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# Lunar and Near-Earth Development

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LUNAR AND NEAR-EARTH DEVELOPMENT

An Interactive Qualifying Project Report

submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

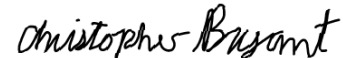
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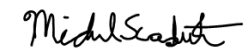
  
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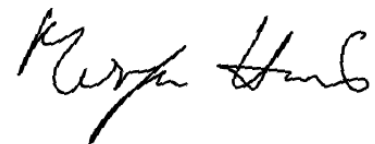
  
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1. space
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3. humanity

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## **Abstract**

We investigated the social and technological aspects and requirements of colonizing the moon and its impacts on humanity. To this end we considered various visionary technologies for the establishment of a successful lunar base. In depth studies were performed regarding the commercial motivations, laws and consumer applications involved in a lunar base. Such a base will serve as a focal point for helium-3 mining, the detection and observation of near-Earth objects and will serve as a spaceport to the planets.

## **Executive Summary**

For ages mankind has been fascinated with the universe. A thirst for knowledge has driven humanity to reach farther out to the world we inhabit, exploring each corner, and to what lay beyond this planet. The reasons to venture out into the universe are as vast as the space to be explored. Many justify this push for learning with the idea of the exploring spirit. As seen throughout history mankind pushes the limits to comprehend the happenings of their surroundings. From conquering the skies to exploring the depths, the exploring spirit has lead mankind to new understandings and new applications to further their quest. Although this spirit does not die too easily, it does raise enough mass involvement need to push mankind to its limits. Threats to survival are evident in that entire species have been wiped out in one cataclysmic event. Branching out humanity, to other parts of space, increases the probability that the human race will endure an asteroid collision, or a sudden ice age. Global dimming has been masking global warming for years. If not kept in check, the pollution from many of mankind's industrial processes will lead to a total climatic change that will test the survival of humanity.

These motivations lead to great technological advances that trickle back down to the consumer level. In order to traverse the vastness of space efficient use of energy is needed by space explorers. This advancement in energy can then be applied to the consumer level and in turn further benefit humanity. New technologies, such as satellite communications and telemetry are developed for use in space, can be applied here on Earth in many areas, such as reprogrammable pacemakers. Ideas can be tested for practical consumer purposes such as a satellite system developed for supplying power. The synergistic effect between the consumer level and the space program leads to mutual development.

A huge limitation to prolonged space exploration is the detrimental effect of radiation. Radiation protection is a key aspect to the future of space missions. New materials as well as novel applications protect the space explorers from the deadly radiation. Radiation shields that utilize the charge of the incoming particles are one method of protecting astronauts. By using a combination of materials such as the Kevlar in astronaut suits as well as the recently developed RXF1, protection technology can be developed that is both function and affordable. When these advances are just not enough missions must rely on the help of robotics.

Artificial intelligence and robots play a large role in the future of space exploration. With the obvious benefits of keeping human life out of harm's way completely, robots will serve as a simple helping hand for astronauts. NASA will be able to use artificial intelligence to send a rover to explore the surface of the moon or any other planet. Software that allows a machine to learn and reason like its human counterpart will propel space exploration. Missions far out of contact from planet Earth will be carried out with a guarantee of success due to the human-like intelligence of its explorers.

These missions that lie beyond this solar system present the obvious challenge of transportation. This challenge is present in the nearest of mission as well. With the development of new transportation technology the feasibility of space missions increases. With NASA's plans for Project Constellation, current fuel methods are optimized while new methods are investigated. With the application of these new methods, a more advanced understanding of the complex laws of gravity that govern motion can increase the efficiency of space travel ten-fold. Low energy orbits link planets to planets like space highways with virtually no fuel cost. These transportation methods will simplify the direct route from the Earth to the moon.

The colonization of the moon is a fundamental step to exploring other planets. There are many challenges presented by the establishment of a lunar outpost. Once the laws are in place to govern the process of moon colonization, the crew and location must be considered. With the presence of a medical expert a must, it is clear that a broad spectrum of fields must be covered by the crew as well as focused expertise. Along with the rigorous criteria for personnel, a plan must be established to supply the crew with resources at the poles of the moon, the most likely point of colonization. Supplying this outpost with water and energy will be a daunting task, which must be accomplished efficiently for future space missions to be successful.

### **Introduction & Motivations**

Francesco Bivona became involved in this project due to his interest in space travel and exploration that he has had since childhood. He is an electrical and computer engineering major, and as such was particularly interested in the technical aspects of a lunar base, such as electrostatic shielding.

Matthew Fabian has been interested in space travel and how it has advanced us both literally and symbolically as a species. His interests in computer science and interactive media have provided a great vantage point for looking at the development of computer technology required for advanced space travel.

Chris Bryant has been interested in space since his early childhood fantasy of wanting to become an astronaut. While his career goals have changed since then to the field of mechanical engineering, his interest in space intrigued him to participate in this project. His mechanical engineering amplitude proved to be a fundamental necessity for the examination of space technology.

Michael Scaduto has always been fascinated by the idea of space travel and colonization from an early age. Interest in space is what led Michael to attend Worcester Polytechnic Institute as an Aerospace Engineering major. Although his major has since changed to Civil Engineering, Michael is still intrigued with the possibilities facing humanity and space over the next half century and felt that this IQP was right for him.

The origins of the universe, as well as the laws that govern it, has always intrigued Matthew Silva Sa. His passion for learning the fundamentals of physics through mathematics led him to become involved in this project. Only by venturing beyond the world we live in can the true nature of the universe be explained. The colonization of the moon is a vital step in acquiring more knowledge of space.

Kathleen's interest in space exploration started at an early age, when she began spending hours stargazing and playing with the telescope of her father, an amateur astronomer. She was always



fascinated by the idea of humanity traveling into space and exploring the unknown. She is mainly interested in aspects of lunar colonization related to powering a potential base.

## **1 Reasons to Explore**

### **1.1 The Exploring Spirit**

There are many psychological and practical motivations for exploring space. Few will deny that deep within mankind lies the urge to discover what lies beyond what is already known. Referred to by many as “the exploring spirit,” it is the reason man has climbed to the tallest point on Earth, conquered the poles and circled the globe in a balloon. It led the conquistadores to explore other areas of the world and it has led to humanity’s inevitable firm grasp that it has on our planet. It is driven by the curiosity instilled in us from our ancestors, and our deep desire to inform ourselves of our surroundings so that we may better prepare for future endeavors. Pride also plays an important role—many European voyages to explore new lands were motivated by a sense of pride and patriotism to be the first to go somewhere or do something.

Much more recently in our history, our spirit, pride and curiosity have led mankind into an age of space exploration. With so much of our planet discovered and documented, space exploration is logically the next step of our curiosity’s focus. Satellites have been launched, probes sent out enormous distances and man has landed on the moon. What we do from here depends on the support that space exploration receives from the public in the decades to come. Many see space colonization as inevitable—it is seen with the same sense of Manifest Destiny of previous thinkers. There may be a day when humans exist but our planet will be uninhabitable from environmental shifts or catastrophic asteroid impacts. Having an extra planet we can call home is reassuring for the survival of our race.

The vacuum of space is a harsh environment. Extreme temperatures and levels of radiation along with the more obvious lack of air and water make space exploration several-fold more complicated than Earth exploration. It is much more costly and difficult to maintain human life outside the confines of our atmosphere.

History has taught us that once the envelope has been pushed, public interest dies quickly. After man had touched the moon's surface, public interest of the Apollo program steadily declined. Even if man were to walk on Mars, then what? Would the public have the patience to support space exploration with no immediate benefit? Would the explorative spirit in us all be enough to sustain us, or would our curiosity die out? The occasional millionaire may want an expensive low gravity vacation, but other reasons would certainly be needed in order for the public to justify paying for the research and development needed for such expensive endeavors.

Long term space colonization rests on several questions. Can we harvest and make use of foreign materials or will all living supplies have to come from Earth? Do we have the political and social interest to fund such expensive ventures? Will potential sources of income emerge as we explore space, allowing commerce within space to go beyond the satellite communications industry?

While a complete cost-benefit analysis should always be considered, there are many more practical and pressing reasons to develop space technology. The universe is not standing idly by. There are many threats to our planet that will require us to be prepared with tried and tested space technology.

## 1.2 Threats to the Planet: Near Earth Objects

With asteroids, environmental issues, gamma-ray bursts and ourselves, it is clear that our stay on planet Earth is a temporary one. Whether the human race can live past such a catastrophe depends on our technology and how effectively we can find and migrate to a “backup” planet.

There are threats posed against our small planet on a regular basis in the form of near-Earth objects (NEOs). These are not the only threat to humanity by any means, but they are one of the most potent. One of these asteroids caused the extinction of the dinosaurs, when it collided with the Yucatan Peninsula 65 million years ago. Such a monstrosity would have exerted a force of 200 billion kilotons on impact, judging by the Yucatan crater.<sup>1</sup>

Asteroid impacts are not always of this caliber, however. Smaller impacts are not so infrequent.

One of the more recent of such impacts occurred on October 1, 1990, when an asteroid only a few meters in diameter collided with the central Pacific Ocean, yielding only 10 kilotons.

Another larger impact brought a force of 100 kilotons to Russia, near Vladivostok in 1947. The smaller of the two was roughly equivalent to the atomic bomb that was used against Nagasaki at the end of the Second World War.<sup>2</sup>

To use nuclear weapons to alter an NEO’s trajectory, we would have to know about it far in advance. While nuclear explosives deliver tremendous force, the mass of the asteroid often negates the impact: a 10 megaton hydrogen bomb would apply about  $10^9$  N of force, but distributed over a mass so large that the generated velocity change is measured in mere thousandths of a meter per second. For such a small velocity to cause the asteroid to avoid a target 12,800 km in diameter, it must be given well over 100 years of time to do so.<sup>3</sup>

Little has been done specifically in this field; the most prominent accomplishment in progress is the Orion program, which plans to bring humans back to the moon. There have also been numerous endeavors to track near-Earth objects, or NEOs. This has been done with increasing vigor over the past decade, with two bills proposed in the United States in 2004: The Pete Conrad Act, which rewards amateur astronomers for sighting NEOs, and the George R. Brown Near-Earth Object Survey Act, which allocates \$20 billion to NASA for NEO surveying.<sup>4</sup> All of this is not particularly effective defense, but it is at least a path on which further improvements can be made. It would be beneficial to perform more detailed, possibly close-range studies on the composition of the asteroids that approach us, but it would be necessary to have actual humans at locations beyond Earth, to speed up the process of interception and to allow for multiple attempts in case the first one does not succeed. Without this, we would be dealing with probabilities with which we would not want to wager the fate of humanity, if not the fate of all life on Earth.

### **1.3 Global Dimming**

Global dimming is the effect of the gradual reduction of the amount of sunlight reaching the Earth's surface. This effect has not been accepted by the global scientific community until very recently.<sup>5</sup> It was observed by taking systematic measurements of the amount of sunlight reaching the Earth's surface since the 1950s. Global dimming has even been suggested to have hidden the effects of global warming.

This phenomenon has mainly three causes. The sun is not getting darker but clouds, air pollution, and aerosols are getting in the way reflecting a portion of the light from the sun back into space. The main cause seems to be aerosols and air pollution being put into the atmosphere by human action.<sup>6</sup> These micron or smaller sized particles are made of sulfates, black and organic carbon,

dust, and even sea salt. These aerosols and other particles absorb solar energy and reflect sunlight back into space. The particles also serve as nuclei for cloud droplets. This is a problem because more pollution results in clouds forming with larger amounts of smaller drops. These small drops reflect more sunlight and make the clouds act like giant mirrors. The small drops also remain in the sky about half a day longer before falling to Earth which dramatically increasing this effect.

Global dimming directly contradicts global warming and as a result the findings of less sunlight reaching the Earth's surface were ignored by much of the scientific community who were embracing global warming. If less sunlight was reaching the Earth then this would cause cooling. This was opposite of the heating effect that was being observed. As it turns out a reduction in global dimming could in fact cause even more global warming. The first publication showing evidence of global dimming was at the Swiss Federal Institute of Technology in 1985.<sup>7</sup> Atsumu Ohmura a geography researcher found that solar radiation hitting the Earth's surface had decreased by more than ten percent during the previous three decades. He published his findings "Secular variation of global radiation in Europe" in 1989. In 1990 Viivi Russak published "trends of solar radiation, cloudiness and atmospheric transparency during recent decades in Estonia" and in 1994 Beate Liepert published "Solar radiation in Germany - Observed trends and an assessment of their causes". These publications were painting a picture that global dimming was something to be taken seriously.

Global dimming has even helped explain one of the greatest mysteries of climatology. If the Earth was getting warmer then the rate of evaporation would be expected to increase but the opposite effect has been observed. In the past fifty years or so there have extensive studies of pan evaporation. This is an experiment using a pan filled with water that is used to determine the

quantity of evaporation at a given location. Pan evaporation has shown that evaporation is decreasing which means that less sunlight is reaching them. Global dimming has provided an explanation for this result.

The amount of dimming reported varies from region to region but the global average seems to be around 2-3 percent per decade. This data is only terrestrial and does not include the area over oceans. However since the early 1990s the trend has been slowly reversing or brightening. The Baseline Surface Radiation Network, which was started in the early 1990s to collect surface measurements, has shown a reduction of four percent in the past decade. This shift occurred at the same time global aerosol levels were beginning to decline. This evidence strongly supports that aerosol pollutants are a main cause of global dimming. It also supports why global warming has had such a strong effect in the recent decade.

Another cause of global dimming is the contrails left by aircraft. This effect only became prevalent after the September 11, 2001 attacks on the World Trade Center. During the three days after the attack nearly all civil air traffic was grounded, providing a rare opportunity to research the effects of these manmade clouds. Dr. David Travis had been researching for 15 years whether contrails were having a significant effect on the Earth's climate.<sup>8</sup> During this rare opportunity he observed an increase of over one degree Celsius in diurnal temperature variation. This is a huge change in climate for just a few short days and shows that the population might be doing more damage to the climate than previously thought.

## **2 Space Technology and Humanity**

### **2.1 Space Technology on the Consumer Level**

The motivations to develop technologies for space-travel are also found in every day life. Space travel is complicated and often requires technology that does not yet exist, but that needs to be created. There are often spin-offs of these technologies that are used commercially and for the benefit of all of humanity, not just astronauts.

A major concern for astronauts is access to clean water. NASA engineers developed water purification systems to recycle water for consumption on the International Space Station.

Astronauts and lab rats aboard the station excrete urine which is purified and exhale water vapor and which is condensed and then purified. The purification process begins with a filter that removes debris and other impurities, then continues with a catalytic oxidation reactor that kills bacteria and viruses. The technology for water purification has applications here on Earth, especially in third-world countries with limited access to clean water.

There were three major advances to technology related to pacemakers brought about by NASA. The need for rechargeable long-life batteries on spacecraft led to similar batteries in pacemakers. Space microminiaturization technology led to a single-chip pacemaker that dramatically reduced the size of pulse generators implanted inside a human's chest. Finally, technology for two-way communication with satellites led the way for two-way communication between doctors and pacemakers, allowing the doctors to reprogram the device without requiring surgery, using bidirectional telemetry.

Formulaid, which is an algae-based oil used in baby formula, was developed as part of a NASA program called Closed Environment Life Support System (CELSS), in which microalgae was

studied as a supply of food and oxygen and as a catalyst in waste disposal that could be used during space travel. It contains docosahexaenoic acid (DHA) and arachidonic acid (ARA), two essential polyunsaturated fatty acids which are found in the grey matter of the brain and in the retina, believed to be closely related to development of mental and visual abilities. Both acids are found in human milk but were not found in most infant formulas. With this new development, however, babies and infants have more necessary nutrients in their formula that they would be receiving if they were breast-feeding.

Catalysts for low-temperature oxidation of carbon monoxide were originally designed by NASA's Langley Research Center for use in a satellite project. In order to enhance the life of carbon dioxide lasers, these were to recapture and recycle carbon dioxide. These lasers, which produce beams of infrared light, have high power levels and are used for cutting, welding, and even surgical procedures. All the oxidation catalysts need in order to function is a flow of gas through them, with no extra energy input required. These catalysts are now used extensively here on Earth, even though the satellite project never launched. A main use is in racecars, in which drivers often used to become sick from carbon monoxide fumes in exhaust because the drivers drive so close to each other for such long periods of time. The catalysts developed by NASA are now used to create filters to prevent carbon monoxide poisoning.

Technology developed by NASA is even used in commercial and industrial products for protection of the environment. Originally, work at the Jet Propulsion Laboratory (JPL) was done to study microencapsulation of live cells. Living cells and biological materials were encased in a sphere tough, semi-permeable material with diameters less than a millimeter. The JPL was investigating the possibility of injecting microcapsules of thyroid hormone cells through a hypodermic needle into humans to treat hormonal disorders. Today, we use the design as the



delivery mechanism for beeswax microcapsules which act as a food source for microbes that consume oil. The most obvious application of this is in the cleaning of oil spills before the oil settles to the bottom, causing liver, reproductive, and growth problems with bottom-dwelling animals. In addition, boat-owners use BioSok Maintenance Systems, a commercial product which clean contaminated bilge water before it is dumped overboard.

As the name suggests, "space blankets" originated from NASA technology. A space blanket, made by dusting aluminum vapor over a light film, lacks the traditional softness often associated with a blanket. It makes up for this, however, in its extremely light weight and ability to reflect 80% of a person's body heat back to them. These qualities make them popular with campers and other outdoorsmen, who value portability and effectiveness over comfort. The material has been incorporated into many outdoor products suitable for temperatures as low as -72 degrees Fahrenheit. The blankets have also been used for humanitarian relief in places such as Pakistan following their 2005 Earthquake.

The space blanket material has been invaluable to NASA, and was used on almost every mission they have launched. Instead of using them to conserve heat, however, they are used to block the sun, as they reflect infrared light, the most thermally intense wavelength found in space. When Skylab was first launched, the material saved NASA millions when Skylab began to overheat immediately after it was launched. By effectively tying space blankets to the outside to cover a damaged heat shield, Skylab was saved.

The first commercial use of space blankets came from marathons, who needed a way to keep runners warm when they finished the race. As they stopped running their body heat would drop quickly, and due to crowded finish lines, they would become hypothermic before being able to

change into their street clothes. It is now expected for marathon organizers to dispense the blankets, which when folded are very small, to runners crossing the finish line.<sup>9</sup>

It is often said that necessity is the mother of invention. Space travel is worth humanity's time in that, like war, it brings with it the motivation to be innovative and ground-breaking. Space travel is an investment that has the potential to pay off. For example, if humans spent the money now to create a lunar colony, we would need to find a way to power the colony, and perhaps this necessity would lead to a way to harvest the energy of He-3. This in turn would then lead to a cleaner energy source. While space travel is expensive, humans have the potential to create much more wealth than they put in.

## **2.2 Satellite Communication Systems**

Research into space travel and exploration has already yielded results that benefit the general public. One of the more significant ways in which this has occurred would be the advent of satellite communication. Satellite communication was envisioned as early as the inception of the space programs of the United States and the Soviet Union, as would be evidenced by Sputnik's primary purpose being the transmission of a simple radio signal. However, the true benefits of this have only reached the majority of humanity within the past couple of decades. Cellular phones, Global Positioning Systems, the Internet – all of these would be either impossible or greatly hindered without the use of satellites. There are multiple techniques for satellite usage, each with its benefits and drawbacks. There are also new developments in satellite technology still in progress, such as the implementation of Ka-band radio transmissions from satellites.

Improvements such as these should continue to be pursued, as well as other aspects of space exploration that could be run alongside it.

There are three typical orbital patterns followed by satellites today. These are Geostationary Earth Orbit (GEO), Medium Earth Orbit (MEO) and Low Earth Orbit (LEO) satellites. As their names suggest, the primary difference between these satellite arrangements is the altitude which the satellites have with respect to the Earth's surface. Their altitudes are roughly 36,000 km, 10,000 km, and 900 km, respectively. The name of GEOs does not imply its altitude so much as the fact that they are at such an altitude that their orbits keep them at the same position above the Earth's surface at all times. Despite it seeming easier to have LEO satellites in place, the closer these satellites are to Earth, the more satellites are necessary for complete coverage. Only three or four are needed for a GEO system, while 24-66 would be needed for LEO systems, with MEO somewhere in between. Another advantage of GEO is that the satellites are always in the same place, and as such ground-based antennae can be kept pointed in the same direction for ideal reception. This advantage is only really present with stationary antennae, however, and not mobile devices (cellular phones, etc.). Due to the higher number of satellites required for a LEO system, another problem presents itself. There would either need to be a large number of mechanisms on the ground for receiving data, or a means of interaction between satellites, which would be a complicated process.<sup>10</sup>

Despite the seemingly incredible advantage GEO systems have over the competition, there are two reasons why LEO or MEO systems have become far more dominant – radiation and propagation delay. GEO satellites extend a good deal beyond the reach of the Earth's magnetic field. This can cause a good deal of interference with transmissions that are also electromagnetically based, as any satellite transmissions would be. This is detrimental in

particular when there is peculiar solar activity in progress. Also, the greater distances involved cause greater propagation delays. LEOs have roughly a 10 millisecond delay, while MEOs have roughly 80 ms and GEOs have between 250-270 ms. This is considering ideal conditions, which are off between 80-180 ms in practice. The threshold for delay without causing issues such as echoing with audio transmissions is 300 ms, so often GEO systems are impractical for this purpose. Still possible for the transmission of data in text form or the like, but overall, MEOs and LEOs perform better. Thus, most satellite arrangements in development or in use (i.e. Globalstar, Iridium, or Odyssey) are exclusively MEO, LEO, or some combination involving one or both of those.<sup>11</sup>

Despite the fact that numerous of these satellite systems are already in place, there is still room for improvement. One of these is the implementation of Ka-band transmission frequencies. Frequency is another important aspect of satellite data transmission, as with higher frequency comes higher rate of data transfer, and less likelihood of congestion within the satellite network. Ka-band frequencies are far higher than those used previous (C- and Ku- band), by over an order of magnitude. C- and Ku- band frequencies are within the MHz or single-digit GHz frequencies, while the Ka-band spectrum is also called the 30/20 GHz spectrum. Systems implementing this broadband capability have been in development since roughly 2000, and continue to be expanded upon.<sup>12</sup>

Thus, there is a good deal of improvement that can still be made upon the satellite communication capabilities we have currently in place. With improvements in band frequencies, a greater benefit to the general public can be obtained. As such, this serves as at least one of the motivating factors for further investment of resources into space travel and exploration. New breakthroughs are always a possibility, and as has already been seen, they have a tendency to

return to the masses in a noticeable way. Not all of the results of space travel will remain solely in textbooks.

### 2.3 Satellite Power Systems

One concept for the use of satellites to benefit humanity is that of a Satellite Power System, in which one or more satellites are kept in a geosynchronous orbit around the Earth, gathering solar power with large, intricate panels, and an equal number of refracting antennae (“rectennas”) collecting the energy on the surface, which would have been converted to microwaves by the satellite(s) and transmitted downward. It is technically a possibility, but for numerous reasons, at present it is both economically and ecologically infeasible.

Why is this? First and foremost, for the transmission of any significant amount of microwaves, a large area of the Earth’s surface is needed to be cleared out for the array collecting energy on the ground. The base formula for the ground area needed is as follows:

$$D = 2.44 d \lambda / D_{\text{trans}}$$

Where  $d$  is the distance from the surface,  $\lambda$  is the wavelength of the transmitted microwaves, and  $D_{\text{trans}}$  is the diameter of the transmitter. ‘ $d$ ’ in this case would be 36,000 km (the altitude required for geosynchronous orbit) and  $\lambda$  would be about 12 cm for microwaves at the desired frequencies. So, the needed surface diameter would be  $10.5/D_{\text{trans}}$ . Proposed plans for a system such as this, to be at all effective at receiving and converting large enough amounts of energy, would require a 1 km transmitting diameter, so over a 10 km diameter is required. Both the difficulties in delivering a 1 km transmitter and the even larger solar panels required, and the necessity for large cleared areas, make this not a cost effective prospect. A possibility, yes, but clearing out a large region of uninhabited forest or desert, along with the maintenance costs in

either location, would prevent such a power source from being a suitable competitor or replacement for current sources of energy.<sup>13</sup>

There are ways of minimizing this. For instance, the solar panels could be made immobile. They would not be effective for as long a period of time, but it greatly simplifies the design. Not only could there be fewer moving parts in the satellite design, but also the transmitter could be placed directly on the panel itself, as oppose to being in some central, immobile portion of the satellite. Wiring is expensive, so this also makes the prospect far cheaper. Even with this, however, at current technological standards, it is still not entirely cost effective. The matter of large transmitter and receiver sizes is still an issue, and one that has yet to be resolved.<sup>14</sup>

Another issue to take into consideration is the effect on the environment. The effect of a constant exposure to 2450 MHz microwave radiation at varying degrees of power per area, on both humans and the environment at large, must be taken into consideration and studied. It may prove to make the process outright infeasible, and if not it may be far more costly to both make it possible and make it safe. Furthermore, a low-humidity and precipitation region may be desirable, as the effect of the system's radiation on mobile cloud cover, let alone the clouds' effect on the system, remain largely unknowns. The likely solution to radiation spread out along the surroundings would be to simply clear out the surroundings and make them inaccessible to the general population, but this would still be costly.<sup>15</sup>

Overall, these combined factors make the process of a satellite power system infeasible. Perhaps with research into other forms of energy transmission (lasers, for instance), along with some of the cost-cutting measures mentioned here, it could be accomplished. It does not seem entirely

unworthy of further study, but at the moment it is slightly beyond the reach of modern technology.

### **3 Radiation Protection**

#### **3.1 Overview**

There are many dangers astronauts face both on the moon and in space. To effectively protect astronauts on the moon or elsewhere in space, effective means of protection need to be developed. The Earth's atmosphere and magnetic field protect us from radiation and micrometeoroids but in space there is nothing to protect astronauts from their deadly effects. Violent explosions on the sun's surface accelerate protons near the speed of light, creating electromagnetic radiation throughout the entire electromagnetic spectrum, known as Solar Particle Events (SPE). Galactic cosmic radiation (GCR), large bursts of high-energy particles that are believed to come from supernovae, also contribute to the bombardment of radiation present in space. Astronauts on long term missions need be concerned with the amount of exposure to radiation they receive.

SPE can have an energy of 100 MeV to 300 MeV and GCR can have an energy of 1,000 MeV to 10,000 MeV.<sup>16</sup> These high energy particles can easily penetrate conventional space craft, as well as the astronauts in them, subjecting them to large doses of radiation. These particles can damage DNA therefore increasing the risk of cancer, cataracts, neurological disorders and non-cancer mortality risks. Large doses of this space radiation can even cause immediate death.<sup>17</sup> If humans are to live in space for extended periods of time then there must be protection from these deadly phenomena.

One possible way to protect astronauts from space radiation and micrometeoroids would be to simply bury a moon base under the surface. This would create a barrier that would help absorb the harmful particles of cosmic rays and solar flares as well as micrometeoroids. The problem with only this solution is astronauts cannot continuously be underground. They need to be protected on the surface as well. The technology already exists to protect astronauts from micrometeoroids in space. A Thermal Micrometeoroid Garment makes up the outer layers of today's space suits and effectively protects astronauts from micrometeoroids. The Thermal Micrometeoroid Garment does this by using seven layers of aluminized Mylar laminated with Dacron and an outer layer of white Ortho-Fabric made with a combination of Gore-Tex, Kevlar, and Nomex.<sup>18</sup> Protection against space radiation is another challenge yet to be developed.

The Apollo missions had no real radiation protection because of the added mass of the required lead. They relied on the scarcity of solar flares and galactic cosmic rays, as well as the overall brevity of the missions. Traveling through the Van Allen belt at their speeds may have only resulted in less than 1 rem of radiation—hardly enough to make anyone even feel ill. However, over the amount of time needed for an excursion to Mars or a permanent colonization of the moon, some form of radiation protection is needed. The dense material option may be too costly due to the cost of the materials themselves, let alone the amount of energy it would take to move a spacecraft or the required materials for a surface structure. The increased mass would put a large strain on the craft's propulsion system.

One possibility that could offer protection against space radiation on the surface of the moon is some type of electrostatic radiation shield that could deflect the charged particles. R. H. Levy was the first to propose such shielding in the early 1960's, but his ideas were never pursued much past the mid-1970's because of the lack long-term space missions requiring such



technology. The simplest device would, like Earth, be a magnetic dipole. Because a particle inside a magnetic field has a curved path, as it approaches the shield it would curve away from it, protecting the craft and people within.

### 3.2 Electrostatic Shielding

This principle is based on deflecting charged particles by means of Lorentz force:

$F = qE + qv \times B$ . Where  $q$  is the charge of a radiation particle,  $v$  is the particle velocity,  $E$  is the electric field of the shield and  $B$  is the magnetic component of the field.<sup>19</sup> This could be achieved by mounting electrically charged spheres on top of 40 meter poles above a populated moon base. One design involves several spheres oriented on three axes, six with a 20-meter radius, charged to -300MV, 160 meters away from the protected region, and six with a 10-meter radius, charged to 300MV, 50 meters away from the protected region (see Fig. 1).<sup>20</sup>

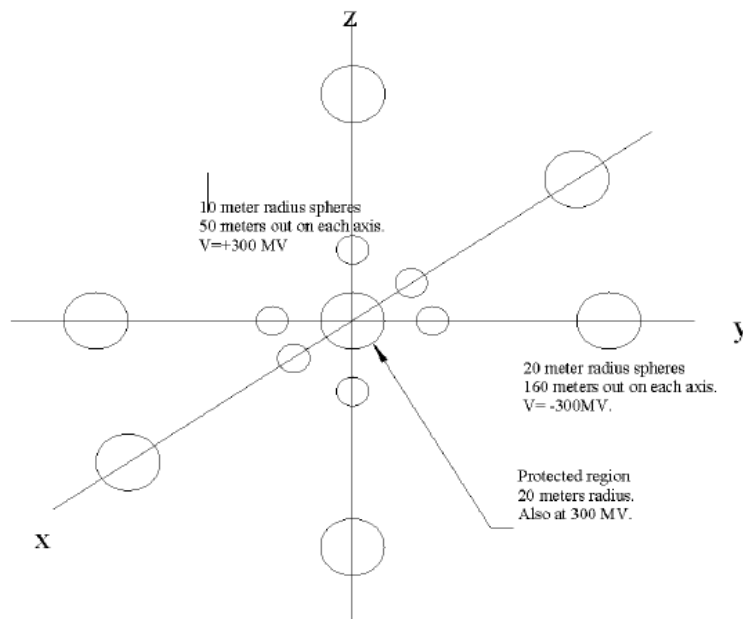


Figure 1

It is estimated that each spherical structure and supports would weigh 20-40 tons, depending on the materials used. This is capable of deflecting or greatly reducing the impact energy of most bombarding particles.<sup>21</sup> Another design is called the multi-shield approach (Fig. 2). This concept employs multiple levels of electrostatic shields made from spherical generators high in the air combined with flat electrostatic screens constructed low to the ground.

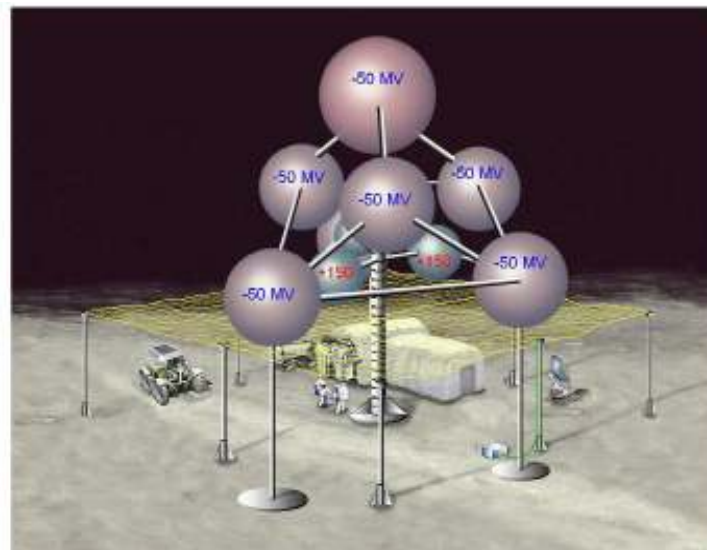


Figure 2

Recent technological advances make the prospect of magnetic shielding not terribly far from reality. First, high strength-to-weight materials are available. The strength of the magnetic field is limited by the tensile strength of the material used. New materials, like Lead(II) oxide (PbO) or Kevlar provide more strength for their weight than steel. Higher-temperature superconductors are now available. These superconductors use separated copper-oxide planes and are able to operate at more than 77K—a temperature range that would allow for the direct radiation of excess heat off into space.

Due to the development of particle colliders, technology in large superconducting magnets has improved recently. Computers are now able to solve direct numerical integration, allowing them to solve particle trajectory problems necessary for running the magnetic shield. Previously, software would need to approximate their integral solutions to be quick enough to be useful. Magnetic radiation shielding may be a viable option in the near future, like in Moon colonization or manned missions to Mars.

### **3.3 Drawbacks**

Despite all of this, the idea is far from perfect, however. The main crippling design challenge for this type of device is power. The power required to run one of these devices is huge and there is currently no available technology to produce it. The power that would be required to protect against solar particles would be at least 100 MV and the power required to protect against cosmic ray particles would be at least 1000 MV.<sup>22</sup> Another problem is that EM fields have potentially been linked to human health risks, such as a certain varieties of cancer.<sup>23</sup> This would have to be avoided, as well as the impact on electronic equipment that EM fields would have. Elevating the spheres well above any sort of settlement would reduce the negative impacts, while still providing protection from radiation originating in space.

In a comprehensive space colonization effort, the protection of astronauts in a space craft is also a pressing issue. One possibility, like on the moon, would be a multi-pole electrostatic radiation shield. This would use three electrically charged spheres aligned along the axis of the ship. Two negatively charged spheres would be at either end with a positively charged sphere at the center near the crew module.<sup>24</sup> This combination should be enough to deflect high energy protons and electrons that would otherwise penetrate the space craft. This still does not alleviate the immense

problem of getting enough power to run this device. That problem would need to be solved in order for this idea to be feasible.

### **3.4 Alternate Methods**

An alternative would be to place the ships cryogenic fluids around the crew module. Liquid hydrogen is typically used for fuel and is also very good at absorbing space radiation. The atoms of liquid hydrogen do not fragment into secondary particles like heavier elements do when hit with high energy radiation. The secondary particles can be as deadly as the space radiation itself.<sup>25</sup>

The materials with which spacecrafts' hulls are constructed could also be changed to be more radiation-resistant. NASA scientists have invented a new polyethylene-based material that is stronger and lighter than aluminum, called RXF1. The real benefit of this material is not its strength to weight ratio but rather the fact that it has superior space radiation shielding properties. Compared to aluminum, RXF1 is 50 percent better at shielding solar flares and 15 percent better at shielding cosmic rays.

The benefit of plastic-like materials rather than heavier materials like aluminum is that they produce a lot less secondary radiation. When the shielding material is bombarded with space radiation particles, small nuclear reactions are produced with the atoms of the shielding material. Those reactions create harmful nuclear byproducts that enter the spacecraft. RXF1 makes a good shielding material because it is made of lightweight carbon and hydrogen atoms that produce minimal secondary radiation particles when bombarded with space radiation while at the same time fragmenting the incoming radiation particles.

RXF1 is amazingly strong and light. Currently the specifications of how it is made are secret because it is patent pending. What is known so far is that RXF1 has three times the tensile strength of aluminum and is 2.6 times lighter. Therefore, it could also potentially serve as a ballistic shield that could deflect micrometeorites. RXF1 is also a fabric so it could be used to drape around molds and even shaped into specific spacecraft components.<sup>26</sup> Overall this is an exciting new material that has potentially many applications in the aerospace industry.

Perhaps power concerns with electrostatic shielding could be worked around with nuclear power, at least for the lower power requirement SPEs have, but that would require even more research. Ultimately it may be necessary to initially construct underground complexes regardless, but that in itself takes time during which taking such precautions against radiation would be useful. Even after subterranean construction, should it occur, radiation is still a pressing issue for long term space transit as well. If and when electrostatic shielding becomes feasible on the moon, it will also be of value to humanity while reaching out to Mars and beyond.

## **4 Robots & Artificial Intelligence**

### **4.1 Early Automata**

As far as history goes back, man has toyed with the idea of creating entities other than themselves that were intelligent. In early Greek history, myths of Hephaestus and Pygmalion talk of intelligent robots. In the 1400's the first clocks were made using lathes and in 1652 the first digital calculating machine was made.

In 1950, Alan Turing proposed that a Turing Machine, a hypothetical computer that uses an infinitely long piece of magnetic tape, defined what is computable through machine intelligence. In other words, if something *can* be calculated or determined, then a Turing Machine could be

constructed to determine it. Things that have this calculating power are called *Turing powerful* and pass a *Turing Test*. It can be argued that a human brain is only Turing powerful, as it is simply a “machine” that takes in input, your current collective memory and sensory input, and provides an output, new electrical impulses in your brain and muscle contractions or relaxations. Far in the future, man may be able to simulate a brain. Today, we already have amazingly complex artificially intelligent (AI) programs. These programs, accompanied with capable robots, are and will continue to be essential to voyages into space.

In 1958, MIT computer scientist John McCarthy invented Lisp, derived from “List Processing Language”. Lisp paved the way for several areas of computer programming, especially AI, to thrive. Lisp, now developed into an entire family of computer programming languages, was originally designed for mathematical notation. However, it quickly became the language of choice for creating artificially intelligent systems. Kent Pitman of HyperMedia Inc. jokingly said, “Please don't assume Lisp is only useful for Animation and Graphics, AI, Bioinformatics, B2B and E-Commerce, Data Mining... Intelligent Agents, Knowledge Management, Mechanical Computer Aided Design, Modeling and Simulation... just because these are the only things they happened to list.”

Mostly everything in Lisp is stored in “linked lists,” a list made of several nodes each pointing to the next element of the list. Lisp’s source code itself is made of linked lists, allowing programmers to effectively rearrange pieces of code during program execution using smaller, domain-specific programming languages imbedded within Lisp. This makes it attractive to AI programmers. It is nearly the oldest programming language still in use today, second only to IBM’s Mathematical Formula Translating System (Fortran).

## 4.2 Artificial Intelligence

Today, we may not be able to simulate true intelligence, but developments in the field of artificial intelligence (AI) have been integral to the development of self-sufficient automata. However, even modern-day complex computer-run systems, like those that run autopilots for aircraft, only need to be able to account for so much. They are usually massive, deterministic sets of algorithms and used merely as tools by humans to aid in the decision making process. Early programs were limited greatly by the relatively slow hardware available at the time. AI was heavily influenced by various academic areas like biology, neural networks, game theory, statistics, logic and philosophy.<sup>27</sup>

As the places humanity aims for become more remote and less inhabitable, the need for robots that can account for a large range of problems becomes more apparent. The decision making capabilities of humans are usually taken for granted until one tries to emulate it algorithmically. However, NASA is continually improving the artificial intelligence of their rovers and their navigation systems in the interest of making them more self reliant and better at humanistic decision making capabilities. These traits will be integral to the construction of remote bases on the moon and mars in the future, as well as assisting human teams in exploration and experimentation.<sup>28</sup>

At NASA Ames Research Center in California, computer programmers are developing complex AI software for rovers. In the past, simple artificial intelligence (AI) systems allowed rovers to make simple navigation and path finding decisions. NASA aims to have a much smarter system to replace the decision making of mission controllers for expeditions millions of miles away, where the speed of light becomes a major issue with communication and direct remote control

becomes impossible. “The Exploration Vision calls for closer cooperation between humans and robots than ever before. Creating robust robotic assistants, as well as making key spacecraft systems self sufficient, requires building systems that can adapt their behavior to environments that are complex, rapidly changing, and incompletely understood.”

The Ames Research center’s Intelligent Systems Division has several artificially intelligent programs open and available to the public “to increase NASA software quality via community peer review, accelerate software development via community contributions, maximize the awareness and impact of NASA research, and increase dissemination of NASA software in support of NASA's education mission.” This software includes a genetic evolutionary program written in Java, a virtual vision framework called *Vision Workbench*, and an AI system for life support.

In late 2005, the Collaborative Decision Systems milestone demonstration showcased rovers built on the Intelligent Deployable Execution Agents (IDEA) architecture, a Linux based goal-oriented system for autonomous agents designed to take and respond to commands. “In the demonstration... during a simulated extravehicular activity (EVA), an astronaut *verbally commanded both rovers* to assist in different ways in getting a microscopic image of a new rock. The operation was overseen by habitat-based crew members ... assisted by a personal agent running on the astronaut's backpack computer which automatically filed data products and kept the astronaut on schedule.”<sup>29</sup>

Here, the goal is to develop robots that will assist human astronauts in extra-vehicular activities and to lighten the overall load of physical labor required of them. While a completely autonomous robot is ideal, a more realistic alternative is to allow different degrees of use



specification. An astronaut can give a very high level command, and very specific command, or directly control the rover, depending on the rover's ability to deal with the situation on its own. This can be a time saver, as more detailed commands can be given only if the robot cannot first figure out things for itself.

Artificially intelligent systems are also needed for much broader decision making. It is necessary to automate the work of the astronauts and information regarding mission control. Because of the signal delays involved in a mission to Mars, for example, the hope is to create a computerized substitute for mission control on Earth.

“The system is designed for tasks that can be decomposed into loosely coupled subtasks that each person and robot can execute. By using a distributed multi-agent architecture, people, robots, tools, instruments, and interfaces can be integrated into a coherent data and workflow system.”<sup>8</sup> Through a system of subtask division, the robot is able to convert a spoken command into a series of subtasks. Those subtasks are broken down further until they can be split into machine level commands, like moving a specific piece of the robot.

Despite these efforts, we are still far away from having completely autonomous systems, capable of exploring the outer depths of the universe completely independent of human intervention. Once this is available, human space exploration will be able to reach a new tier in how far it can go and what it can accomplish.

Dennis Gorelik, a Montana software developer who specializes in AI, outlines what he calls a True Artificial Intelligence System (AIS). AIS tried to completely simulate and implement the functionality and thinking capacity of the human brain. An AI system should be able to learn like a child without any help from programmers and should be able to think abstractly enough to

learn in any field of study.

An AIS has eight essential components. First is main memory which would hold a table of established concepts and a table of established cause-effect relationships that the AIS has learned. Second is a motivation system. The motivation system drives the AIS similar to an animal being driven by its instincts. It includes a hierarchy of goals based on their importance and relevance. Third is an integration of the main memory and the motivation system. Here, you have “super” goals and “sub” goals. “Super goals recognize specific events and generate a reward based on these events. Sub goals are modified by a reward value.” Goals that are hard-coded into the system should constantly evaluate and make conclusions based on where it is relative to its ultimate goals. Fourth is a decision making system that is tightly knit with the motivation system. The last four can be described as constantly learning, reading outside input from the world, forgetting useless information, and being able to alter its own program on the go.

Fundamentally, many of the principles of Gorelik’s supposed AIS come from the way humans think. For example, Gorelik believes that sight (digital image processing) is not necessarily required for intelligence, as blind people are still intelligent. In deciding whether or not an AIS should be able to explain how it logically came to any given decision, Gorelik proposed that very few humans are able to do this, so it does not make sense as a requirement for AI. Deciding whether or not to use a statistical algorithm depends on whether or not humans would. For example, if a person sees “ $4 + 5 = ?$ ”, most people do not calculate the sum of four and five, but rather instantly remember that four and five make nine. On the other hand, larger numbers would need to be calculated normally.

Another important feature of AI systems is being able to identify and communicate with other intelligent entities, namely humans. “After all, we get a lot of what we learn based on the

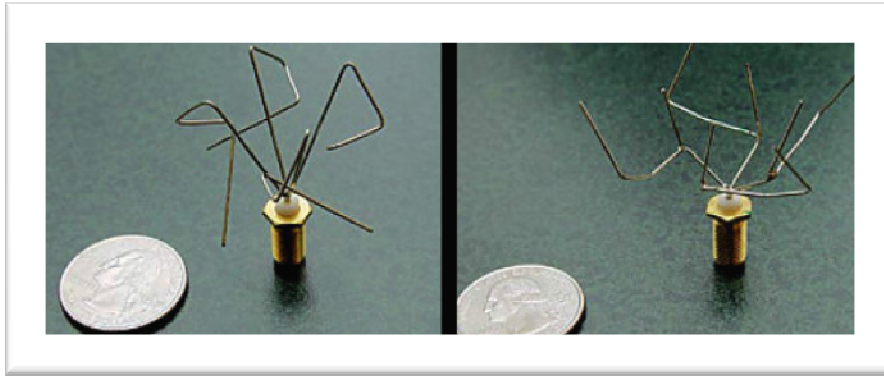
feedback of other intelligent entities.” Computers must be able to learn, from others and from themselves, the rules of which the universe runs by. “Many AI developers try to put the ‘practical rules’ into code directly. This is just wrong. The consequences of putting practical rules in the code are severe: development takes a huge amount of time... My estimation is that [these programs learn] at least 10 times slower than average human... That means that programming a ‘practical rule set’ of 20-year-old will take at least 200 man-years. Huge development time is not the major problem though. The real problem is that such system still is not able to learn.”

### **4.3 Evolutionary Software**

Evolutionary software works by creating a system where different components of a device or algorithm can be created, tested and mixed with other components based on their performance. This system creates a Darwinian method of coming up with device/software designs or configurations where the computer mixes and matches aspects of top-performing components to come up with a naturally selected solution.

The Intelligent Systems Division’s artificial evolutionary software program is quite powerful. One project, lead by Kalmanje Krishnakumar, sought to optimize the design of antennae using evolutionary software.<sup>30</sup> Instead of a manual design, which is labor intensive, the program uses evolutionary algorithms to generate an optimal shape and size for the antennae. It started with random antenna designs refined those using thousands of evolutionary iterations. “We told the computer program what performance the antenna should have, and the computer simulated evolution, keeping the best antenna designs that approached what we asked for. Eventually, it zeroed in on something that met the desired specifications for the mission," Ames Center

researcher Jason Lohn said. The results were unlike anything any engineer would think up.<sup>31</sup> This 2.5 cm<sup>2</sup> antenna can is designed for satellite communication with Earth. The evolutionary software it was written runs on 120 separate computers.<sup>32</sup>



*Two antennae designs generated from NASA's evolutionary AI software.*

Evolutionary software was used by a lab in Sussex, England to create a chip that could distinguish between two distinct tones.<sup>33</sup> Dr. Adrian Thompson, a researcher for the Department of Informatics, used a Field-Programmable Gate Array (FPGA)—a chip whose logic is not hard-wired and can be rewritten. FPGAs are slower and produce more heat, but are obviously much more flexible.

Using only 100 logic gates, the first generations seemed almost random. By generation 220, the chip could reproduce the tone it was given. By generation 1400 it could distinguish between tones half of the time, and by generation 4000 it was completely functional. Thompson took it further by later making it respond to verbal “stop” and “go” commands. The chip only used 37 logic gates and 5 completely separated areas of circuitry. Despite being seemingly independent, disabling one section caused the chip to stop working. Not even Dr. Adrian Thompson knew how it worked.<sup>34</sup>

Using evolutionary software to create complex AI architectures has its share of advantages and disadvantages. While AI programming can create very complex programs using very little resources, its future is limited. Systems that ensure the safety of others, like medical equipment or military navigation systems, must be thoroughly tested and declared safe and bug-free. With AI programming, it is entirely possible for vestigial or dormant traits to appear in programs, making them unpredictable or unreliable. Relying on AI software to run our lives would be dangerous, and many would be thinking that *The Matrix* has predicted the future.

#### **4.4 Robots in Space**

In 2000, a company called Applied Space Resources (ASR), in coordination with physicist Mark W. Tilden, created a couple different designs for robots they would like to send to the moon in their own endeavors. These very small, insect-like devices could sift through the surface and pick up loose dust. This dust would interfere with larger devices if left unaltered. These would have to be cheap, and built in large numbers. The idea envisioned by Tilden is something along the lines of an ecosystem, but involving robotic equipment. Tilden's ideas do greatly resemble an ecosystem. The robots he envisions have a base set of tasks they do consistently, as opposed to being directly instructed.<sup>35</sup> This makes autonomy a key element. Without it, constant communication would be necessary for every device on the surface, and this would be complicated and expensive.

Sending simple machines for simple tasks, and then sending more advanced robotics for construction of infrastructure is sensible. Unfortunately, it does not seem that these commercial endeavors have been carried out or developed to a great extent. They were initially slated for 2004, but this has not been the case. Given that there was little information available on the

technical aspects of this plan of Tilden's, it may this was nothing more than a pipedream before it was shot down, possibly due to the fact that it was not government-backed. However, the principle in the broadest sense is sound. Preparations for colonization should involve preliminary robotic work automated via artificial intelligence. This can be followed by remotely controlled robotics and human settlement.

The moon is a very hostile place for humans. Once humans have started colonizing, robots would be invaluable in sharing the workload and lessening the amount of harmful exposure astronauts would be exposed to on a day to day basis. Unlike humans, robots are not as ill fitted for surviving in the harsh environment of space.

Currently the Robot Systems Technology Branch at NASA's Johnson Space Center in a collaborative effort with DARPA is designing a humanoid robot called Robonaut. Robonaut is being designed for Extravehicular Activity (EVA), or spacewalks. Its goal is to have greater dexterity, work envelope, ranges of motion, strength and endurance than that of a suited astronaut. Robonaut's design concept is an anthropomorphic robot that is the size of an astronaut in a space suit. It has two arms, two five fingered hands, a head and a torso. Its dexterous arms enable dual-arm operations and its hands can directly interact with a wide range of interfaces without special tooling. Robonaut's hands each have fourteen degrees of freedom. Its forearm houses the motors and drive electronics with a two degree of freedom wrist, and its hand is fully functional with respect to a human hand.<sup>36</sup>

Robonaut's arms are designed with human equivalent strength, human scale reach, thermal endurance for an eight hour EVA, fine manipulation and a motion range that is better than a

human. Each arm contains thermal vacuum rated motors, harmonic drives and fail safe brakes. Each joint contains sixteen sensors of strain gages, encoders, and absolute position sensors.



*Robonaut*

Robonaut's head is mounted on an jointed neck. The head houses two color camera eyes that are capable of producing stereo vision with a third smaller camera for peripheral vision. The vision system is capable of tracking moving humans and objects. The head is protected by a helmet made of an epoxy resin that is made using a stereo lithography machine at the Johnson Space Center.

Robonaut's control system combines cooperator commands, force data, and safety rules that provides real time control. It can be controlled directly by what is called telepresence, by shared

control or by full autonomy. Telepresence uses a human operator to control the actions of Robonaut remotely. Since Robonaut has 47 degrees of freedom and is anthropomorphic the best way to control it is a kind of master-slave control mechanism that can duplicate the same motions of the robot. The control system includes a Helmet Mounted Display that shows what Robonaut sees, force and tactile feedback gloves and posture trackers. It resembles a virtual reality type system that effectively immerses the operator in Robonaut's workspace. The Helmet Mounted Display can display stereo or bi-ocular view, field-of-view and it has graphical overlay capabilities. It also has speech recognition capabilities.

The hands are controlled by glove based finger pose sensors and bend sensitive materials that track the motion of each of the teleoperator's fingers. Then that information is used to move Robonaut's fingers in the same way. This way complex manipulation tasks are performed easily by just moving one's own hands. The motion of the head, arms and torso are performed in much the same way as the hands except the teleoperator's movements are acquired by magnetic based position and orientation sensors. In this way Robonaut can be controlled precisely and safely from a remote location.

Robonaut is designed so the torso can be mounted in a variety of different ways depending on its application. It could be mounted on a rover for mobility on the moon, a Space Shuttle arm for space walks or even some kind of biped legs.

Robotics and advanced AI development are two industries that will have a mutually beneficial relationship with space travel. Devices like Robonaut and artificially intelligent rovers will be essential in doing the heavy lifting in man's space endeavors.



## **5 Transportation Technology**

### **5.1 Overview**

Transportation technology is the foundation of any space endeavor. In this section current as well as future transportation technologies, programs and trajectories will be discussed. The future development of safe and efficient transportation technology will be imperative for future colonization of the moon and beyond.

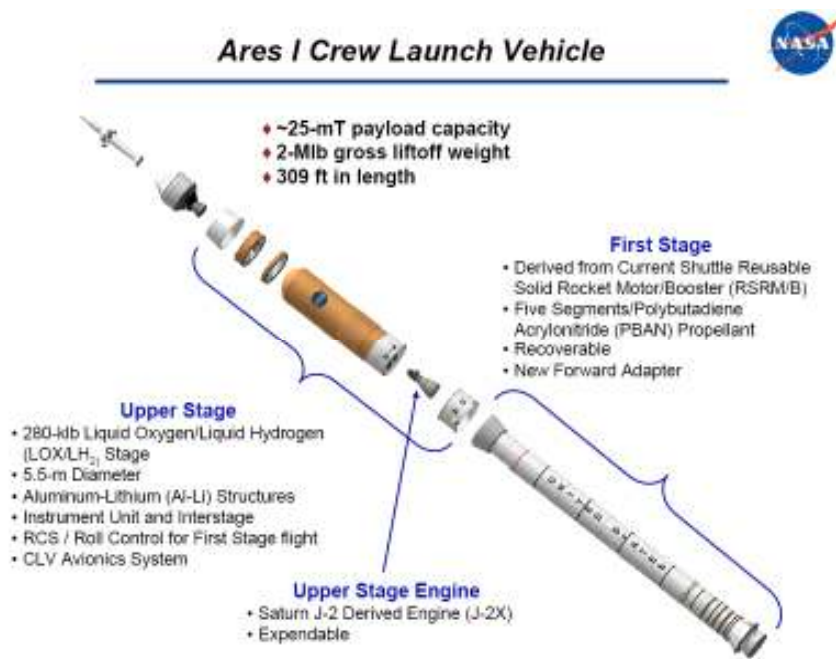
Viable, safe and economical transportation to the moon is an extreme technological challenge. NASA has already begun the process of designing components to achieve this goal. Instead of designing a whole new space vehicle to go to the moon, NASA announced in September 2005 that they are going to rely on a lot of existing technology to enable more efficient construction. The basic technology needed for this task has already been used successfully during the first Apollo missions to the moon. Now this technology needs to be improved not only to go to the moon, but to stay there for extended periods of time.

NASA has started Project Constellation to create the latest generation of spacecraft for human spaceflight. Project Constellation consists of the Ares I and Ares V launch vehicles, the Orion crew capsule, the Earth Departure Stage and the Lunar Surface Access Module. All these spacecraft are necessary for a mission to the moon.

### **5.2 Project Constellation – Ares I**

The Ares I launch vehicle, also known as the Crew Launch Vehicle, will be a two stage rocket. The first stage will be a single Solid Rocket Booster. Its design will be adapted from the current

Space Shuttle Solid Rocket Booster to produce more thrust, burn longer and therefore be able to reach a higher orbit. The main design change to be made to the first stage is an additional segment. The Solid Rocket Booster on the Space Shuttle today has four segments. The improved design will have five segments. The upper stage of the Ares I will be powered by a J-2X rocket engine. The J-2X is fueled by liquid hydrogen and liquid oxygen and its design was derived from the J-2 rocket engine that was used on the Saturn IB and Saturn V rockets. Ares I is capable of carrying a payload of up to 25,000 mT to low Earth orbit.<sup>37</sup>

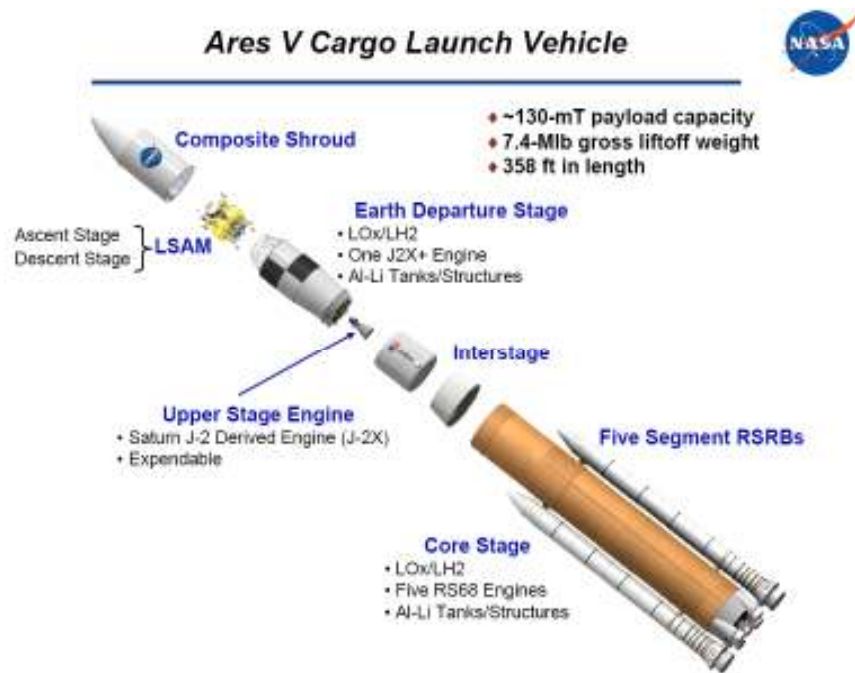


*Courtesy of NASA*

## 5.2 Project Constellation – Ares V

The Ares V launch vehicle, also known as the Cargo Launch Vehicle, will also be a two stage rocket. The first stage will use both liquid and solid fuel engines simultaneously producing about 8.9 million pounds of thrust with a burn time of about 150 seconds. It will use two Solid

Rocket Boosters like the single Solid Rocket Booster on Ares I in conjunction with five RS-68 liquid fueled rockets. The Rocketdyne RS-68 Rocket System is the largest existing liquid hydrogen and liquid oxygen fueled engine and it is capable of producing 663,000 pounds of thrust. The upper stage will use a J2-X rocket engine like the second stage of the Ares I. Ares V will be capable of carrying up to 65,000 mT of payload to lunar orbit or 130,000 mT of payload to low Earth orbit.<sup>38</sup>



*Courtesy of NASA*

#### 5.4 Project Constellation – Orion

The Orion Crew Capsule will be able to carry a crew of four to six astronauts. It consists of four main parts: the Crew Module, Launch Abort System, Service Module, and Spacecraft Adapter. The Crew Module will be used for, as the name implies, carrying the crew. It will be able to automatically dock to the International Space Station. It will use parachutes to slow its decent to Earth after reentering the atmosphere and will land as well as be recovered at sea. The Crew

Module will also be able to be reused up to 10 times. The Service Module will hold the propulsion system and expendable onboard supplies. It will be propelled mainly by an Aerojet AJ-10 rocket engine that will be fueled by nitrogen tetroxide and monomethyl hydrazine. It will also contain a Reaction Control System that will consist of maneuvering thrusters that will use the same propellants. The Launch Abort System will be able to separate the Crew Module from the launch vehicle in the event of an emergency. It will be able to do this on the launch pad or during the ascent. It will use a solid rocket powered launch abort motor that will use reverse flow to separate the Crew Module from the launch vehicle. The Spacecraft Adapter is what links the Service Module to the launch vehicle.<sup>39</sup>



## 5.5 Project Constellation – LSAM

The Lunar Surface Access Module (LSAM) will be used as the transport vehicle to and from the moon. It will have two parts, an ascent stage and a descent stage. The ascent stage will house the crew and the descent stage will contain the crew's consumable resources and scientific equipment. The LSAM will not be reusable. The Earth Departure Stage is propelled by a J2-X

rocket engine. It will be used as the main propulsion system to deliver the Lunar Surface Access Module and Orion to the moon.<sup>40</sup>

## **5.6 Project Constellation – Execution**

The whole system of Project Constellation will work as follows. First Ares V will be used to launch the heavy cargo load of the Earth Departure Stage and the Lunar Surface Access Module to low Earth orbit. Then two to four weeks later Ares I will be used to launch Orion to low Earth orbit. The advantage of having two separate launch vehicles is it enables more specialized designs for the different purposes the rockets need to fulfill. The next step will require Orion to dock with the Lunar Surface Access Module and the Earth Departure Stage. Then the Earth Departure Stage will be fired and propel the three parts to 25,000 mph towards the moon. The Earth Departure Stage will then be jettisoned. Three days later Orion and the Lunar Surface Access Module will arrive at the moon. The LSAM will use its rocket engine as a brake to enter into orbit around the moon. The crew will then leave Orion, enter the LSAM, undock and the LSAM's decent stage will be used to deliver the crew to the moon. Orion will remain in orbit for up to six months.

When the crew are ready to return to Earth the LSAM's ascent stage will be used to rejoin Orion in its lunar orbit. It will leave the decent stage behind. The crew will then reenter Orion and jettison the ascent stage that will eventually crash on the dark side of the moon. Orion will then fire its rocket engine propelling itself toward Earth. Three days later Orion will reach Earth and jettison its Service Module that will burn up in Earth's atmosphere. The Crew Module will then reenter Earth's atmosphere, after which its parachutes will deploy to slow its decent. The Crew Module will finally land in the ocean where it will be recovered and used again. While NASA's

Project Constellation is a great relatively short term solution it only requires the currently available technology of chemical rockets. In the future other transportation technologies will need to be explored.

## **5.7 Propulsion Alternatives**

One of the most obvious technological barriers standing before mankind is our inability to move through space at sufficient speeds. Even our modern space shuttles cannot break 30,000 km/hr. One design study program, titled “Project Orion,” sought to design a vessel with a high thrust and high specific impulse in the interest of enabling fast, cheap interplanetary travel. Started in 1958, Project Orion explored the possibility of using nuclear pulse propulsion, an idea originally proposed by Stanislaw Ulam in 1947, to allow for theoretical speeds of up to six percent the speed of light. The *Nuclear Test Ban Treaty* of 1963 brought Project Orion to an unfortunate end.

The design of the Orion worked by releasing a nuclear device several hundred meters behind the craft and then detonating it. The impulse from the plasma wave would be absorbed into large pusher plates attached to a two stage shock absorber. An Orion ship could be as large as materials allowed. One proposed model would place the ship at 400 m long and over 8 million tons. The nuclear reaction mass used to create explosions would be disk shaped to create a long and cylindrical plasma wave. This would allow the collimation factor, the fraction of the plasma wave that hits the absorption plates, to be much higher than normal. A proposed “Super Orion,” using thermonuclear propulsion would be able to travel to the edge of the outer planets and back in under a year. A trip to Proxima Centauri would take only 44 years. The use of thermonuclear explosions would increase the top speed to nearly .10c.

Realizing a nuclear propelled craft is not without its own problems. Launching an Orion or detonating a nuclear bomb in a low orbit would create an EMP blast that would hurt nearby electrical equipment. The craft's creation and testing would violate the *Nuclear Test Ban Treaty* and previous attempts to create exceptions in the interest of space travel have not been successful due to international pressures. The pressure plates could erode away after continued subjection to large forces and temperatures as high as 67,000° C. Engineering pressure plates capable of withstanding such erosive forces would be hard to test, as creating an environment capable of containing repeated nuclear explosions would be very difficult. However, calculations show that a pusher plate could be designed that would only erode away 1 mm after continued use, and that if protected by an oil, it would not erode at all.

Another potential problem is the levels of radiation astronauts would be exposed to at each nuclear pulse, however the very protection that keeps harmful solar flares from hurting the crew could be increased and would be able to account for such radioactivity. Detonating in low Earth orbits would be acceptable so long as it is done well above our magnetosphere, so fallout would not return to Earth. To avoid the complications of launching directly from Earth, any vessel or space station of such a large magnitude would have to be built in space.

While there are many obstacles preventing nuclear propulsion from being a reality now, it is an attainable landmark in our explorations into deeper space.

Another possible alternative to traditional chemical propulsion is electrical propulsion. As opposed to simple driving force from reacting chemicals, a fuel can be ignited and controlled with electricity. Not only is it possible, but it can be implemented with far greater fuel efficiency.

It is not without its drawbacks, of course, but it is available now, and has been in development over the past forty years.

Indeed, research into electrical thrusters dates back as far as 1950s, and testing as in 1962. Between then and the mid-1980s, 77 flight tests of electrical thrusters have taken place. These can be divided into three categories: electrothermal, electrostatic (ion), and electromagnetic (plasma).<sup>1</sup> Ion seems the most popular of the three, and a great deal of resources have been poured into it. By the 1980s, two varieties of ion propulsion had emerged. One of these involves ionizing a fuel (generally Mercury or Xenon) with electrical current run through a coil at high frequencies. Another bombards the fuel directly with electrons. Both of these approaches were implemented, and both had wide ranges of effectiveness, with driving force varying from 10-250 mN.<sup>2</sup> The key here is that the force is measured in milli-newtons, a very small amount.

How can this prove useful? The answer to this is that, at present, ion propulsion is not effective as a means of primary thrust off the surface of the planet. It does serve its purposes once in orbit, or in deeper space, however. Applications in orbit include maintenance and maneuvering. In any environment beyond removal from the atmosphere, electrical propulsion at present can be used for attitude control.<sup>3</sup> The downside of electrical propulsion is that a great deal of electrical power is needed even for this small thrust. Thus, unless an alternate power source is implemented (something surpassing solar and chemically generated electricity), electrical propulsion will only play this smaller, yet still crucial role. Furthermore, it does so far more efficiently than its chemical counterparts when doing the same job. For the same amount of fuel, if it is ignited electrically instead of chemically, the time a thruster can remain active is an order of magnitude higher for an electrical thruster than it is for a chemical one.<sup>4</sup> Furthermore, by its very nature, electrical propulsion has a greater deal of control post-ignition than chemical propulsion.



Adjusting current or rate of bombardment can adjust the potency of an electrical thruster at any time, while chemical propulsion relies on a prior balance of fuels to deliver the desired amount of driving force.

Electrical propulsion is already in use and to be used to its fullest potential, new power sources will be needed. As it is, generating thrust forces measured in mere mN on the mass of a small satellite would require power along the lines of kW. Barring the restraint of greater electrical power being required if it is to be used with a driving force beyond a few Newtons, it proves to be more effective. At present the best that could be put to use would be nuclear power. This means of power has yet to be implemented in space, so much work in that area would be required. Time will tell how electrical propulsion can be utilized effectively to replace chemical propulsion outright. And not much time is needed, at that.

### **5.8 Space Elevator – A Solution to Escape Velocity?**

Another interesting space transportation concept is the ‘space elevator.’ The concept of a space elevator has been one frequently considered among authors of science fiction, most notably Arthur C. Clarke’s *Fountains of Paradise*. The concept has been around for decades – a cable of some material extending above the Earth in a geosynchronous orbit (actually significantly longer, as the center of mass is what would be needed to be kept geosynchronous), with a satellite or facility at the other end for receiving supplies or passengers, is not a very foreign concept to the collective minds of humanity. However, practicality had always been a hindrance, largely due to lack of adequate materials to create such a structure. With the advent of carbon nanotubes (the first material to meet the tensile strength requirements and in fact surpass them) in recent years, the practicality of such a mechanism has increased by leaps and bounds, and is

actually a worthwhile consideration. Why would this be desirable? Launches of crafts from the Earth's surface to beyond the reaches of our atmosphere are some of the most costly, risky aspects of all present space travel. An elevator system, after construction, and would have a much lower cost of maintenance and operation once the construction is complete. It could even perhaps lead to habitable public space above the surface of the Earth, or result in being a tourist attraction on top of the scientific or economic gains received from a low-gravity environment. Overall, it would be a worthwhile endeavor to pursue.

How it would be accomplished is actually not that complex a process in the grand scheme of things. It would be perhaps comparable to the building of intricate bridges or skyscrapers in the past. The first step would be the primary craft, which would remain on the far end of the eventual cable, to be launched into a geosynchronous orbit. From there the spooled initial cable, only capable of supporting perhaps just below two metric tons on its own, would be lowered, and the craft would make its ascent to the required height (roughly 100,000 km). This results in the cable being held at its required length. After that point, "climbers" would be built to ascend the cable and either descend or be discarded, each trip upward augmenting the cable with more of the carbon nanotube material, reinforcing it. Over the course of two years and repeated climber runs, the cable would be sufficiently strong to allow for its more mainstream uses.<sup>1</sup>

One of the more pressing issues of design, next to what once was the primary issue of suitable materials, is the matter of power. Most conventional means of power would either be insufficient or excessively heavy at first, and new methods would need to be designed. One of the more promising of these methods would be the use of lasers. Fortunately, this has already been in development for some time as a possible means of powering satellites in orbit. A company called Compower has been in development of a system which would utilize a 200 kW laser provided by

the University of California at Berkeley, directed toward the desired target by an orientation of mirrors similar to those used by current high-power telescopes. 200 kW was the initial research level of power. Currently it has reached levels of 350 kW and could ultimately be expected to supply 1.75 MW. For the application upon the climbers, roughly 2.4 MW would be required, so either further alterations to the system or simply multiple lasers being emitted from different locations would be necessary. Far more power would be needed for the final elevator transport when the cable is complete, but by then either a heavier power supply could be supported or more research would have to be put into the laser power concept. Still, for the construction of the structure at the very least, this is sufficient.<sup>2</sup>

Even though the technology is roughly within our grasp, there are, as always, difficulties posed. These result from both the Earth's atmosphere and the rigors of the environment beyond it: wind, lightning, meteors, corrosive atomic Oxygen, radiation, and lower orbiting objects would all pose a threat. Each of these can somehow be avoided or the risks greatly reduced, however: Wind conditions can be minimized by proper placement (low-wind regions), and making the cable as thin as possible to minimize aerodynamic drag. There are some lightning free locations on the Earth, or at least locations where lightning is very infrequent. These, or high on the peaks of mountains, would potentially be suitable locations. One location that meets both low-wind and low lightning-risk areas is the region west of Ecuador (either on an above-water platform or a ship), and is proposed as a likely site by Bradley Edwards, in his book regarding the subject. Meteors and Low Earth objects are perhaps the most potent risk. Meteors are less so as given the size of the ribbon and density of meteor impacts one is only expected over the course of several decades, and depending on angle it may not do significant damage whatsoever. However, to avoid this risk, reinforcing the cable as soon as possible is advised. LEOs pose a much greater

risk, as they follow an orbital path which will bring them back to the cable each time they complete an orbit. However, LEOs are more easily predicted than meteors, and could be avoided by slightly moving the cable. Atomic oxygen can be remedied by a very thin coating of metal (such as gold) already known to be resistant to its corrosive properties. Radiation protection could be kept roughly at the state it currently is for space travel near the Earth.<sup>3</sup>

So it is clearly not without its risks. However, the concept of a space elevator is not so farfetched as to be completely discarded. No endeavor is without its risks, and this need not be an exception. However, the risks are able to be reduced, and the gains are worthwhile. Further research and development should be made in this field. Feasibility is not too far off, and the opportunity awaits us.

## **5.9 Low Energy Trajectories**

Aside from new propulsion technologies, future space travel may also require the use of low energy trajectories. With the first successful moon landing in 1969, the possibilities seemed endless; however this was just a stepping stone. In order to reach Earth's largest satellite it took the best technology of the time and a lot of fuel. Even today, with new technological advances, space flight is still constrained by fuel. Flight trajectories must be optimized in order to use as little fuel as possible. Methods of optimization involve using the gravitational pull of the Sun, the Earth, the other planets, and their moons in order to navigate the solar system. A direct flight from planet to planet would require a vast amount of fuel, while utilizing gravitational orbits can reduce that cost.

The earliest space missions utilized trajectories called Hohmann transfers, named after Walter Hohmann, a principal contributor to early orbital dynamics. The basic method of this type of

transfer is piecing together several conic section orbits determined by which celestial body is dominating the force experienced by the spacecraft. These transfers rely on several spacecraft maneuvers that provide a thrust force to alter the spacecraft's acceleration. Typically these transfers are direct shots; the spacecraft is sent at a significant velocity to towards its target. It must then decrease its velocity sufficiently enough to be placed into orbit around its target. This drastic change in velocity consumes a large amount of fuel. The problem that arises when planning a successful trajectory in terms of fuel budget is to minimize the change in velocity.<sup>41</sup>

Lagrange points are one solution to that problem. These are five points associated with a basic three body gravitational problem, such as a satellite and the moon and the Earth or the Earth and the sun. At these points particles remain relatively stationary with respect to the two body reference frame. The Lagrange points mark where combined gravitational forces provide the exact centripetal force in order for an object to rotate with the two larger bodies. The distance of

the first and second Lagrange point can be determined from  $\frac{GMm}{r^2} = \frac{mv^2}{r}$  where M is the mass of the Earth and m is the mass of the moon, by solving for r. The other three can be derived using

the more general set of equations,  $\vec{F}(t) = m \frac{d^2\vec{r}(t)}{dt^2}$  and

$$\vec{F}(t) = -\frac{GM_1m}{|\vec{r} - \vec{r}_1|^3}(\vec{r} - \vec{r}_1) - \frac{GM_2m}{|\vec{r} - \vec{r}_2|^3}(\vec{r} - \vec{r}_2)$$

where M1 and M2 are the masses of the moon and

the Earth, m is the mass of the object at the Lagrange point, and r, r1, and r2 are position vectors that are a function of time. L4 and L5, discovered by Joseph-Louis Lagrange, are located sixty degrees behind and in front of the smaller body, while L1, L2, and L3 lie in line with the two bodies.

The first three points are unstable; after a short period of time the orbits spiral away from these points. Not only do the particles spiral away but they also spiral towards these stationary points. Particles can drift into these points and collect there for a period of time. The spiraling orbits that lead towards and away from these points map about manifolds or 'tubes' that can be traversed without changing energy.

These manifolds, discovered by Poincare, are based in a six dimensional frame. This involves the three Euclidean dimensions as well as the particles velocity in each direction. A particle traveling in one of these unstable periodic orbits will travel out along the surface of one of these tube-like manifolds as long as it stays at the same energy. It just so happens, if you consider two three body systems with overlapping bodies you can find intersecting manifolds that will connect, say Mars'  $L_2$  point with Earth's  $L_1$  point. This would allow a spacecraft to travel between these two points without using as much fuel as it would take to take a direct route. This method would sacrifice time, instead of fuel. It is similar to taking the long scenic route instead of taking the freeway.

As the demand for understanding of our universe grows, so does the complexity of our questions. Advancement in mathematical methodology is needed to attempt to find answers for these questions. The study of the motion of objects in space, dynamic astronomy, and the study and development of space mission trajectories, astrodynamics, rely heavily on the mathematical analysis of the challenging N-body problem. This problem can be simplified in order to yield rough solutions; however in order to obtain a in depth understanding of celestial motion advanced techniques and computations from other disciplines, which share the mathematical basis, must be employed.

By studying the motion of celestial bodies and using the laws of gravitational attraction an ephemeris is produced listing the positions and velocities of the  $N$  bodies with respect to time. The accuracy and breadth of this solution is dependent upon the number of assumptions made in order to analyze the problem. This accuracy is dependent upon the goal of the analysis or space mission. One of the earliest methods in mission design was utilizing the well understood two body solution and a patched conic solution. A three body problem can be approached by linking two two-body solutions. An example of this would be a system involving a spacecraft, the moon, and Earth. A trajectory could be designed by combining the solution of the Moon-spacecraft problem and the Earth-spacecraft problem. The two body solutions are basic conic section trajectories that do not account for other gravitational attractions outside of the limited system.

Design criterion, such as minimal fuel consumption and transit time, determine the accuracy of the trajectory design. The goal is to minimize the total change in velocity due to spacecraft maneuvers while maintaining a certain transit time. By increasing the complexity of the analysis from a patched conic approximation to the patched three-body problem, low energy, low fuel, transfers can be obtained. This veers away from the simplified trajectories of the Voyager and Galileo missions, to the more complex trajectories of Japan's Hiten and ESA's SMART-1 spacecraft trajectories. Due to the high change in velocities of the simplified trajectories, the spacecrafts are not as perturbed by the gravitational attraction of bodies not being considered in the system. More complex trajectories are low energy, low relative velocities, which take better advantage of the  $N$ -body dynamics, a method originally discovered by Belbruno.

By using Belbruno's low energy trajectories, two link three-body solutions are used as an initial guess for a more accurate four-body solution that can reduce the energy consumption by at least half. Using an analysis of a spacecraft's kinetic and potential energy with respect to the other

bodies in the system, region called Hill's region can be determined. This region is where the spacecraft's motion is restricted to, that is, where the difference between the ship's energy and effective potential is greater than or equal to zero. These regions are connected to the Lagrange points of the system. The invariant manifolds produced by the periodic orbits around these points create an opportunity to insert a spacecraft into orbit around a new body outside of the original system.

In order to further analyze these tubes and trajectories, techniques for other fields are used. Techniques from molecular systems as well as software designed for fluid systems have shared the same mathematical basis with celestial mechanics. This leads to successful missions, such as NASA's Genesis Discovery Mission. This four year mission, launched in 2001, sent a vessel to orbit the Sun-Earth  $L_1$  point in order to collect debris from solar winds. The vessel was in the halo orbit around this point for two years before returning to Earth with its solar wind payload. This trajectory had a zero change in velocity; it relied entirely on the low energy manifolds to guide it through its mission.

The possibilities of these equilibrium points are endless. As new techniques are developed and new software is created to help understand the motion of the celestial bodies, new missions such as manned planetary missions will be tangible. By relying on computers to do the heavy computations, celestial motion can be relatively easy to predict. The probability of an asteroid riding a low energy manifold from beyond Jupiter to Earth can be found. These new methods and techniques, with their mathematical basis, can help understand the formation of not only our solar system but entire galaxies.



Although this method is not direct it still has various applications. By studying these ‘tubes’ astronomers can trace the routes of nearby comets and asteroids and predict how close these will come to Earth. This method would give ample warning of an impending collision. Another application is human travel and shipping. Although some trajectories take decades, even millennia, they could be used to ship supplies to far off colonies or even from the Earth-Moon  $L_2$  point to a colony on the moon. If some people do not mind taking a ten year tour of through the solar system then this method can be used to travel to nearby planets.

Using these special trajectories make a lunar colony more feasible. An important issue with the formation of a lunar colony is the limited amount of resources on the moon. Utilizing these tube-like highways in space offers a solution for obtaining some scarce resources such as water. A comet is a very good source of useable  $H_2O$ ; several of these giant balls of ice come relatively close to our moon-Earth system. By gently altering the trajectory of a comet with very little, it can be forced to travel along these tubes and aimed at the moon. The collision would supply the lunar base with a useable amount of ice. Using these energy cost efficient trajectories is viable way to supply a lunar colony with resources. Advances in technology and further computational analysis will give a better idea of how these trajectories behave, and more importantly where they lead.

### **5.9.1 Simulating Low Energy Trajectories**

All massive celestial bodies warp the empty space through gravity. This idea was first introduced into mainstream by Albert Einstein in the early twentieth century. Due to curved space the simplest trajectories are no longer straight lines; gravity must be taken into account when planning a mission trajectory. Computer software aids the design of space missions by

using unique and novel algorithms to help find paths of least resistance through space, or low energy trajectories.

Although computers are a tremendous advantage it is still immensely difficult to plan a mission trajectory that takes into account all of the celestial bodies in the universe. Even limiting the problem to just the planets and sun close to Earth is challenging. Therefore, assumptions must be made to find approximate solutions.

MATLAB is a useful programming language that allows for easy modeling space trajectories with certain assumptions. By considering the problem of launching a rocket to the moon, MATLAB is used to find an optimal launch angle. In order for this program to have a reasonable run time several assumptions must be made. The problem is simplified from an N-body gravitational problem in three dimensions to a three body problem in two dimensions. The rocket is launched from the Earth, experiencing the gravitational forces of the Earth, the moon, as well as the Sun. By considering the sun as fixed, the trajectories simulated are heliocentric. This allows for easy determination of the Earth's orbit, which can be simplified to circular or kept as elliptical.

The overall shape of the Earth's and the moon's orbit depends on the initial velocities. The initial positions are chosen such that they all lie in line with each other with the Earth at its maximum distance from the Sun and the moon the maximum distance from the Earth. The trajectory that the rocket takes after launch is calculated by numerically solving the basic gravitational integrals of motion. By using Euler's method for solving the system of second order differential equations an approximate trajectory is formulated that has relatively small error than an actual trajectory due to the time step chosen. In order to find a launch angle that will

lead to lunar contact several iterations are performed with different angles chosen. After the second iteration is completed a new angle is interpolated from the first to so that the rocket will be closer to the moon after the allowed two days have progressed. After several more iterations, the interpolations converge on a successful launch angle, which is then reported with the trajectory model.

The use of MATLAB and other powerful math languages to model trajectories is essential for space mission success. By analyzing the paths a rocket will take, new methods can be discovered to study comets, and other near Earth objects. This will give a better understanding of the infinite amount of low energy trajectories that connect all of the planets. By increasing the complexity of the MATLAB code a more applicable model can be used to find these trajectories from the Earth to the moon. This will lead to a drastic decrease in the cost of a flight to the moon, increasing the feasibility and success rate of a lunar colony.

For the purpose of demonstration, the following code was written by Matthew Silva Sa:

```
% function RelD= SEMsim2(Theta,deltaTheta,N)
Theta=0;
deltaTheta=0.5;
N=10;
% SEMsim is used to find a successful rocket trajectory from the surface of
% the Earth to the surface of the Moon within a time period of 3 days. The
% rocket is launched with an initial magnitude of 11.34km/s relative to the Earth.
%
% This function assumes:
% (1) a heliocentric two-dimensional system, with the Sun's position
%     fixed at the origin.
% (2) the Sun, Earth, and Moon are perfectly spherical with uniform
%     densities and are the only bodies in the system.
% (3) the rocket only experiences gravitational forces.
% (4) the Euler method of numeric integration is sufficiently
%     accurate to approximate the motion of the Earth, Moon, and rocket.
% (5) the Earth's orbit around the Sun is elliptic with slight
%     perturbations due to the Moon's gravitational force.
% (6) the Earth and the Moon are in an elliptical binary orbit with
%     slight perturbations due to the Sun's gravitational force.
%
%Input:
% Theta: the launch angle of rocket in radians between 0 and pi/4.
%       0 radians point straight at the Moon a initial conditions.
% deltaTheta: an angle in radians between 0 and pi/4.
% N: Maximum number of iterations.
%
%Output:
```

```

% RelD: Three element row vector of the distances between the
%   Center of the Earth to the rocket,
%   Center of the Moon to the rocket,
%   Center of the Earth to the center of the Moon.
% Figure(1): Plot of the trajectories of the Earth's
%   center of mass in blue, Moon's center of mass in green, and rocket in red.
%
%Program runs until a successful trajectory is found or maximum number of
% iterations is reached.
%
%Sun radius 695500km
%Earth radius 6371km
%Moon radius 1737km
format long %Prevents significant error in accuracy.

% Reads Earth and Moon Trajectory for 3 days.
Ex=dlmread('RexEllip.txt'); % x-coordinates for the Earth.
Ey=dlmread('ReyEllip.txt'); % y-coordinates for the Earth.
Mx=dlmread('RmxEllip.txt'); % x-coordinates for the Moon.
My=dlmread('RmyEllip.txt'); % x-coordinates for the Moon.

% Sets constants.
G=6.67428*10^-20; % Gravitational constant.

Rs=[0,0]; % Heliocentric model.
Ms=1.9891*10^30; % Mass of the Sun.
Me=5.9736*10^24; % Mass of the Earth.
Mm=7.3477*10^22; % Mass of the Moon.

totalT=172800; % Maximum time in seconds, do not exceed 3 days.
deltaT=30; % Time step in seconds, 30sec matches time step of the text files.
n=floor(totalT/deltaT); % Total number of steps.

% Initialize variables.
Ang=zeros(1,N); % Initializes vector for launch angles of each iteration.
DMR=zeros(1,N); % Initializes vector for distance between Moon and the rocket for each iteration.
I=0; % Initializes iteration count variable for While loop(1).
Dmr=1800; % Initialize distance between Moon and rocket with false constant to start while loop.

% While loop(1) continues as long as the distance between the center of the
% moon and the rocket is greater than the radius of the Moon and as long
% as the number of iterations is less than or equal to N.
while and(Dmr>1737,I<=N) % While loop(1)
    I=I+1; % Counts each iteration of while loop(1).

    % Set initial variables.
    T=0; % Initial time.
    Ang(I)=Theta; % Inputs Theta values into vector Ang for each iteration.
    Rr=[149604371,0]; % Initial rocket coordinate, surface of the Earth.
    % Initial distance between the center of the Moon and the rocket.
    Dmr=sqrt(sum((Rr-[Mx(1),My(1)])).^2));
    % Initial velocity of the rocket, includes orbital velocity of the Earth around the Sun
    % Initial velocity of the rocket, includes orbital velocity of the Earth around the Sun
    Vr=[0,sqrt(G*Ms/149598000)]+11.34*[cos(Theta),sin(Theta)];
    and a launching velocity with fixed magnitude.
    i=0; % Initializes iteration count variable for While loop(2).

    % Initialize trajectory vectors.
    Rex=zeros(1,n); % Initializes x-coordinates of the Earth's center.
    Rey=zeros(1,n); % Initializes y-coordinates of the Earth's center.
    Rmx=zeros(1,n); % Initializes x-coordinates of the Moon's center.
    Rmy=zeros(1,n); % Initializes y-coordinates of the Moon's center.
    Rrx=zeros(1,n); % Initializes x-coordinates of the rocket.
    Rry=zeros(1,n); % Initializes y-coordinates of the rocket.

    % While loop(2) builds the Earth's and the Moon's trajectories, while
    % calculating the trajectory of the rocket in steps of deltaT. Loop
    % continues while the time progressed, T, is less than totalT. Loop
    % breaks if the rocket is within 1737km of the moon, or the distance
    % from the Earth to the rocket exceeds that from the Earth to Moon.

```

```

while T<=totalT
    i=i+1; % Counts each iteration of while loop(2).

    % Build Trajectory vectors for plotting.
    Rex(i)=Ex(i); % Inserts ith x-coordinate for the Earth's center of mass.
    Rey(i)=Ey(i); % Inserts ith y-coordinate for the Earth's center of mass.
    Rmx(i)=Mx(i); % Inserts ith x-coordinate for the Moon's center of mass.
    Rmy(i)=My(i); % Inserts ith y-coordinate for the Moon's center of mass.
    Rrx(i)=Rr(1); % Inserts ith x-coordinate for the rocket.
    Rry(i)=Rr(2); % Inserts ith y-coordinate for the rocket.

    % Calculate acceleration of the rocket.
    As=-G*Ms*(Rr-Rs)/sqrt(sum((Rr-Rs).^2))^3; % Acceleration due to the Sun.
    % Acceleration due to the Earth.
    Ae=-G*Me*(Rr-[Ex(i),Ey(i)])/sqrt(sum((Rr-[Ex(i),Ey(i)]).^2))^3;

    % Acceleration due to the Moon.
    Am=-G*Mm*(Rr-[Mx(i),My(i)])/sqrt(sum((Rr-[Mx(i),My(i)]).^2))^3;
    Ar=As+Ae+Am; % Sums all of the acceleration to find the total acceleration.

    % Integrals of motion.
    % Uses Euler method of numerical integration to find the rockets velocity.
    Vr=Vr+deltaT*Ar;
    Rr=Rr+deltaT*Vr;
    % Uses Euler method of numerical integration to find the rockets position vector.
    % Distances
    % Distance between the rocket and the center of the Moon.
    Dmr=sqrt(sum((Rr-[Mx(i),My(i)]).^2));
    % Distance between the rocket and the center of the Earth.
    Der=sqrt(sum((Rr-[Ex(i),Ey(i)]).^2)); % Distance between the center of the Earth and the
center of the Moon.
Dem=sqrt(sum(( [Mx(i),My(i)]-[Ex(i),Ey(i)]).^2));
RelD=[Der,Dmr,Dem]; % Groups the distances for output.
% If statement(1) stops while loop(2) if the rocket is within 1737km from the center of the Moon.
    if Dmr <= 1737
        for k=0:n-(i+1)
            Rrx(n-k)=[]; % Trims x-coordinate vector of the rocket.
            Rry(n-k)=[]; % Trims y-coordinate vector of the rocket.
            Rex(n-k)=[]; % Trims x-coordinate vector of the center of the Earth.
            Rey(n-k)=[]; % Trims y-coordinate vector of the center of the Earth.
            Rmx(n-k)=[]; % Trims x-coordinate vector of the center of the Moon.
            Rmy(n-k)=[]; % Trims y-coordinate vector of the center of the Moon.
        end
        display('Success, you hit the Moon.');
```

% Outputs success message.

```

        display(Theta); % Outputs successful launch angle.
        break
    end
    % If statement(2) stops while loop(2) if rocket is farther from Earth than Moon.
    if Der>Dem
        for k=0:n-(i+1)
            Rrx(n-k)=[]; % Trims x-coordinate vector of the rocket.
            Rry(n-k)=[]; % Trims y-coordinate vector of the rocket.
            Rex(n-k)=[]; % Trims x-coordinate vector of the center of the Earth.
            Rey(n-k)=[]; % Trims y-coordinate vector of the center of the Earth.
            Rmx(n-k)=[]; % Trims x-coordinate vector of the center of the Moon.
            Rmy(n-k)=[]; % Trims y-coordinate vector of the center of the Moon.
        end
        display('Sorry, you missed the Moon.');
```

% Outputs failure message.

```

        break
    end
    T=T+deltaT; % Adds time step to total time progressed.
end % Ends while loop(2)

DMR(I)=sign(-Rr(1)+Mx(i))*Dmr; % Builds vector of Moon to rocket distances. A negative sign
means the rocket is to the left of the Moon with respect to x-axis.

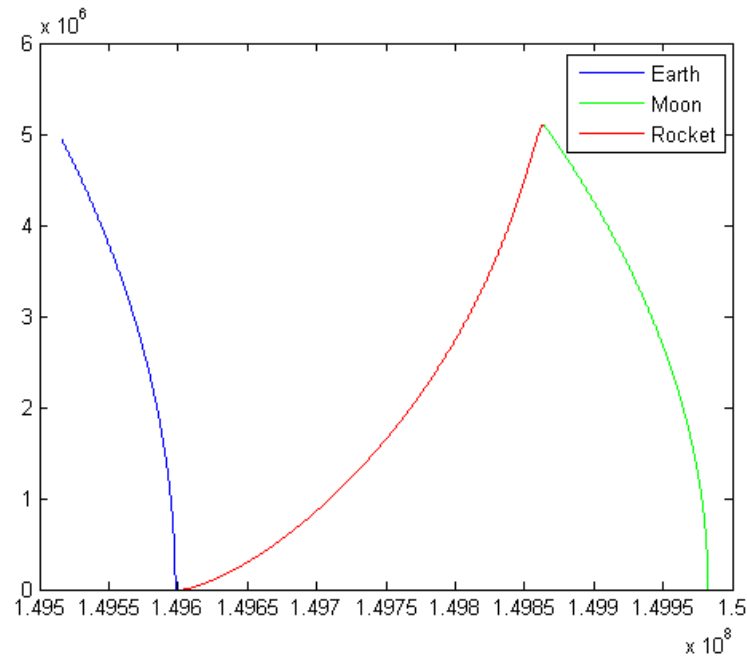
% If statement(3) determines the value of the launch angle, Theta, for
% the next iteration.
if I==1
    % If the first iteration does not yield a success the angle is increased or decreased
    depending on the sign.

```

```

    Theta=Theta-sign(-Rr(1)+Mx(i))*deltaTheta;
else
    % After two iterations, a successful angle is approximated using a line interpolating the
    % data from the last two iterations.
    Theta=(Ang(I)-Ang(I-1))/(DMR(I)-DMR(I-1))*(1737-DMR(I))+Ang(I);    end
end % Ends while loop(1)
% Plots the Earth's trajectory in blue, the Moon's trajectory in green, and the rocket's in red.
plot(Rex,Rey,'b',Rmx,Rmy,'g',Rrx,Rry,'r');
legend('Earth','Moon','Rocket');

```



*Resulting low-energy trajectory of Matlab program from Earth to Moon*

## **6 Moon Colonization**

### **6.1 Introduction**

Orchestrating a colonization program with regard to the moon is a multi-faceted process. There are many economic burdens placed upon nations that seek to pursue it; the amount of equipment, resources, and manpower required would be tremendous. Resources in particular would be a key issue, one which could not be resolved with a single shipment of supplies. Materials and equipment would be required in regular shipments, in addition to being acquired from the moon itself when possible. This can be in the form of mining metals, or recovering lunar ice to augment or replace shipments from Earth. Staff would have to be carefully selected, as

requesting additional personnel would be a serious undertaking once the selected population had already arrived. Resources are also needed in another sense – a means of electrical power. This can be satisfied by solar power, if the time is taken to establish a power infrastructure. Also, once the basic needs of survival are met, a lunar colony would require a great deal of attention and reform to be brought to our legal systems with regard to places beyond our planet.

Constructing a permanent base on the moon is not going to be an easy task for humanity, yet it is a necessary step if mankind is to take its next step toward further exploring the solar system and beyond. The processes and timelines for the establishment of a lunar base need to be thoroughly researched and carefully constructed if mankind is to return to the moon in 2020 with the intention of staying. For this project of humanity to get off the ground we must accept the staggering costs that come with the development, construction and supplying of a permanent lunar base. The establishment of a moon base involves 4 stages: unmanned exploration, manned prospecting and surveying, base construction, and base operation, upgrading, and expansion.

Stage one in the establishment of a lunar outpost involves the use of unmanned reconnaissance probes. The use of unmanned probes on the moon is nothing new and this stage of setting up the outpost has been going on for a good number of years. The knowledge we have gained about the moon over the past 50 years has been very extensive and it is safe to say that the data points to either of the moon's poles as being a suitable spot for a lunar outpost. This is a key point because it will enable NASA or any other space agency to rely on solar energy to power the outpost, instead of using nuclear power which would be highly controversial.

A good number of unmanned missions have surveyed and mapped the moon over the years but in the next decade a number of new probes critical to the establishment of a lunar outpost will be

sent to the moon. Some examples of probes being sent to the moon are the Lunar Reconnaissance Orbiter and its child probe LCROSS. The Lunar Reconnaissance Orbiter is 500kg lunar orbiter slated for launch in the fall of 2008. This orbiter is being sent to characterize deep space radiation in lunar orbit, map the topography in selenodetic global topography, 0.5mm maximum high resolution mapping to assist in the selection of future landing zones and the probe will attempt to confirm the existence of lunar ice at the poles.

LCROSS, or Lunar Crater Observation and Sensing Satellite, will be launching with the Lunar Recon Orbiter and the objective of this mission is for the probes centaur upper stage rocket to impact the side of a permanently dark crater and analyze the plume of debris for any sign of the lunar ice that was possibly discovered by the Clementine mission of 1994. Following this stage the mission will end with LCROSS itself impacting on another part of the crater four minutes after the other impact.

NASA's Robotic Lunar Exploration Program, which encompasses the LCROSS and LRO is NASA's first step toward establishing a lunar outpost and it is the correct first step in the process. After LRO and LCROSS, NASA is planning on a robotic lunar lander mission in 2009 or 2010 and on having continuous lunar orbiters and surface probes until humans can arrive back on the moon in 2020.

The next step toward the establishment should involve the use of four person teams of astronauts engaging in reconnaissance trips to each of the lunar poles to further study sites selected through the analysis of the information gathered from a decade of unmanned probes. For a period of a year or two astronaut missions, through hands on analysis and further research on Earth a suitable site should be able to be decided either at the north or south lunar pole.



Following the selection of the site for a lunar outpost pre-planned construction plans can be put into action and construction of it can begin. For the initial construction stages of the base an agency should maximize the capacity of the Orion spacecraft and send six astronauts up instead of four, although the six man capacity is supposed to be reserved for any future Martian expeditions. The first priority of construction crews should be the establishment of a solar power array and the installation of communications equipment. The next mission should focus on setting up the habitat which astronauts will be able to call home. This step is the most important and will require the most missions in order to get life support, electronics, and filtration systems online and in working order. More missions will be required to fix any bugs that may arise and install scientific equipment. Eventually after about ten to fifteen missions varying in length between one and two weeks the outpost should be able to sustain a crew of 10-12 for up to six-month long deployments.

After four to five years back on the moon humanity will have constructed a lunar base at either the southern or northern lunar pole. The dimensions of the base that NASA is considering to build will make it about the size of the Washington Mall (309.2 acres), this dimension includes the landing zone and all other facilities required at the outpost. It is feasible to have crews of 10-12 crew members serve at least six-month long tours at the lunar outpost. Ten crew members would use the current capacity of two Orion Spacecraft, while twelve would need to use two of the planned six-man version of the Orion, which at this point is only planned for use on a mission to Mars. Since the six-man version of Orion probably will not be used then it would be a crew of ten calling the moon home. This crew would have to be hand picked by a review board to monitor several factors including age, sex, the ability to cope with isolation, and the ability to work as a team for six-months or more.

The constitution of the ten man crew needs to be carefully thought out, yet it is safe to say who should go on a mission to the moon based on common sense. A crew of ten should consist of two medical doctors, three engineers, three scientists, a mission commander, and a psychologist. The two medical doctor system is the most important feature in the team because they will provide for the physical well being of the crew and quickly diagnose any medical threats that could damage the mission. Why not use one? In the event one medical doctor is incapacitated, it is always prudent to have a back-up, especially in the harsh environment on the moon. Engineers and scientists are always a good choice when assembling a team to live on and study the moon. The engineers can work to make devices more efficient and fix problems that might arise. The science team could run experiments much like on the ISS and space shuttle. For an effective team of engineers and scientists, the selection criteria for a lunar outpost should include engineers in the mechanical, aerospace, and the electrical and computer fields, as well as scientists in the fields of physics, chemistry, and biology. The need for a psychologist arises out of the fact that an agency running the outpost needs to make sure everything runs smoothly among the crew in all situations regarding stress, home sickness, and overall tension that arises from a small group confined to an area for a long period of time. The mission commander role is necessary because someone needs to direct and remain in control of whatever situations may arise. The constitution of the crew is probably the single most important issue facing any nation or group of nations planning on setting up a permanent outpost on the moon.

With a lunar base set up and running smoothly, a space agency could have many options on how to move forward. They could choose to expand and upgrade the current station or work to set up more stations elsewhere. With the plans of multiple nations, including China, Japan, NASA, India and Russia, and even private companies, Virgin Galactic and Bigelow Aerospace, either to

go to or to establish outposts on the moon in the next twenty years, the moon promises to become an even hotter topic. At this point in time it is tough to imagine the conflicts that could arise over Helium-3, lunar ice, and laws governing the moon.

The plan of a moon base should not be to just stay put with what is initially built but to eventually upgrade and expand to open up the moon to more and more people. In the next fifty years it is foreseeable that there will be a good number of lunar outposts as well as tourist resorts on the moon. In a hundred years, if technology permits, we may see the formations of colonies of people in the thousands on the lunar surface.

## **6.2 Energy**

If a lunar base is to be developed, one of the main concerns would be the way in which the base would be powered. Many theories exist, but two of the most promising are the use of solar and nuclear energy.

The creation of solar power plants remains one of the most feasible means of providing both electrical and thermal energy. The technology for this method already been demonstrated here on Earth and in space, such as on the Mir space station and the Hubble telescope.

A lunar day and a lunar night each lasts 336 hours, so for 336 hours in each of these cycles, there needs to be a way of providing energy, even when a lunar base is receiving no direct sunlight.

One possibility is several “solar farms” placed at certain increments around the equator to increase the amount of time that solar energy could be collected. A distance of 1500 km between each plant, for example, would increase availability of solar energy by 24 hours, meaning that 14 plants at these distances would provide constant access to the sun’s energy.<sup>42</sup>

Each of these plants would require about 50 to 100 square kilometers in order to produce roughly 10 gigawatts of power. The energy collected and stored at these plants could be transmitted back to the lunar base either through power lines or wirelessly, using microwaves. There exist DC to RF (Direct Current to Radio Frequency) converters that are 83% efficient, and once the microwaves reach their destination, rectennas convert the microwave beam into electricity. Current rectennas operate at more than 85% efficiency. In addition, microwaves at approximately 2.45 GHz experience less than 1% attenuation while traveling through the Earth's atmosphere and normal precipitation and about 30% while traveling through heavy rain. On the moon, such environmental factors would not even exist, and attenuation would be even less. The photovoltaic panels themselves have about a 5% conversion rate.<sup>43</sup> The energy from photons hitting the cells knocks loose electrons, and the remaining positive charges and electrons repel each other, flowing through the semiconducting material, like silicon, creating an electric current.

Alternatively, if a polar base site is chosen, solar power is by far the most easily implemented long-term power source possible for a lunar base. With no atmosphere, there are no environmental obstructions to getting sunlight save for the orbit of the moon itself. Solar cells, or more specifically a "solar film", can eventually provide up to a megawatt of power over several years.<sup>44</sup> This provides sufficient power to suit the needs of future colonists, at the very least temporarily.

The state of present solar technology makes it practically ideal for not only use on the moon, but manufacture there as well.<sup>45</sup> This means that in addition to potentially meeting all the power needs of a colony, the equipment would not need to be brought along in its entirety. The extra

space resulting from having only necessary parts to *assemble* power supplies on the moon, and enough power resources to last until those were established would be invaluable.

Two features of the moon make construction of a film of solar cells possible: a vacuum environment and the presence of the prerequisite materials in abundance on the surface. These materials include iron, silicon, magnesium, calcium, aluminum, etc. Solar cell manufacture requires a vacuum to take place, and is accomplished by laying down the required materials in five layers: the substrate, the bottom electrode, N-type silicon, P-type silicon, antireflective coating, and the top electrode.<sup>46</sup>

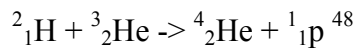
The moon's environment is not without its drawbacks regarding construction, but much of this can be resolved using robotics. Research into the specifications of this equipment has yet to be fully investigated, but ultimately it would have to accomplish two tasks. Apparently, it would need to be able to assemble the layers of the solar cells autonomously on the moon's surface. In addition to that, it would have to do any necessary resource gathering and purification.<sup>47</sup>

Furthermore, the environment after construction poses risks as well; with no atmosphere, the moon is under a persistent bombardment of meteorites. A solar power network would have to sprawl across large areas in order to not be critically damaged by this threat at any one time, and damage would have to be regularly repaired. Were the same robots assigned to construct the solar cells also designed with the ability to autonomously repair them, as well as the cells themselves being distributed on varying areas of the moon, the risk would be greatly reduced. If such technology is developed, and current knowledge of solar energy is implemented, solar power on the moon is already in our grasp.

Nuclear power also remains promising, especially given the relative abundance of helium-3, a relatively clean nuclear fusion reactant, on the moon. In addition, nuclear power would be available at all times, not just during the day.

The reasons for an attraction to helium-3 for this use are many. Helium-3 is an isotope of helium containing two protons and one neutron. In a fusion reaction involving helium-3 and deuterium, a high-energy proton and alpha particle (a helium-4 ion), are produced. As a charged particle, that proton could be contained in electric and magnetic fields, directly providing electrical power. In addition, due to the structure of helium-3, these reactions produce few loose neutrons that would activate materials in the structure of the power plant.

The idea of a fusion reaction has to do with the binding energies of the reactants involved. In the case of He-3 and deuterium, the following reaction occurs:



After this reaction occurs, the resulting sum of masses is slightly less than the sum of masses of the reactants. This difference in mass is known as the mass defect, and it is accounted for by a release of energy, given by Einstein's famous equation,  $E = mc^2$ , which can be re-written using conversion factors to obtain:

$$E_b = (Z * m_H + N * m_n - m_{\text{isotope}}) * 931.5 \text{ MeV} / \text{amu}$$

Where:

$$\begin{aligned} E_b &= \text{binding energy, in MeV} \\ Z &= \text{number of protons} \\ m_H &= \text{mass of a hydrogen atom, in amu} \\ N &= \text{number of neutrons} \end{aligned}$$

$$m_n = \text{mass of a neutron, in amu}$$
$$m_{\text{isotope}} = \text{mass of the isotope}$$

In the case of the above reaction, the amount of energy produced is about 18.4 MeV, meaning that there is a mass defect of  $18.4 \text{ MeV} / (931.5 \text{ MeV} / \text{amu}) = 0.0198 \text{ amu}$ .<sup>49</sup>

A large-scale mining operation would be necessary to make use of this valuable resource. There are several favorable locations for this, such as at the poles, on the far side of the moon, or in the Mare Tranquillitatis.

The reasoning for favoring the far side of the moon is that the Earth's magnetotail shields the moon's near side for about a week per month, resulting in less depositing of solar-wind-implanted gases, or SWIs, on the near side. The far side, then, experiences a larger average flux of solar wind, which results in a greater amount of SWIs.<sup>50</sup>

The poles are also a good candidate for location because temperatures there are more constantly lower than at other locations on the moon, and the desorption rate of implanted gases is directly proportional to the expression  $\exp(-U/kt)$ , where  $U$  is the activation energy, the energy that must be overcome for a reaction to occur, to  $k$  is the Boltzmann constant, and  $t$  is the temperature.

This means that as temperature decreases, desorption dramatically decreases, meaning that SWIs like helium-3 have a longer surface residence time in colder temperatures.<sup>51</sup>

And the Mare Tranquillitatis is a good candidate because there is a direct correlation between titanium concentration and helium-3, and the Apollo 11 and 17 missions demonstrated the abundance of titanium-rich mare in the southern and northern regions, respectively, of this Sea of Tranquility.

Even though there is much more helium-3 on the moon than here on Earth, the concentration of helium-3 on the moon is still quite small. This means that millions of tons of regolith would need to be processed in order to extract a decent amount of helium-3. Whether or not this is economically feasible might have to depend on whether the mining of helium-3 "piggybacks" on mining operations for other resources on the moon. In addition, the technology for all of this, especially fusion technology such as inertial electrostatic confinement, the use of an electrostatic field to contain plasma during a fusion reaction, still needs to be further developed.

The most feasible method of providing energy is through solar power. Perhaps one day we will have the technology to mine He-3 on the moon and harvest its energy from fusion reactions, but as of now, the technology simply does not exist, while the technology for solar power both exists and is widely used. If we are to see a lunar base happen in our lifetime, we need to make use of what we already know to be effective, and take relatively unnecessary technological risks later.

### **6.3 Personnel**

The number of people we send to the moon at first needs to be a balance between the human resources available to construct and run the moon and resources necessary to sustain those humans. While people could perform multiple tasks, certain tasks are specialized or time-consuming and would require one person to dedicate all his time to it.

There would be many opportunities for work on a lunar base, whether they are in the government, law enforcement, sanitation, operation of facilities for an energy source, such as a fusion reactor or maintenance of solar panels, geology for the study of the moon, and astronomy for the observation of near-Earth objects.



One of the most critical parts of the colony's personnel would be two or more doctors to take care of emergencies and medical check-ups, and to ensure that the crew is in good health and that the physiological effects of living on the moon – muscle atrophy, radiation, etc. – are within normal limits. While not working as doctors, they could perform as “farmers”, cultivating plants using hydroponics as a secondary food source and lightening the load of cargo sent from Earth. There should be several engineers to control robots that would do a large portion of construction and excavation. Geologists would be required to explore the landing site for materials that can be mined. All in all, the crew of the lunar base could contain about ten people and still address the main necessities of the base – construction, food, and medical care. Anything else would be, at first, an unnecessary luxury.

People that should *not* be sent to the moon, at least until a well-developed society with full medical supplies is in place – are fertile women. The possibility of babies being conceived or even born in space is too much of a risk, both to the child and to the rest of the crew. Babies are especially susceptible to prenatal radiation exposure. When the unborn child is only a cluster of cells, damage to a cell can cause death of the embryo. In addition, if a child is brought to term and born, the child would require constant attention, special dietary restrictions, frequent medical care, and other supplies not readily available if not prepared for.

#### **6.4 Resources**

There are many technical and economic challenges associated with a lunar base. It would cost about \$25,000 per pound to ship materials to the moon. This extensive cost will make it a necessity to either mine or manufacture most of the materials needed for an outpost on the moon. In a crater basin it might be possible to extract water for drinking and farming as well as oxygen

from ice crystals deposited by comets or asteroids. Some data suggests that some craters could be holding hundreds of millions of metric tons of water ice. This ice has been deposited there from billions of years of comet impacts.

Strip-mining regolith could be used to get calcium, nitrogen and hydrogen-free silicon. Calcium can be used to make cement, nitrogen can be used for farming and hydrogen-free silicon can be used to make glass and ceramics whose crystal structures are potentially structurally superior to those made on Earth. Silicon can be passivated by hydrogen and this can cause light induced degradation of the material. The lunar soil also contains useful elements like titanium, iron and aluminum.

In order to take care of food and water, at first supplies would likely have to be delivered directly from Earth. Later, though, there is the possibility of growing vegetables in a greenhouse and using hydroponics and a blend of incandescent and fluorescent lights, and breeding animals for food.

Another way to help reduce the amount of outside resources needed to be shipped from Earth is an efficient recycling system. Once water is delivered from Earth, much of it can be recycled at about 97% efficiency from urine and water vapor exhaled by human inhabitants and the possible animals, much like it is on the International Space Station (ISS). Over time, human water output is roughly 0.1% less than water input. In one day, a human consumes roughly 1000 mL of water by drinking, 1200 mL from food, and 300 mL from metabolizing food. Humans excrete roughly 1650 mL, sweat 500 mL, and exhale 350 mL.<sup>52</sup> Daily, each human would require 2500 mL of water, from which slightly less than 2422.6 mL can be recovered, with a loss of more than 77.4 mL per person per day. Therefore, eventually, water would have to be either delivered or mined

from somewhere else. However, any future transfer of water would be in far smaller quantity than the initial transfer.

One such alternative location for acquiring water would be from the moon itself, in the form of lunar ice. Scientist Harrison Brown and his associates first brought up polar ice in early 1960. On the lunar surface, the bottoms of some polar meteor craters never receive any sunlight—the moon has an estimated 14,000 km<sup>2</sup> of these areas. Brown reasoned that when a meteor containing ice hits the lunar surface, most water molecules would vaporize but some would get trapped in these permanently dark areas. These molecules build up over the moon's long, multi-billion year history, and may have amassed into a large quantity of collectable ice.

For safety reasons, the Apollo missions were performed near the moon's equator. Samples of lunar rock that were brought back to Earth were completely dry. A Lunar Polar Orbiter was planned that would map the chemical composition of the lunar surface. However, this was later canceled and public interest in the possibility of lunar ice died out. Under the Reagan administration, public interest again waned toward space exploration, this time in the form of developing technology for ballistic defense.

In 1998, NASA sent the unmanned Clementine Lunar Prospector to orbit our moon for 18 months. Clementine found large amounts of hydrogen in the moon's south pole by bouncing radio waves off of the lunar surface and comparing the bounced waves with those from ice. This may indicate that hundreds of millions of tons of ice are available for mankind to harvest. Since then, there has been no new information concerning lunar ice—whether or not there is ice on the moon and if it exists in usable quantities.

NASA is currently planning to send the Lunar Reconnaissance Orbiter (LRO) in October of 2008. This is, according to NASA, the best chance we will have to resolve the lunar ice debate from orbit. If the LRO has positive results, it could pave the way for a robotic expedition on the surface. The French currently have the SMART-1 orbiting the moon, armed with an infrared spectrometer to try to gather more evidence for the existence of ice. However, if the ice is sparsely embedded in layers of dry rock, a sample taken from the surface will be necessary.

So far, all that can be confirmed is the existence of hydrogen. This can either be ice trapped in dark areas of the moon, as described earlier, or the hydrogen can be fixed to the surface from billions of years of solar wind. Either way, NASA will be able to make use of the hydrogen. If it exists in the form of water, oxygen and hydrogen can be extracted using electrolysis.

Hydrogen is highly valuable to NASA's efforts and the prospect of lunar colonization because it is an essential ingredient in rocket fuel. If hydrogen could be collected, in one way or another, directly from the moon instead of bringing it all from Earth, not only would the moon be more independent of Earth's resources, but also it would be able to be a launching point – promoting more effective and profitable space exploration beyond the moon itself.

## **6.5 Location**

A suitable location for a lunar base must be chosen. Some areas have advantages over others. The poles of the moon show the most promise. One advantage of the poles is the temperature varies moderately ranging from negative 30 degrees Celsius to negative 50 degrees Celsius, compared to the high temperature at the equator of 132 degrees Celsius. A greater advantage the poles have is its resources. Near the south pole, there are high crater rims that are almost continuously exposed to sunlight. This would serve as an excellent place to construct sun-

tracking solar arrays that could provide nearly constant power. In addition, if some of this power was stored in batteries then they could be relied on during the short periods of darkness.

## **6.6 Law**

There are laws that various governments have already agreed upon regarding space travel. They have suited us well when there have not been permanent residents of space, but when that comes about they may become antiquated and require revision. Case in point, there is no distinct provision for land ownership on the moon. Although some have tried to cash in selling land on the moon, no one can technically own any celestial body or any part of space. In 1955, Robert R. Coles sold acres at one dollar a piece, and in 1966 the town council of Geneva, Ohio created a Declaration of Lunar Ownership, where they take “full possession and responsibility” of the moon. However, the *United Nations* (UN) outlined rules and regulations regarding the exploration of space long ago.

There are numerous other treaties that govern nations’ ability to explore the stars. The *United Nations Office for Outer Space Affairs* (UNOOSA) was formed to promote international cooperation between different nations in using outer space for peaceful and beneficial purposes. In 1962, UNOOSA wrote the *Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space*. Regarding the ownership of space, it states that “outer space, including the moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means.”

UNOOSA, under the *Convention on the Registration of Objects Launched into Outer Space* (The Registration Convention) of 1974, distributes studies and research publications on space travel and the technology surrounding it, making information available to smaller countries looking to

join in the arms race. They also maintain and monitor an index of all objects launched into outer space since 1957. Companies or individuals wishing to place a satellite in orbit need to be able to put it in a place that is not only useful to them, but is free of other satellites in the immediate area and their orbital paths. This information is made freely available over the internet, indexed by factors such as launch date, whether it is nuclear powered and the type of orbit it has, for example.

In addition, UNOOSA declared a series of legal principles that outline the attitudes nations and companies must have while exploring the depths of space. This is known as space law, and is defined by five core principles and five international treaties. Principles and treaties being that the treaties are binding to the countries that ratified them, while the principles tend to shape the treaties and procedures employed. As UNOOSA says on their website, “The primary goals of space law are to ensure a rational, responsible approach to the exploration and use of outer space for the benefit and in the interests of all humankind.”

*The Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space* states that all exploration should be done for the benefit of all countries. This includes using any sort of nuclear or weaponized satellite, as well as not using any natural satellites (the moon) for anything but peaceful purposes. *The Principles Governing the Use by States of Artificial Earth Satellites for International Direct Television Broadcasting* of 1982 takes care of international conflicts and rights of countries concerning TV satellites, as well as mandating that the UN be notified for any object to be sent into space. *Principles Relating to Remote Sensing of Earth from Outer Space* says that remote sensing, which includes using the properties of electromagnetic waves emitted or reflected from the planet’s surface, “shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of

economic, social or scientific and technological development, and taking into particular consideration the needs of the developing countries.” There is also principle concerning the use of nuclear power on satellites, making a clear distinction between nuclear power and nuclear weapons, and a principle outlining international cooperation. The latter is more fully explained in the treaties UNOOSA has put forward.

*The Treaty on Principles Governing the Activities of States in the Exploration and use of Outer Space, Including the Moon and Other Celestial Bodies* (The Outer Space Treaty) calls out to different nations to help each other in an effort to bring together as much help as possible in order to develop the technology needed for space travel. They go as far as mandating that “in order to promote international co-operation... [Other nations shall] be afforded an opportunity to observe the flight of space objects launched by those States.” In the *Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space*, UNOOSA mandates that in times of emergency one nation should do everything in its power to help astronauts of a different nation, reasoning that astronauts are “envoys of mankind” and must be highly regarded as such. In cases of emergency, astronauts and space objects recovered on foreign soil must be returned to their original owners with full cooperation.

The *Convention on the International Liability for Damage Caused by Space Objects* takes into account any international conflict that could occur from space exploration in lower Earth orbits. For example, if a satellite were to crash into Earth and land on foreign soil, the original owners of that equipment have a right to collect it. The fact that a craft has traveled and left a nation or gone through space does not change its ownership. If said equipment damages property in foreign land, the nation that own the equipment must take responsibility for damages. “Each State... that launches...an object into outer space... is internationally liable for damage to

another State Party to the Treaty...in air or in outer space, including the moon and other celestial bodies.”

The creation of such a document seems so useless, as only a select few nations have put anything in space, and even fewer put something manned in space. With the exception of certain specific issues with communication satellites, many of the articles they lay out do not apply to anything. Like most UN treaties, countries are free to drop out with no real consequences (since the UN has limited resources for enforcing the regulations it creates). It is easy for a country to ratify a treaty that will have no effect on them, but as space exploration becomes more relevant to smaller countries, their participation in UN space law may change.

However, the UN has looked past that and has prepared for the future of space travel and the political and environmental hazards that may come about as a result. Meetings are regularly called in, usually concerning communications satellites. However, as technology improves and space activity becomes more relevant, international space law will be updated to reflect such change. States effected by UNOOSA’s principles and regulations include The US, The UK, France, Germany, Japan, Russia, Argentina, Australia, Canada, Finland, Hungary, Indonesia, New Zealand, Philippines, Korea, Slovakia, Sweden, South Africa, Tunisia, and Ukraine.

However, some countries will only ratify one of the five treaties, for example. The Outer Space Treaty has been ratified by 98 countries, while The Registration Convention has only been ratified by 46 countries. Space exploration that may be done in the future by private companies are subject to the regulations that the particular country signed to.



## **Conclusions**

The exploring spirit has historically led mankind to conquer and inhabit uncharted territory. While humankind has shown its dominance on Earth, there still remains the impossibly large final frontier of space. The first steppingstone to inhabiting space is the colonization of our closest celestial body, the Moon. With current technology and appropriate funding, a lunar base could already exist. To accomplish this on a more realistic budget, further development is needed in protecting humans from the dangers of space, artificial intelligence, robotics and long-distance transportation. Also required is an understanding of the psychological and humanitarian aspects of space travel. A fully functioning Moon base would fully disclose its benefits for humanity as a near-Earth object detection post, spaceport to the planets, and a helium-3 mining operation—something that may eventually bring an end to our planet’s energy crisis. The future is ripe with the endless applications a functioning Moon base could enable. This is an essential step and learning opportunity that will be relied upon to prepare for more ambitious endeavors to Mars and beyond. While what the future holds may be unknown, it is decidedly certain that the future will entail humanity in space.

## **Recommendations for future IQPs**

After completing our IQP on humanity and space it is easy to see several areas that a future project could build on. Taking into account areas of our IQP namely moon colonization and transportation technology it is clear that each section could in fact be expanded into more detailed IQPs. The humanity and space project was a broad survey into all the aspects of getting to and colonizing the moon and not focused on a specific sub-topic.

In further studies of space transportation technologies it is recommended that groups engage in projects focusing less on current and near-future NASA technology for space exploration and look into alternative technologies that are possible and technologies contemplated for use by other nations. In regards to alternative technologies nuclear pulse propulsion and the use of nuclear power on spacecraft should be looked at on all levels legally, socially, and economically to see whether or not humanity could live with sanctioning the use of nuclear technology and allowing it to circumnavigate the test ban treaty of 1963. The space elevator could also be studied further and developed into another IQP focusing on the economic and social impacts of constructing the elevator.

In regards to moon colonization future IQPs can easily build upon a large number of areas in the sub-sections dealing with this topic. In a future project a group of students could create a more detailed mapping of how a moon base would be set up and calculate what methods would be the most economical. If the sole objective of an IQP was to establish a complete and detailed blueprint for the establishment of a colony on the moon it would be able to go into a lot more detail than our project was able to. This project attempts to give a broad and lightly detailed perspective on the requirements for the establishment of a lunar outpost. A future project should and can easily build upon this by further establishing more refined blueprints for the establishment of a lunar base.

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