of mankind raging not only from the sciences (including biology, chemistry, physics, and electrical and mechanical engineering), but also from other areas (such as the arts, politics, social sciences, and ethics). It is only a matter of time before we need to leave the Earth. If it doesn't get hit by an asteroid or we don't destroy the Earth ourselves, the Sun eventually will. Aside from that is the fact that human curiosity knows no bounds. To really understand the universe, we will need to experience more of it.

I hope that by doing this project, I will understand where we currently stand in terms of space colonization and what more we need to do to make it a reality. I would like to get a sense of what the process is to create policies and create some theoretical short term and long term goals for a realistic space program.

Zachary Starkweather

Space has always interested me. When my family would rent a beach house over the summers, we would just sit outside, and watch the stars, counting satellites, and naming constellations. After high school I did a post-graduate year at a prep school in western mass. There I took an astronomy class and was able to learn even more and deepen my fascination with space. In my senior year of high school, I read a book about Stephen Hawking, and from that moment on I have wanted to be an astrophysicist, much similar to him. Just last year, I took intro to Astrophysics and I loved it.

Also, we will eventually need to leave this planet in order to colonize a new one, or just live in space. If humans live long enough to see the end of the sun then we will have to find a new solar system to call home. Perhaps there will be some man-made disaster that brings the earth to an end, such as a nuclear or chemical or biological war. However, the most likely scenario is that it will be a natural disaster. This includes a massive earthquake, or something happens to the climate and we fall into another ice age, or we are hit by a near-earth object. It is better to begin thinking about what to do now, than wait until it is too late.

I want to participate in this IQP because it is the perfect project for me to further my knowledge of space. And, I hope to devote the rest of my life to studying space.

Chapter I: Ancient Civilizations

Ancient Greece

Space and their beliefs about the universe played a pivotal role in the religious beliefs of the Ancient Greek peoples. For the most part the ancient Greeks believed that their gods came from space, and that some of them lived there. The Greeks created and named constellations after their gods and other myths they believed in. They believed that what they saw when they looked up at the sky was actually the heavens. So while they saw all these planets and stars and constellations, they saw them as being in the heavens. Perhaps, the most famous of these is Orion, whom the Greeks believed to be a great hunter. The gods gave him the gift of immortality by casting him into the night sky, so he can live forever there. They also named all of the planets after each of their major gods.

The ancient Greeks believed, as did just about everybody at that time, that the earth was the center of the universe. While there were philosophers, such as Aristarchus, who believed that the earth truly did revolve around the sun, their views were not accepted and they were generally frowned upon. The ancient Greeks views on space were heavily clouded by their religious beliefs. For example, they believed that the sun came every day, because it was pulled along by a god in a chariot, who was supposedly the son of Hyperion, the sun-god. They believed that the stars came out in a similar manner. The ancient Greeks believed that what they were looking at when they looked up at the sky was a “star shell” surrounding the earth.

Ancient Egypt

Mankind has been fascinated with space since from the very beginning. We currently have advanced technology that enables us to view high quality images of space from the Earth as well as from outside of the Earth. This allows us to study space in great detail and even perform experiments in space to test our current theories about it. We strive to refine our knowledge of the stars in terms of the laws that allow the universe to exist. Ancient cultures did not have the benefit of our modern technology, but they too studied the heavens and came up with their own interpretations of it. For the ancient Egyptians, for example, the study of space played a major role in the development of their religion, calendar, and architecture.

The ancient Egyptian religion had many different Gods that governed different aspects of the universe (such as the Sun, the moon, the sky, the afterlife, etc.). Most of these Gods were created to explain natural phenomena that the Egyptians observed. The Sun god Ra, for example, personified not only the Sun itself, but also anything that the ancient Egyptians thought that he had created (such as all life forms). He was able to ride his “solar boats” (not as in solar powered, but as in related to the Sun) for travel, which was used to explain the apparent movement of the Sun. The Gods were intertwined with nature and thought of as a part of a balanced whole. The sky, for example, was thought to be a form of the sky God, Nut, which was held up by other Gods. The Earth itself was thought of as the God Geb. The God Shu was the God of air right between the sky and Earth. The ancient Egyptians simply did not have the technology to view space in details, so they, like many other cultures, used the concept of Gods to explain what they observed.

While they may have had fantastical explanations for their observations, the observations themselves were quite good. An example of this is the Egyptian calendar that developed from observing the cycles of the Sun, the Moon, and the periodic seasons. The result was a calendar of 12, 30-month days, with 5 extra days at the end. This is fairly close to our modern calendar. It was particularly important to be able to have a good calendar system that showed accurate season changes because most of the population was composed of farmers. It was by studying the solar and lunar cycles as well as the stars that the Egyptians could create a good calendar.

Further evidence of the observations of the cosmos by the ancient Egyptians is apparent through their architecture. The famous pyramids were created as tombs for the pharaohs, who were thought to be divine. These structures were built so that that the souls of the dead pharaohs would be able to ascend to the heavens. The Egyptians were even able to point structures very close to true North (with a deviation of about a 20th of a degree) using the stars “Kochab” and “Mizar,” in the little and big dippers, respectively. This ties back in with the

Egyptian religious beliefs. The Egyptians observed the skies and nature, created stories behind the observations, and even created architecture to reflect those beliefs. Since it contributed to so many different aspects of ancient Egypt's culture and was intertwined with their religious beliefs, the study of space is certainly one of the major reasons why Egypt thrived at the time.

Ancient Mayans

In today's society in the United States, there is a growing divide between science and religion. There are those who consider their religious views as the truth and those who look at the universe through scientific facts. Then there are those who incorporate both science and religion to try to come to a better understanding of where they came from. If we look to the past and study ancient Mayan culture, it is clear that they saw how science and religion could go hand in hand to obtain a better sense of their world.

The ancient Mayans saw science, and especially astronomy, as a way to understand their god's place in the universe as well as their own. In their culture, celestial bodies represented certain deities, with the most important objects in the sky being the Sun, the Moon, Mercury, Mars, and Venus. They directed most of their attention, however, toward Venus because it had connections with their major deity Quetzalcoatl, whom they worshipped as the creator. This is evident in not only surviving documents and pictures, but also in the construction of a large number of ancient Mayan buildings and cities. When one closely examines the alignment of certain buildings, it is clear that they are aligned in a certain direction to see the rising or setting of certain stars or planets. For example, the Caracol tower of Chichen Itza has peculiar asymmetries that actually correspond to the rising of Venus. In addition, the Governor's house in Uxmal points outward toward Venus's southern position over a pyramid in a neighboring city. One reason for this was that they believed that if a person could predict the actions and movements of astronomical objects that represented their gods, then they would be in communication with them. Because of this, it is not surprising that the Mayans went to great lengths to calculate the orbits of the different stars.

The ancient astronomers who studied the sky were also priests. Therefore, it was not only their job, but also their desire to be in communication with the god's that led them to write the Dresden Codex. It is the earliest known book written in the Americas and contains extraordinarily accurate astronomical tables. Probably the most famous of these tables are the Lunar and Venus series. Over centuries of careful calculations, the Mayans were able to develop intervals that predicted lunar eclipses as well as ones that correlated with the movement of Venus. Thus, they were able to calculate the orbit of Venus, Mars, the Moon, and Mercury to be 584, 780, 29.53, and 117 days, respectively. All of these calculations are extremely accurate, with the largest difference between the actual values being less than one day. The reason they were able to do this was that they had developed a complex base 20 mathematic system that included the concept of zero and placeholders by around 500 B.C.E. The concept of zero was an advanced feature that simplified their orbital calculations and allowed for equations that were more complex. However, it is unclear if they developed this mathematic system independently from their astronomical calculations or if their observations of the night sky aided in its development.

When we look back at the ancient Mayan culture to study their attraction to outer space, it is easy to see that it was not only scientific, but also religious. They believed that the celestial bodies were their god's way of communicating with them and therefore they devoted much of their efforts to studying the movements of the stars and incorporating them into their culture.

Ancient Sumerians

The Sumerians believed in what is now considered 'ancient astronauts'. This is what many scientists believe to be the missing link between Earth and how life began. The Sumerians believed that their gods, the Anunnaki, were extraterrestrial and that they brought the seed of creation so that life could be sustained on Earth. There is some evidence which leads to the conclusion that this is possible, but there is not enough proof to mark this as a valid theory. Some evidence of this is the level of Sumerian intelligence and out-of-place artifacts.

The Sumerians were one of the most intelligent civilizations for their time. Around 3500 B.C. they already had a strong grasp on written script, literature, and law, and possessed hospitals, temples, schools, advanced mathematics, and astronomy. This is perhaps why the Sumerians are considered a very mysterious culture, as they were highly sophisticated very early in their cultural history. It is written on Sumerian clay tablets that “Our knowledge is given by Gods who live in Nibiru.” The Sumerians believed that “Nibiru” was another planet separate from the one they were on, and this sparked an interest in the sky above. An interesting fact is the translation of Anunnaki. An means sky, na means come down, and ki means ground. This roughly translates to those who come down from the sky.

Several artifacts recovered from Sumerian cities have a striking resemblance to modern space equipment. There are several clay tablets which depict rockets and what appear to be winged saucers. Authors like Zecharia Sitchin believe that these carvings are solid evidence that advanced life forms came to earth and bestowed their knowledge upon the Sumerians. There are also statues of the Sumerian goddess Ishtar where she is wearing what appears to be a robe resembling a space suit as well as a headdress which is very similar to a space suit helmet. The Sumerians were proficient in tool making, but lacked the materials to create flying machines. They utilized irrigation and division of labor. This organization eventually led to writing. They also developed cuneiform, which was writing on wet clay with reeds. The Sumerians were known for the invention of the wheel (through the potter’s wheel), writing (through the use of cuneiform), and widespread use of irrigation.

Fig 1. An artifact recovered depicting the "Annunaki"

(*Courtesy of http://www.bibliotecapleyades.net*)

The Sumerians also had a connection to the number 60. Their system of mathematics was based on a sexagesimal system (base 60). This has significance in that the number sixty, or its factors, is apparent in many things today. For example, in one hour, there are 60 minutes, and in each minute there are 60 seconds. The number of months in a year is 12, a factor of 60, and the average number of days, 30 is also a factor of 60. The number of degrees in a circle is 360, a multiple of 60. This system originated with the Sumerians in the 3rd millennium BC, and was passed on to the Babylonians and further on from there. It is interesting to note that the Sumerians were the first to create a calendar which was synchronized with the solar year, meaning it follows the current format of seasons and included an extra month every four years for the difference between the current year and the year of the seasons.

When we take a closer look into the validity of a connection between the Sumerians, alien life, and modern astronomy, it is hard to confirm its reality, because of the contradictory facts which can be proved by modern science. If we examine the idea of the planet Nibiru, which is said to rest beyond Pluto, it is told to us that this planet could sustain life and is where the Sumerian gods came from. We can dispute this by observing the planetary motion of such a planet. We can tell from the eccentricity of the orbit as well as the distance at which it is said to rest with relation to the Sun that the planet would remain behind Pluto for 99% of the time. This clearly proves that this would be a technical impossibility. We can look at Zecharia Sitchin's argument as a convincing one to one who glazes over the individual details, but upon closer inspection of separate facts, we can see that the case is flawed.

Chapter II: The Case for Expanding Civilization

Impact Event

In the book *The Survival Imperative* by William Burrows, the author details a possible doomsday scenario in which an asteroid threatens modern civilization. However, it is a worst-case scenario, so the probability of such an event occurring is relatively low, but it does reveal important aspects about what might happen and why humanity would benefit from expanding their civilization into space.

In this worst-case scenario, an asteroid called Rogue came from the Oort cloud around 2 million years ago. As it circled around the far side of the Sun, it broke into a six-hundred-mile long chain of smaller chunks of rock, ice, and other debris moving at around 400 miles per second. The first asteroid exploded high over Australia, scattering debris all over the region. The rest of the chain impact all over the rest of the world with Western Europe and Asia sustaining the most damage as it is more densely populated. Each subsequent impact shot earth and other debris into the atmosphere that added to the blanket that was now covering the Sun. This "nuclear winter" would last for years and cause a dramatic drop in global temperature. In addition, firestorms, tsunamis, and acid rain would ravage the surface of the earth. However, the most important factor that would contribute to the fall of modern society would be the human factor.

In the face of utter devastation, humans would begin to fall back on their more primitive survival instincts. This would occur over a period after the impacts, however. The initial event would be the breakdown of the basic functions of society. The world economy would disintegrate causing money to be useless, supply lines would stop functioning, telecommunications would be down, and mass transportation would be nonexistent. There would be widespread looting, murder, and utter chaos and anarchy as supplies ran low and people fought to survive this disaster. As Burrows stated, "To kill was to survive."

The main question that arises is how likely is a doomsday scenario to happen? To put this in a more realistic perspective, figure A represents the estimated frequency of impacts of Near Earth Asteroids (NEA) of a relative size. As shown, NEAs of less than 4 meters in diameter enter the Earth's atmosphere every year but burn up before they reach the ground. Whereas, it is estimated that NEAs of greater than 9 kilometers are much rarer, with the last impact of such a magnitude being the event that ended the time of the dinosaurs. Currently, the NEA Apophis has a remote chance, about 1 in 12.3 million, of impacting the Earth in 2036. However, if it were to collide with Earth, the resulting impact would be devastating. It is possible to calculate its energy at impact by using the kinetic energy formula. If the mass of the NEA is around $2.7 * 10^{10} kg$ and is moving at just over 11 kilometers per second then the kinetic energy would be:

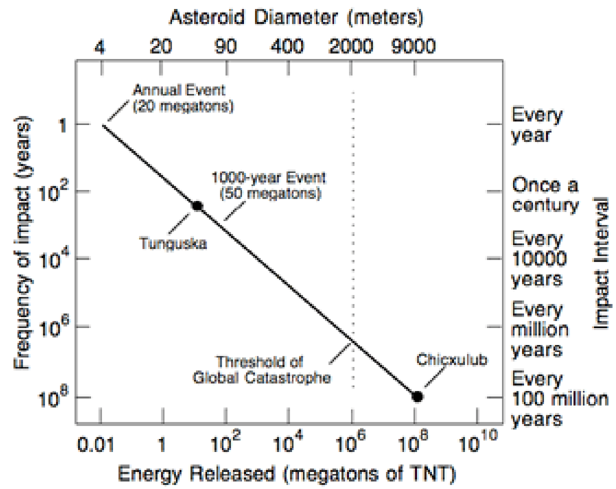

Figure 2(*Courtesy of Geology.com*)

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

$$K = \frac{1}{2}(2.7 * 10^{10})\left(11134\frac{m}{s}\right)$$

$$K = 1.6736 * 10^{18} joules * \frac{1\ Megaton}{4.184 * 10^{15}\ joules} \cong 400\ Megatons$$

This result is purely the kinetic energy of the NEA under ideal conditions and using the assumption that its velocity is known. If needed, however, it is possible to obtain a more accurate kinetic energy value by accounting for the change in velocity due to the effect of the atmosphere. This can be done by utilizing and manipulating the drag equation, which gives the force on a solid body moving through a fluid:

$$\frac{dv}{dt} = -\frac{3\rho(z)C_D}{4\rho_i L_0}v^2$$

Where:
$\rho(z) = \rho_0 e^{-\frac{z}{h}}$
ρ_0 = Surface atmospheric density = 1 kg/m^3
z = Altitude about Earth's surface
h = Scale height = 8 km
C_D = Dimensionless coefficient of drag ≅ 2
ρ_i = Density of NEA
L_0 = Diameter of NEA
V = Velocity

Then, by making the substitution $dt = -\frac{dz}{v sin\,\theta}$, where θ and v_0 is the angle of entry into the atmosphere and initial entry velocity respectively, the equation can be simplified and rearranged further.

$$\frac{d}{dz}(\ln v) = \frac{3\rho(z)C_D}{4\rho_i L_0 sin\theta}$$

$$\int \frac{d}{dz}(\ln v)\, dz = \int \frac{3\rho(z)C_D}{4\rho_i L_0 sin\theta} dz$$

$$V(z) = v_0 e^{\frac{3\rho(z)C_D h}{4\rho_i L_0 sin\theta}}$$

Therefore, the resulting equation gives the velocity of the NEA inside the Earth's atmosphere as a function of its height above the surface of the Earth. However, this effect is also largely dependent on the size of the NEA. If it is too small, the NEA burns up in the atmosphere due partly to the rise in stagnation pressure, or the point at which the velocity of the fluid flow equals zero at the front of the body. If it is large and dense enough to penetrate the atmosphere, the force of the atmosphere provides for only a small change in its velocity. Because as:

$$\lim_{L_0 \to \infty} v_0 e^{\frac{3\rho(z)C_D h}{4\rho_i L_0 sin\theta}}$$

The exponential term approaches $e^0 = 1$ and thus the equation becomes $(z) = v_0$. As a result, it is clear that the NEA Apophis would impact the Earth with around the same velocity as it did when it was approaching. The resulting energy of the impact would be equivalent to around 400 Megatons of TNT. The nuclear bomb that was dropped on Nagasaki during World War II was approximately .02 Megatons. Therefore, based on what was previously calculated, a NEA impact of such a magnitude would be equivalent to about 20,000 World War II era nuclear bombs.

Ultimately, it is easy to see how in a matter of days, centuries of human culture, traditions, and history would be destroyed. Only structures that survived the initial impact the NEA would stand as a testament to the past. Even if humanity is not faced with extinction as a species, a catastrophic event could destroy all evidence and all the knowledge of our technologically advanced civilizations and force us back to the metaphorical Stone Age. Therefore, this is one main reason why humanity should expand into space and take precautions to guard the Earth; to not only preserve humanity but also its knowledge and achievements.

Biological Disasters

Mankind has come a long way in terms of technology, particularly in technology involving biology and medicine. One example of this is vaccines for various diseases that have allowed us to nearly wipe out certain diseases and severely limit others. New technologies and research have allowed us to increase our life spans and decrease threats to life in general. This does not, however, mean that we are only seeing benefits from increasingly complex biologically and medically related technology. There are potentials for disasters so large that it could wipe out humans. This can be shown by looking at vaccines and their full effects, by looking at the rise of Africanized Honey Bees, and by the threat of bioterrorism. All of these reasons are very good ones to have a backup plan in case the Earth becomes uninhabitable.

Modern technology allows us to study things in great detail at the microscopic (and now even nanoscopic) level. Microbes and pathogens are often studied in detail in such a manner and they are often manipulated in the name of research. This manipulation, while often well intentioned (e.g. while trying to make a virus or bacterium weaker to make a vaccine), can have disastrous results if proper safety procedures are not followed. It is not always a simple process to manipulate such complex things and something stronger may inadvertently be created. If a strong pathogen gets out into the wild, it could spread more quickly than we would be able to suppress it. Even if the results of a research project are considered fruitful, this still does not mean that we are in the clear. On the contrary, there needs to be continuous research (and therefore continuous risk for a biological disaster), to keep information up to date. Bacteria and viruses, for example change over time and vaccinations need to be updated. In fact using vaccines has a major impact on the evolution of a pathogen and makes it stronger. Merely researching such things can pose a risk for a disaster, but letting the pathogens develop immunity to our vaccines also poses a major threat to our existence.

A different type of demonstration of a biological disaster can be shown by the case of Africanized Honey Bees. These bees were the result of experiments by Warwick Estevam Kerr to create a bee that would yield more honey, but ended up creating bees that were more aggressive than regular European bees. These were inadvertently let loose. They were much better suited to the environment than indigenous bees and spread very quickly over the southwest United States, overpowering other bees. While these bees are not an immediate threat to mankind, it does show how well intentioned research can be disastrous.

The final and most powerful threat of a biological disaster is the threat of bioterrorism. This is especially dangerous because it involves the governments of nations as well as terrorists who are either using or doing research about using biological pathogens to kill their enemies. This is because biological weapons are relatively cheap to produce and need to only affect a small number of individuals to start off with. Disease can then spread among the population naturally and lead to the destruction of large populations of people (and other life) very quickly. The main danger is the scope at which large militaries could potentially use this kind of technology.

These are just a few of the ways that biological disasters can occur and threaten our existence. We need to have another safe haven in case the Earth becomes inhospitable, whether it is due to negligence of safety codes or a fully planned biological attack over a large portion of the Earth. Going to space offers us many more opportunities to be able to rebuild in case of such an emergency.

Natural Disasters

Scientists say that 99% of all species that have ever lived have gone extinct. This seems like a huge number, but considering our 4.5 billion year history, that 1% is still a relatively large number. The preservation of the human race is one of the many reasons why we want to go to space. Natural disasters occur all across the globe every day, but one of an unnatural magnitude could happen in the blink of the eye and erase humanity from the universe's history.

The sun is the most prominent figure in our sky today. But far beyond the Milky Way galaxy, there are many stars which burn just as brightly, and have been burning for much longer. Gamma-ray bursts occur randomly in space, but some are believed to be associated with a star burning out and forming a black hole. A gamma-ray burst is an explosion of energy. This burst of energy is $10 * 10^{16}$times more powerful than our sun. It is thought that gamma-ray bursts emerge from the poles of a collapsing star and radiate high energy photons in a narrow cone shaped pattern. Planets outside this cone of energy would be safe, but those inside the cone would be in danger of global environmental changes and biospheric damage. It is hypothesized that the Ordovician Mass Extinction which occurred 450 million years ago occurred due to a gamma-ray burst. The mass extinction crippled many life forms which were water dependent at the time, and is considered to be the second most devastating extinction in the Earth's history. If a burst like this ever happened, the Earth would surely be doomed. The gamma rays would burn the atmosphere and create nitrogen oxides which would in turn destroy the ozone layer. Without the ozone layer, the sun's ultraviolet rays would hit the Earth's surface at full force and would cause mass skin cancer. Worse even, is that the rays would kill the plankton in the ocean that create oxygen and supply the bottom of the food chain. All observed gamma-ray bursts have occurred outside of our galaxy. Outside of the environmental changes, the energy itself can cause tremendous harm to the human body. To compare its effects, we have observed the effect of these gamma-rays on the D. Radiodurans bacterium. A gamma-ray burst can destroy the bacteria into bits, but it can patch itself together again. Unfortunately, the amount of energy required to break it down is 3000 times the amount needed to kill a human being. Currently, satellites observe on average one gamma-ray burst a day. Based on the sheer number of galaxies, and the frequency, it is estimated that one gamma-ray burst occurs in the Milky Way every 100,000 to 1,000,000 years. Recently, studies have been done that show gamma-ray bursts tend to occur in metal diminished regions of space. The Milky Way, being metal rich may be less likely to be hit by a direct gamma-ray burst in the foreseeable future.

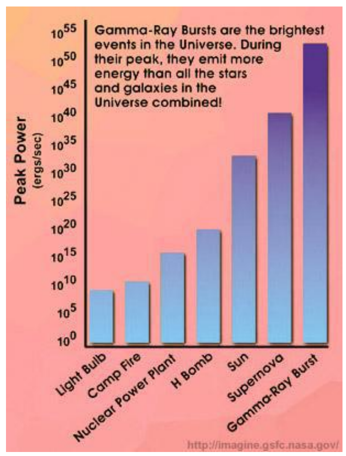

Fig 3. Comparison of GRB to other power sources

(*Courtesy of AstroCapella.com*)

Rogue black holes are another threat to our planet. These gravity wells could throw off the Earth's orbit around the sun, causing extreme climate changes, or could rip the Earth out of its orbit all together, sending it into frigid deep space. A more likely scenario though, is a rogue black hole could pass through the Oort cloud, and send comets from the edge of the universe towards Earth. The velocity at which these comets could come hurtling at Earth is believed to be on average 124 miles per second. If a comet roughly 1500 m in diameter hit the ocean at this speed, it would create a tsunami wave height of nearly 240 meters, almost 8 times the height of the one that occurred in Indonesia in 2004. It is estimated that there are around 10 million black holes in the Milky Way galaxy. It is hard to forecast when, or if, a black hole would come too close to our array of planets, because the gravity possessed by black holes is so great that it bends and swallows light that we need to see them. Kelly Holley-Bockelmann of Vanderbilt University has been leading research on black holes, and says that there is a 1 in 10 Billion chance per year of this happening.

Solar activity is a double-edged sword. We rely on it for heat and energy, but it can be extremely lethal for us as well. A super-flare from the sun, sending charged sub-atomic particles would disintegrate the ozone layer leaving the Earth's surface vulnerable to harsh ultraviolet rays. Equally as dangerous as a super-flare would be a decrease in solar activity. If the sun's output dropped by even 1%, the consequences would be devastating. Such a drop in activity could send us into an ice age. Scientists attribute seventeen or nineteen of the last cold periods to a decrease in solar activity. Recently, NASA has announced the possibility for a solar flare to occur in the next few years, which could shut down electronics globally; from air traffic control devices to personal computers. This could be extremely devastating considering how reliant on electronics human beings are, and could rack up a multi-billion dollar damage total unless we are prepared for it. It has been estimated that areas with fragile power grids could go without power for days or weeks due to a large solar storm. The damages that could occur across the globe could be twenty times that from Hurricane Katrina.

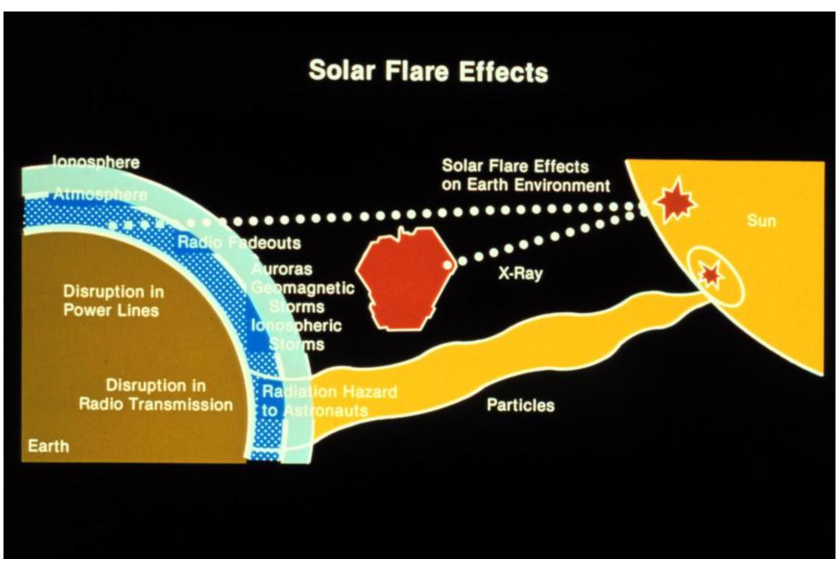

Fig 4. Effects a solar flare would have on the Earth

(*Courtesy of NOAA.gov*)

In recent history there hasn't been a volcanic episode which has caused widespread damage. Around 65 million years ago, a volcanic eruption occurred in India which caused untold damage to the Earth's surface and the atmosphere. The eruption did not occur just once, but again and again for centuries. If this were to happen again, the aftermath of the destruction would be insurmountable. Volcanic eruptions release large amounts of the Halide acid HCL, which alone does not do much damage to the ozone layer, but in conjunction with chlorofluorocarbon (CFC) gases - which are human produced, this combination can decrease the ozone layer up to 15-20% around the eruption area, and nearly 50% over the Antarctic pole. Eruptions can be more detrimental to the atmosphere in the gases that they emit. Contrary to popular belief, the amount of ash that is created is not the leading culprit in changes in the atmosphere. The sulfur rich gases which are released combine with water droplets in the stratosphere and create sulfuric acid droplets, and these large clouds can lower the global temperature. No recent catastrophic eruptions have occurred, but some significant ones in the past such as the eruption of Laki in Iceland lowered the temperature globally by 4.8 degrees centigrade below the historical average. A larger eruption could have even more drastic effects on our environment.

How to Deflect Asteroids

Scientists estimate that a near earth object (NEO) with a diameter of one kilometer or more collides with Earth on average every 500,000 years, with larger collisions occurring much less frequently, about once every ten million years. Even though these seem like long periods, there is no telling when the next impact event will occur. Therefore, it is essential that long-range telescopes across the world scan the sky for potential NEOs that might threaten the survival of modern civilization or humanity itself. Once humanity knows these objects are on a collision course, there is a plethora of ideas available using current and yet to be invented technology to reroute NEOs.

The first proposed method, which has been immortalized by Hollywood and the silver screen, is to plant a nuclear device on or within the NEO in an attempt to destroy it. Despite what Hollywood says, this is actually not a very good idea for a number of reasons due to the numerous factors that would be involved. For example, depending on the size of the NEO, there might not be enough firepower delivered to it to destroy it. Instead, the blast might knock off chunks of rock and ice, creating a chain that would inevitably cause more devastation. In addition, there is only a limited amount of knowledge that can be gained from observations of the NEO. Thus, there is the possibility of other factors that might not be accounted for, such as a change in rock density. Because it is difficult to destroy an NEO, scientists have been developing other ways to avoid such a cataclysmic event.

The next best technique of avoiding an impact event would be to use currently available technologies to force the NEO off its collision course with Earth. Essentially, this would require a large force (or a smaller force over a longer period of time), to change its trajectory. To be clear, all of the changes to the asteroid's motion will always be perpendicular to its motion; therefore it will be along a line pointing from the sun to the asteroid. There are several methods to accomplish this. Thus, depending on which method we use there is a minimum force or velocity required for us to be positive the asteroid will not collide with Earth. There are two different ways for us to make sure the asteroid will be off course. First, we can impart a large force which will give the asteroid an initial velocity which won't change very much since there is very little in space which will cause resistance. So, to calculate this minimum velocity an asteroid must have, we will state that the minimum displacement that the asteroid must have is equal to the radius of the Earth; for the simple reason that if it is headed toward the center of the Earth, a displacement of $6.38 \times 10^6\mathrm{m}$ will make sure that the asteroid is clear. So, to calculate this velocity, we will also say that it will be in effect 10 years prior to its collision date, so the asteroid has 10 years to move off course. We can compute the velocity using the following equation:

$$v_{min} = \frac{d}{t} = \frac{6.38 \times 10^6 m}{10yr * 365\frac{days}{year} * 24\frac{hours}{day} * 3600\frac{seconds}{hour}} = 0.0202\frac{m}{s}\,or\,2.02\frac{cm}{s}$$

So, we must give the asteroid an initial velocity of at least $2.02\frac{cm}{s}$, perpendicular to its current line of motion, in order for it to be completely off course.

First we will look at the case of a collision with a rocket. This method is also known as a kinetic impactor, which consists of anything that makes a large change in the asteroid's kinetic energy rather than applying a force over time. For this problem we can use conservation of momentum to compute the final velocity of the asteroid. Assuming that the collision is completely inelastic, in that the rocket will become a part of the final mass of the asteroid, we can use the equation:

$$m_r v_r = (m_r + m_A) v_{r+A}$$

For the mass of the rocket we will use $2 \times 10^4 kg$ and its velocity will be $4.0 \times 10^4 \frac{m}{s}$, which is a reasonable speed for a spacecraft to attain, and we will use the asteroid 99942 Apophis which has a mass of $2.7 \times 10^{10} kg$, since that is the most likely candidate that any of these methods will be used on next. Therefore, calculating for the final velocity change, we arrive at $v_{r+A} = 0.0296\frac{m}{s} = 2.96\frac{cm}{s}$, this is greater than the value we calculated above, so this method would be successful. We used a mass of $4.0 \times 10^4 kg$ for the mass of the spacecraft, this is around twice as massive as the space shuttle, so we would need to make some changes to the design, but it is not an unreasonable request if it means our survival.

The second method is to detonate a nuclear warhead not directly on the asteroid, but nearby, boosting its kinetic energy to change its course. The largest yield nuclear bomb we, as humans, have created is the Russian "Tsar Bomba", with a blast energy of 50 megatons of TNT or 210 petajoules, which is equal to $210 \times 10^{15}\ Joules$. While the actual energy imparted on the asteroid depends on how far away from the rock the bomb is detonated, we will make the assumption that 1/1000th of the total blast energy is given to the asteroid as kinetic energy. Thus, using the following equations, we can find out how large of a velocity shift the asteroid will have gained and whether it will be enough to change its course enough.

$$K = \frac{1}{2} m v^2$$

Since we are stating that all of the imparted energy will become kinetic energy, we can use conservation of energy to make the calculation.

$$Q + K_0 = K\text{, but } K_0 \text{ is zero, so,}$$

$$\frac{210 \times 10^{15} J}{1000} = \frac{1}{2} * 2.7 \times 10^{10} kg * v^2$$

Therefore, the final velocity of the asteroid is $124.7\frac{m}{s}$, which is well above the minimum required velocity.

The other method is to apply a constant force on the asteroid, and once again we will need to calculate the minimum force required for the asteroid to miss the Earth. We can use both Newton's Second Law of Motion, $F = m * a$, and kinematics equations (equations of motion) to relate the acceleration to the displacement of the asteroid; e.g.

$$d = d_0 + v_0 * t + \frac{1}{2}at^2$$

But since d_0 and v_0 are zero for the perpendicular motion, the equation reduces to:

$$d = \frac{1}{2}at^2$$

Therefore,

$$a = \frac{2d}{t^2} \text{ and } F = m * (\frac{2d}{t^2})$$

$$F_{min} = \frac{2.7 \times 10^{10} kg * 2 * 6.38 \times 10^6 m}{(3.15 \times 10^8 s)^2} = 3.472\ Newtons$$

One of these methods, which been gathering an increasing amount of attention the past few years, is a gravity tractor. The idea consists of sending a spacecraft up to the oncoming NEO and then having it hover near its surface. The purpose of this would be then to use the mutual gravitational attraction every object has on one another to eventually pull the NEO off course. To show this mathematically, let's assume that the NEO is the near-Earth asteroid 99942

Apophis, which has a mass of $2.7 * 10^{10} kg$ and the spacecraft has a mass of $2.0 * 10^{4} kg$. To simplify the calculations, lets also assume that it is a sphere and that its surface properties, internal structure, and state of rotation can be neglected. Therefore, by using Newton's equation of gravitational attraction shown below, where G is the gravitational constant, M and m are the masses of the NEO and spacecraft respectively, and d is the distance between the two objects, it is possible to calculate the force applied to the NEO. Therefore,

$$F = G\frac{Mm}{d^2}$$

$$F = (6.673 * 10^{-11})\frac{(2.7 * 10^{10})(2.0 * 10^{4})}{150^2}$$

$$F = 1.602 \text{ N}$$

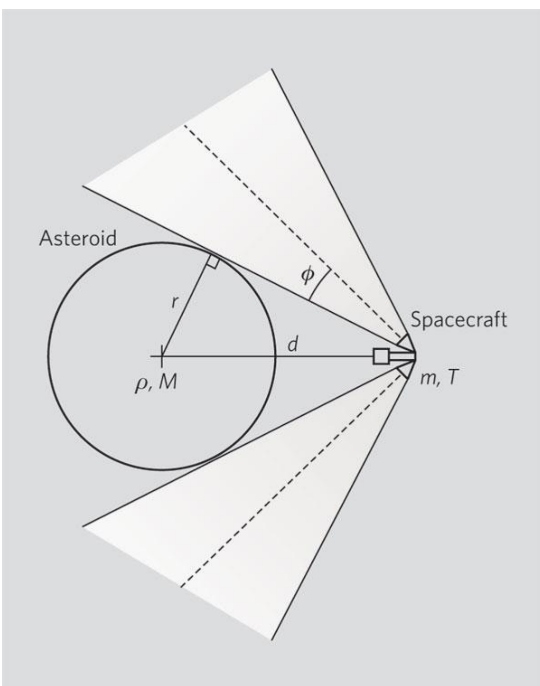

Figure 5: Gravity Deflection of Asteroid

(Courtesy of *Nature*)

Therefore, the force applied to the NEO would be around 1.602 Newtons. Depending on the actual required force to achieve the specified change in trajectory, it would be relatively easy to adjust the distance between the spacecraft and the NEO. Since the calculated force for the numbers we have used here is less than the required force, this scenario wouldn't work. However, this method is still very popular because all we would need to do is increase the mass of the rocket by about a factor of 3 or move the rocket closer to the asteroid by a factor of 1/9th the original value to get the proper results.

Because the gravitational attraction imparts a force on both objects, the spacecraft would have to produce thrust to counteract the force due to gravity. Therefore, this is another factor that must be accounted for. In the international science journal *Nature*, Edward T. Lu and Stanley G. Love wrote an article describing one equation for calculating the required thrust force that would balance the gravitational force that was previously calculated. From the diagram to the left, the balanced force equation would be:

$$Tcos\left(\sin^{-1}(\frac{r}{d}) + \phi\right) = \frac{GMm}{d^2}$$

$$Thrust = \frac{GMm}{d^2 \cos\left(\sin^{-1}(\frac{r}{d}) + \phi\right)}$$

Where ϕ represents half the width of the exhaust plume. The plumes are tilted away to prevent them from having an effect on the NEO. Through this equation, it is easy to calculate the required thrust a spacecraft would have to generate if it was similar to that of Lu and Love's design.

Another method using a constant force is to attach a conventional solid rocket motor onto the asteroid to physically push it off course. This is partly a mix between the two general methods because the rocket engine wouldn't need to accelerate the asteroid the entire time it could just use up its fuel and that should be sufficient. To calculate this, we will use the numbers from the most powerful solid rocket motor we have built to date, with a thrust reaching $1.601 \times 10^7\ Newtons$. So, we can calculate the amount of time that the engine needs to be active. Since,

$$F = m * a \text{ and } a = \frac{2d}{t^2}$$

The time it will take for the asteroid to be displaced the radius of the Earth is,

$$t = \sqrt{\frac{2dm}{F}} = \sqrt{\frac{2 * 6.38 \times 10^6 * 2.7 \times 10^{10}}{1.601 \times 10^7}} = 1.47 \times 10^5 seconds$$

Therefore, the thruster only needs to push the asteroid for about 41 hours. Using this technology, we wouldn't need to activate the plan ten years in advance, though 41 hours of fuel is a lot especially at the output that this rocket burns at. Even if we are not able to accomplish this, however, we could always use a lesser rocket which consumes less fuel but takes more time. This would be far easier to accomplish with regards to resources, especially since 41 hours is small compared to the amount of time for the other methods. Another problem is that if the asteroid is spinning as it approaches Earth, we would have to expend more resources to prevent this from happening so that the rocket would always push in one direction.

The third method using a constant push is to attach solar sails to the rock. Solar sails will be explained in full later on in this paper; however, for now, a solar sail is basically a giant mirror which reflects photons and uses these photons to propel itself through space. The force on the sails depends on the area of the sails in question and the distance from the sun, since the sun is the source of these photons. The equation for the force on a solar sail is,

$$F = \frac{LA}{2\pi c R^2}$$

Where L is the luminosity of the sun, A is the area of the sail, c is the speed of light, and R is the distance from the sun. We will keep R constant in this case because even though the sail exerts a force on the asteroid, it will move away from the sun thus decreasing the force. The displacement is negligible compared to the distance away from the sun, which is about 0.9 AU (astronomical units; where the distance from the Earth to the Sun is equal to 1 AU), this is the average orbital radius of the asteroid 99942 Apophis. The last spacecraft to launch with solar sails on board was the IKAROS launched by the Japanese Space Agency and it had solar sails with an area of 278.7 square meters; this is what we will use to calculate the force on the asteroid.

$$F = \frac{3.827 \times 10^{26} * 278.7}{2\pi * 3 \times 10^8 * (.9AU * 149.6 \times 10^9 \frac{m}{AU})^2} = 0.00312\ N$$

Obviously, this force is much too low to propel the asteroid away from its looming impact, so how big do the sails have to be in order to accomplish this?

$$A = \frac{2\pi c R^2 F_{min}}{L} = \frac{2\pi * 3 \times 10^8 * (.9 * 149.6 \times 10^9)^2 * 3.472}{3.827 \times 10^{26}} = 3.1 \times 10^5\ m^2 = 0.31\ km^2$$

So the sails would need to have an effective area of at least 0.31 square kilometers. This is not unreasonable; scientists have had plans to build spacecraft with solar sails on the order of a full square kilometer. Again, like with the rocket thruster, a problem here is if the asteroid is spinning we will need to spend more time and energy stopping that, which we might not have in certain circumstances.

Currently, both the technology and capability exists for humanity to avoid an impact event by using gravity to nudge a Near Earth Asteroid off its collision course. Because this method requires a long period to be effective, one of humanity's main priorities should be creating and establishing an international program to track possible deep space NEOs. In this way, if an NEO were detected to have a high probability of impacting Earth, there would be a sufficient amount of time to redirect it using a gravity tractor or any of the other methods.

Natural Curiosity

If disasters were not enough of a reason to make it desirable to colonize space, there is always the simple reason to colonize it to satisfy human curiosity. We have learned much about the universe by studying space from the Earth. We learned a bit more with extra-terrestrial telescopes, such as the Hubble Space Telescope. We went further with satellites that reached the edges of our galaxy. We have already gotten good at sending people into space as far as the moon so they can experience and study outer space first hand. All of this research has gained us much knowledge about the origins, composition, and possible fate(s) of the universe. In addition, we have gained other technological benefits through the space program, such as Tempur-Pedic mattresses and better data storage technologies. In short, space colonization is a very good thing to explore in order to satisfy natural human curiosity about the universe, to advance our technology, and to unite humanity.

Mankind has studied space for centuries. We previously looked at ancient cultures that studied space and, though they came to very different conclusions, they had two things in common: 1) they were trying to explain how their world worked and 2) they found practical uses for using the skies (for navigation and for making calendars, for example). The first reason is a very human thing to do. That is, curiosity is a very powerful human characteristic. We want to make sense of the world for the simple reason that we naturally want to know it. Though we have come very far in our understanding the universe, there is still plenty more that we don't know. We cannot know all about the universe by being limited to one relatively small region of space. Observations can only go so far. We will need to go beyond the galaxy to discover new phenomena and find explanations for known phenomena. Therefore, space colonization needs no other reason than simply for the sake of knowledge.

As a side effect to the knowledge, however, we will gain technological advances. We will need to gain them if we hope to go beyond our current limitations. Space travel requires quite a bit of engineering to begin with, but then we would need to worry about food and waste products, as well as creating better propulsion systems. If we come to a point where space travel for the masses is feasible, we would first have to become very efficient at recycling waste products. This includes reusing material items, food waste, and even human waste products. We currently have fairly simple filters that can filter out urine, for example. This is primarily used in developing countries where clean water is scarce, but this method has some limitations. One is that the filters need to be replaced and those old filters themselves become waste products. We will need to find a way to minimize the amount of material that needs to be brought on board as well as minimize the amount of waste material that will form.

Once we have that, we would still need to make a propulsion system that would let us travel a lot faster than we can currently go in order to ever reach far into space within a human lifetime using a limited energy source. Beyond that, if we want to colonize other planets or moons, we will need to figure out how to make terraforming work. One area of research that will help in this regard is growing food on a space shuttle itself using hydroponics. This process involves growing plants using only nutrient and mineral-rich water and no soil. This would reduce the amount of food needed to be brought from the beginning and more could be grown as needed. Then, it will simply be a matter of time and research in figuring out how to integrate the plants in a protected area on a planet (or a moon as the case may be).

Solving these problems would have immediate benefits for the Earth right now, but there is currently not as much of a need to think about these kinds of problem, so they will not advance as quickly. For example, much of the technology to minimize and recycle waste would be directly applicable to developing nations or in cases of droughts. Technology used for space propulsion could lead to newer forms of energy for vehicles on Earth. For space travel, these would be just the beginning steps and, given enough incentive, people would come together and solve these issues quickly. We are not as limited in space travel technology as many people believe, but we are limited in terms of not providing proper resources to the proper people. Once we are willing to invest more fully in space travel, our technological abilities would increase at much faster rate than if were to limit ourselves to thinking only of the Earth.

Chapter III: Escaping Earth

Rockets

One aspect of space travel that we have already advanced greatly is in getting to space in the first place. Currently, this is done using rockets. For larger projects, such as taking astronauts to the moon, multistage rockets are used. It is very important to study the systems we currently use to see what we are currently capable of, what our limitations are, and what the future holds.

Rockets work by using some kind of fuel and oxidizer (the propellants) to expel gas at a very fast rate, which produces the thrust that lifts them off. The fuel can be chemical, solid, and even nuclear (though this case is a bit different than traditional rockets). In the context of space travel, these rockets burn a very large amount of fuel in a very short amount of time. For example, the Saturn V rockets that took us to the moon used liquid fuel and burned about 560,000 gallons of propellants in about 2.75 minutes. This is one of the reasons that multistage rockets are used. Once the fuel is burned off, the empty containers only add to the total weight needed to be lifted without providing any benefit. For this reason, in multistage rockets, the fuel container is dumped when empty. This means that less fuel is required in each following stage to take the remaining mass to space. Multistage rockets generally have between 3-5 stages.

The most common propellants used in rockets are liquid propellants. In this case the fuel is usually liquid hydrogen, but can also be other fuels like kerosene. The oxidizers are usually liquid oxygen, nitrogen tetroxide, and hydrogen peroxide. They require complex piping and usually compose about 90% of the weight to be launched at liftoff. In addition, the combustion chamber needs to be very tough titanium or steel (because temperatures typically reach 6,000^{o}F and pressures typically around 3,000 lbs/in^{2}). This also adds considerable weight. The Saturn 5 rocket, for example could carry a payload of 100,000 pounds, but weighed about 6 million pounds at lift off because of all the fuel that the three stage rocket system used. Despite the complexity, liquid propellants are commonly used for launching space vehicles containing astronauts and/or scientific instruments because they provide much more thrust than equivalent amounts of solid propellants. Another benefit of using liquid propellants is the combustion can be started or stopped as desired by controlling the fuel and oxidizer valves.

Solid propellants are much simpler to maintain because all they require is ignition. They are also lighter than the liquid propellants and do not require the fuel and oxidizer to be mixed using piping. Another advantage of solid propellants is that they burn at a lower temperature than liquid propellants do (3000 to 6000 degrees F), so epoxy can be used as internal shielding as opposed to heavier steel or titanium. The downside of this is that once the reaction starts, it cannot be stopped. This is undesirable in case the acceleration needs to be adjusted for any reason. Solid propellants are stored in the form of a cylinder and burn at a rate of about 0.6 in/sec. These kinds of rockets are most often used by the military and for fireworks displays because of how easy they are to store and launch.

Hybrid rockets are another type of rocket that can be used. Hybrid rockets use a liquid oxidizer, but a solid fuel that lines the combustion chamber. These are simpler to build than liquid fuel rockets because the piping for the fuel is not required. Despite the simpler piping, however, hybrid rockets still allow adjusting for thrust by varying the amount of oxidizer sent to the combustion chamber. This makes them more desirable than solid fuel rockets for larger projects. The problem with hybrid rockets is that they burn much slower than pure solid or pure liquid propellant rockets (at a rate of about 0.04in. per second).

Multistage rockets are necessary for large payloads (such as shuttles that contain astronauts). The first three stages of the Saturn V rocket weighed 288,000 pounds, 80,000 pounds, and 25,000 pounds when empty. Once they are empty it is desirable to get rid of the extra weight so that less fuel is needed in each following stage.

In each of these cases, the main point is to get leave the earth very quickly. In order to leave, the rocket simply needs to continuously be lifted. It never needs to reach “escape velocity." Escape velocity refers to the velocity at which something would need to travel away from the Earth at in order to “escape” the Earth, provided that no additional thrust is applied. Escape velocity can be calculated by using the equation:

$$\mathrm{v} = \sqrt{\frac{2\mathrm{GM}}{\mathrm{R}}}$$

where G refers to the gravitational constant (6.67300 × 10-11 $m^3kg^{-1}s^{-2}$), M refers to the mass of the Earth (5.9742 × 10^{24} kilograms), and R refers to the radius of the earth (6,378.1 kilometers). This yields the result 25,030mph. In the case of rockets, however, continuous thrust is provided, so theoretically speaking, it would be possible for a rocket to launch to space very slowly. In practice, however, this is simply too impractical to seriously consider. Lifting such large masses requires a lot of fuel, so if the rocket is being lifted slowly, it would simply run out of fuel before reaching orbit. The quicker the rocket goes up, the less fuel it will need to burn. This is because, as the rocket gets further and further from the Earth, the gravitational pull of the Earth has a smaller and smaller effect on the rocket. This, combined with a multistage rocket that loses mass as needed, makes much more sense than using a slow-rising rocket.

In the case of a single stage rocket, the total mass of the rocket is the combined mass of the payload, the rocket structure, and the total fuel. The only mass that changes in this case is the mass of the fuel in the form of gases. The force provided by the velocity of the gases being expelled needs to counteract the force of gravity on the rocket by the Earth. The velocity of the rocket is given by the equation:

$$v = v_i + v_{gases} * \ln\left(\frac{m_{initial}}{m(t)}\right) - g$$

where g refers to the effects of gravity. If v_{gases} is about 3km/s or higher, then the g becomes negligible. The final velocity of the rocket, when the fuel is depleted is given by

$$v = v_i + v_{gases} * \ln\left(\frac{m_{initial}}{m_{pauload} + m_{structures}}\right)$$

Ideally, we would reduce the mass of the fuel container at the same rate as the fuel is expelled from the container, but that is not practical, so a multi-stage rocket can be used instead. In this case, the whole fuel container can be dumped once the fuel is exhausted. In the case of a three –stage rocket, the total mass of the rocket consists of the payload, the mass of the fuel, and the masses of the various stages. The final speed of the rocket at various stages depends on the velocity of the gases being expelled and the current mass of the rocket. At the end of the first stage on a three-stage rocket, the velocity is given by:

$$v = v_{gases} * \ln\left(\frac{m_{total}}{m_{pauload} + m_2 + m_3 + m_1^*}\right)$$

Where m_1^* is changing with respect to time. Similarly, the velocity at the end of the second stage is given by

$$v_2 = v_1 + v_{gases} * \ln(\frac{m_{payload} + m_2 + m_3}{m_{payload} + m_3 + m_3^*})$$

And the velocity at the end of the third stage the velocity is given by:

$$v_f = v_{gases} * \ln(\frac{m_{total}}{m_{payload} + m_2 + m_3 + m_1^*} * \frac{m_{payload} + m_2 + m_3}{m_{payload} + m_3 + m_2^*} * \frac{m_{payload} + m_3}{m_{payload} + m_3^*})$$

Therefore, the final velocity can be maximized by having a high amount of initial thrust and a lower weight.

Chemical Propulsion in Rockets

Currently, all spacecraft use chemical propulsion. This is true for both satellites and space shuttles. Chemical propulsion is a necessity to provide enough thrust to escape Earth's gravitational pull and reach a height which can serve as a geostationary orbit. Most satellites use chemical thrusters or resistojet rockets, which causes propulsion through heating a fluid via resistor and incandescent filament and expelling expanded gas through a nozzle, for altitude adjustment during their service time. Interplanetary travel also makes common use of chemical thrusters, though newer electric thrusters have been tried with incredible success. Even more recently, plasma thrusters have undergone testing and have yielded encouraging results for future applications. Chemical thrusters are still in use today, but are being replaced by electric thrusters; this tells us that there are still some advantages and disadvantages to using them.

The idea of interstellar propulsion is one with many problems and no tried and true answers as of yet. Thrust can be achieved by many small impulses or a large impulse over a short time. At least one large impulse must be used in order to escape the gravitational pull of the Earth. This necessity ties into the idea of creating a moon base which can be used as a launch site or fueling station. Beyond the Earth, another problem is apparent; what method of thrust can we use effectively? Propulsion is achieved by accelerating mass in the opposite direction of travel. In chemical thrusters, rockets use solid or liquid fuel to create reactions which produce mass out the exhaust nozzle. To produce a large amount of thrust, as in the first stage of a multistage rocket, a large amount of mass must be ejected. Thus, a vital question is raised; how can we produce the thrust necessary, while maintaining a mass-efficient vehicle? Our current answer to this question is via a detachable launch vehicle.

The advantage of a solid-fuel rocket in comparison to a liquid-fuel rocket is that they are capable of holding more propellant than liquid fuelled rockets, the cost is lower, the rocket assembly and performance is safer, and the setup is simple. Disadvantages of the solid-fuel rocket are they will create a high mass-propellant ratio, defects in the ‘grain’ (or propellant structure) can cause explosions during burn, thrusters cannot be stopped after ignition, and thrust cannot be outwardly controlled. The basis for solid rocket fuel is related to the composition of gunpowder. Instead of the ratios of 75%-15%-10% (Nitrate, Carbon, Sulfur; respectively) for gunpowder, the ratios 72%-24%-4% yield a fuel which burns rapidly but will not explode when activated. The average burn time of a Solid rocket booster (SRB) for a space shuttle mission is two minutes, burning over 1 million pounds of fuel. An example ratio of a SRB for a space shuttle launch is a total weight of 3,300,000 pounds, with the propellant comprising only 1,100,000 pounds. This means that the rocket structure itself comprises two-thirds of the overall booster mass. Pressures within the combustion chamber can reach 3200 psi. Grain defects can cause explosions during the burn and will lead to a deadly rise in pressure in the combustion chamber.

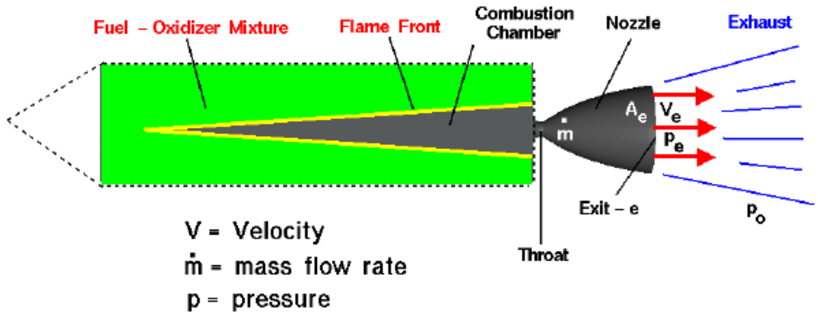

Fig 6. Solid Rocket Schematic

(*Courtesy of exploration.grc.nasa.gov*)

Advantages of liquid-fuel rockets include the ability to shut down the process and restart it if necessary, the lack of high mass materials for the combustion chamber, and a higher specific impulse (the ratio of thrust created per pound of propellant burned). The solid fuel rocket burns until it runs out of fuel or is destroyed during detachment, something the liquid fuel rockets do not have to do. Extinguishant can be introduced into the combustion chamber to stop the process and can be restarted once adjustments are made (during testing). The combustion process produces high pressures and temperatures so the combustion chamber and nozzle must be cooled with cryogenic liquids. High pressures are required to maintain the liquid oxidizer in its liquid form and not in a gas before it is ready for combustion; otherwise the reaction between the two will not occur. Disadvantages of the liquid fuel rocket include problems with the oxidizer (liquid rockets use a liquid fuel + an oxidizer) being unstable, toxic, and/or dangerous to work with, as well as the need for many seals and valves which need to be constantly monitored for stable performance.

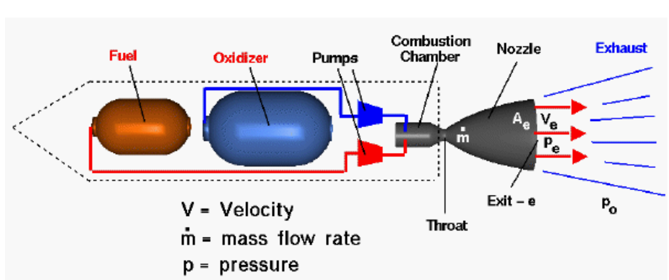

Fig 7. Liquid Rocket schematic

(*Courtesy of grc.nasa.gov*)

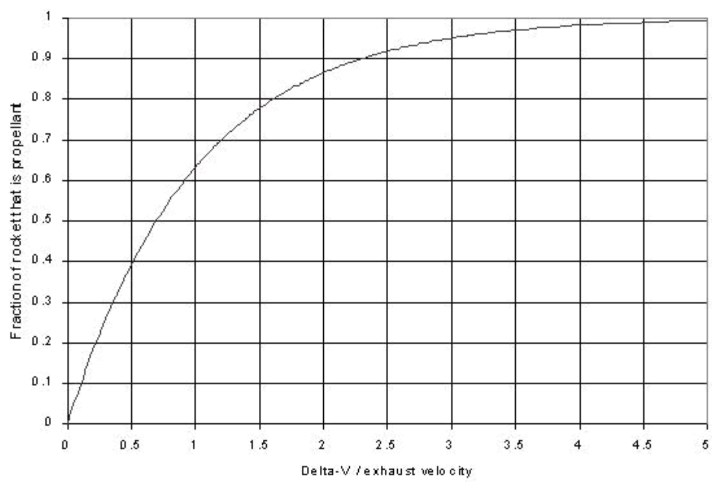

Fig 8. Comparison of propellant required versus exhaust velocity

(*Courtesy of spaceshipsofezekiel.com*)

Amount of fuel required for launch into orbit

When space craft launch from the Earth, it takes a tremendous amount of fuel to lift that mass into orbit, this is because Earth's gravity is so high. While it is not yet plausible, in the near future we would definitely need to put a base on the moon, so that space craft can launch from there. The gravity on the moon is far less than the Earth, about 1/6th as much, where Earth's gravitational acceleration is 9.8 m/s^2 and on the moon it is 1.626 m/s^2. So for long journeys it is essential to give the astronauts as many resources as possible, and this is manageable by reducing the amount of fuel needed to take off, and put other important materials in its place, such as food and water.

To calculate the amount of fuel needed to reach an orbit after launching from the moon, Earth, or Mercury, we will need to make a few assumptions. The first and biggest assumption is that the time it takes the craft to reach orbit is eight minutes, which is the time it takes a space craft to reach a low Earth orbit after launching from Earth. Clearly it is not going to be the same amount of time launching from the moon and Mercury, and if we were to use a higher-output engine, but it can be tremendously complicated to calculate this amount of time. Adding to this is the fact that the higher the thrust, the less amount of time it will take, but the difference is not going to be huge, not hours or days, just minutes, or seconds even. The second assumption is that we are going to be using a single stage rocket in our calculations; while this is not the most efficient way, it is far simpler to calculate.

In order to obtain this data we will be using the equation for rocket thrust:

$$ma = uk - mg$$

Where m is the mass of the rocket at a given time, a is the acceleration, u is the effective exhaust velocity, k is the rate of change of mass over time, $\frac{dm}{dt}$, and g is the gravitational acceleration at each of the locations we will be launching from. In order to get an easier equation to work with, we are going to divide by m and take an integral of the equation:

$$\frac{dv}{dt} = \frac{uk}{m} - g$$

$$\int dv = \int \frac{uk}{m} dt - \int g dt$$

Here, $m = m_0 - kt$, so $dm = -kdt$, thus we get the equation,

$$\int_{v_0}^{v} dv = -u \int_{m_0}^{m_0 - kt} \frac{dm}{m} - \int_{0}^{t} g dt$$

which results in the Tsiolkovsky Rocket Equation:

$$\Delta v = u \ln \frac{m_0}{m_0 - kt} - gt = u \ln \frac{m_0}{m} - gt$$

Since we are going to be looking at the ratio of the initial mass to the final mass (which is the ratio of the payload and fuel to the mass of the payload), we can simplify this equation down to:

$$\frac{m_0}{m} = e^{\frac{\Delta v + gt}{u}}$$

Now we need to calculate the numbers, we are going to be using a gravitational acceleration on Earth of 9.8 m/s^2, on the moon at 1.626 m/s^2, and on Mercury at 3.700 m/s^2. These were all calculated using the fact that, at the surface of the planetary body, with no acceleration, your body weight is equal to the force due to the gravity. We are also going to be using a few different effective exhaust velocities, so that we can compare different thrusters, and find which are the most efficient. These three different engines are a Solid Fuel Rocket Booster, which has an exhaust velocity of 2500 m/s, a Bipropellant Chemical Booster with an exhaust velocity of 4400 m/s, and an Ion Booster, which has an exhaust velocity of 125,000 m/s.

	Earth	Moon	Mercury
g	9.8 m/s^2	1.626 m/s^2	3.700 m/s^2
Δv required for orbit	7704.6 m/s	1608.0 m/s	3318.5 m/s
SFRB $\frac{m_0}{m}$ Ratio	143.1	2.600	7.674
BCB $\frac{m_0}{m}$ Ratio	16.78	1.721	3.183
Ion $\frac{m_0}{m}$ Ratio	1.104	1.019	1.042

Table 1. Comparison of Different Rocket Booster from Different Launch Sites

What these ratios signify is how much of the original mass of the space craft is fuel. For example, if we look at the Chemical Boosters launching from Earth, we can see that the ratio is 16.78; therefore, the amount of fuel needed is 16.78 times the mass of the rocket's actual payload. This is accurate when you look at the massive fuel containers that the space shuttle needs in order to enter orbit. On the opposite end of the spectrum, you have the Ion Boosters. Here the ratio is 1.104, so the amount of fuel needed to take off from the Earth, is only 10.4% of the mass of the rocket's payload. From these numbers, we can see why a lunar base is so much more efficient for long journeys, especially if we have a colony on Mercury, and we need to send supplies or more colonists to assist their efforts.

Lunar Trajectories

A body in orbit is described by Kepler's three laws of planetary motion. While he wrote the laws to describe the planets' motions, they apply to any object in orbit. The first law states that the planets travel in elliptical orbits with the sun at a focus. The second law says that a line drawn from the sun to a planet will sweep out equal areas in equal times. Lastly, the third law says that the square of the period of the planet is proportional to the cube of the semi-major axis of the planet's orbit. This is given by the equation,

$$T^2 = ka^3$$

where k is a constant given by $k = \frac{4\pi^2}{GM}$, where G is the gravitational constant and M is the mass of the stationary body.

In order for a rocket to get to the moon, it first takes off normally and enters a low earth circular orbit. Once it is in this orbit, the spaceship must orbit the earth until it is properly timed up with the moon. When the spacecraft is ready, it fires its engines and increases its velocity. Now the rocket is in an elliptical orbit, this is called the transfer orbit, which is just one half of a normal elliptical orbit. The idea of a transfer orbit to the moon is that the apogee (the furthest distance from the origin) will be equal to the radius of the moon's orbit. Of course, the spaceship has to wait in the low earth orbit so that the moon and the spaceship will reach the same point in the moon's orbit at the same time.

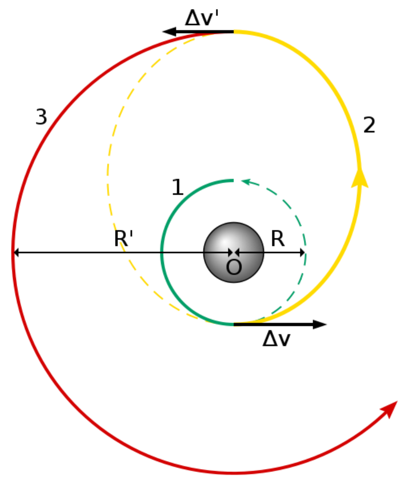

Fig 9. Hohmann Transfer Orbit Schematic

(Courtesy of http://en.wikipedia.org/wiki/File:Hohmann_transfer_orbit.svg)

At this point the space craft must reduce its velocity so that it may enter into an orbit around the moon. For the Apollo-11 mission and other unmanned missions to land on the moon, a lander will depart from the spacecraft and make its descent to the moon's surface. For the return journey, the spacecraft has to leave the moon's orbit and essentially finish the transfer orbit, by completing the other half of the ellipse. To accomplish this, the spaceship must reduce its velocity to reenter the transfer orbit.

To find the velocity of the spaceship in its orbit around earth we use

$$v^2 = \frac{GM}{R}$$

where G is the gravitational constant, M is the mass of the earth, and r is the radius of orbit. Thus, the velocity of the spacecraft in the low earth orbit (orbit 1 in figure 1) is 7704.6 $\frac{m}{s}$.

To find the velocity needed to get the spacecraft from the low earth orbit into the transfer orbit (orbit 2 in figure 1), we use

$$v^2 = GM(\frac{2}{R} - \frac{1}{a})$$

And again G is the gravitational constant, M is the mass of the earth, r is the distance from spacecraft to earth, and a is the semi-major axis of the transfer orbit. We will use r and a from the Apollo-11 mission, where r = 6,712,595 m and a = 288,852,900 m. In this case, the velocity must be increased to 10,828.8 $\frac{m}{s}$. Thus, the ΔV in figure 1 is 10,828.8 – 7,704.6 = 3,124.2 $\frac{m}{s}$. The eccentricity of this transfer orbit can be found using the equation

$$R_p = a(1 - e)$$

where R_p is the periapsis distance, the radius of the low earth orbit in this case. Using Kepler's second third law, we can calculate the time it takes for the spacecraft to reach the moon's orbit. Therefore, we have an eccentricity of .977, which is very high (a perfect circle has an eccentricity of 0). The orbit of the moon has an eccentricity of .055, which we can approximate to be a circle.

Since

$$T^2 = \frac{4\pi^2}{GM} a^3$$

we find T to be 1,545,252 seconds, but because the trip to the moon is only half of the orbit, the spacecraft takes 772,626 seconds or 8.94 days to get there.

Once the spaceship is at the apoapsis, R', the moon's orbit, the spacecraft's velocity is 126.7 $\frac{m}{s}$given by

$$v_{ap} = [\frac{GM}{a} * \frac{1 - e}{1 + e}]^{1/2}$$

However, the moon's velocity is 1018.7 m/s, so the spacecraft must increase its velocity so that it can enter into a lunar orbit (orbit 3 in figure 1). Therefore, ΔV' in figure 1 is 892.0 $\frac{m}{s}$. To enter in an orbit at 1896 km (the orbital radius of the Apollo-11 mission), the spacecraft must again increase its velocity to 1608.0 $\frac{m}{s}$.

The thrust of the rockets engines takes the form

$$m\dot{v} = uk$$

where k is equal to $\frac{dm}{dt}$ or the rate of change of mass over time, $m = m_0 - kt$, which is the mass of the rocket at time t. u is the velocity of the rocket fuel being ejected. Thus, in space this equation can be reduced down to

$$v = v_0 + uln(\frac{m_0}{m}).$$

To find the time needed for the engines to fire to reach the required velocity to enter the transfer orbit from the low earth orbit we can use $m\dot{v} = uk$ and rearrange the terms to get

$$t = m_0/(\frac{uk}{v-v_0} + k).$$

If we use m_0 = 500,000 kg, u = 2500 m/s, k = 2500 kg/s and the known velocities, then we find that the engines need to fire for 111.1 seconds. The second time the rocket needs to thrust is when it is at the apoapsis and needs to accelerate to keep up with the moon's velocity, the engines have to fire for 52.59 seconds. Because the rocket is now moving at 0 $\frac{m}{s}$ with respect to the moon, it needs to provide thrust for 78.29 seconds, in order to begin orbiting around the moon.

Alternative methods to escape Earth

Currently, one of the major problems with human space travel is the initial launch into space. For any spacecraft to escape Earth's gravity, it must achieve an escape velocity of around 11.2 kilometers per second given by the equation

$$v = \sqrt{\frac{2GM_e}{r_e}}$$

where G is the gravitational constant, M_e is the mass of the Earth, and r_e is the radius of the Earth. This velocity is independent of an object's mass, however, so the main factor that is involved in launching an object into orbit is the thrust, and consequently the amount of fuel, required to put it there. Using conventional rockets, the cost per pound is around $10,000. Therefore, it is easy to see the need for a more efficient and cost effective space transportation system if humanity is to begin to expand into space. One such idea in particular has been gathering momentum over the past few years.

This idea comes in the form of a space elevator. It is a proposed structure stretching from the Earth's surface to an end point in geostationary orbit. A module, powered by a free electron laser system, would then carry passengers as well as cargo up this tower into space. There is, however, much more work to be done in the development process until this method becomes a viable option because of the underlying technical and engineering challenges. One of the main issues in building such a tall tower is that there is no currently available material that is both strong and light enough to withstand the associated stresses. To show this mathematically, the forces acting on the tower must be in equilibrium so the balanced force equation for a small differential element of distance, dr, is:

$$AdT = \frac{GM(Adr\rho)}{r^2} - (Adr\rho)\omega^2 r$$

Where M, R, and ω represent the mass, radius, and rotational velocity of the Earth, and A and ρ represent the cross sectional area and density of the tower, respectively. Next, after rearranging and integrating, it is possible to represent the tensile stress as a function of a geostationary height R_g.

$$\frac{dT}{dr} = GM\rho(\frac{1}{r^2} - \frac{1}{R_g^3})$$

$$T(R_g) = GM\rho(\frac{1}{R} - \frac{3}{2R_g} + \frac{R^2}{2R_g^3})$$

Therefore, as an example, if the tower was made of a titanium alloy, the tensile stress would be:

$$T(42300m) = G(5.98 * 10^{24}kg)(4510\frac{kg}{m^3})(\frac{1}{6370000m} - \frac{3}{2*42300000} + \frac{6370000^2}{2*(42300000)^3})$$

$$Tensile\ stress = 2.19 * 10^{11}Pa = 219\ GPa$$

Therefore, the stress within the tower would be on the order of magnitude of 10^{11} Pascals. When compared to the maximum tensile strength of titanium of around $9.0 * 10^8$ Pascals, it is easy to see the difference in order of magnitude. Once the stress passes the tensile strength of a material, necking (the decrease in cross sectional area) and deformations within the material begin to occur. Because the stress in the tower would be around 1000 times greater than its tensile strength, severe deformation and failure is assured. Thus, it would be impossible to use conventional materials in such a tower.

Because of this limitation, scientists and engineers have now been developing a material that might indeed make the space elevator possible: carbon nanotubes. Carbon nanotubes are a relatively recent development in the field of nanotechnology and are the strongest and stiffest materials currently known. They are built with a cylindrical nanostructure and are able to possess a tensile strength of around 63 GPa while having a density of only around$1.3\ g/cm^3$. As a result, it seems likely that these carbon nanotubes would be able to withstand the stresses in such a tall tower. To check this mathematically using the equations above, the actual tensile stresses in such a tower would be around 63.15 GPa, which is almost exactly the maximum tensile strength of the material. Thus, it is possible that within two decades, a space elevator made of carbon nanotubes might actually be a common occurrence due to the development of nanomaterials.

Launch Platforms

One problem that NASA and other space organizations face is the tremendous amount of energy required to send an object from Earth to space. If a base were to be constructed on the moon, we would be able to use it as a fueling station for rockets that we send into deep space, or even as its own launch platform. The amount of energy required to send a rocket into space from the moon is much less than the energy required to send a rocket from the Earth to space because of the moon's low gravity. Rockets must divert a large amount of their fuel capacity to creating enough thrust to overcome the Earth's gravitational pull.

It serves to reason with the mechanics of rockets that the larger the force required, the larger the acceleration required, and thus the larger amount of fuel that must be expended to create that acceleration. The same theory applies to escape velocity. For escape velocity, you must take into account the mass of the object you are escaping, as well as the radius.

$$Escape\ Velocity, v = \sqrt{2GM/r} \qquad \text{(Eq. 1)}$$

If we consider that G, the gravitational constant is steady, the difference of velocity required to escape an object varies only by the mass of that object, M, and the radius of that object, r. The mass of the Earth, 5.975 x 10^{24}, is nearly 100 times the mass of the moon. The radius of the earth is nearly four times the radius of the moon. If we let the mass of the earth equal one, and the radius of the earth equal one, we can calculate the escape velocity required:

$$Escape\ Velocity, v = \sqrt{2(1)(1)/(1)} \qquad \text{(Eq. 2)}$$

We see that the escape velocity is equal to 1.414.

If we compare this to the escape velocity for the moon,

$$Escape\ Velocity, v = \sqrt{2(1)(0.01)/(0.25)} \qquad \text{(Eq. 3)}$$

We see that the escape velocity is equal to 0.28.

This is a savings of 80% of the velocity. This can also translate into the required thrust being much less.

$$Thrust, T = \dot{m}v + 1000(Pe - Pa)(Ae) \qquad \text{(Eq. 4)}$$

If we consider an equal pressure differential and area of exhaust, Ae (i.e. an identical rocket design), we see that the velocity differential relates directly to the amount of thrust required. We can then calculate the thrust efficiency of the rocket given two different velocities and calculate the fuel requirements of each. This shows us that using the moon as a launch pad for future space missions will significantly lower the amount of fuel dedicated to escape velocity. With a smaller fuel tank required, we can apply that newly freed up mass to supplies, or even crew, depending on the objective of the mission. From the Earth, the payload may be as small as 1.5% of total mass. Launching from the moon, up to 50% of the mass can be devoted to payload.

If we now take into account that we can either transport more payload, or require less propellant, we can consider the travel times to other interplanetary destinations. If we wish to travel to other destinations we can use the Hohmann Transfer, which is the most efficient type of planetary transfer, based on time and required velocity. We can also use the fast transfer, which increases the velocity of the Hohmann transfer and deceases the time of flight. This may be necessary eventually, as we do not know the full effects on the human body of a lengthy journey through space.

We can use differential equations of space flight to show the time of flight:

Angular momentum of a trajectory is defined as

$$H = rV\,cos\varphi \quad \text{(Eq. 5)}$$

We can rewrite this equation, as V*cosΦ is the tangential component of the velocity vector, or r$\dot{v}$

$$H = r^2 \frac{dv}{dt} \quad \text{(Eq. 6)}$$

Rearranging for time…

$$dt = \frac{r^2}{H} * dv \quad \text{(Eq. 7)}$$

Integrating from initial conditions t=0, v=0…

$$t = \frac{1}{H}\int_0^v r^2 dv \quad \text{(Eq. 8)}$$

dA, the area swept out during any interval of time dt is

$$dA = \frac{1}{2} r^2 dv \quad \text{(Eq. 9)}$$

Integrating from v=0, A=0

$$A = \frac{1}{2}\int_0^v r^2 dv \quad \text{(Eq. 10)}$$

$$\int_0^v r^2 dv = 2A \quad \text{(Eq. 11)}$$

Thus

$$t = \frac{2A}{H} \text{ or } A = \frac{Ht}{2} \quad \text{(Eq. 12)}$$

To find time of flight on an elliptical (Hohmann Transfer)…

$$dt = \frac{2}{H} dA \qquad \text{(Eq. 13)}$$

Integrate over one complete orbit, 0 – 2π radians…

$$P = \int_0^{2\pi} dt = \frac{2}{H} \int_0^{2\pi} dA = \frac{2}{H} A_{ellipse} \qquad \text{(Eq. 14)}$$

$A_{ellipse}$ = πab (a = semimajor axis, b = semiminor axis). Since c = aε, $a^2 = b^2 + c^2$, p = $a(1 - \varepsilon^2)$ = $H(a/\mu)^{1/2}$

$$b = \sqrt{a^{2-} c^2} = \sqrt{a^2(1 - \epsilon^2)} = H\sqrt{\frac{a}{\mu}} \qquad \text{(Eq. 15)}$$

Substituting into (Eq. 14)…

$$P = 2\pi\sqrt{\frac{a^3}{\mu}} \qquad \text{(Eq. 16)}$$

Mean anomaly, M, is defined as

$$M = \frac{2\pi t}{P} \qquad \text{(Eq. 17)}$$

Thus, the equation for t is

$$t = \frac{P}{2\pi} M \qquad \text{(Eq. 18)}$$

Time of Flight (TOF) is the differences between two points (a, b) on an ellipse.

$$TOF = t_b - t_a = \frac{P}{2\mu}(M_b - M_a) \qquad \text{(Eq. 19)}$$

We can calculate the velocity changes required to do this, by calculating V_1 and V_2 based on the orbit being left and the one being transferred into. Adding these together yields the total change in velocity.

For example, a simple transfer from LEO to GEO showed that by using a fast transfer, it cut the transfer time in half, but increased the total velocity change by 54%, We can apply this to an interplanetary transfer as well, but the results are not as spectacular. We can expect that from a much larger distance, say from Earth to Mars, we could double the total velocity change, but we would only reach Mars 10% faster than if we took a Hohmann transfer there.

Chapter IV: Mars

Atmosphere on Mars

According to modern hypotheses, the atmosphere on Mars changed over the course of a few billions of years. Gamma-ray evidence sent back from the robotic spacecraft Mars Odyssey indicates that about one third of Mars was once covered in oceans. Therefore, scientists now believe that the surface was once a much more hospitable place. The question that is subsequently raised is what happened to the atmosphere? In order to answer this, the gas molecules within the atmosphere must be examined.

As in all gases, the molecules are constantly moving and colliding with one another. This is called kinetic theory, and explains the macroscopic properties of gases such as pressure, temperature, or volume by taking the motion and collisions into account. As the Sun's energy reaches Mars, the gas molecules that are contained within the atmosphere absorb it and as a consequence, their internal energy, and thus their average speed, is increased. This can be shown mathematically by:

$$V_P = \sqrt{\frac{2RT}{M}}$$

Where the gas is assumed to be ideal, V_p is the most probable speed, R is the molecular gas constant, T is the temperature, and M is the molar mass. The Martian atmosphere has an average temperature of -55℃ or 218 Kelvin and consists of 95% carbon dioxide, 3% nitrogen, 1.6% argon, and contains traces of oxygen, water, and methane. Therefore, because the majority of the atmosphere is made up of carbon dioxide, let us use that as an example.

$$V_P = \sqrt{\frac{2*8.314*218}{.04401}} = 287\ m/s$$

Then, the escape velocity of Mars is given by:

$$V_{esc} = \sqrt{\frac{2\mu_M}{r}} = \sqrt{\frac{2*4.297*10^{13}}{3.393*10^{6}}} = 5032.75\ m/s\ or\ 5.032\ \ km/s$$

Where $\mu_M = 4.297 * 10^{13}\ m^3/s^2$ and $r_M = 3.393 * 10^6\ m$. Even though the atmosphere is not located directly at the surface of Mars, the height of the atmosphere above the surface will cause a negligible change in the radius when added to the radius of the planet.

Therefore, in order to escape the gravitational pull of Mars, the carbon dioxide molecules would have to undergo a 94% increase in velocity. This is a good indication that Mars does indeed have a large enough gravitational pull to hold an atmosphere. However, because carbon dioxide is a relatively heavy molecule, the lighter gas molecules, such as oxygen, might be able to escape.

$$V_P = \sqrt{\frac{2RT}{M}}$$

$$V_P = \sqrt{\frac{2*8.314*218}{.016}} = 475.97\ m/s$$

Even though oxygen is a much lighter molecule with an atomic weight of around $16\ grams/mol$ compared to carbon dioxide, it still will not have the required velocity to escape the gravitational pull of Mars. Therefore, the main factor in determining a molecule's probable speed is the energy absorbed by it from the surrounding environment. As an example, the temperature on Mars would have to increase to around 24,364 degrees Kelvin in order to give oxygen the appropriate velocity to escape from the surface. Therefore, it can be concluded that Mars does indeed have enough of a gravitational pull to hold an atmosphere.

Moving Mars

Our original plan to move Mars into an orbit closer to the sun, which would be nearer to the habitable zone, is not feasible. To do so, we must move the orbit closer to the Sun by approximately 0.2 AU. To move Mars' orbit, we require two changes in velocity ΔV_1 and ΔV_2, one to move Mars from its current orbit and another to stabilize it into its new orbit.

First, we obtain the data from the two orbits that Mars will be in, currently and after the move. We need to know the radius of the orbits, inner and outer, as well as the velocities and energies of these orbits. We are using the process of orbit lowering in this case, meaning any μ value will be that of the Sun, because that is the object we are using as a focus for the orbit. μ is the gravitational parameter of the larger body, required for making any calculations regarding a two-body system. This is made to simplify the problem, as three or more bodies being involved will drastically increase the difficulty of making accurate calculations.

Data for outer orbit:

$$r_o = 2.279 * 10^{11}\ m$$

$$v_o = \sqrt{\frac{\mu}{r_o}} = \sqrt{\frac{1.327 * 10^{20}}{r_o}} = 24130\ m/s$$

$$E_o = \frac{-\mu}{r_o} = -2.88 * 10^{8}\ m^2/s^2$$

Data for inner orbit:

$$r_i = 1.98 * 10^{11}\ m$$

$$v_i = \sqrt{\frac{\mu}{r_i}} = \sqrt{\frac{1.327 * 10^{20}}{r_i}} = 25888\ m/s$$

$$E_i = \frac{-\mu}{r_i} = -3.35 * 10^{8}\ m^2/s^2$$

Now, we find the data for the transfer trajectory which Mars will take to its new inner orbit. We calculate the semi-major axis ($2a_t$) and the momentum (H) of the trajectory. These two parameters are required to calculate the energy of the transfer and the momentum of the transfer, both of which are required to calculate the velocity the object will need to change from its current orbit to the transfer trajectory, and the trajectory to the new orbit. From these values we can calculate the changes in velocity required. The two values v_{ti} and v_{tp} are the velocities at which Mars will enter and exit the trajectory, allowing us to calculate the changes in velocity from the circular orbits required.

Data for transfer:

$$2a_t = (r_i + r_o)^2 = 4.259 * 10^{11}\ m$$

$$E_t = \frac{-\mu}{2a_t} = -1.56 * 10^8\ m^2/s^2$$

$$v_{tp} = v_{ti} = \sqrt{2(E_t + \frac{\mu}{r_i})} = 32068.74\ m/s$$

$$H_t = r_i * v_{ti} = 6.349 * 10^{15}\ m^2/s$$

$$v_{ta} = v_{to} = \frac{H_t}{r_o} = 27858.7\ m/s$$

Required Delta-V's

$$\Delta v_1 = v_i - v_{ti} = -6180\ m/s$$

$$\Delta v_2 = v_{to} - v_o = 3728\ m/s$$

Two Delta-V's are required, as the orbit is going from outer to inner. The first Delta-V is required to slow it down to a transfer orbit, and the second one is required to speed it up into its inner circular orbit.

To create these Delta-V's, we must determine whether mass or velocity of the incoming comet/asteroid is constant. With constant mass, we can determine how fast it must be travelling, and with constant speed, we can determine which asteroids (or fitting mass) are eligible for this type of collision.

This assumes that the impact will be inelastic (i.e. Mass from comet/asteroid will be added to Mars's)

Rough work for this:

$$17950\frac{m}{s} = \frac{m_{comet}}{m_{comet} + 6.4191 * 10^{23}} * v_{comet}$$

The left hand side of the above equation represents the target speed (of Mars) which would need to be acquired to enter the transfer trajectory. The bottom of the right hand side of the equation would be the mass of Mars along with the additional mass of the impacted asteroid or comet.

We find that even with the greatest mass of asteroid or comet we can find (Ceres, a dwarf planet having a mass of 10^{20}) we need to speed it up to an unreasonable value. We hypothesized that even should we leave mars in an elliptical orbit, we would need to speed up Ceres by approximately 2000 km/s (it is currently traveling at 17 km/s). This, by the means available to us today, is not nearly feasible enough to be executed. Even had we the means to speed up the asteroid comet, if it is as large as Ceres, we do not know the repercussions that the collision would have on Mars itself.

We then looked into the possibility of moving Mars using only one collision. In order to make this orbital, we would need a rather large orbiting body. The only body that really fits our needs is the dwarf planet, Ceres, which has a mass of 10^{20} kg. Using the equation

$$Rp = a(1 - e)$$

we can find the eccentricity, since we know Rp is 2.17×10^{11} m and a is 2.22×10^{11} m, so we get an eccentricity of .0256. With these numbers we can use the equation

$$V_{ap} = [\frac{GM}{a} * \frac{1-e}{1+e}]^{1/2}$$

where V_{ap} is the velocity we need to decelerate Mars to in order for it to enter an elliptical orbit closer to the sun, G is the gravitational constant, M is the mass of the sun, a is the semi-major axis of the new elliptical orbit, and e is the eccentricity. We find V_{ap} to be 23,816.9 m/s which is a drop from its original velocity of 24130 m/s.

In order to calculate the required velocity of Ceres to move Mars in one hit we can use the equation for conservation of momentum for an inelastic collision

$$m_c V_c + m_m V_m = (m_c + m_m) V_{ap}$$

Thus we find V_c to be 2.016×106 m/s or 2016 km/s. Since Ceres's current velocity is 17 km/s, we would need to increase Ceres' velocity by 11859%. This change in velocity is just not feasible, if we were to use multiple impacts with smaller asteroids we would have to have many, many impacts or use fewer impacts with higher velocities, all of which are much too difficult to accomplish.

Even if all of this was feasible, it would all take too much time. In order to establish a colony on Mars, it would be preferable to do it in the near future, around 100 years from now. However, all of these preparations will take far longer than that, just aligning the colliding bodies so that they hit in the right way, would take several centuries. After the impact, we would have to wait at least another hundred years just for all the dust to settle down, so we could begin colonizing the planet.

Chapter V: Mercury

Due to its proximity to the Sun and its harsh surface conditions, it would seem unlikely that Mercury would ever be considered a target for inner solar system colonization. Surprisingly, however, it is very similar to the Moon and has key advantages that would help make colonization possible. Coupled with these advantages, Mercury contains tremendous amounts of potential for both scientific research, technological advancement, and, if scans reveal the presence of theorized resources, a new supply of resources.

One main advantage that colonists on Mercury would benefit from would be the presence of the planet's magnetic field. Scientists believe that the due to a large molten iron core, the movement of these hot metals around the inside of the planet generates this field. Because of its size, the magnetic field produced is only about 1/100th the strength of Earth's magnetic field. However, this is sufficient enough to deflect solar winds around the planet at an altitude of 1000 to 2000 kilometers from the surface during normal solar activity. During periods of high activity, safe zones would still be required for the colonists within the settlement as small amounts of harmful radiation would reach the surface. As shown in the picture on the right, one can see the magnetic field lines that outline the planet as well as the bow shock. The bow shock is the boundary at which the speed of the incoming solar wind drops from supersonic to subsonic due to the presence of the magnetopause, or the plasma trapped by the magnetic field, on the other side. The threshold through which the speed drops can be shown by the equation

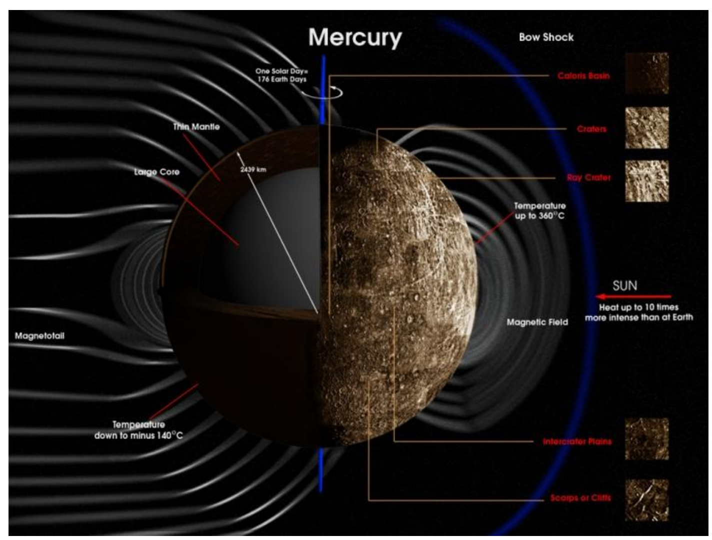

Figure 10: Visualization of Mercury's magnetic field

(Courtesy of NASA)

$$C_s^2 = \frac{\gamma P}{\rho}$$

where C_s is the speed of sound through the plasma medium, γ is the ratio of specific heats, and P and ρ are the pressure and density of the plasma, respectively. As the solar particles cross the bow shock, they are deflected around the magnetopause along the magnetic field lines. Thus, this is how colonists on the surface would be protected from the harmful solar winds.

The other main advantage is the theorized presence of ice in the planet's deep craters. In 1991, images like the one to the right showed radar bright regions near Mercury's poles. After comparing them to images obtained from other icy moons and the poles of Mars, scientists proposed that there were significant deposits of ice within these craters. Another advantage would be that, for its size, Mercury has a relatively high gravity, about one-third of Earth's or almost 2.5 times greater than the gravity on the Moon. Therefore, colonist would not only have an easier time moving around but also would not have to worry as much about health problems due to low gravity.

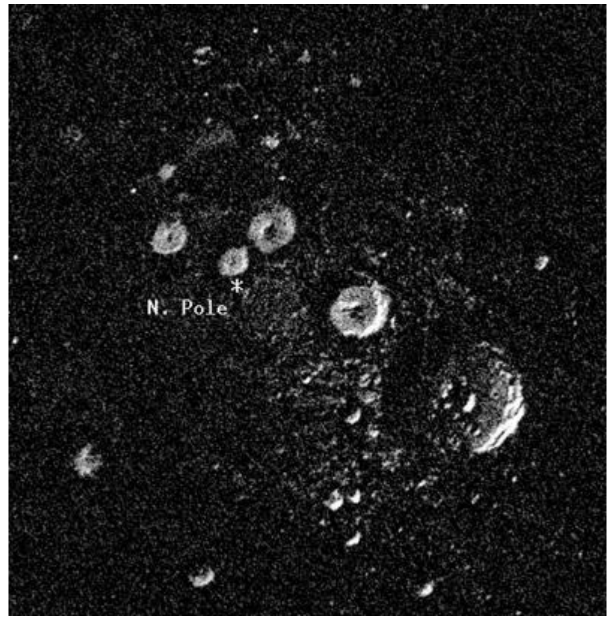

Figure 11: North Pole of Mercury

(Courtesy of NASA)

Ultimately, these key aspects of the planet would not only allow humanity to establish an outpost on the surface without requiring massive technological advancements but also to exploit the benefits that Mercury has to offer. For example, launching materials mined from the planet's surface could prove to be extremely lucrative considering its composition. Behind Earth, Mercury is the second densest planet in the solar system with a density of 5.427 g/cm^3 compared to 5.515 g/cm^3 for Earth. Therefore, taking into account the size comparison of the two planets, it indicates that anywhere from 60-70% (by weight) of the planet is composed of metals with the rest primarily being silicates. In addition, it is theorized that Mercury may have some of the highest concentrations of several valuable minerals and metals of any surface in our solar system and in extremely concentrated ores on top of that. Other predictions include the possibility of large quantities of helium-3, an essential element of future fusion power plant.

The benefits obtained from an outpost on Mercury would not only be economical, but also scientific due to the planet's proximity to the Sun. Scientists and equipment on site could provide unparalleled insight into learning more about the Sun and solar activity. The outpost could also serve as an advanced warning for solar flares and periods of high solar activity that could endanger traveling ships, other colony planets, or even Earth.

Surviving on the Surface

In order to sustain life for any prolonged period of time, we need to have a suitable habitat. Creating a base on the moon would require us to either bring our own materials from the Earth to construct our buildings and structures, or utilize the materials already on the Moon.

One option is to use the Earth's orbit to bring materials into LEO (Low Earth Orbit, between 100-1300 miles above the Earth) and to construct structures which would then be able to be transported to the Moon's surface by shuttle or thrusters. With this method, we can use materials from Earth to create our habitat, and we already have some advanced knowledge of how these materials would react to the environment present on the surface of the Moon. This would also allow us to have ready-made structures immediately ready for settlement, even if not permanently. The technology exists today, and is a feasible course of action for creating a forerunner to long-term settlement. Currently, the ISS (International Space Station) is in LEO, and could be used as an intermediary between the trip between Earth to Mars, and the construction of the structures.

Use of local materials would be necessary for creating a self-sufficient colony on the Moon. To be able to create, expand, and repair if necessary are criterion for a self-sufficient colony. Use of materials on the moon can be used to shield us from the Sun's radiation (as the Moon has a very thin atmosphere which provides little to no protection from the harmful ultraviolet rays). The surface of the Moon is covered in Regolith, a lunar dust, formed over the past 4-5 billion years from the constant shower of micro/meteoroids. These meteoroids can travel as fast as 60,000 mph, which impacts and melts the surface, and then it re-freezes. This process has covered the planet in lunar regolith, which, if harnessed, can provide us an excellent radiation shield for lunar structures.

Building using local materials will be time consuming and difficult, meaning, for at least the beginning of Moon colonization, the colony would be heavily Earth dependent. It may be possible to use the Moon's sulfur rich soil to create a new type of concrete that does not require water (water exists on the Moon, but will be at a premium for other purposes). Sulfur can be extracted from the Moon's surface using chemical processes, melted and used as the binding agent with lunar dust or regolith to create a stronger concrete. The concrete can then be used in conjunction with a support such as fiberglass or metals for greater stability. We are currently unsure about this in practice, but in theory the low gravity environment and fine lunar dust make this new concrete sound promising.

The Moon also has large deposits of Helium-3 (in the scale of a million of tons) where the United States and Europe could be powered with 25 million tons of He-3. Helium-3 is a crucial component to nuclear fusion reactors.

One idea is to use a large scale 3-D printer to create structures on the lunar surface. The regolith could be used much like basalt is used on the Earth (formed from melting and rapid cooling). This would provide moderate tensile strength (about ten times the strength of concrete) and radiation shielding from the Sun. It may be possible to combine the ideas of construction of structures in space (via this 3-D printer) and to send lunar materials into orbit to the printer, which could yield benefits on fuel costs. Structures which have been competed in orbit could then be transported along with a rocket or shuttle to its next destination, requiring less fuel than transporting it from the surface of the Earth or Moon.

Structures on the Moon must fulfill certain criteria. First, the habitat must be pressurized to simulate the Earth's atmosphere. Secondly, the habitat must be able to be powered, and there must be appropriate living quarters for its crew. The first is the most important as we do not know enough about the long term effects of a low gravity and thin atmosphere have on the human body. The second is also very important, as power will be needed for everyday living, equipment, and maintaining the atmosphere. The final criterion is mandated by NASA which states that there must be at least $20m^3$ of space per crew member, and ideally, $120m^3$ of space. This is very similar to the current conditions of those who work on the international space station.

To minimize the cost of the creation of the structure, functionality and floor space must be optimized. This includes the maximization of available space to the living spaces, equipment, life support, and storage. To maximize the functionality of the base, creating sections that are side by side can reduce the area exposed to the Sun, and loose regolith can be used to cover the sections as an effective radiation shield.

Possibility of Using Lunar Regolith

To substantiate any sort of human presence in space (i.e. the Moon, Mars, or beyond) we must be able to construct some sort of habitat or site which can serve as a scientific center or base of operations. To do so, we must be able to construct it ideally with a majority of the resources coming locally from the construction locale. We need to be able to utilize the local resources available to us because the cost of transporting anything from the Earth to, for example the Moon, is astronomical. Currently the economic state of affairs the leading space exploring nations cannot afford the $10,000-40,000/kg price tag involved with transporting materials from the Earth to its destination.

Concrete is an obvious choice of material because all of its necessary components are available on the Moon. Testing of concrete making processes have already been undertaken on Earth. Two types of this testing have occurred: one using regolith simulant and one using actual lunar regolith. Both types have had great success, proving that concrete can be created using lunar regolith and it has even greater physical properties than that of Earth based concrete.

There are two steps involved in the creation of concrete, first creating cement and then mixing it with the local soil (in our case, regolith) to create concrete. The cement production process involves taking ground lunar basalt and mixing it with ground basalt (terrestrial) to form the cement mix, and "cooking" it at a high temperature to evaporate some of the basalt constituents and creating a more favorable composition of elements. By cooking the basalt mixture at 2200K (via solar-heating processes) the resulting makeup of the mixture is a ratio of 43:53:5 of CaO, Al2O3, and SiO2, respectively. Next, you mix the concrete with lunar regolith and water, or some available binder, to create concrete. Note that the water does not have to be in liquid form, as the optimum process of casting concrete involves DMSI, or dry-mix steam injection, to cure the concrete mix into its final form.

Impacts of micrometeoroids melt and refreeze the lunar soil into agglutinates, jagged and glasslike rocks and particulate. These are formed under very particular temperature and pressure conditions, not found on earth. It has been tested in 1961 by the USAF's Cambridge Research Laboratories that creation of tektites (a similar form of agglutinates found in very rare cases on Earth) cannot be created by fusion of terrestrial materials by any means (i.e. meteorites, asteroids, comets, or lightning). Agglutinates chemical properties are not well known. Tektites, which are a close relative, rank between a 6-7 on the Mohs Hardness Scale, about the strength of steel. Its specific gravity is 2.5, lower than aluminum. So, it is a material as strong as steel with less mass/volume than aluminum. These properties make it a prime material for construction considering its plentiful nature on the Moon.

Because of the physical properties of the lunar regolith, it melts at a much lower temperature than that of Earth-based concrete, and small grains of the lunar regolith weld onto the larger grains, creating a material with is very strong to bond with. The approximate sizes of the grains are of the order of 10 μ and considerably less than 100 μ in the samples encountered. In the tests that were undertaken by T.D. Lin, a Japanese scientist, the concrete that was produced in this way provided two times the compressive yield strength than that of terrestrial concrete.

Making the Journey to Mercury

In order to travel from the Earth to Mercury, the spacecraft will still need to enter an elliptical transfer orbit. It doesn't matter whether or not you start from a lunar base; although, a launch from the moon will require far less fuel, so the rocket itself can be made lighter, or it could be made to hold a larger payload, either in terms of passengers or materials to build structures on mercury. In either case the trip will most likely have to be made in more than one spacecraft because of all the requirements.

Because the distance from the moon to the earth is negligible compared to the distance from the earth to the sun, we will, for now, assume that the craft's original orbit radius around the sun is equal to that of the Earth. Because we know that the aphelion radius (R_{ap}, the farthest distance from the sun in orbit) is the Earth's orbit, and the perihelion radius (R_p, the closest distance to the sun) is Mercury's orbit, we can find the semi-major axis of the transfer orbit. The semi-major axis, a, is equal to

$$\frac{R_{ap} + R_p}{2}$$

so, a is 207.5×10^9 meters. Knowing this value we can calculate the eccentricity of the orbit, which is required to obtain the required velocities for the spacecraft. Since,

$$R_p = a(1 - e)$$

We find e to be 0.721. Putting this value into the equations

$$V_{ap} = (\frac{GM}{a} \times \frac{1-e}{1+e})^{1/2} \text{ and } V_p = (\frac{GM}{a} \times \frac{1+e}{1-e})^{1/2}$$

where G is the gravitational constant and M is the mass of the sun. Therefore, we find the required aphelion velocity to be $10.2 \times 10^3 m/s$ and the perihelion velocity to be $62.8 \times 10^3\ m/s$. The velocities are relative to the sun, so after taking off from a lunar base the spacecraft would enter into an orbit about the moon which was previously found to have a velocity of $1608.0\ m/s$, but the moon is also moving about the Earth at a speed of $1018.7\ m/$

s. So assuming the moon will be on the opposite side of the Earth as the Sun, and the craft will be on the opposite side of the moon as the Earth, therefore relative to the sun, the velocity of the craft will be the sum of all the orbital velocities. So, relative to the sun, the craft is moving at $32{,}406.7\ m/s$, therefore, the spaceship will need to slow down to $10{,}200\ m/s$ in order to enter the transfer orbit.

Once at the far side of the transfer orbit, the craft will have a velocity of $62.8 \times 10^3\ m/s$, so the craft will have to again slowdown in order to stay with mercury which is moving at $47.87 \times 10^3\ m/s$ around the sun. Now we want to enter an orbit around Mercury at $2000\ km$. Thus the spacecraft needs to decrease its velocity to $3318.5\ m/s$.

The Messenger was a satellite launched from Earth to Mercury in August 2004. It had a fuel capacity of 592.3 kg of fuel that allows a total ΔV of 2.25 km/sec for the life of the mission. If the spacecraft that we use is similar to this design, then, making a rough assumption, we can calculate the amount of fuel that is required for a given ΔV.

$$\frac{Amount\ of\ Fuel}{\Delta V} = \frac{592.3\ kg}{2.25\ km/s} = 263.2\frac{kg}{km/s}$$

The total ΔV for our trip to Mercury is $81.688\ km/s$, so the total amount of fuel needed is $21{,}500.3\ kg$. This does not account for the takeoff from the base on the moon or the fuel that will be needed to land on Mercury. Currently, the fuel for rockets is at $0.76 per kilogram, so the cost of the fuel will come to $\$16{,}340.2$.

Using Kepler's Third Law, which says that

$$T^2 = \frac{4\pi^2 a^3}{GM}$$

we find the total orbit period is $5.16 \times 10^7 seconds$ or about $1.64\ years$. Thus to find the total trip time, we just divide by 2, so the trip itself would take $0.818\ years$ or $299\ days$. Since Mercury's orbit period is 87.97 days, by the time the trip is complete, Mercury will have made about 3.4 orbits around the sun.

Because we are looking to set up a mining colony on Mercury, we would be sending raw materials regularly back to Earth. Since, it is going to cost a great deal of money to send these materials back the normal way, it would be preferable to find an alternate fuel source. One option here is to use solar sails (described in detail on the next page) because Mercury is closer to the sun, so the force will be larger here than at Earth. Now, it would be preferable to just send these return shipments straight back to the Earth instead of elliptical transfer orbits, and because directly to the Earth would mean, the sails are perpendicular to the sun's rays, but there is a problem with this method. The force propelling solar sails takes the form:

$$F = \frac{LA}{2\pi c R^2}$$

where L is the luminosity of the sun ($3.827 \times 10^{26}\ Watts$), A is the area of the sails, c is the speed of light, and R is the distance from the sun to the craft. If we use an area of 1000 square meters, and R as the orbital radius of Mercury, we find the force to be 0.061 Newtons. We also have to take into account the force of gravity from the sun, which follows the equation:

$$F = \frac{GMm}{R^2}$$

Where m is the mass of the craft. Obviously we want a large mass, because we don't want to be sending these materials back in tiny shipments, so we will take a mass of 10,000 kg, which will give us a force of 395.9 Newtons, which is quite larger than the force on the spacecraft. So, unless we also have a rocket propelling the craft, we will still need to keep the craft in elliptical transfer orbits, which means the shipments will take 299 days to get back to Earth. This is fine as long as we don't need these raw materials immediately.

These solar sails are essentially giant, super-thin mirrors. When a photon strikes the surface and bounces off, the surface experiences a force on it. This is conservation of momentum at work. Multiply this by the billions of photons emitted from the sun, and you have a legitimate method for space propulsion. While a rocket engine seems more practical because of its ability to reach extremely high accelerations, it has a relatively small supply of fuel, so it can't keep up that acceleration for very long. Solar sails on the other hand, can't hope to achieve the same accelerations, but they have a huge fuel supply (the sun), and so they can keep up their acceleration, no matter how small, for long periods of time, thus reaching extremely high velocities.

In order for a solar sail to be practical form of space propulsion, it would have to obey these characteristics: first, the sail would have to have a large enough area so that the sunlight would actually affect the movement of the spacecraft. Second, although a larger area would increase the force due to the sunlight, it must be kept lightweight, or else increasing the size would cancel out the increase in force. And lastly, the sail needs to be very durable. There are many dangers in space to such a fragile piece of equipment, such as temperature changes, charged particles, and micrometeoroids. Thus, to meet these conditions, the majority of sails are made from thin, metal-coated, durable plastics, such as Mylar or Kapton.

The Cosmos-1 was launched in 2005, in order to test solar sails. However, a malfunction in the rocket caused the satellite to never reach its intended orbit. Its sail, though, was made of aluminum-coated Mylar, which has a thickness of 0.0002 inches or 5 microns. To put this in perspective, saran wrap is about five times thicker than the sail. Also, the sail had an area of 6,415 square feet or about 600 square meters.

These solar sails are created in three major designs. First, is a square sail, second is a heliogyro sail (where the sail is divided into blades, like a helicopter and they must rotate to remain stable) and last is a disc sail. The IKAROS probe is the world's first spacecraft to successfully demonstrate solar sailing as the main propulsion, and it uses a square sail. On the Cosmos-1, the sail was a cross between a square sail and a heliogyro sail. So that the square was divided into eight equally sized triangular "blades". The area of the sail on the IKAROS is 200 m^2 and the probe has a total mass of 315 kg.

The force on a solar sail can be shown via the equation, F = 2(P*A)/c. Where P is the power of the sunlight per square meter, A is the area of the sail, and c is the speed of light, at $3*10^8$ m/s^2. At 1 astronomical unit, the distance from earth to sun, the power is about 1400 W/m^2. If the sail has an area of 200 m^2, then the force on the sail is about $1.87*10^{-3}$ Newtons. Thus, if the spacecraft has a mass of 315 kilograms, the acceleration is $5.94*10^{-6}$ m/s^2. However tiny, this is constantly accelerating, so the velocity would eventually reach extremely high values. Over one year the velocity would increase to 187.32 m/s.

Chapter VI: Social Implications

Technological Benefits from Extraterrestrial Colonies

There have been over 30,000 discoveries and inventions that came about due to space exploration. Because of all the different needs that astronauts have in space, these inventions range from standard athletic apparel to state of the art medical equipment. In 2007, USA Today ran an article about the "Top 25 Scientific Breakthroughs." Nine of the top twenty-five came from space, with eight coming directly from NASA. Though not all of these have uses in everyday life, it does to show what kind of benefits come, commercially or otherwise, from space.

NASA calls these technologies, which have uses in everyday life and in space, spinoffs. Lately, NASA has been partnering with private industry to develop technologies that have uses in space and on Earth. This makes the process cheaper for NASA, and, thus, the taxpayers.

Fabrics are one area where there have been several commercial developments. The use of aluminized materials on satellites and spacecraft as insulating material, helped to change how we use reflective insulating material on Earth, such as survival blankets, water heater insulation, and home insulation. Aluminized glass cloth is capable of withstanding radiant temperatures in excess of 2000°F and a maximum continuous temperature of 350°F. Aluminized materials can also be made to come in a braided fiberglass sleeve, and are then coated with rubber silicon compounds, in spacecraft, these are used to form a protective barrier and extend the life of hydraulic lines, hoses, wires and cables in areas of extreme heat exposure in hazardous environments. These sleeves have continuous protection to 500°F, and short-term exposure through 2200°F. Firefighter's suits came from the need of extremely strong fire-retarding materials; in space these are used to limit the amount of flammable materials, the last thing you need in space is a fire, which not only is dangerous itself, but it would consume a lot of the precious oxygen. NASA currently uses Beta Glass as its primary fireproofing material. Also developed were Teflon-coated fibers which are extremely strong yet lightweight. These have been used as roofing materials for places like Atlanta's Georgia Dome. In space they are used for astronauts' space suits.

Another area where NASA's space technologies have found uses commercially are materials. Composite materials, which are a mixture of fibers and resin, are designed to provide great strength, but stay lightweight. These have found many uses from airplanes to materials used in helmets, tennis rackets, and other sporting goods. Memory metals, originally developed by NASA, which are metals that "remember" their former shape when bent, are now used in flexible metal eyeglass frames; however in spacecraft, these memory metals are used for quick connect/disconnect joints on the spacecraft. In order to protect delicate spacecraft parts, NASA created scratch-resistant coatings, which are now used for eyeglasses. To help astronauts walk around on the surface of the moon, with their heavy suits, NASA developed shock-absorbing spacers, these are now used in many athletic shoes. We also have NASA to thank for memory foam mattresses, which astronauts use to sleep on.

Electronics are a major part of everyday life and many commercial applications came from NASA's space program. Smoke detectors, originally developed for NASA's early '70s Skylab spacecraft, are currently required by law to be placed in all homes. Quartz timing crystals which are located in wristwatches and small clocks were initially created as a high-accuracy, lightweight and durable timing device for the lunar-bound Apollo spacecraft. Once on the moon, astronauts used specially developed, battery operated, electric tools, these were the forerunners of today's range of rechargeable power tools. Lastly, NASA used barcodes to help keep track of millions of spacecraft parts.

Finally, the medical breakthroughs developed by NASA have been immense. Because of NASA we have programmable pacemakers which incorporate multiple NASA technologies. Automated urinalysis and the fluid dynamics studies done at NASA have helped to develop a system which automatically removes and analyzes sediment in urine. Because of NASA teleoperator and robot technology, we have voice-controlled wheelchairs, which respond to voice commands and help the user perform daily functions.

Other spinoffs include pool purification systems, which NASA used to purify water for flights with long travel times. Also, golf balls use aerodynamic properties originally developed by NASA for better spaceships. Another spinoff is portable coolers and warmers. In space the astronauts do not want to needlessly use energy to heat or cool food so they have to keep it warm or cold for as long as possible. There are so many “spinoffs” from NASA that it would be hard to go through a basic daily routine without interacting with one of them. The space program has both directly and indirectly helped us to revolutionize how we operate and function over the last couple decades.

Therefore, it is easy to see that technological advancements made in relation to the space program have greatly benefitted humanity as a whole and this would be no different for advances attributed to the Mercury base program. In fact, because of the relative isolation of the outpost, technologies would be in place that would allow the occupants of the base to deal with whatever crisis or emergency that arises, with only limited instruction from Earth. Thus, these types of technological advancements would be sure to have a noticeable impact when given practical applications on Earth. A few examples would be advances in automation techniques, efficient hydroponic farming, water and waste recycling, and air filtration and recycling. This is only the beginning of how humanity can benefit both technologically and scientifically from an outpost on Mercury.

Effects of Radiation

As the next era of space travel becomes a reality, we humans will be dealing with more and more sophisticated technologies in all areas and a whole new space culture will develop to go along with it. Mechanical innovations will be needed to make the most efficient space vehicles possible. Technologies related to energy and electronics will also be inevitably improved. Humans who are born into and grow up in such a culture will surely take space travel and the advanced technology for granted. For example, in the last few decades, the internet has gone from a way for the military to communicate to a worldwide phenomenon that is deeply embedded in our daily lives and infrastructure. So too will space travel achieve such a state where it is considered part of the normal culture. New job opportunities will be available for people in space ranging from engineering to administrative to custodial. In order to get these jobs, people will be motivated to specifically train for them. A new aspect that will come into play for space jobs will be genetic modification.

Genetic modification is the modification of DNA to either change a particular trait or engineer a new one. It is currently not very well developed, but seems very promising. There have been many tests done on animals such as rats, cows, pigs, and other animals, but only for very specific and limited modifications. An example of this is using genetically engineered hamsters, cows, and goats to make milk that has proteins to help humans who suffer from diseases such as Gaucher, Fabry and Pompe disease. It is just as possible, though largely frowned upon, in regards to humans. In the context of space travel, genetic engineering would most likely primarily be used to make humans more resistant to radiation.

Radiation is a broad term that can refer to any part of the electromagnetic spectrum ranging from radio waves (low wavelength) to gamma rays (very short wavelength) being dissipated. In the context of space travel, the main concern is with radiation from the Sun that is harmful to humans. The Sun emits radiation from almost across the entire spectrum, with Ultraviolet Radiation (UV) being of most concern.

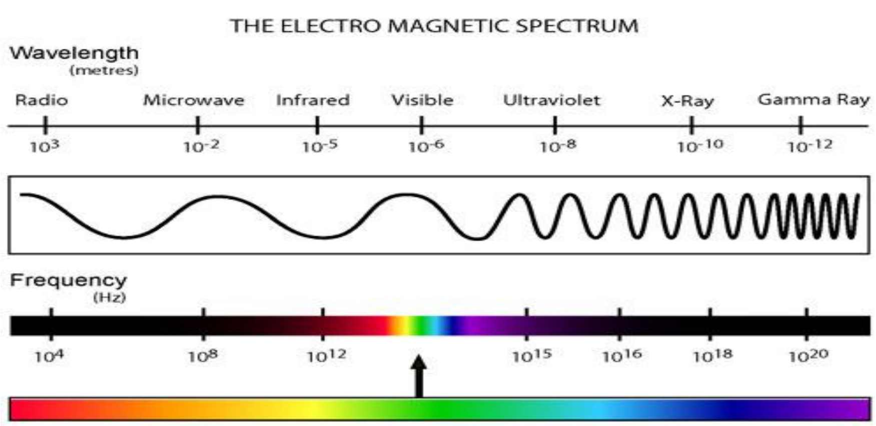

Fig 12. The spread of the EM Spectrum

(Courtesy of: http://www.kollewin.com/blog/electromagnetic-spectrum/)

UV consists of both ionizing (having enough energy to ionize atoms) and non-ionizing radiation in the 10 to 400nanometer range. Ionizing UV radiation has higher energy and is more dangerous, but is generally absorbed by the Earth's atmosphere. In space, however, this would not be the case, so we need to have some sort of protection against it. A simple, but not very cost-effective method is to use lead, which would block the radiation completely. This is not practical because lead is very heavy and the cost of transporting it to space would be very high. One solution to this is genetic radiation resistance. The problem is that this is not directly feasible using any current known methods. Radiation can physically modify DNA. There is no way to change DNA so that it can't be affected by radiation. What can be done is to have the DNA fix itself if radiation changes it.

During cell division, DNA replicates itself by splitting into two halves and each half adding new base pairs. This works because each base pairs with only its opposite pair (adenine with thymine and cytosine with guanine). Cells use certain proteins to verify that the DNA has formed correctly at various points, but radiation can provide enough energy to bond two of adjacent base pairs. This can lead to mutations in the DNA that may not be caught because the protein that interprets the pair gets the wrong signal and attaches the wrong base pair. This can lead to mutations in the DNA that to lead to health problems like cancer. The key factor in preventing this would be having better verification for DNA once a mutation does occur.

A study done in Columbia University in New York examined the bacterium *Bacillus subtilis* and found that treating it with small doses of UV or X-Ray radiation led to resistance to those types of radiation. This indicates that (indirect) radiation resistance is possible at the DNA level. In fact, this is believed to be how the first land organisms developed. The early Earth atmosphere had no ozone layer, which blocks a lot of the ionizing UV radiation from the Sun. When early life forms ventured to land, most died out. Those that survived were able to do so by repairing their DNA after damage. This kind of mechanism would be a very useful trait for long-term space exposure, but there are lots of limitations.

One issue is that the human life cycle is very long compared to bacteria. The bacteria are able to multiply exponentially in a matter of hours and days. This means that that they are able to evolve at a much faster rate than humans.

Another issue is that even if it were possible to change DNA so that it is more resistant to radiation, it could have long-term health implications. Radiation is currently used today to help eradicate cancer cells in a practice called radiotherapy. If the DNA in those cells somehow became resistant to radiation, then the treatment using radiotherapy would be ineffective if someone did get cancer due to carcinogens, obesity, or infectious diseases. Only about 10% of cancer occurs as a result of radiation, so to prevent cancer with radiation resistance would have negative long-term consequences. It would rule out radiation as a therapy for 90% of cancer cases.

Genetic Engineering

With the advent of new technology, comes a debate on what we as a human race should use it for, in this case, the technology we are discussing is genetic engineering. It has long been debated and will continue to be debated; however, for all the negative reasons people use to discredit genetic engineering in humans, there are many positive ones, which outweigh the negative. As we enter into a new age that will be defined by our space exploration, genetically modified astronauts will be crucial to our success in the colonization of space and other extraterrestrial locations, such as Mars, Mercury, and the moon, to name a few.

One of the ways genetic engineering could be used for good is in the case of disease prevention. Even just by genetically screening people who are genetically prone to certain hereditary diseases, we can be prepared to treat, and even prevent these diseases with early action and certain preventative steps. Genetic screening is non-invasive in that we don't change anything within the patient's DNA, but just observe it to see if they are prone to certain diseases. We used genetic screening before when, in 2009, a baby was genetically screened before it was born to see if it was prone to hereditary breast cancer. This was the first time we used it, but it has become fairly popular. Preventative measures in disease control are also possible by implanting genes into our DNA that code for antiviral proteins specific to each antigen, and to block genes which cause hereditary diseases.

Second, people can be "tailor made" to show desirable characteristics. While, this could be easily abused, it could also help people immensely. Even just in the space exploration community, astronauts could be genetically modified to increase positive traits such as strength and stamina to be able to better withstand the g-forces they feel in space; radiation resistance can also be increased. There is a microbe, Deinococcus radiodurans, which can survive radiation doses of up to 7000 times what would kill a human. This bug can reassemble its DNA immediately after it gets blown apart by the powerful radiation. Once scientists can figure out how to incorporate these rapid DNA repair genes into our genome, astronauts won't have to worry about the high radiation they encounter in space. Another problem astronauts face during space flights is bone deterioration, which occurs in low gravity environments. Scientists can genetically modify astronauts to have genes which code for robust bone regeneration.

Another positive result of genetically modifying humans is extended life. Scientists have discovered an enzyme, telomerase, which prevents DNA from unraveling. Every time our cells divide, some of this is lost, meaning that every time your body heals or grows its ability to regenerate itself is diminished. Medical scientists are looking for ways to rejuvenate telomerase or prevent its loss entirely. Someday, when we decide to send an astronaut party out past our solar system, or even to its far edges, we will be able to send out a smaller team, because they will be able to live for multiple generations. We won't be limited to a single generation of space flight time when astronauts can live for hundreds of years. There will be no need to send out an entire colony of people just to explore the out limits of our own solar system.

Genomics pioneer Craig Venter has pushed NASA to begin using genetic screening and genetic engineering techniques, so that it will be far safer and more efficient for humans to explore space. Once scientists can identify what genes make good astronauts, or cause humans to fare batter during space travel, NASA can screen potential candidates for these genes.

Space causes many problems during extended stays, and even brief stays. One of the major problems plaguing astronauts is bone deterioration. The reason we do not have these problems on Earth is because our bone structure is used to supporting our weight in Earth's gravity. Once we decrease this gravity by moving to another planet, or remove it altogether by going into space, our bones begin to deteriorate. In order to combat this problem, scientists are looking for ways to genetically engineer astronauts to have genes which code for robust bone regeneration.

As it stands right now, the human microbiome, which is a teeming mass of microbes that live on and inside all of us, helps us to accomplish a great many things. These include anything from helping us to digest food to keeping our immune system's inflammation response from going overboard. Venter suggests that we engineer a synthetic microbiome for astronauts in space. Theoretically, an engineered microbiome could help astronauts take up nutrients more efficiently. It could also eliminate some pathogens, such as certain bacteria which cause dental disease. While this might not look directly relevant to space travel, if you could eliminate dental problems, you wouldn't need to have a dentist or anyone responsible for dental issues on board long space flights, so you could pack more supplies, or some other specialist.

Finally, another area where genetic engineering can drastically help us out for space flight is synthetic organisms. The simplest way for these to help out would be to process materials into biofuels or food. We would need to engineer these organisms to survive in extreme environments. While this seems science fiction, we have already been doing it. Scientists have created a strain of E. coli which can survive at much lower temperatures by adding genes from a cold-tolerant organism found in sea-ice. One example of an organism that can provide for astronauts is a synthetic version of spirulina, which is a dietary supplement made from microscopic algae produced by cyanobacteria. Spirulina is a complete protein, meaning it contains all of the essential amino acids humans need in their diet. Right now, it is naturally produced in ponds in Hawaii, so we would need to engineer it to live in colder temperatures and in a different atmosphere if needed.

Social Space

Recently, the current administration has decided to abandon a return to the moon to establish a base, instead planning on making a direct journey to Mars. This decision had been made based on the financial problems faced in creating a lunar base. The Beijing Declaration stated that international cooperation would be focused into the construction and maintenance of a lunar base.

The Center for Strategic and International Studies (CSIS) has approximated that the cost of development of a lunar base for a crew of 4 would be $35 billion. These costs include supplies from the Earth and landing equipment. The base itself is not outlandishly expensive, but that is also because of its limited capabilities beyond scientific research. The major costs would be in the transformation of the lunar base into a shuttle launch station, and the costs involved with increased utilization of the ISS. Annually, it is expected that around $7.5 billion would be also required for maintenance of equipment as well as supplies for the crew members.

Aside from the high financial costs of sustained life in outer space, there are social difficulties that must be faced as to prevent any problems occurring between crew members. One involves the crew member as the individual and the other is the crew member as a part of a team. These problems can be contrasted to those faced by crews on submarines as well as those in secluded arctic stations, but are a whole new area within social problems which need to be understood to assure the success of long term space life.

The Russian Federal Space Agency has been using a method called “Alone in Public” where they place an astronaut in solitary confinement where he cannot see outside, but others can see him. This helps the astronaut to not let the solitary confinement of the capsule get to him/her. This helps with one of the problems faced by astronauts, especially those with limited crew, where the stress of being alone or isolated from major communication can disturb the astronauts decision making process.

NASA uses a series of tests to screen the astronaut’s capability for space flight, but not to the extent at which the RFSA does. NASA screening tests for psychological factors which might disrupt the mission, but does not include any “hard” testing as the Russians employ.

One problem that may be faced with an international effort towards a lunar base is the language barrier. It has been shown (as on the ISS) that the language barrier creates a difficulty in understanding one another, especially since facial expressions and the coinciding vocal counterpart do not always mean the same thing. It would be a wise decision for there to be language training, or a way of translating ones words into the language of a crew member who cannot understand.

Technical language is also a problem that could be faced on a lunar base. Since technology around the world is not universal, difference in functionality can lead to problems when working together. Especially in the case of an emergency situation, being unable to communicate information quickly and accurately could be catastrophic, especially without any outside aid.

Human-Robot Interaction is a branch of research today that has close ties with space exploration. It appears that, since we are without a current outpost up and operational, robots may assume the major part of labor services on such a station. HRI deals with the interactions between robots and humans, and how they communicate with one another. Three areas of research are on the forefront in regards to HRI, perception of humans, motion planning, and cognitive models.

Perception of humans deals with how the robot takes in facial expressions and vocal tones. Without the know-how to be able to comprehend these expressions, the robots will seem like a lifeless statue, which will cause more duress to the crew should they be required to interact with the robots on a daily basis.

Motion planning is important for robots, especially ones that are not stationary. Currently it is common to have up to 40 degrees of freedom (movement) in a dynamic environment, and still nearly 10 degrees in a static environment. Robots need to be able to plan their movements to avoid collisions with humans, and to prevent hazardous conditions for the crew or other robots.

Cognitive models deal with AIs which have personality. It has been recorded that with cognitive models, when they are not in use often enough, the robot acts in a “depressed” fashion, where it feels as if it is not needed and an annoyance. Robots which perform the function of crew member, or a person who human crew can interact with to relieve stress, this can be a problem if the robot is unable to reciprocate correct emotion.

Two areas which NASA is making strides in are the speaking and gesturing functions of robots, both being able to perform them as well as understand them, and also the reasoning of robots. This part is important so that robots will understand the reasoning behind complex decisions taking many things into consideration, and not following a straight rulebook like guideline.

Cultural Restructuring

According to the bureau of labor statistics, aerospace engineers contribute to around 90,000 jobs in the US currently. This accounts for about 6% of the 1.5 million engineering jobs currently held in the US. Consider now that there are approximately 154.4 million jobs in the US. In the grand scheme of things, aerospace engineering, and jobs related to such a field, is but a drop in the bucket. But, why is it such a small percentage of the job market?

One factor could be that aerospace engineering is a heavily science based field of study. It involves comprehensive knowledge of physics, mechanics, and math. It is a labor intensive pursuit of knowledge, which many are not so interested in because of the work needed to be put in, or because of the more limited number of employers in the job market. This leads to another question, why is the number of employers so low?

In recent history, there has not been a historic event to take place and shake up the world's interest in space. During the space race, aerospace engineers were in high demand to prove that one nation could reach the moon before their competitors. It seems that recently there have only been glimpses of what lies beyond the earth, but no one has discovered how to travel there. If one nation could prove that space travel was possible and fruitful in research or enterprise, there would be a renewed interest in going to space.

It is not so far off from reality to think that with such a venture in to the reaches of space, students would be more interested in the field, and that would create more jobs. With the economy in a state as it is, any growth of a sector would provide a boost. Also, in a time where the news is plagued with rebellions and war, news of a new space mission would be something to pique the interest of prospective students and younger generations.

Not all jobs related to advancing space travel would be solely aerospace-related. A good majority of the jobs would be delving into the talent in many other fields. For example, interaction between groups of people for large periods of time would be a large issue for psychologists to examine. The biomedical field would also be needed to study the effects of space travel on the human body. Architects would be needed to plan and oversee the construction of living habitats. Thus, it is clear that the cultural impact of space exploration will be very beneficial to society. An increase of jobs within a wide spectrum of industry will lead to many new technologies and innovations. Future generations will only become progressively smarter, continually revolutionizing methods which we find remarkable today.

Chapter VII: Commercial Benefits

Space Based Solar Power

The photoelectric effect is the basis behind solar panel cells or photovoltaic cells. It states that certain materials produce small amounts of current when exposed to light. Solar cells are made from semiconductor materials, such as silicon, which is used in the microelectronics industry. When used in solar cells, the thin silicon wafers are specially treated with a process called doping, a process involving purposely adding impurities to a material so it will exhibit certain properties. For solar cells, the silicon wafers are doped with phosphorous on one side, so that it is N-type (negatively charged), and the other side is doped with boron to make it P-type (positively charged). Because the wafer now has one positive side and one negative side, it now exhibits an electric field. When photons strike the cell, electrons are knocked loose from the atoms in the semiconductor. When the solar cells are part of a circuit, the electrons form a current. Solar panels are made up of a large number of these cells.

The plan is to send a conventional rocket up into a geosynchronous orbit, at about 35,786 km above sea level. A geosynchronous orbit is where an object in space will have an orbit time equal to that of the Earth. Therefore it will appear from the perspective of an observer on Earth that the object is hovering directly above a single spot all the time. Here, the solar panels would unfurl and begin receiving near constant sunlight. Because they are in space, there will be no clouds or adverse weather to affect their status. While solar farms on the surface of Earth can receive sunlight 12 hours a day at most, the panels in space will bask in continuous sunlight. In order to send this solar energy back to Earth, the orbiting solar farm would collect energy from the sun and then convert it into radio waves, which would then be beamed back to antennae stationed on Earth. From here, the transmissions would then be converted into electricity and fed back into our conventional power grid. The plan is being put into place by Pacific Gas and Electric, who have run tests on converting solar power into radio waves, which they have successfully done in between two Hawaiian islands ninety miles apart.

Another company leading the way is Space Energy. Their solar array would be able to generate one gigawatt or one billion watts of power, just about continuously; this output is equal to that of a large nuclear power plant.

The biggest disadvantage to the whole plan, however, is cost. The cost of manufacturing the panels, the cost of sending them up into a geosynchronous orbit, and lastly, the cost of maintaining the solar panels, which would involve sending crews up to manually repair any damage, or just to keep them operating at one hundred percent. These costs easily reach into the billions of dollars. However, compared to the alternative, the cost does not seem so much. The United States alone spends about $700 billion annually on foreign oil imports. Compared to our oil dependence, this multi-billion dollar investment for our future seems insignificant. Regular maintenance for solar panels would merely include keeping them clean. For a solar panel to operate at maximum efficiency, the panel's surface must be clear of any debris. While solar panels on Earth are more likely to gather dust and dirt from the elements, the panels in space can also acquire dust that is floating around in space. Besides regularly maintaining these solar panels, if they were to get hit by just about anything that is floating around in space, from comets to asteroids, and even small bits of debris, these panels' conditions could be in serious jeopardy. Therefore, a crew would be sent up to determine the scope of the damage and repair what they could, or replace a panel if the damage is too severe.

As for the technology required for this to happen, we already have everything. The only reason these companies need to wait, is because they need to be given the go-ahead to begin spending these large amounts of money, and then they just need to manufacture the parts required. Pacific Gas and Electric plans to have their "solar farm" in orbit by 2016, transmitting a continuous 200 megawatts of power back to their receiving station in California.

Fusion Reactor

Fusion reactors are one way which nations around the world are putting time and technology in order to meet the world's growing energy demand. So far, seven fusion reactors have been built, but none of them has produced more thermal output energy than the electrical energy needed to start the reactions. The ITER, or International Thermonuclear Experimental Reactor has been developed to be the first fusion reactor to break this boundary. It is an international effort funded by seven countries, including the European Union, the US, Russia and China, among others. It is designed to produce 10 times the electrical input as thermal output, on the scale of 50,000 MW input to an output of 500,000 MW. The Joint European Torus, or JET, reactor holds the current world record for fusion power, at a value of 16 MW.

Fusion reactors work through the process of fusing two atomic nuclei together to form a heavier nucleus. In this process, as the two atoms fuse, a large amount of energy is released. As two nuclei fuse together, a formed nucleus possesses a smaller mass than the sum of the original two. Thus, according to Einstein's energy equation, the difference in mass is released as energy. This only occurs for certain instances, otherwise more energy must be input to initiate the reaction. "Light" nuclei are classified as having lower atomic mass than iron-56, and "heavy" nuclei are above this. If the two nuclei are above this line, that is "heavy", the energy will be released as nuclear fission energy. The energy needed to produce this reaction lies in heating the atoms to strip them of electrons and leaving them as bare nuclei and in a state of plasma. The energy required is a based on the net total change, so hydrogen, having the smallest charge, requires the least amount of energy, and thus reacts at the lowest temperature. Helium has an extremely low mass per nucleon and is therefore favored as a fusion product. Most fusion reactors combine isotopes of hydrogen (protium, deuterium, and tritium) to form isotopes of helium (H_3 or H_4).

Fuel combination is the main point of debate among fusion physicists. The combination of deuterium and He-3 create a Helium-4 molecule and a highly charged proton. This combination allows for a large fraction of the energy released to be as charged particles, a state which allows for easy conversion to electricity either electrostatically (particle transport losses) or electromagnetically (photons impinging directly on a rectifying antenna which converts microwave energy to DC electricity). This process seems like a perfect reaction, i.e. it does not start out radioactive and does not produce any radioactive waste, but the deuterium in the reaction could form radioactive waste along the d-d (deuterium-deuterium) chain reaction. Another option is the reaction of two He-3 nuclei. This is in fact a perfect nuclear reaction, requiring no radioactive material and producing no radioactive waste. This also allows for the maximum efficiency in energy harvesting from the reaction, possessing an efficiency of 70-80%. The measure of effectiveness required for successful fusion energy creation is having a fusion energy gain factor, Q, greater than one. Currently the highest Q that has been realized has been a value of 0.7 by the JET reactor.

If this is the optimal reaction, why is it not being universally used? For one, Helium-3 is relatively scarce in the atmosphere. It has been researched that He-3's abundance in the atmosphere is 7.2 ppt (parts per trillion). It has been speculated that there may be 100 thousand to 1 million tons of He-3 in the mantle of the Earth's crust. This stockpile of He-3 is not very accessible, and even if it was, the energy costs of extracting it from the crust and from the seafloor would be greater than that which could be produced through nuclear fusion. It is thought that there is a greater abundance of He-3 on the moon. Researchers believe that there is about 0.05 ppm of He-3 in lunar regolith. Though it seems small, it is much more accessible than that in the Earth's crust. The concentration of He-3 in lunar regolith is still much greater than that which is accessible in the earth's atmosphere.

In terms of safety, fusion reactors are much safer than fission reactors. There is no chance of catastrophic accident. This is because the process of nuclear fusion requires precisely controlled temperatures, pressures, and magnetic fields to generate energy, and if one of these parameters is disrupted, the reaction would rapidly cease to function. While, in fission reactors, the reaction would continue and produce radioactivity from beta-decay from the melting of the fuel rods. In fusion reactors, plasma is burnt at optimal conditions, and if there is a change to those conditions, the plasma will cease to function and is unable to produce excess heat. This is extremely safe in comparison to fission reactors, which normally are loaded with enough fuel to run for years. Fusion reactors create far less radioactive material than fission reactors, and the radioactive waste would be the reactor core itself. This is also favorable to fission reactors because the time which the core would be harmful is much less than the radioactive waste created by fission reactors. The core would be dangerous for about 50 years, considered low-level waste at 100 years, and by 300 years, it will have the radioactivity of coal ash. Fission reactor waste will be radioactive for thousands of years. Lithium and deuterium are currently the most common used fuels in fusion reactors. The lifespan of lithium is 3000 years, the lifespan of lithium from sea water is 60 million years, and the lifespan of deuterium from the sea is 150 billion years. This is about 10 times the currently measured age of the universe and 30 times the remaining lifespan of the sun.

Disposal of Space Debris

Space debris poses a great threat to many space activities. It is estimated that there are tens of millions of particles which surround the earth in low-earth orbit and geosynchronous orbit (100-1200 miles and 22.000 miles respectively.) These particles range from flecks of paint to scraps of satellites. Of this vast number, only around 600,000 are above 1 centimeter, and even smaller still is the number able to be tracked- only 19,000. One commercialization opportunity that would be opened up would be de-cluttering this area of orbital debris around the earth. Currently, we lack the technology to deal with this problem in the most efficient way, but there are three proposed ideas which might help to mitigate the problem. The first is to use a laser to slow down the speed of the particles, and they will slowly fall back into the earth's atmosphere, where they will burn. The second proposed idea is to create a large mass of aerogel and as particles come in contact with the aerogel and stick, will increase the mass and eventually the aerogel will gain enough mass to fall back into the atmosphere and burn on re-entry. A third proposal would be to gather waste and debris from near the international space station to create additional shielding.

Nicholas Johnson, chief scientist and program manager for the orbital debris division of NASA believes that the application of a laser to slow down orbital debris is one idea that may be a possibility for removing space debris. "It's like any environmental problem," he said. "It's growing. If you don't tackle it now, it will only become worse, and the remedies in the future are going to be even more costly than if you tackle it today." It has been theorized that the construction of a ground based laser could remove all orbital debris up to 800 km within 2 years. Studies have shown that such a laser facility would cost roughly 200 million dollars. This is a small investment especially considering the hundreds of millions it costs to launch a satellite, and the nearly half-billion price tag on shuttle launches. The laser does not vaporize the debris itself, but imparts a small force such that it will be slowed and dragged into the atmosphere.

"If a high-energy laser pulse of sufficient intensity strikes a piece of orbital debris, a micro-thin layer of material is ablated from the object's surface. This superhot vapor rapidly expands outward, imparting a tiny amount of force to the object. Since current laser technology easily produces ten to one hundred pulses per second, the ablation interaction can be rapidly repeated, over and over. The cumulative thrust acting on the object, if applied at the appropriate point in the object's orbit, is sufficient to lower its perigee below two hundred kilometers (km). At that altitude, atmospheric drag increases sufficiently to terminate the object within a few hours."

- Col. Jonathan W. Campbell, Aerospace Power Journal, 2000

A second proposition is the use of aerogel, a manufactured material with the lowest density of any porous solid. The idea is to launch a shuttle or rocket into a large cluster of debris, and release a large mass of the aerogel. The aerogel would expand to cover a large swath of area, and passing debris will collide with the mass and become stuck to it. As the buildup of debris increases, the mass of the aerogel tangle will increase. Drag will increase and the aerogel mixture will descend back towards earth and will burn during re-entry into the atmosphere. Aerogel provides a very cost effective plan of action to remove space debris. The compacted mass can be stored within a rocket or aboard a shuttle, and will not add much payload to a separate planned mission. The amount of debris removed will be directly proportional to the area of the mass of the aerogel that is released. This is a more economically safe option than the laser, because if it does not work, the costs induced are only for the one mission, rather than the construction of an entire complex.

The third proposal is to create additional shielding for the international space station by gathering orbital debris into a junkyard. As the ISS is growing older, some modules may become outdate and replaced. Instead of simply destroying the older module, it may be used in combination with other sizable orbital debris to form a junkyard of sorts to provide the ISS with greater fortifications. The solar panels and certain arrays are particularly vulnerable to orbital debris and the weathering effects that come with them. By creating a perimeter around these exposed parts, the service life and functionality of the modules can be extended. A visible flaw with this plan is the limitation of sizable debris. But, as only the sizable debris can be tracked by satellite, it would make the construction of such a barricade easier from a timetable standpoint.

Conclusion

Humanity's fascination with space has existed for as long as humanity itself has existed. The two main reasons for this are curiosity and practicality. The curiosity is simply part of the human instinct to learn as much as possible about the world. Humans have been constantly learning about their environment for the sake of survival. The skies must have been especially interesting because they were out of reach and constantly changing. The night sky in particular must have been hard for ancient civilizations to understand. Many cultures tried to explain what they saw in the form of gods. The Egyptians, for example, described different phenomenon (such as wind or life) and celestial bodies (such as the Sun and Moon) as physical forms of various gods. Practicality for ancient civilizations occurred by observing patterns in the sky. Constellations, for example, were used for navigation. The lunar cycle was the basis for various calendar systems. For these reasons, space has interested humanity from the beginning.

This interest has carried over into contemporary times. At this point, we have actually gone into outer space. We have put up hundreds of communication satellites, sent ships to other planets, sent people to outer space and even landed on the moon. We have benefited greatly from space exploration in terms of technological advances. By going through the process of creating space technology we have been able to make great advances in every field including optics, food storage, data storage, memory foam mattresses, worldwide communications and just about every aspect of modern society. Even with all this advanced technology, however, we have only begun to scratch the surface on what is possible. This project looked at several possibilities for a future space program.

First, we looked at various ways that could cause the destruction of life on Earth, which would make space travel a very good idea for the continuation of our species. The biggest threats to the Earth are major impacts from large Asteroids, biological disasters, and natural disasters. Large asteroids would not only cause considerable damage upon impact, but would also cause long-term damage through sever temperature change and a rise in acid rain, tsunamis, and firestorms. From the biological side, we are threatened with a disease (whether natural, or some sort of disease modified to be stronger by humans) that could wipe out the world if enough people can contract it. Finally, natural phenomenon can also be a threat to the Earth. The Sun, for example, could release a large enough solar flare that would wipe out most electronics on Earth, while at the same time a decrease in solar activity could lead to another ice age. In addition to this, we would also be devastated by large scale tectonic activity (such as tsunamis, earthquakes, and volcanic eruptions). In each of these cases, the threat to the Earth is clear. By having isolated colonies independent of the ones on Earth, we would be able to decrease the likelihood of such disaster wiping out the entire human race.

We next looked at ways to use space technology to minimize the risk from the aforementioned large asteroids. This can be accomplished in several ways. One way is to hit the asteroid with a large enough mass and with enough force so that it causes a large change in the kinetic energy of the asteroid in a short amount of time. This would require space craft of mass on the order of 10^4kg. Another method would be to use a nuclear warhead nearby the asteroid in order to change its trajectory. Finally, we looked at applying a constant force on the asteroid to change its course over a longer period of time. This last method is the most viable, provided that we can sight a potential threat early enough, especially when used in conjunction with solar sails. These solar sails would take the energy given off by the sun in the form of photons and use it to steer the asteroid away from the Earth. The solar sails would need to be around 0.3km^2 in size to be effective. These methods showed that an impact even is avoidable if we are willing to invest in the technology to deflect the threat.

We then studied rockets and propulsion systems to get us into space. Currently, the most effective rockets are multi-stage, liquid fueled rockets that use a fuel and oxidizer to expel gas. This gas provides the thrust required for liftoff into space. The different stages are fuel containers that are discarded when empty in order to decrease the amount of thrust required for subsequent stages. Liquid fuel rockets provide a large amount of thrust that helps the rocket leave the Earth quickly. Other rockets use solid propellants, which are lighter and easier to implement, but they do not provide as much thrust as liquid propellants do. In addition to this, hybrid rockets exist that take some of the benefits of both systems, while avoiding some of their problems. Aside from rockets, there exists the possibility of using a space elevator to take people (or supplies) into space. A space elevator is a structure that starts at the Earth and connects to a point in geostationary orbit above the Earth. If such a structure could be built, it would provide a much cheaper means of getting into space, but currently it is not feasible because it requires materials that could handle stress on the order of 10^{11} Pascals. In comparison, the maximum tensile strength of titanium is around $9.0 * 10^8$ Pascals. A solution to this problem exists in the form of nanotubes, which are have a cylindrical nanostructure and have a tensile strength of about 63 GPa. Since launching things into space is very expensive and space elevators are not yet possible, the next best thing would be to have launch platforms on the moon. Because of the moon's low gravity, launching larger spacecraft from there would be much less expensive than launching similar masses from the Earth. If we use the resources on the moon to construct parts of a ship, we would be able to travel much farther with more supplies at a lower cost than we currently can.

One area that would be particularly interesting to launch to from the moon would be Mars. Mars was once thought to have life, so it has been a popular planet to study and send spacecraft to. While we have gained a lot of knowledge about the planet through remote observation and through machine soil analysis, we would undoubtedly be able to get a lot more information much more quickly if humans could go there directly. The problem, of course, is making sure that there are enough resources to not only get to the planet, but also to get back. This is simply not possible to do at the moment, even using the moon as a Launchpad. Therefore, we proposed an idea that would make this journey more feasible: to move Mars closer to the Earth using impact events. Not only would this make it easier to travel to, but would also bring it closer to the habitable zone, which would aid in terraforming it for life.

In order to see if this is possible we decided to see what it would take to move Mars just 0.2 AU closer to the Earth using both a single impact event and multiple impact events. We concluded that while this is theoretically possible, it is not currently worth pursuing because of the time scales involved. Finding and aligning asteroids and comets to hit Mars with would take time on the order of centuries. Then, we would need to make sure to collide objects on the other side to slow down Mars so that it gets to the appropriate zone. On top of that, the collision(s) would likely leave Mars uninhabitable.

We also considered what kind of impact space travel will have on the economics and societies of Earth. There are currently many avenues for space commercialization. Space offers new possibilities for obtaining energy and resource mining in general. Helium-3, for example, is a rare resource on Earth, but relatively more common on the Moon and Mercury. This could be mined and used in various applications (such as fusion reactors) to obtain more energy for both the Earth and a moon base. The moon is the most viable place to create a base because of its proximity to the Earth and because of its low gravity. We would use large scale 3D printers to build structures on the moon necessary for launching ships or storing materials. The material for these structures would be created from the very strong lunar regolith and some sort of binding agent. Once we have a moon base, we could use the Hohmann transfer orbit to get supplies to and from Mercury in 300 days. This number can be decreased with the addition of solar sails. These are just some of the ways that we would get resources for the Earth from outer space. Other possible avenues for commercialization are fixing up or recycling old satellites. These satellites are vital to communication on Earth because they are used for applications like sending cell phone and GPS signals and for providing Internet access to remote areas. Cleaning up the old satellites and other debris will make space travel easier and safer for future generations.

On the societal side, we have the possibility of using genetic engineering to make people more resistant to radiation. Scientists have discovered bacteria that can take damage at the DNA level from radiation, but that fix their DNA right back up. This would be a very useful trait for humans in space that would be much more likely to suffer from the ill effects of radiation. One of the problems with this is that once we can genetically modify humans to be more resistant to radiation, we would be able to use similar technology to modify other aspects of humanity, which poses an ethical issue. Who gets access to this technology? How do we decide if certain traits are truly better than others? In general, there is no “best” trait because different traits fare better in different environment. In the context of this project, we have decided that only genetic engineering relating to minimizing health risks specifically for space travel should be pursued.

Another way that society on Earth would be impacted by space travel is through using technology designed specifically for space back on Earth. The NASA program, for example, has led to technologies that are currently used in data storage, athletic shoes, memory metals, smoke detectors, clocks, robotics, cell phones, and countless other areas. Future space travel technology would likely influence technology on Earth in a similar fashion. This will create a new kind of "Space Culture" that we have not seen before. Space travel will become a norm and advanced technology by today's standards will be much more commonplace and this will create new perspectives for future generations that we can only dream of.

Further advances in space technology will usher in a whole new era for humanity. We currently have trained professionals (i.e. astronauts) that can visit space, but the gears are already in place so that in future generations, everyone will be able to travel to space and even live outside the Earth. This is particularly important because humanity will not be able to exist on the Earth indefinitely. The Earth could be devastated by a collision with a large NEO (near-Earth object), by a biological disaster, by rouge black holes, by natural events such as mass earthquakes or catastrophic volcanic eruptions, etc. If none of that occurs, then the Sun will pose a threat as it enters the Red Giant phase in about 5 billion years. In any case, if humanity is to survive a few billion years for now, we will need to be able to colonize other plants.

Works Cited

Anand, Preetha, Ajaikumar B. Kunnumakara, Chitra Sundaram, Kuzhuelil B. Harikumar, Sheja T. Tharakan, Oiki S. Lai, Bokyung Sung, and Bharat B. Aggarwal. "Cancer Is a Preventable Disease That Requires Major Lifestyle Changes." *Cancer Is a Preventable Disease That Requires Major Lifestyle Changes*. 15 July 2008. Web. 13 Feb. 2011. <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2515569/?tool=pmcentrez>.

"(99948) Apophis." *AstroSurf*. Web. 11 Oct. 2010. <http://www.astrosurf.com/comets/neos/99948_Apophis/99948.htm>.

Aravind, P. K. "The Physics of the Space Elevator." *American Journal of Physics* 75.2 (2007): 125-30. *Scitation*. Web. 12 Oct. 2010. <http://scitation.aip.org/journals/doc/AJPIAS-ft/vol_75/iss_2/125_1.html>.

"Ancient Aviation." *NASCA*. Web. 08 Sept. 2010. <http://www.nasca.org.uk/Ancient__Aviation_/ancient__aviation_.html>.

"Antarctic Meteorite Newsletter, Volume 24, No. 1." *NASA Technical Reports Server*. Johnson Space Center, Feb. 2001. Web. 12 Sept. 2010. <http://ntrs.nasa.gov/search.jsp?R=231882&id=1&as=false&or=true&qs=Ntt=20050182971&Ntk=all&Ntx=mode+matchall&Ns=HarvestDate%7c1&N=0>.

Arya, Subash C. "Use of Urine Cultures in a Novel Filter Paper Dilution System." *NCBI*. J Clin Microbiol, July 2000. Web. 14 Sept. 2010. <Use of Urine Cultures in a Novel Filter Paper Dilution System>.

Astronomy Courses Admin. "Sumerian 6 Sign Zodiac and Mayan Calendar 360-Day-Tun-Years » Astronomy Courses." *Astronomy Courses*. 2011. Web. 07 Sept. 2010. <http://www.suncityastronomy.org/sumerian-6-sign-zodiac-and-mayan-calendar-360-day-tun-years>.

Axford, Roy A., Thomas C. Jedrey, and Michael A. Rupar. "Advanced Shipboard Communications Demonstrations with ACTS." *NASA Technical Reports Server*. 03 Nov. 2004. Web. 11

Sept. 2010.
<http://ntrs.nasa.gov/search.jsp?R=878616&id=1&as=false&or=true&qs=Ntt=20000084157&Ntk=all&Ntx=mode+matchall&Ns=HarvestDate%7c1&N=0>.

B., Phil. "The Problem with Space Debris and Possible Solutions « Phil for Humanity." *Phil for Humanity*. Web. 25 Feb. 2011.

BBC. "BBC NEWS | Science/Nature | Cosmos 1: Sailing on Sunlight." *BBC News*. 22 Jan. 2005. Web. 20 Sept. 2010. <http://news.bbc.co.uk/2/hi/science/nature/4104282.stm>.

Bellis, Mary. "How a Solid Propellant Rocket Works." *About.com*. Web. 20 Sept. 2010. <http://inventors.about.com/od/rstartinventions/a/SolidPropellant.htm>.

Belmonte, Juan A., and Mosalam Shaltout. "ScienceDirect - Advances in Space Research : Keeping Ma'at: An Astronomical Approach to the Orientation of the Temples in Ancient Egypt." *ScienceDirect - Home*. 23 Aug. 2009. Web. 8 Sept. 2010. <http://www.sciencedirect.com/science/article/B6V3S-4X2JSY4-1/2/f4b27a7a512b5e2260e904a48195ecf2>.

Biology Online. "Genetic Engineering Advantages & Disadvantages - Biology Online." *Biology Online*. 28 Apr. 2006. Web. 25 Jan. 2011. <http://www.biology-online.org/2/13_genetic_engineering.htm>.

Bluck, John. "NASA - NASA Developing Robots with Human Traits." *NASA - Home*. 24 Mar. 2005. Web. 19 Dec. 2010. <http://www.nasa.gov/vision/universe/roboticexplorers/robots_human_coop.html>.

Bluth, B. J. "Sociology and Space Development." *NASA/JSC Software, Robotics and Simulation Division*. California State University. Web. 19 Dec. 2010. <http://er.jsc.nasa.gov/seh/sociology.html>.

Bonsor, Kevin. "How Space Elevators Will Work" 06 October 2000. HowStuffWorks.com. 12 October 2010 <http://science.howstuffworks.com/space-elevator.htm> .

Bonsor, Kevin, and Julia Layton. "HowStuffWorks "Mapping the Human Genome"" *Howstuffworks*. 10 May 2001. Web. 23 Jan. 2011. <http://science.howstuffworks.com/environmental/life/genetic/designer-children1.htm>.

Braeunig, Robert A. "Basics of Space Flight: Orbital Mechanics." *Rocket and Space Technology*. 1997, 2005, 2007, 2008. Web. 04 Oct. 2010. <http://www.braeunig.us/space/orbmech.htm>.

Braeunig, Robert A. "Basics of Space Flight: Rocket Propellants." *Www.braeunig.us*. 1996, 2005, 2006, 2008. Web. 20 Sept. 2010. <http://www.braeunig.us/space/propel.htm>.

Braeunig, Robert A. "Basics of Space Flight: Rocket Propulsion." *Rocket and Space Technology*. 1997, 2005, 2007, 2009. Web. 04 Oct. 2010. <http://www.braeunig.us/space/propuls.htm>.

Brain, Marshall. "HowStuffWorks "Solid-fuel Rocket Engines: Fuel Mixture"" *Howstuffworks "Science"* 1 Apr. 2000. Web. 20 Sept. 2010. <http://science.howstuffworks.com/rocket3.htm>.

Cain, Fraser. "Solar Flares." *Universe Today*. 17 Sept. 2008. Web. 12 Sept. 2010. <http://www.universetoday.com/18273/solar-flares/>.

Campbell, Jonathan W. "Using Lasers to Remove Orbital Debris." *Findarticles.com*. 2000. Web. 25 Feb. 2011. <http://findarticles.com/p/articles/mi_m0ICK/is_4_14/ai_75578183/?tag=content;col1> .

Caroll, Michael. "Solar Power From Space?: Orbiting Solar Panels Are on Companies' Drawing Boards." *Suite101.com: Online Magazine and Writers' Network*. 29 Sept. 2009. Web. 12 Feb. 2011. <http://www.suite101.com/content/solar-power-from-space-a154044>.

Committee on International Space Station Meteoroid/Debris Risk Management, Aeronautics and Space Engineering Board, Commission on Engineering and Technical Systems, and National Research Council. "Protecting the Space Station from Meteoroids and Orbital Debris." *The National Academies Press*. 1997. Web. 25 Feb. 2011. <http://www.nap.edu/openbook.php?record_id=5532&page=R1>.

Crystalinks. "Sumerian Calendars and Astronomy - Crystalinks." *Crystalinks*. Web. 07 Sept. 2010. <http://www.crystalinks.com/sumercalendars.html>.

De Selding, Peter B. "Space Forecast Predicts Satellite Production Boom | Space.com." *Space, NASA Information & News | Outer Space Flight Videos & Pictures | Astronomy, Solar System Images | Space.com*. 15 June 2009. Web. 25 Nov. 2010. <http://www.space.com/news/090615-satellite-futures.html>.

"Employment Situation Summary." *U.S. Bureau of Labor Statistics*. 4 Feb. 2011. Web. 4 Feb. 2011. <http://www.bls.gov/news.release/empsit.nr0.htm>.

"Ephemeris.com Early History of Astronomy - Ancient Greece." *Ephemeris.com - Sun to Sedna*. 2003-2004. Web. 5 Sept. 2010. <http://ephemeris.com/history/greece.html>.

Ericson, Gwen. "Common Genetic Mutation Makes Cancer Resistant to Radiation, Siteman Cancer Center." *Siteman Cancer Center*. 8 June 2009. Web. 12 Feb. 2011. <http://www.siteman.wustl.edu/ContentPage.aspx?id=3712>.

Faul, Henry. "VEBTC: Tektite Information Page." *Home | The University of Texas at Austin*. 1966. Web. 10 Dec. 2010. <http://www.utexas.edu/tmm/npl/meteorites/tektites/tektite_info.html>.

Firth, Niall. "How Solar Panels in Space Could Be Used to Beam Renewable Energy Back to Earth." *The Daily Mail Online*. 18 Apr. 2009. Web. 09 Feb. 2011. <http://www.dailymail.co.uk/sciencetech/article-1170945/How-solar-panels-space-used-beam-renewable-energy-Earth.html>.

Frankfort, Henri. *Ancient Egyptian Religion: An Interpretation*. Harper and Row, 1961. Print.

Freudenrich, Craig. "Howstuffworks "How Nuclear Fusion Reactors Work"" *Howstuffworks*. 11 Aug. 2005. Web. 11 Feb. 2011. <http://science.howstuffworks.com/fusion-reactor.htm/printable>.

Freudenrich, Craig. "HowStuffWorks "How Solar Sail Technology Works"" *Howstuffworks "Science"* 6 Apr. 2001. Web. 19 Sept. 2010. <http://science.howstuffworks.com/solarsail1.htm>.

Friedman, Louis. "Solar Sail Update, June 23, 2008 - What We Do." *The Planetary Society*. 23 June 2008. Web. 20 Sept. 2010. <http://www.planetary.org/programs/projects/solar_sailing/20080623.html>.

Greensfelder, Liese. "Why Astronauts Suffer Bone Loss." *Medical News Today: Health News*. 23 Feb. 2004. Web. 06 Mar. 2011. <http://www.medicalnewstoday.com/articles/6098.php>.

Globus, Al. "Space Colonization Basics." *Space Settlement*. NASA, 12 Jan. 2010. Web. 11 Sept. 2010. <http://settlement.arc.nasa.gov/Basics/wwwwh.html#why>.

Gronwall, Caryl. "Motions of the Earth and Moon." *Astronomy and Astrophysics*. Web. 05 Oct. 2010. <http://www.astro.psu.edu/users/caryl/a10/lec2_2d.html>.

Harvard-Smithsonian Center for Astrophysics and World Science Staff. ""Rogue" Black Holes out There, but Fear Not: Astronomers." *World Science - Science News*. 29 Apr. 2009. Web. 13 Sept. 2010. <http://www.world-science.net/othernews/090430_blackhole.htm>.

Hawke, Chris. "Coming Soon: Immortality? - CBS News." *Breaking News Headlines: Business, Entertainment & World News - CBS News*. 13 Feb. 2005. Web. 30 Jan. 2011. <http://www.cbsnews.com/stories/2005/02/13/tech/main673726.shtml>.

Hayflick, L. "The Illusion of Cell Immortality." *British Journal of Cancer* (2000): 841-46. Print.

Herbert, George W. "Lunar Concrete (George Herbert)." *Yarchive*. 9 Mar. 1988. Web. 10 Dec. 2010. <http://www.yarchive.net/space/science/lunar_concrete.html>.

Hilo, Jessica. "Bacteria Working in the Shadows: Deinococcus Radioduran." *Smart Journalism. Real Solutions. Miller-McCune.* 20 Oct. 2010. Web. 13 Sept. 2010. <http://www.miller-mccune.com/science-environment/space-age-conan-the-bacterium-24373/>.

Hirata, Chris. "Rockets and Space Transportation." *The Spaceships of Ezekiel*. Web. 12 Sept. 2010. <http://www.spaceshipsofezekiel.com/html/misc-info_on_specific_impulse.html>.

Hoooker, Richard. "Sumerians." *Washington State University - Pullman, Washington*. 06 June 1999. Web. 07 Sept. 2010. <http://www.wsu.edu:8080/~dee/MESO/SUMER.HTM>.

Hough, Andrew. "Nasa Warns Solar Flares from 'huge Space Storm' Will Cause Devastation - Telegraph." *Telegraph.co.uk - Telegraph Online, Daily Telegraph and Sunday Telegraph - Telegraph*. 14 June 2010. Web. 12 Sept. 2010. <http://www.telegraph.co.uk/science/space/7819201/Nasa-warns-solar-flares-from-huge-space-storm-will-cause-devastation.html>.

"How Do Volcanoes Affect World Climate?: Scientific American." *Science News, Articles and Information | Scientific American*. 15 Apr. 2002. Web. 13 Sept. 2010. <http://www.scientificamerican.com/article.cfm?id=how-do-volcanoes-affect-w>.

"Insulation and Heat Resistant Materials." *Baker Precision*. Web. 13 Sept. 2010. <http://www.bakerprecision.com/insulat.htm>.

Jones, Brent. "Straight from the Laboratory - USATODAY.com." *News, Travel, Weather, Entertainment, Sports, Technology, U.S. & World - USATODAY.com*. 19 Aug. 2007. Web. 25 Feb. 2011. <http://www.usatoday.com/news/top25-science.htm>.

Keim, By Brandon. "How to Defend Earth Against an Asteroid Strike | Wired Science | Wired.com." *Wired News*. Web. 29 Sept. 2010. <http://www.wired.com/wiredscience/2009/03/planetdefense/>.

Knier, Gil. "How Do Photovoltaics Work?" *NASA Science*. Web. 9 Feb. 2011. <http://science.nasa.gov/science-news/science-at-nasa/2002/solarcells/>.

Lahanas, Michael. "Ancient Greek Science and Technology." *Hellenica, Information about Greece and Cyprus, Michael Lahanas*. Web. 5 Sept. 2010. <http://www.mlahanas.de/Greeks/Greeks.htm>.

Lemonick, Michael D. "Solar Power from Space: Moving Beyond Science Fiction by Michael D. Lemonick: Yale Environment 360." *Yale Environment 360: Opinion, Analysis, Reporting & Debate*. 31 Aug. 2009. Web. 11 Feb. 2011. <http://e360.yale.edu/feature/solar_power_from_space_moving_beyond_science_fiction/2184/>.

Livanis, Grigorios, and Charles B. Moss. "The effect of Africanized honey bees on honey production in the United States: An informational approach." *Ecological*

Economics 69.4 (2010): 895+. *Academic OneFile*. Web. 15 Sept. 2010.

"LexisNexis® Academic & Library Solutions." *LexiNews*. 03 Apr. 2010. Web. 08 Feb. 2011. <http://www.lexisnexis.com/hottopics/lnacademic/?verb=sr&csi=8422&sr=lni(7Y50-R130-Y9NT-21XW)>.

Love, Jamie. "The Earth's Motion." *Synapses*. 1997-2011. Web. 05 Sept. 2010. <http://www.synapses.co.uk/astro/earthmot.html>.

Lovgren, Stefan. "Space Junk Cleanup Needed, NASA Experts Warn." *National Geographic*. 19 Jan. 2006. Web. 01 Mar. 2011. <http://news.nationalgeographic.com/news/2006/01/0119_060119_space_junk_2.html>.

Lu, Edward T., and Stanley G. Love. "Gravitational Tractor for Towing Asteroids." *Nature* 438 (2005): 177-78. *Nature Publishing Group*. 9 Nov. 2005. Web. 11 Oct. 2010. <http://www.nature.com/nature/journal/v438/n7065/full/438177a.html>.

Magnuson, Stew. "DARPA Studying New Ways to Repair Satellites, Remove Space Debris." *National Defense*. National Defense Magazine, 15 Apr. 2010. Web. 25 Feb. 2011. <http://www.nationaldefensemagazine.org/blog/Lists/Posts/Post.aspx?ID=108>.

Malik, Tariq. "Space Station Astronauts Lose Bone Strength Fast | Space.com." *Space, NASA Information & News | Outer Space Flight Videos & Pictures | Astronomy, Solar System Images | Space.com*. 26 Jan. 2009. Web. 06 Mar. 2011. <http://www.space.com/6354-space-station-astronauts-lose-bone-strength-fast.html>.

Milligan, Tim V. "How Multi-Stage Model Rockets Work." *Apogee Rockets*. Web. 22 Sept. 2010. <http://www.apogeerockets.com/education/how_to_multi-stage.asp>.

Minard, Anne. "Gamma-Ray Burst Caused Mass Extinction?" *Daily Nature and Science News and Headlines | National Geographic News*. 3 Apr. 2009. Web. 12 Sept. 2010.

<http://news.nationalgeographic.com/news/2009/04/090403-gamma-ray-extinction.html>.

Moskowitz, Clara. "Microbes With the Right Stuff? Synthetic Life Could Make Mars Trips Easier | Space.com." *Space.com*. 23 Sept. 2010. Web. 23 Jan. 2011. <http://www.space.com/9173-microbes-stuff-synthetic-life-mars-trips-easier.html>.

Munchen, Helmholtz Z., Michael Dingfelder, Pavel Kundrat, and Peter Jacob. "ScienceDirect - Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis : Track Structures, DNA Targets and Radiation Effects in the Biophysical Monte Carlo Simulation Code PARTRAC." *ScienceDirect - Home*. 31 Jan. 2011. Web. 12 Feb. 2011. <http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6T2C-522SHT7-1&_user=74021&_coverDate=01/31/2011&_rdoc=1&_fmt=high&_orig=search&_origin=search&_sort=d&_docanchor=&view=c&_acct=C000005878&_version=1&_urlVersion=0&_userid=74021&md5=6ca2f060e8be2e18ede8859481d452ff&searchtype=a>.

"NASA - Exposure to the Microgravity Environment of Space Causes Astronauts to Lose Calcium from Bones." *NASA's Space Biology Outreach Program - Web of Life*. Web. 06 Mar. 2011.

"NASA - NASA and World Book." *NASA - Home*. Web. 22 Sept. 2010. <http://www.nasa.gov/topics/nasalife/features/worldbook.html>.

NASA. "NASA - Spinoff Technologies." *NASA - Home*. 29 Dec. 2009. Web. 12 Sept. 2010. <http://www.nasa.gov/offices/ipp/centers/jsc/spinoff/index.html>.

NASA/JSC Office of Public Affairs. "SPAACSE -- Benefits from Space." *SPAACSE, Inc.* 1999-2000. Web. 12 Sept. 2010. <http://www.stars4space.org/Benefits.html>.

National Ait and Space Museum. "NASM--Apollo to the Moon--Steps on the Flightpath." *Smithsonian National Air and Space Museum*. July 1999. Web. 05 Oct. 2010. <http://www.nasm.si.edu/exhibitions/attm/flightpath/a11.steps.html>.

Park, Albert. "Messenger Mission to Mercury." *University of Colorado*. 2004. Web. 26 Nov. 2010. <http://ccar.colorado.edu/asen5050/projects/projects_2004/park/>.

Pidwirny, Michael. "Solar Radiation." *Encyclopedia of Earth*. 24 Jan. 2010. Web. 25 Nov. 2010. <http://www.eoearth.org/article/Solar_radiation>.

Powell, Corey S. "20 Ways the World Could End Swept Away." *Lambert Dolphin's Library*. Oct. 2000. Web. 12 Sept. 2010. <http://ldolphin.org/twentyways.html>.

Powell, Russel, and Allen Buchanan. "Sign In — J Med Philos." *Oxford Journals | Humanities & Medicine | Journal of Medicine and Philosophy*. 12 Jan. 2011. Web. 11 Feb. 2011. <http://jmp.oxfordjournals.org/content/early/2011/01/12/jmp.jhq057.full>.

"Race to Mars : Known Effects of Long-term Space Flights on the Human Body." *Race to Mars*. Discovery Channel. Web. 19 Dec. 2010. <http://www.racetomars.ca/mars/article_effects.jsp>.

"Reports outline bioterrorism research from Centers for Disease Control and Prevention." *Medical Letter on the CDC & FDA* 12 Sept. 2010: 4. *Academic OneFile*. Web. 15 Sept. 2010.

"Research Probes Astronauts' Bone Loss In Outer Space." *Science Daily: News & Articles in Science, Health, Environment & Technology*. 17 July 2006. Web. 09 Feb. 2011. <http://www.sciencedaily.com/releases/2006/07/060717091230.htm>.

"Rockets and Missiles - Humans, Body, Used, Water, Process, Earth, Law, Type, Chemical, Energy, Methods, Reaction, Gas, System, Oxygen, Air, Parts, Cause." *Science Clarified*. Web. 20 Sept. 2010. <http://www.scienceclarified.com/Ro-Sp/Rockets-and-Missiles.html>.

Rusell, Randy. "Atmosphere of Mercury." *Windows to the Universe*. 11 Aug. 2010. Web. 26 Nov. 2010. <http://www.windows2universe.org/mercury/Atmosphere/atmosphere.html>.

Russel, Randy. "The Multispectral Sun." *Windows to the Universe*. 18 Apr. 2007. Web. 14 Feb. 2011. <http://www.windows2universe.org/sun/spectrum/multispectral_sun_overview.html>.

Sato, Y., T. Takeda, and J. Iwamoto. "Interventions to Prevent Bone Loss in Astronauts during Space Flight." *PubMed.gov*. US National Library of Medicine, 5 June 2005. Web. 09 Feb. 2011. <http://www.ncbi.nlm.nih.gov/pubmed/16077253>.

S, Zamenhof, Bursztyn H, Reddy TK, and Zamenhof PJ. "Genetic Factors in Radiation Resistance of Bacillus Subtilis." *PubMed.gov*. July 1965. Web. 22 Feb. 2011. <http://www.ncbi.nlm.nih.gov/pubmed/16562003>.

Sabathier, Vincen G. "Costs of an International Lunar Base." *CCIS*. 24 Sept. 2009. Web. 19 Dec. 2010. <http://csis.org/publication/costs-international-lunar-base>.

Science Daily. "Hundreds Of Rogue Black Holes May Roam The Milky Way, Swallowing Anything That Gets Too Close." *Science Daily: News & Articles in Science, Health, Environment & Technology*. 29 Apr. 2009. Web. 13 Sept. 2010. <http://www.sciencedaily.com/releases/2009/04/090429120851.htm>.

Shandilya, Anju. "Benefits of Genetic Engineering." *Buzzle Web Portal: Intelligent Life on the Web*. Web. 25 Jan. 2011. <http://www.buzzle.com/articles/benefits-of-genetic-engineering.html>.

Sharma, Rakesh. "Chemical, Biological, Radiological, and Nuclear disasters: Pitfalls and perils." *Journal of Pharmacy and Bioallied Sciences* 2.3 (2010): 155. *Academic OneFile*. Web. 14 Sept. 2010.

Singh, Timon. "Space: The Final Junkyard | GDS Publishing." *European Construction and Infrastructure News | GDS Publishing*. 24 Aug. 09. Web. 25 Feb. 2011. <http://www.euinfrastructure.com/news/Space-The-Final-Junkyard/>.

"Solar Flares." *Hesperia*. Web. 12 Sept. 2010. <http://hesperia.gsfc.nasa.gov/sftheory/flare.htm>.

"Space Solar Power." *National Space Society*. Web. 09 Feb. 2011. <http://www.nss.org/settlement/ssp/>.

Stone, Marcia. "A Microbe Tough Enough For Mars Reveals Its Survival Tactics." *Suite101.com: Online Magazine and Writers' Network*. 4 June 2010. Web. 13 Sept. 2010. <http://www.suite101.com/content/martian-microbe-reveals-astounding-survival-tactics-a244700>.

"Sumerian Culture." *World History International: World History Essays From Prehistory To The Present*. Web. 07 Sept. 2010. <http://history-world.org/sumerian_culture.htm>.

Than, Ker. "Earth under Threat from Rogue Black Holes | COSMOS Magazine." *COSMOS Magazine | The Science of Everything*. 20 Jan. 2008. Web. 13 Sept. 2010. <http://www.cosmosmagazine.com/news/1777/earth-under-threat-rogue-black-holes>.

Toothman, Jessica, and Scott Aldous. "HowStuffWorks "How Silicon Makes a Solar Cell"" *Howstuffworks*. 1 Apr. 2010. Web. 29 Feb. 11. <http://science.howstuffworks.com/environmental/energy/solar-cell2.htm>.

The New York Times - Breaking News, World News & Multimedia. Web. 29 Sept. 2010. <http://www.nytimes.com/2007/12/09/magazine/09_5_asteroid.html>.

The Ultimate Space Place. "NASA Spinoffs, Space Benefits, Space History, NASA Space Spinoffs, NASA Technology Products." *The Space Place*. 02 Feb. 2004. Web. 13 Sept. 2010. <http://www.thespaceplace.com/nasa/spinoffs.html>.

"United States Unemployment Rate." *TradingEconomics.com - Free Indicators for 231 Countries.* Web. 4 Feb. 2011. <http://www.tradingeconomics.com/Economics/Unemployment-Rate.aspx?Symbol=USD>.

Vieru, Tudor. "First Genetically-Screened Baby Born in the UK - Softpedia." *Latest News - Softpedia*. 9 Jan. 2009. Web. 25 Jan. 2011. <http://news.softpedia.com/news/First-Genetically-Screened-Baby-Born-in-the-UK-101613.shtml>.

"Volcanoes and Climate." *COTF*. Web. 13 Sept. 2010. <http://www.cotf.edu/ete/modules/volcanoes/vclimate.html>.

Wall, Mike. "Biologist: Space Travelers Can Benefit From Genetic Engineering | Space.com." *Space, NASA Information & News | Outer Space Flight Videos & Pictures | Astronomy, Solar System Images | Space.com*. 01 Nov. 2010. Web. 23 Jan. 2011. <http://www.space.com/9439-biologist-space-travelers-benefit-genetic-engineering.html>.

Wall, Mike. "Rocket Blasts off with Solar Sail and More - Technology & Science - Space - Space.com - Msnbc.com." *Breaking News, Weather, Business, Health, Entertainment, Sports, Politics, Travel, Science, Technology, Local, US & World News - Msnbc.com*. 19

Nov. 2010. Web. 01 Dec. 2010. <http://www.msnbc.msn.com/id/40278972/ns/technology_and_science-space/>.

Wall, Mike. "Want to Mine the Solar System? Start With the Moon | Space.com." *Space, NASA Information & News | Outer Space Flight Videos & Pictures | Astronomy, Solar System Images | Space.com*. 30 Oct. 2010. Web. 19 Dec. 2010. <http://www.space.com/news/moon-mining-space-exploration-101030.html>.

Webre, Alfred L. "2012 May Bring the "perfect Storm" - Solar Flares, Systems Collapse - Seattle Exopolitics | Examiner.com." *Washington DC News, Washington DC Information, Washington DC Events - Examiner.com | Examiner.com*. 1 Apr. 2009. Web. 12 Sept. 2010. <http://www.examiner.com/exopolitics-in-seattle/2012-may-bring-the-perfect-storm-solar-flares-systems-collapse>.

Williams, David R. "Moon Fact Sheet." *NSSDC*. 02 Feb. 2010. Web. 04 Oct. 2010. <http://nssdc.gsfc.nasa.gov/planetary/factsheet/moonfact.html>.

WIlliams, David R. "Planetary Fact Sheets." *Welcome to the NSSDC!* 06 Jan. 2005. Web. 13 Dec. 2010. <http://nssdc.gsfc.nasa.gov/planetary/planetfact.html>.

Wilson, J.r. "NASA - Space Program Benefits: NASA's Positive Impact on Society." *NASA - Home*. 27 Aug. 2008. Web. 13 Sept. 2010. <http://www.nasa.gov/50th/50th_magazine/benefits.html>.

Wright, Jerome L. "Space Sailing - Solar Pressure." *Space Sailing - Solar Sailing - Light Sailing*. 2001-2007. Web. 1 Dec. 2010. <http://sail.quarkweb.com/light.htm>.

Appendix A – Hohmann Transfer Orbit Simulation

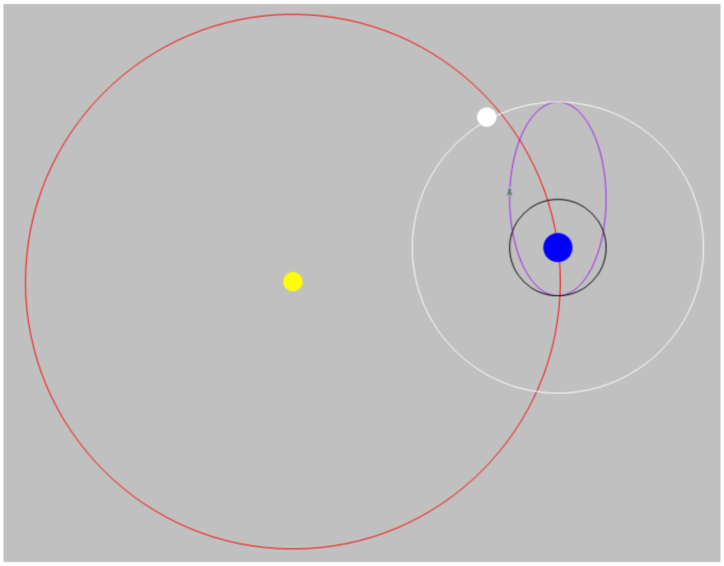

Figure 13 – Transfer orbit animation example

As discussed in the report, the Hohmann transfer orbit is an efficient way to transfer the orbit of a rocket orbiting one body in space to another body. The rocket is launched into an ellipse using some thrust and slowed down to the target area by another thrust. For this project, we have an animated example of such a transfer. It was complete using a variation of the functional programming language, Scheme, called Racket. The animation is not done to scale because it would require an unreasonably large screen to be accurate. In addition, the slightly elliptical orbits of the Earth and Moon have been simplified to be circular orbits. This is because the intent of the animation is simply to show what kind of flight path a rocket would take in order to complete the transfer. Therefore, the orbits of the Earth and Moon can be assumed to be circular without affecting the intended result.

The animation starts out with the Earth orbiting the Sun and the Moon and rocket both orbiting around the Earth. This motion was calculated using the definition of a circle and a given radius. Once the moon hits a certain point, the rocket launches into an elliptical orbit such that it reaches the top of the orbit at the same time as the moon. Throughout the whole illustration, the orbit paths of the all three bodies are continuously shown.

The animation was accomplished using the following code using the Intermediate Language with Lambda Teachpack in DrRacket:

```
;; Canvas
(define maxw 1000) ; Width of Canvas
(define maxh 800) ; Height of Canvas
(define zeropos (make-posn 0 0)) ; Top-left of Canvas
(define centerpos            ; Center of Canvas
  (make-posn (/ maxw 2)
        (/ maxh 2)))

;; Bodies
;Sun
(define sunrad 10)
(define sunpic (circle sunrad "solid" "yellow"))

; Moon
(define moonrad 10)
(define moonorbit 150)
(define moonpic (circle moonrad "solid" "white"))
(define moonpos
  (make-posn (posn-x centerpos)(- (posn-y centerpos) moonorbit)))

; Earth
(define earthrad 15)
(define earthorbit 275)
(define earthpic
  (circle earthrad "solid" "blue"))
(define earthpos
  (make-posn (posn-x centerpos)
        (- (posn-y centerpos) earthrad)))
```

```
; Rocket
(define rocketrad 50)
(define rocketpic .)

; Other
(define earthorbitring (circle earthorbit "outline" "red"))
(define moonorbitring (circle moonorbit "outline" "white"))
(define rocketorbitring (circle rocketrad "outline" "black"))
(define launchring (ellipse (* 2 rocketrad) (+ moonorbit rocketrad) "outline" "purple"))

;; Structures
(define-struct body (pic pos speed rad theta center))
(define-struct rocket (pic pos speed rad theta center))

(define-struct world (earth moon rocket))

;; Test Structures
(define earth
  (make-body earthpic earthpos 0.25 earthorbit 90 centerpos))
(define moon
  (make-body moonpic moonpos 1 moonorbit 90 earthpos))
(define rocket1
  (make-rocket rocketpic
        (make-posn (posn-x centerpos)
              (- (posn-y earthpos) rocketrad))
        3 rocketrad 90 earthpos))



(define background
  (place-image earthorbitring
        (posn-x centerpos)
        (posn-y centerpos)
```

```
           (place-image sunpic
                    (posn-x centerpos)
                    (posn-y centerpos)
                    (place-image
                     (nw:rectangle maxw maxh "solid" "silver") 0 0
                     (empty-scene maxw maxh)))))

(define world1
  (make-world earth moon rocket1))

;; Functions
(define (deg2rad ang) ; Converts angle given in degrees into radians
  (/ (* ang pi) 180))

(define (movebody body) ; Moves the planets in a circular orbit
  (make-posn (+ (posn-x (body-center body))
            (* (body-rad body)
              (cos (deg2rad (body-theta body)))))
          (- (posn-y (body-center body))
            (* (body-rad body)
              (sin (deg2rad (body-theta body)))))))

(define (moverocket world) ; Moves the rocket in a circular orbit
  (make-posn (+ (posn-x (rocket-center (world-rocket world)))
            (* (rocket-rad (world-rocket world))
              (cos (deg2rad (rocket-theta (world-rocket world))))))
          (- (posn-y (rocket-center (world-rocket world)))
            (* (rocket-rad (world-rocket world))
              (sin (deg2rad (rocket-theta (world-rocket world))))))))

(define (launchrocket world) ; Launches the rocket into an elliptical orbit
  (make-posn (+ (posn-x (rocket-center (world-rocket world)))
```

```
              (* (rocket-rad (world-rocket world))
                 (cos (deg2rad (rocket-theta (world-rocket world))))))
            (- (- (posn-y (body-pos (world-earth world))) (rocket-rad (world-rocket world)))
              (* (- (body-rad (world-moon world)) (rocket-rad (world-rocket world)))
                 (sin (deg2rad (rocket-theta (world-rocket world))))))))

(define (launch? world) ; Decides if the rocket is ready to launch
  (<= (body-theta (world-moon world)) -235))

(define (orbit world) ; Starts the orbit animation and launches the rocket
  (make-world
   (make-body (body-pic (world-earth world))
             (movebody (world-earth world))
             (body-speed (world-earth world))
             (body-rad (world-earth world))
             (- (body-theta (world-earth world))
                (body-speed (world-earth world)))
             centerpos)
   (make-body (body-pic (world-moon world))
             (movebody (world-moon world))
             (body-speed (world-moon world))
             (body-rad (world-moon world))
             (- (body-theta (world-moon world))
                (body-speed (world-moon world)))
             (body-pos (world-earth world)))
   (make-rocket (rocket-pic (world-rocket world))
              (cond
                [(launch? world) (launchrocket world)]
                [else (moverocket world)])
              (rocket-speed (world-rocket world))
              (rocket-rad (world-rocket world))
              (- (rocket-theta (world-rocket world))
```

```
        (rocket-speed (world-rocket world)))
       (body-pos (world-earth world)))))

(define (done? world) ; Stops the animation when the moon and rocket are close enough
  (and (<= (abs (- (posn-x (body-pos (world-moon world)))
        (posn-x (rocket-pos (world-rocket world))))) 2)
    (<= (abs (- (posn-y (body-pos (world-moon world)))
        (posn-y (rocket-pos (world-rocket world))))) 2)))

; Draws the next image of the world
(define (draw world)
  (place-image (body-pic (world-earth world))
       (posn-x (body-pos (world-earth world)))
       (posn-y (body-pos (world-earth world)))
       (place-image (rocket-pic (world-rocket world))
            (posn-x (rocket-pos (world-rocket world)))
            (posn-y (rocket-pos (world-rocket world)))
            (place-image (body-pic (world-moon world))
                 (posn-x (body-pos (world-moon world)))
                 (posn-y (body-pos (world-moon world)))
                 (place-image moonorbitring
                      (posn-x (body-pos (world-earth world)))
                      (posn-y (body-pos (world-earth world)))
                      (place-image rocketorbitring
                           (posn-x (body-pos (world-earth world)))
                           (posn-y (body-pos (world-earth world)))
                           (place-image launchring
                                (posn-x (body-pos (world-earth world)))
                                (- (posn-y (body-pos (world-earth world))) rocketrad)
                                background)))))))

;; Display the results
```

```
(big-bang maxw maxh 1/60 world1) ; Sets the redraw rate at 60Hz
(on-tick-event orbit) ; Calls the orbit function every 1/60 of a second
(on-redraw draw) ; Calls the redraw function every 1/60 of a second
(stop-when done?) ; Calls the stop function
```