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HUMANITY AND SPACE

AN INTERACTIVE QUALIFYING PROJECT

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ABSTRACT

Our IQP investigates the possible functionality of another celestial body as an alternate home for mankind. This project explores the necessary technological advances for moving forward into the future of space travel and human development on the Moon and Mars. Mars is the optimal candidate for future human colonization and a stepping stone towards humanity's expansion into outer space. Our group concluded space travel and interplanetary exploration is possible, however international political cooperation and stability is necessary for such accomplishments.

EXECUTIVE SUMMARY

This report provides insight into extraterrestrial exploration and colonization with regards to technology and human biology. Multiple locations have been taken into consideration for potential development, with such qualifying specifications as resources, atmospheric conditions, hazards, and the environment. Methods of analysis include essential research through online media and library resources, an interview with NASA about the upcoming Curiosity mission to Mars, and the assessment of data through mathematical equations. Our findings concerning the human aspect of space exploration state that humanity is not yet ready politically and will not be able to biologically withstand the hazards of long-term space travel. Additionally, in the field of robotics, we have the necessary hardware to implement adequate operational systems yet humanity lacks the software to implement rudimentary Artificial Intelligence. Findings regarding the physics behind rocketry and space navigation have revealed that the science of spacecraft is well-established. Moreover, our group has learned that the Moon holds significant quantities of water locked in the regolith and that it would serve as a sufficient outpost for human expansion into space. Finally, our findings on Mars affirm that the atmosphere is relatively thin compared to Earth due to a weaker magnetosphere, yet habitability is still possible because of an Earth-like environment. Our group concludes that Mars is the better exploration and colonization candidate because Mars has more suitable planetary conditions compared to the Moon. While the Moon may be closer, a colonization effort has a better chance for successful habitation on Mars regarding human biology. Furthermore, we have determined that the technology for robotics, spacecraft, and railguns are sufficiently developed for use in space but have not yet been extensively tested in isolated conditions. Recommendations discussed during the project include further research on genetics and medicine for human biology with regards to space, developing railguns purposed for Near Earth Object defense, and exploring new materials and methods for extraterrestrial habitat construction. Limitations our group has encountered during this project are the lack of resources and ability to test our findings in a physical medium by building the technologies we discuss as well as being unable to conduct in-person interviews for the majority of our research due to transportation difficulty.

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INTRODUCTION

Since the dawn of the space age, space-related technology has been contributing to advancements that would provide an opportunity for the human race to flourish on another world. Humanity would want this prospect in the case of a potential apocalyptic circumstance. Such an event could occur within the next hundred years, including solar flares, a large Near Earth Object collision, or extremely devastating tectonic activity. In order for humanity to survive such an event, there should be another location where the legacy of humanity will continue. This would entail a worldwide effort to develop an outpost or colony on another planet. Besides an emergency situation, retaining an outpost on another world will provide research opportunities and valuable resources that can be used both in space and here on Earth. Thus, humanity's pursuit of knowledge of the solar system continues to proliferate so technological advances and interplanetary exploration become possible for the future.

Our group decided to pursue this IQP for various reasons. The team is made up of two Electrical and Computer Engineers, a Robotics Engineer, and a Chemical Engineer. Space interests us because it holds multiple curiosities to uncover and mysteries to unravel. Our personal motivations for exploring aspects regarding humanity and space include forming foundational knowledge about reengineering the solar system to suit humanity's needs, expanding beyond the Earth to discover new cosmic phenomena, and determining the overall process involved in colonizing a celestial body. The group has been able to apply our knowledge towards such aspects within our solar system. Our future careers will involve futuristic technologies such as robots that will be used in extraterrestrial missions, such as surveying other celestial bodies, improving communication infrastructure of spacecraft antenna, integrating circuits and power systems for spacecraft, and finding new resources and safer chemicals to use in nuclear reactors.

Science fiction has placed humans throughout outer space in multiple situations, providing an innovative outlet for developing solutions to space, and makes the idea of colonizing and exploring other planets more acceptable to the human mind. Two celestial bodies that seem most plausible for humans to develop are the Moon and Mars, because of their close proximity to the Earth and their relatively favorable environs compared to the rest of the solar system. Although both worlds pose their own set of risks, developing technology is able to counteract these hazards and provide a safe haven for human beings. It will take centuries to fully colonize another world, beginning with intensive research and technological advancements. This project will begin to identify the processes necessary to achieve space expansion and the impact on human society from such endeavors.

1. HUMAN ASPECTS

1.1 EXPLORATION MOTIVATIONS

Each day new technology, theories, experiments, and research help progress human intelligence. Civilization has come a long way from the development of the first computer, which weighed 30 tons and had dimensions of eight by three feet—unimaginable nowadays—and our lives have therefore become much more interesting, convenient, and, unfortunately, dangerous. It is important to remember that natural disasters or other planetary catastrophes can occur at any moment, and that we should take advantage of modern science's technological progression to prevent such a tragedy from happening. However, sometimes humanity's new inventions are harmful to our planet, and we are decreasing our own chances of sustaining life on Earth. To preserve mankind in the event of such an emergency, a space based colony could be used as a new location for humans to thrive.

Political and environmental issues are quickly coming to a climax as the human race enters the 21st century. Dilemmas such as a third World War, severe effects from mishandled nuclear waste, and atmospheric pollution are entering the foreground of political and scientific media. According to Carl Sagan, famed astrophysicist and producer of the 1980s TV series "Cosmos", the chance of life continuing to exist on Earth is (determined to be) less than 1% per century, when factoring in the multitude of events in the "sample space" of Earth that could cause global extinction of humanity. This seems like a rash statement, but there are valid reasons that there will be an ending to mankind eventually. One example would be an epidemic. Between 1346 and 1368, the "Black Death", or the bubonic plague, spread through Europe and an estimated 25,000,000 people died, an entire quarter of the continent's population. Around 30,000,000 people died in the summer and fall of 1918 from the "Spanish" Influenza, wiping out 2% of the World's population [40]. It seems unlikely that such a devastating illness could occur within the near future, since we have vaccines for many fatal diseases and medicine is quickly advancing, but there's a chance that these vaccines or other medical developments hold hidden dangers. Britain's famous medical journal, the "Lancet", stated throughout 1979 and 1980 that "there is a relationship between crib death and immunizations" and that "at last count there was

2,525 cases of children reduced to vegetables by vaccine damage" [24]. Vaccines may have unpredicted side effects, such as blindness, deafness, or heart defects, which have been linked back to the German measles, Salk polio and other various vaccinations. Scientists must also be careful when completing experiments in genetic laboratories, one mistake could lead to the development of a deadly virus, a mutated strain of DNA, or toxic bacteria. To limit scientific accidents, 140 leading genetic researchers met at the Asilomar meeting in 1974 to discuss the hazards of genetic manipulation and to set guidelines to protect mankind from the potentially disastrous consequences of modern science. This protocol cannot be governed however, and if someone does make a mistake, or does not abide by the rules, it will be helpful to have a completely separate colony-- such as outer space-- where a part of the unharmed population could temporarily, if not permanently, escape.

Another issue is the possibility of creating "runaway pollution" [40]. The "runaway greenhouse" concept was developed while scientists were studying Venus and is defined by a planet's temperature increasing, therefore causing increased water evaporation, which then causes greater infrared absorption, causing an even greater temperature increase and so on until a new, significantly different, equilibrium is stabilized. Earth's atmosphere has been, and is being, strongly modified by man, and the risk of a runaway effect is possible. Industrial pollution emits a variety of substances that are harmful to the atmosphere; toxins such as chlorofluorocarbons (CFCs), which can be found in refrigeration systems and aerosol propellants, and methane, a product of industrial and mining activities, eventually make their way to the upper stratosphere and interfere with the production of the ozone layer by the Sun's rays [125]. The ozone layer is an important part of the Earth's atmosphere that protects life from deadly ultraviolet and X-rays which are constantly emitted by the sun. In the last half dozen years there has been shifting changes in our global weather patterns. The changes are highly unpredictable and we know very little about the complicated, non-linear interaction between various pollutants and our environment. By moving mankind to outer space, we can be sure that there is another life-supporting station outside of Earth's realm, and that if anything catastrophic was to happen, humans would not become extinct. Our intelligence is valuable, and we should be sure to take advantage of its thoughts and capabilities in space colonization.

1.2 IMPACT OF SPACE ON HUMANITY

One of the most significant events of the 20th century occurred on July 20, 1969. America held its breath as Neil Armstrong took “one small step for man; one giant leap for mankind”. Hence, society’s growing interest in space began. Humanity’s knowledge has been growing exponentially since the Stone Age, and by expanding our creative thoughts into the solar system, many new stimulating opportunities arise. After a devastating Tsunami rocked the Indian Ocean in 2004, the InterAcademy Panel on International Issues (IAP) began an initiative known as the “Natural Disaster Mitigation”. This protocol involves Earth-observation satellites and the cooperation of nations throughout the World to predict and protect against any coming natural disasters. Earth-observation satellites are used to monitor every portion of the Earth’s surface, including weather patterns, ocean currents, and clouds. Observational remote sensing systems are installed on the satellites which are then sent to orbit around Earth, providing us with meteorological, land, sea, and oceanic observations, some of which help predict weather patterns that our daily lives are based upon. Satellites orbiting the Earth also play a large part in long distance communication systems. Communication satellites allow radio, television, and telephone signals to be sent in real time to anywhere in the world. Unfortunately, communication signals travel in straight lines and cannot bend with the curvature of the Earth, making extremely long distance land communication impossible. The introduction of space satellites solved this issue and further advanced society by making it possible to send direct signals to a satellite in space, which then redirects the signals to another specific location, which could be halfway across the World [43].

Space exploration has been a major driving force behind many recent technological advancements. As NASA and other space agencies develop new hardware or scientific devices for robots, spacecrafts, and humans to withstand the harsh environment of the solar system, they’re also taking giant leaps in technological applications that we can use here, on Earth. In 2007, USA Today released a list of the “Top 25 Scientific Breakthroughs” that had occurred within the last 25 years. Nine of them came from the pursuit of space exploration, and eight were directly related to NASA. Space technology has helped firefighters, doctors, and the common workman in numerous ways. Technology used during the Apollo missions produced a lighter breathing apparatus for firefighters, and includes a mask that allows for greater peripheral vision. A handheld drill that was developed by Black & Decker and NASA for Moon soil samples spurred the production of a line of cordless tools that make construction and gardening for a business or homeowner easier. One of NASA's most prominent developments is the Ventricular Assist Device, or DeBakey Blood Pump, that uses the Space Shuttle's turbine technology to pump blood in a multitude of situations, such as supporting and sustaining an injured heart. Heart surgeon Dr. Michael DeBakey collaborated with NASA on this project, and is proud of how these "spinoffs" so positively affect life here on Earth. A "spinoff" is any beneficial device that was derived from space technology and is now used commercially. So far NASA has had more than 1,500 successful spinoff stories [141].

Besides useful developments for Earth living, space influences humanity's moral life as well. When the United States of America landed on the Moon, American pride heightened. The excitement of space exploration continues today, as over 1,000 people watched the live Curiosity landing on Mars in August. Space provides hope to society, and assures that there are more things to be discovered and studied. It is important to be looking at the Universe in such a profound way, so that scientific and creative attention can be focused and applied to somewhere other than Earth. As humanity's technology and knowledge expands, we use up more and more of Earth's valuable resources. Our goal should be to conserve our planet, and we can do so by utilizing the solar system.

1.3 Effects of Low Gravity

Making a permanent base on the moon is becoming an attractive option for the future of space travel. Plans are unclear so far as to whether this base would most likely be run and maintained as a fulltime living community, or used more as a jumping point for the transit to other planets and space locations. Regardless, the impact and effects of low gravity on the human body are issues that need to be contended with in order to make a permanent base on the moon into a realistic possibility.

The human body is a very complex system, capable of adapting to numerous extremes. When long amounts of time are spent on earth, “the body as a whole system establishes an ‘earth-normal’ condition” [72]. This is the condition the body assumes as normal for its given environment—the earth. When the body is relocated to the moon, it must readapt to a “moon-normal” condition. That is, the condition the body adapts to in order to maintain a stable and healthy state in lowered gravity.

Whenever the body moves from high gravity, like that on earth, to lowered gravity, such as space or the moon, it must take time to readjust. The moon’s gravity is roughly one sixth that of the earth, so perhaps the most noticeable change is a feeling of lightness and agility. This feeling, however, comes with strong physiological implications. Because all the body’s organs and fluids are being pulled downwards with only one sixth of the force as in an earth-normal state, a strong upwards fluid migration will occur. Because of the lessened downward pull of gravity, “fluids are redistributed to the upper part of the body and away from the lower extremities” [72]. This effect is more prevalent in micro-gravity conditions, however, after long periods on the moon it is speculated that some symptoms will become noticeable, the most common of which includes swelling of the facial features, and shrinking of the fatty tissues in the lower half of the body.

Perhaps the most troublesome issue of spending long amounts of time in a low-gravity system is the fact that muscles begin to atrophy. Because the gravity on the earth is six times greater, the muscles in the body must work much harder on a day to day basis than they would on the moon. Because of this, after long periods of time spent on the moon, muscles will weaken because they are not bearing as much weight as they would on earth. Additionally, bones will lose density and therefore strength. The release of calcium that comes with loss of bone density also poses a threat to the kidneys as the body tries to absorb the misplaced calcium. The most dangerous implication as the body weakens is the “deconditioning and decrease in size of the heart” [16]. Upon returning to the earth, the body will weigh six times what it has become used to on the moon, meaning that the heart will have to work six times as hard. This could result in any number of life-threatening cardiac complications in addition to the fact that weakened bones are more prone to fractures and breaks, and the rest of the bodies muscles will have to be built back up through physical therapy.

In order to combat these issues, specialized aerobic and strength training exercises will need to be formulated to target specific areas of the body which are most susceptible to atrophy and weakening. Weight bearing exercises to simulate the earth's gravity will be crucial in the months leading up to a return trip to earth, if one is made, as well as preventative exercises throughout one's stay on the moon. As living and working on the moon becomes more and more a possibility for the future, it is necessary to be mindful and realistic about the different gravitational environment and how to take care of the body under such circumstances.

1.4 BIOENGINEERING

In past manned space exploration missions, advanced health regulating technology was needed to monitor the vital signs of the crew, administer nutrition, and manage waste. Current technology will suffice for future trips to the moon; however, further developments need to be made in the bioengineering field in order to facilitate trips to Mars and other explorations in the future.

Currently, NASA's bioengineering branch is working on a complex life-support system that will closely regulate crew members and passengers on future trips to Mars. Such technologies will need to include air contaminant removal and filtration systems, water and waste recycling systems, as well as food processing systems, among others [93].

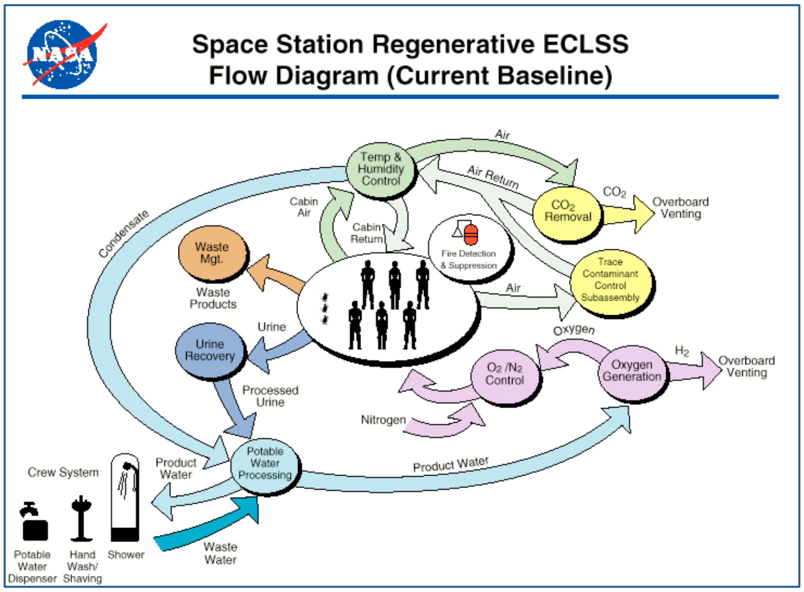


Figure 1. Enronmental Contola and Life Support System. A diagram explaining the life support systems used in the space station. (NASA)

In the figure above, the complex system used to sustain the humans on the space station is broken down into a flowchart. A complex system like this would be needed for any extended human presence in space, such as the long commute to Mars [70].

Currently, most research for bioengineering as it pertains to space is focused on refining such life sustaining systems for the future of space travel. This being said, it is important to also consider what re-engineering the human body could bring to table. Although it seems that the technology is still far off, replacement organs would be a solid option for the difficult issue of solar radiation. In addition to solar radiation, there are many other cancer-causing aspects of space, such as hyper-accelerated particles that can rip through bodies, and even space ships. On the current level of technological advancement, synthetic organs are only capable of standing in for real organs while patients await donor organs from the transplant list. As technology develops, perhaps cancer resistant lab-made synthetic organs can be replaced in a person's body prior to space travel.

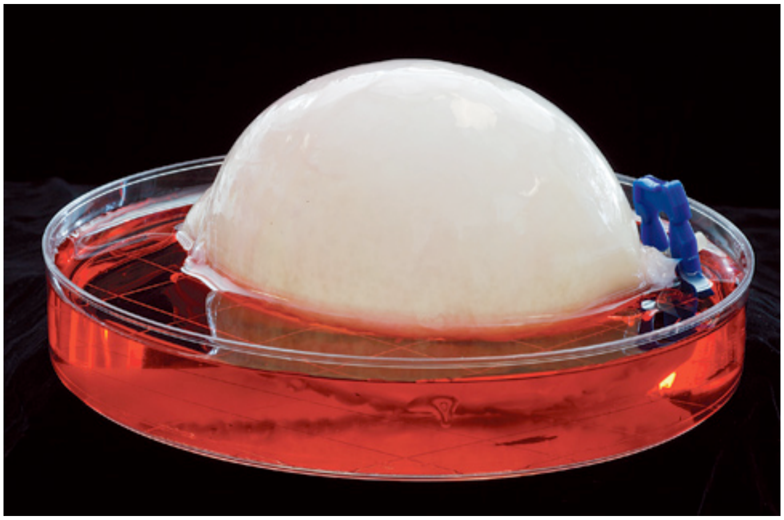


Figure 2. A lab-grown bladder. (Syntheticorgans.yolasite.com)

Once humans begin to colonize other space locations such as Mars and the moon, constructing safe shelters and habitats quickly will be of the utmost importance in order to find protections from solar radiation and possible meteorites. Sending robots ahead to complete this task is a great idea in theory, but it is likely that a human presence will be needed for supervision and management. One way to cut labor needs down is to increase the strength of each individual using robotic exoskeletons. Robotic exoskeletons are a type of robot that is worn by a human and works with the wearer's natural movements to aid them in strength and endurance. While these machines are not autonomous, they read signals from the body and adapt to move with the wearer and increase their natural strength greatly.

Figure 3. An example of a robotic exoskeleton being used by the military. (Gizmag.com)

Currently, the US Defense Advanced Research Projects Agency (DARPA), is funding a 50 million dollar project known as "Exoskeletons for Human Performance Augmentation." Although actuation, power supply and storage suitable for the human body are still problems that need to be tackled, in comparison to other bioengineering alternatives, exoskeletons are a much more feasible possibility for the near future. Most of the robotic exoskeletons under current development will be first produced for military use, however, their applications will surely extend to space travel. Such exoskeletons will not only increase strength, but will also protect the wearer from harsh elements, as well as increasing stamina [89].

Bioengineering is an indispensable technological field for the future of space travel. From life-support systems, to synthetic organs, to robotic exoskeletons, the field is incredibly vast and capable of impacting the speed of space development greatly. Robotic exoskeletons will help with the progress of making other planets habitable, while replacement organs and life-support will be important aspects of maintaining human safety on the journey away from earth.

1.5 INTERNATIONAL RELATIONS

China has recently entered the top-end network of spacefaring countries, standing alongside the United States and Russia. In 1992 the Chinese government approved a steady, slow-paced space exploration plan that includes the development of human spaceflight, a robotic lunar exploration program, and space effort towards national security. China successfully launched the Shenzhou 9 spacecraft during June of 2012. Three astronauts boarded the spacecraft and achieved China's first manned space docking with the country's orbiting module Tiangong 1 [36]. China has only seriously collaborated on its space technology with a small number of nations, specifically Russia and Brazil. Russia worked with the Chinese to help develop the Shenzhou 9, which was based upon the successful Russian Soyuz vehicular design, as well as allowing the country to purchase Russian spacesuit designs. China and Brazil have been scientific partners since 1988, when the China-Brazil Earth Resources Satellite (CBERS) Program was developed between the two nations. The countries work together to improve the construction, launching, and operation of satellite technology. China also belongs to the Asia-Pacific Space Cooperation Organization (APSCO), whose headquarters are in Beijing, and has pledged to cooperate on space exploration matters with a few other countries of the Asian-Pacific region, including Iran and Pakistan [36].

The United States however, has not been involved in such friendly spatial relations with China. The main complication is the U.S.'s mistrust of China's military intentions; space technology can be used for both civilian and military purposes, and it is difficult to foresee whether military space assets are intended for offense or defense. China's space program is primarily run by the military, making it difficult for the U.S. to cooperate with the country. It is unknown whether Chinese aeronautical firms will be willing to sell their missile technology to nearby Asian countries, such as North Korea, Iran, and Pakistan, that are serious threats to the U.S. China could easily join forces with these nations, empowering and strengthening their global standing in hopes of the U.S.'s demise.

The U.S. delegation proposed using foreign satellites to monitor carbon dioxide emissions in China, since the country has been the largest CO2 contributor since 2004, making the stabilization of international atmospheric greenhouse gases very difficult. The Chinese strongly resented this idea, claiming it would be an "infringement upon their national sovereignty" and tension between the nations has grown. When it comes to space, the two countries prioritize different issues, the United States being most concerned with space security while China is most interested in commercial space cooperation and the expansion of market opportunities [64].

A goal listed in the United States National Space Policy is to "strengthen stability in space through domestic and international measures to promote safe and responsible operations in space" [135]. In order to fulfill this goal, the U.S. must be willing to cooperate with China. The abbreviation of the U.S. space program has provided a great opportunity for Chinese and American space efforts to collaborate. Budget cuts within the space program have increased American dependency upon foreign space technology, and could definitely help the two countries form a closer relationship. China is one of the few countries where space budgets are stable, with promise of growth, and proves that the country may be a vital potential partner in future space endeavors. Through this partnership the U.S. could gain a more explicit understanding of China's interests and intentions in space. President Obama and Chinese president Hu Jintao have visited one another and have emphasized their willingness to cooperate on matters of space exploration. Hopefully this is not an empty promise [64].

1.6 NEAR EARTH OBJECTS

Near Earth objects (NEOs) are one of the greatest hazards that lie outside of Earth's realm and are capable of regional, and even global, damage if not discovered in a timely manner. Near Earth objects are classified as asteroids, comets, or meteorites that come within 8 million kilometers of Earth's orbit. These can then be further classified into Potentially Hazardous Asteroids (PHAs) if they are within this close range and have a diameter of 140 meters or greater. Currently, NEOs and PHAs are detected by satellites sent on space missions or by ground based telescopes. NASA recently launched a mission to specify the amount of NEOs out there and gather information on them. Results were obtained from data found by the asteroidhunting portion of NASA's WISE mission, known as NEOWISE, and 4,700 asteroids were observed. One thousand three hundred and twenty of these are considered PHAs, meaning that they are close enough to cause a threat, and big enough to survive passing through Earth's atmosphere, therefore causing damage on a regional, or greater, scale. The WISE mission retired in late 2011, and there is currently no other space-based observatory vehicle in our solar system. The Canadian Space Agency (CSA) is expected to launch the world's first space telescope that is solely dedicated to detecting and tracking NEOs sometime in 2012. The NEOSSat (Near-Earth Object Surveillance Satellite) will be 800 kilometers above Earth and will circle the globe every 100 minutes while scanning outer-space near the Sun. Moving NEO observatories to the sky is a great idea, since ground-based telescopes can be limited by the Earth's day-night cycle, geographic location, or weather [6].

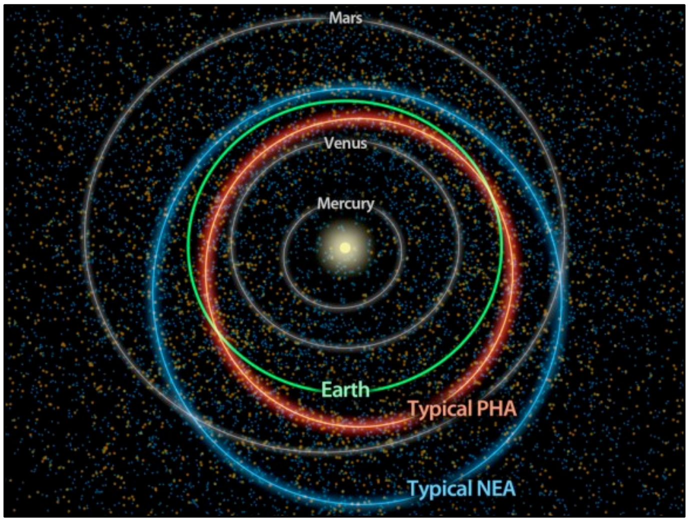


Figure 4. This diagram illustrates the differences between orbits of a typical near-Earth asteroid (blue) and a potentially hazardous asteroid, or PHA (orange).
(Neowise 2, Atkinson)

With this information it is clear that an accurate approach to the detection of PHAs, and protection from them is needed. John D. Matthews, a professor of electrical engineering at Penn State, is convinced that artificial intelligence is the answer to space-related problems. We have the technology to develop these exobots, but the lack of a compact power source is causing a delay on this frontier. Exobots would have two main purposes, to clear existing debris and monitor space junk as well as monitoring the 1,300 PHAs and other NEOs. The first step in this process would be to launch robot vehicles that will learn about the asteroids and place beacons on them for identification and tracking. Ultimately Matthews would like to see a network of exobots spread throughout the solar system and into the galaxy communicating through a series of infrared (IR) lasers. This network would be composed of the autonomous robots previously described that are able to determine the exact location and time of their observations and send this information through IR lasers that will finally convey the information to Earth. Surprisingly, the most expensive part of developing and launching this technology is escaping the surface and gravity of Earth. These exobots would make targeting space debris in near Earth, and geosynchronous, orbit easier and will be able to recycle their findings [109].

The NEOWISE project put this idea of IR sensors to use while detecting NEOs and PHAs. With the IR sensors, the robot-like vehicle was able to detect the heat of asteroids and therefore could pick up both dark and light objects, resulting in a more representative look at the entire NEOs population and improving the ability of astronomers to take good measurements of the asteroids' diameters. Eight hundred and forty-three near Earth asteroids with a diameter of approximately 1 kilometer of larger were detected. WISE realistically sampled 107 PHAs to make predictions for the entire population as a whole. NEOWISE uncovered the fact that there is an overabundance of low-inclination PHAs, meaning that these PHAs will move closer to Earth as time continues.

There are four mitigation techniques and defense mechanism plans that are still quite new and under-developed that could be used in the event of a disaster. These include civil defense, a "slow pull" or "slow push" method, kinetic methods, and nuclear explosions. Civil defense is a basic technique used when severe weather or other natural hazards occur and includes evacuation, sheltering, and emergency infrastructures. This method could be used for small NEO impact events and would be a necessary part of mitigation for larger NEO events. The "slow push" method is practical for NEOs that are tens of meters to 100 meters in diameter, and includes a spacecraft exerting a force on the target object that will gradually change its orbit to avoid a collision with Earth. Kinetic methods would also include flying a spacecraft into the NEO's orbit to defend against moderately sized objects (hundreds of meters to a kilometer in diameter). A nuclear explosion is the only current, practical way to defend against large NEOs that are greater than a kilometer in diameter. None of these methods are fully developed or easy to complete, and decades of warning time would be needed.

Future generations would greatly benefit from having a NEO observatory and defense station on the Moon. The best way to implement this would be by using existing technology, such as the NEOSSat, which is orbits around Earth, therefore watching every part of the sky, observing and tracking PHAs, then sending this data to a Lunar-based space station which could analyze the PHAs and provide mitigation techniques from there. Colonizers on the Moon could produce spacecrafts that could be launched from mass drivers or rail guns, further explained in section 3.5, towards a PHA where it could then tow or push the object away from Earth's orbit using mechanical arms. This is a better alternative to using nuclear explosions because the debris from an explosion could potentially cause as much damage as the PHA itself.

1.7 RESEARCH AND ZERO-G

When the human body encounters conditions existing in space, it will need certain protection. Shielding is used for such dangers as cosmic radiation, and pressurized, sealed environments are maintained for a place of rest and research for humans. However, the effects of zero-G on the human body must be met in a different manner. Extended amounts of time in zero gravity situations, such as those periods experienced by astronauts aboard the International Space Station (ISS), will result in detrimental health effects on the human body. In zero gravity the main issue that occurs is the equalized distribution of body fluids within the body, so that fluid pressure in the head reaches equilibrium with fluid pressure in the feet; the usual pressures are 80mmHg for the brain and 200mmHg for the feet, a decent difference [144]. The body senses the pressure buildup around the cranial cavity and combats damage to the brain by excreting excess fluids in the urine, leading to astronauts tending to be thirsty after extended space flights on their return. This natural action brings down the overall blood pressure within the body so the brain is safe, though this develops a further problem of the cardiac muscle deteriorating.

Therefore, utilization of a “lower body negative pressure chamber”, which causes blood to accumulate in the lower extremities through use of lower pressure within the chamber than outside it and on the upper body, allows the heart to work harder to properly circulate blood and maintain its strength [144]. A body centrifuge is also used to force fluids into the lower extremities, and works much like a normal centrifuge in that it uses centripetal acceleration. The reason for other muscles, such as skeletal muscles, deteriorating is that they are simply not used as much as on Earth in a 1G environment. To combat this type of muscle fatigue astronauts are advised to utilize on-board resistance training since normal weights would have no use in a zero-G setting. It is vitally important to exercise skeletal muscles since the spinal and other muscles can lose up to 20% of their mass while bones can lose from 40 to 60% [144]. The vertebrae in the spinal column also decompress and stretch, sometimes painfully, in zero-G situations, causing an astronaut to be up to 2.5 inches taller [26].

The immune system also weakens due to the body fluid disruption and equalized distribution, since the body operates best in directional circumstances. That is, many biological, chemical, and physical interactions on a cellular level depend highly on gravity to operate efficiently or at all. One example of this is the necessity of the sinus passages draining after a cold since they cannot drain if there is no gravity, the mucus will simply backup. A common occurrence is a recurrence of childhood chicken pox in astronauts. Antibiotics and other medication are supplemented to the astronauts to combat infections or to strengthen weakened immune systems; however these are also limited in efficiency due to necessity of gravity [26]. Effects of zero-g ignore the lethal side effects of cosmic radiation. Most, if not all, of the effects of zero-g dissipate after returning to Earth, though no astronaut so far has been in continuous zero-g conditions for longer than a year.

Concerning the research on the ISS, one such project is actually aiming to extensively study the effects of zero-g and microgravity situations on the perceptions of the human body. Termed “Bodies in Space Environment” (BISE), this project will follow six astronauts in zero-g conditions, including on-Earth underwater neutral buoyancy and aircraft microgravity tests, and how their terrestrial perceptions and corresponding body/vision cues differ on Earth compared to on the ISS [15]. Another project is the Analysis of a Novel Sensory Mechanism in Root Phototropism (Tropi), which will investigate the effects of varying light and gravity levels on the root systems of Arabidopsis Thaliana (thale cress) [5]. The varying gravitational conditions will be simulated using an on-board centrifuge, and the genes for successful plant growth in microgravity will be analyzed. The goal of this project is to develop a durable long-term habitation solution for space travel concerning life support and food supply.

ISS research is currently strongly based in medical, botanical, and chemical applications; however, there has been criticism as to the actual materialization of end product. Medical researchers from the Center for Macromolecular Crystallography at the University of Alabama in 1999 reported that “this research has led to the development of a new generation of pharmacologicals that are currently in preclinical or clinical trials for diseases such as T-Cell Lymphoma, psoriasis, rheumatoid arthritis, AIDS, influenza, stroke and other cardiovascular complications” [34]. Critics raise their collective voice to this by questioning where the commercial product is. And in response to this is the statement that getting anything, especially space-grown meds, past FDA regulations is a nightmare. If there are any products on their way to the American consumer, they should materialize within the current decade or the next.

Furthermore, there are products and research resulting from projects conducted on Earth, either in preparation for projects on the ISS or for space-based applications. The following is a shortened summary of a few such projects from the years 2007 to 2012.

The iRobot PackBot Tactical Mobile Robot

Created from the Rocky-7 prototype Mars Rover, which Spirit and Opportunity are based on; this robot is currently used by the military for surveillance and uncovering IEDs. [55]

Flexible Aerogel

Created for a temperature barrier during rocket launches in response to the fragile silica aerogels; currently used for rocket umbilical cord insulation and in footwear insoles for hikers. [55]

Intrifuge CellXpansion

Created as a “rotating wall bioreactor” to simulate microgravity situations on the ISS during the lapse of time that the US had no readily viable space transport after the Columbia Shuttle disaster; currently used in numerous medical applications where a three-dimensional cell culture is necessary, as opposed to a two-dimensional petri dish. [55]

Eagle Eyes Optics

Created for protection against solar radiation on the eyes of astronauts and developed from naturally-occurring oil droplets found within the eyes of birds of prey; currently used for solar radiation protection and in consumer sunglasses that filter out UVA, UVB, and blue-light radiation to prevent cataracts and age-related macular degeneration. [55]

Micro Algae Nutritional Supplements

Developed from research into providing proper nutrition by using algae as a food supply; implemented in infant formula since the algae Crypthecodinium cohnii contains high levels of DHA omega-3 fatty acid (docosahexaenoic acid) and a fungus (Mortierella alpine) that yields ARA (arachidonic acid). The acids are present in breast milk, but not in previous infant formulas. [55]

ArterioVision

Developed from NASA Jet Propulsion Laboratory video imaging software for surveying and measuring the solar system; detects plaque, blood flow, and possible atherosclerosis of an artery in a non-invasive manner while previous technologies only detected plaque and blood flow. [55]

Petroleum Remediation Product (PRP)

Developed from NASA’s biological encapsulation research and the orbital production of microspheres; currently used in most oil and chemical spills around the world. [55]

Emulsified Zero-Valent Iron

Developed from research at the Spaceport Engineering and Technology Directorate at NASA's Kennedy Space Center, EMZI is used to eliminate Dense Non-Aqueous Phase Liquids (DNAPLs). DNAPLs are a form of chemical that are heavier than water and do not dissolve in water, thus contaminating groundwater and raising the toxicity in the rest of the water table. [55]

The potential for the advancement of technologies created from ventures in the ISS, both for use in space and on Earth, is too great to ignore and must be furthered for the benefit of mankind.

2 . ROBOTICS

2.1 DURABILITY

One of the most important variables to consider in space exploration is durability. Any journey through space is going to be extremely long. In order to ensure the success of the mission, the spacecraft must be durable enough to suffer harsh temperatures in space or on another planet. The spacecraft must also be able to withstand air resistance when entering an atmosphere and landing on a hard surface. In order to survive these tough conditions, two things are needed. One being a great design, and the other is a strong building material.

The Mars Exploration Rover mission (MER) utilizes both intelligent design, and resilient components. Both rovers were launched in June of 2003, and arrived on Mars in June and July of 2004 [80]. Only one rover is still active on Mars, while the other rover has not relayed communication since March of 2010. The durability of the Mars Exploration Rovers is very impressive. The spacecraft that transported the rovers from Earth to Mars was made of several different components that helped to keep the rover intact during its journey to Mars.
The cruise stage is the component that goes from Earth to Mars. It is primarily made of aluminum and covered with solar panels. The solar panels could provide up to 600 watts of power near Earth and 300 watts at Mars [80]. The energy created from the solar panels is partially used to keep the batteries warm during its travel through the cold space. The heat required to keep the batteries working on the Mars Exploration Rover come from electrical heaters, eight radiosotope heater units, and the heat given off by electrical components.

The aeroshell, which was a protective covering for the lander during the voyage to Mars was made of an aluminum honeycomb structure that was placed in between graphite-epoxy face sheets [80]. On top of that is a layer of phenolic honeycomb filled with a blend of corkwood, binder, and tiny silica glass spheres [80]. Upon entering Mar’s atmosphere this blend will react and take away heat. This heat loss in turn lowers the kinetic energy of the spacecraft, therefore slowing it down for a safer landing. At an altitude of 10km the parachute is deployed [80]. The aeroshell contains the parachute, which is made of polyester and nylon. It also has a triple bridle made of Kevlar, which connects to the back of the spacecraft.

The lander itself is a lightweight structure made into a tetrahedron shape. The beams are made of graphite fiber woven into a fabric that is then layered [80]. The beam is lighter than aluminum, and more rigid than steel [80]. The lander deploys its airbags before hitting the surface of Mars. The airbags are made of Vectran, which is a manufactured fiber that has almost twice the strength of Kevlar [80].

Overall, the spacecraft design used for the Mars Exploration Rover mission is one that should be used as a guide for other space exploration missions. The success of keeping its rover safe and intact through all the hazards of space travel proves that it is of durable design and material.

2.2 CURIOSITY

Subsequently, NASA is making yet another attempt at sample analysis on Mars. Starting this year on August 6th at about 1:30 am EST, Curiosity will be landing on Mars in pursuit of unlocking the mysteries of Mars' environment and history. Curiosity will be headed for Gale crater to seek out and analyze layered rock deposits. Since the MER landed in 2004, NASA has made many technological advancements with their rover design. With the addition of many technologies like a new more precise landing method and a new power source, Curiosity can almost guarantee a successful and safe mission.

The entry, descent, and landing functions of Curiosity utilize a combination of successful technology from past missions as well as some new ones. The most notable change of this set-up is in its final landing maneuvers. This particular landing system will use a sky crane touchdown system. This improvement was absolutely necessary, as the airbag-assisted method used for the MER would not be able to supply a safe landing for the colossal 950 kg rover [88]. This new method allows for much more precise and safe landings. The airbag-assisted landing method yielded an estimated 93 by 12 mile landing ellipse area. The new sky crane method minimizes the projected landing area to only a 4 by 12 mile ellipse [88]. The sky crane is the last part of the landing function and it used after the heat shield has been separated and the parachute has slowed the vehicle significantly. With four steerable engines, the descent stage will continue to lower the rover until a velocity of near zero is attained. Once this approximate velocity is reached, a bridle connected to the rover from the descent stage will lower the rover the remaining distance to the ground. Upon the detection of the rover's safe landing the descent stage will cut the bridle and throw itself at full throttle away from the landing site of Curiosity [88]. This is to ensure that no damage or additional obstacles are in Curiosity's way upon landing. The large landing zone that the MER had made exploring certain areas of Mars dangerous or just impossible. With this new high precision landing system, most of Mars could potentially be explored.

Another new feature of Curiosity is its power source. The new rover has a radioisotope power system that generates electricity from the heat of plutonium's radioactive decay. Previously, solar panels were used as the power source for Spirit and Opportunity. While both of these rovers managed to well exceed their predicted life span, they could not be used during periods of no sunlight. Also, Spirit and Opportunity could only produce in between 0.499-0.590 kWhr of power in the span of one Martian day. With this new power source, Curiosity can be running at all times and is predicted to produce 2.5 kWhr in one Martian day [88]. With the additional power supply, Curiosity will also provide an enhanced payload capacity as well as the ability to explore a much larger range than any previous mission. The estimated lifespan of this mission is to be at least one Martian year (687 days) [88]. However, it is not the power source that will be the limiting factor for this mission. The power supply is more than enough to keep the rover rolling much longer than that. The uncertainty of how long the mechanical instruments will be able to last should be the limiting factor [3]. Keep in mind though that both Spirit and Opportunity were only expected to have a mission lifespan of 3 months. One of the rovers managed to last 6 years, and the other one is still in function to date giving it over 8 years of service. With the many variables that could impede a rover's lifespan its hard to accurately predict how long Curiosity could actually last. If it's anything like Spirit and Opportunity however, Curiosity has the potential to be exploring and analyzing Mars for a whole decade.

Overall, the new design and operation of Curiosity could unlock the many mysteries of Mars, and open up new ideas for more improved rover designs. Hopefully this mission will provide sufficient data to make more accurate conclusions about Mars, as well as make the idea of putting a man on Mars more plausible. The potential of discovery on Mars come August 6th is greatly anticipated and could make a very important impact on the future of space exploration.

Recently, Curiosity successfully landed on Mars after its 36 weeklong journey on August 6th, at 1:32 am EST [88]. Since the landing, Curiosity has calibrated and tested many of its features already. Including taking samples, vibration tests, taking color/panoramic/black & white photos, and arm tests. The most recent news as of October 4th is that Curiosity is in the correct position on Mars to begin taking scoops of soil for analysis [88]. Curiosity still has plenty of time and potential to discover great things on Mars. The results of this mission are of great interest for potentially forwarding space exploration efforts.

2.3 LUNAR ROBOTS

To assist with construction and gathering of resources on the Moon, robots will need to be capable of moving large quantities of regolith in short periods of time. Moonraker 2.0 (figure 5) is an autonomous robot developed at WPI for NASA. The 167 pound robot is capable of excavating and transporting nearly 1000 pounds of regolith in under 30 minutes, using a series of narrow troughs to scoop up the lunar soil and deposit into its onboard bin. Machines like this will be an asset when lunar shelters must be quickly constructed, and resources must be gathered on short notice. Its predecessor, Moonraker 1.0 is more compact, weighing less than half as much at 35 pounds. Moonraker 1.0 (figure 6) uses an arm and conveyor belt strategy, which would allow it to fit in more compact spaces. Technology such as Moonraker would have to undergo substantial modifications for use on Mars because Martian soil is much denser than regolith, due to its high iron oxide content. This being said, technology similar to Moonraker would be essential to the formation of a Martian settlement. Robots like Moonraker would be able to go to Mars ahead of humans and lay the ground work for a human habitat [101].

Figure 5. Moonraker 2.0. (Paul's Robotics)

Figure 6. Moonraker 1.0. (Paul's Robotics)

Additionally, robots sent to other planets for explorations purposes, and to search for additional suitable living environments will need to have independent power sources such as solar panels, a long wheelbase, and over four to six large wheels, making it easier to traverse obstacles. Robots such as this—the Spirit and the Opportunity—have made missions to Mars in past years with great success. The Spirit and the Opportunity were sent to Mars with no intention of being retrieved. Although the robots were only intended for temporary use, they far surpassed their lifespans, providing valuable information about Mars for many years. Both robots weigh 400 pounds, and use an articulated rocker-bogie suspension system that allows the wheels to maintain contact and traction when an obstacle or hole is encountered. The rovers are powered with rechargeable lithium-ion batteries that are recharged using a solar array that can generate up to 140 Watts of power. Robots like these can be improved upon in the future, and if designed for a return trip, will be able to retrieve environmental samples that will provide essential information about the bacterial content of the soil and so on for finding future habitable space locations [79].

Here on earth, robots are beginning to become more commonplace in the construction world, however, many of these robots require human supervision or operation, such as the Wacker Neuson RTSC2, which is a remotely operated steamroller that is used to level hard to reach places for construction work.

Figure 7: the Wacker Neuson RTSC2. (Wacker Neuson)

Although this machine is not autonomous—and some would say not even a robot—it is a shadow of the possibility of robot aided construction on other planets perhaps such remotely operated machines could be controlled from earth to create a stable living environment on the Moon or Mars. Although currently there is little to be found on the market as far as autonomous construction robots, inventor Lars Asplund is laying the groundwork for a lunar mission with a robot capable of assembling a small cottage on the Moon's surface. Although the cottage will weigh only five kilograms, it is an example of what robots will need to achieve on the Moon or Mars before humans officially get there [128]. There are currently many autonomous robots in the industry, monitoring power plants, being used for military purposes, and even up and coming in the medical field. Because autonomy is on the rise, with the future of space travel looming, it is clear that autonomous robots will be present in the future of space travel.

2.4 EXOSKELETONS

Another important robotic advancement that could greatly add to the future of space travel is the aforementioned robotic exoskeleton. Currently, the best exoskeletons for space travel is being funded by DARPA and supervised by Homayoon Kazerooni of the University of California at Berkeley. The Human Load Carrier (HULC) can operate for 20 consecutive hours between recharges, and allows the user to carry up to 200 pounds of cargo. Additionally, this lower body exoskeleton enables the user to consume fifteen percent less oxygen while wearing the suit and carrying the load, versus carrying the load alone. The decrease in bodily exertion allows the user to require less oxygen, a very important feature for space use. Because of this, as well as its long battery life, the HULC would be a good option to assist humans with the rapid construction of a habitat in space. The HULC is able to sustain its battery life for so long by capitalizing on the force transferred from the ground when the user walks. The HULC uses hydraulics and an onboard micro-computer to ensure that the machine moves fluidly with the user [1]. The HUCL is currently being designed for military and biomedical purpose—replacement of the wheelchair—but it's moving parts prevent the user from being able to wear the suit without a thick protective layer underneath, with minimal future adaptations, it may be a perfect addition to a spacesuit. The HUCL is only the beginning of advances that will take place in the near future for robotic exoskeleton space technology.

2.5 ARTIFICIAL INTELLIGENCE

One of the most essential aspects of future autonomy is Artificial intelligence. Although many advances need to be made before it is achieved, it is certainly a growing field. When the term “Artificial Intelligence”, or AI, is used in the technology industry it usually refers to software and programming, such as logistics and data mining; dissimilar to the science fiction archetype that society equates with the term. Frankly, with the term used by the technology industry, we can already consider ourselves to have the appropriate AI for an extraterrestrial venture. The values emulated for an AI of this type, which can be considered as “weak” or “applied AI”, are speed, short-term memory, and long-term memory [127]. Weak AIs are systems that are not designed to emulate human sentience, and may be perceived mainly as a program that observes its environment through sensors which helps to maximize its chances of success for various algorithms.

For weak AI, speed can be demonstrated by the powerful computing platforms developed such as the K Computer, the fastest supercomputer currently in existence with a computing power of 10 petaflops and a computational speed of 10.51 quadrillion computations per second [62]. The human brain can only perform approximately 0.1 quadrillion computations per second, so computers already outmatch human computational power [53]. Short term memory, based in RAM, or Random Access Memory, and long term memory, based in the computer’s hard drive, are already quite efficient and extensive. RAM is already easily cost-effective at 8 gigabytes per “stick”, while hard drives are in the terabyte range and still increasing. Utilizing a large array of RAM and hard disk drives, Watson, a computing platform built by IBM for analysis and data generation/mining, is the best example of an applied AI. The goals for speed and short- and long-term memory for applied AI have already been met.

However, if we are to associate the term Artificial Intelligence with the idea that machines are self-governed and autonomous we would quickly realize that science has much to do in the way of research to attain that goal of a true AI. True Artificial Intelligence, also known as “strong AI”, require the same values as applied AI of speed, short-term memory, and long-term memory [127]. However, strong AI also require sentience and the intellectual mechanisms demonstrated by human beings. Intellectual mechanisms, such as a rudimentary display of emotion or simulation of human-like behavior, can be seen in early examples like that of the robot Kismet of the Massachusetts Institute of Technology. The Kismet robot incorporates auditory and visual sensors to perceive its immediate environment, and responds to external stimuli through synthetic speech or simulated facial cues. Facial cues are initiated by using motorized components across its face, which includes a mouth, eyes, eyebrows, and ears to appear human. Even with these forms of response, accurate bi-directional communication and refined emotive traits are still a ways off.

Sentience, in any shape or form, has not been achieved by or in a computing platform to date. One reason behind this is that the fields of neuroscience and psychology have yet to fully reveal the intricate aspects of the brain and the mind, respectively. Researchers reason that if we cannot understand our own brain mechanics then how could we possibly replicate it in a machine to initiate sentience? This may be worked around by utilizing networked computing to simulate the human brain with its network of neural pathways. Furthermore, researchers wonder if Artificial Intelligence will even have similar thought processes to humankind if they do attain sentience. Artificial Intelligence could become outright hostile, like in many science fiction plots, and kill their creators, like Skynet in the *Terminator* film series, or control them, like the machines in The Matrix. To prevent this, humanity will most likely implement Isaac Asimov's Three Laws of Robotics [143] which are

1. A robot may not injure a human being or, through inaction, allow a human being to come to harm.
2. A robot must obey the orders given to it by human beings, except where such orders would conflict with the First Law.
3. A robot must protect its own existence as long as such protection does not conflict with the First or Second Laws.

with a zeroth law included that states a variation on the first law that "a robot may not harm humanity, or, by inaction, allow humanity to come to harm" [143]. These laws, if ingrained enough in an Artificial Intelligence's programming, would hopefully shackle and prevent the AI from rebelling. Though, this may lead to the AI essentially being enslaved, which, if it truly has sentience, could pose a moral issue. This sort of restraint may also inhibit the full function of the AI, depending on how it is programmed. Either way, sentience has yet to be attained and the moral issue need not be visited currently. Yet, on that same note, research has a long way to go in the field of Artificial Intelligence and robotics if a true AI is to be produced.

Although bold claims about the future of Artificial Intelligence are frequently made, and seldom fulfilled, Thanks to MoNETA (Modular Neural Exploring Traveling Agent), such claims may soon become reality. Such technology is being developed at Boston University with the goal of creating a brainlike infrastructure coupled with software that will be able to learn on its own much like an animal in the wild. With this colossal project underway, the main funding behind this research, the U.S. Defense Advanced Research Projects Agency (DARPA), Claimed in 2010 that "Within five years, powerful, brainlike systems will run on cheap and widely available hardware" [136]. While this may at first seem like just another empty promise, the groundbreaking invention of the memristor makes it a reality. Developed by HP, the memristor is a new class of electronic device that not only changes in resistance based on the applied voltage, but is also capable of remembering its previous state. This functionality will be used to mimic synapses in the brain, where information is both stored and processed.

With this onslaught of breakthroughs, the future is looking very bright for AI. It is important to understand how future technology will differ from the simulated AI of yesterday. Traditional computers separate where information is processed, and where it is stored. This is a key difference from the mammalian brain, which processes and stores information simultaneously. Because of this detail, traditional computers are only able to carry out tasks which they are specifically programmed to do. When future AI is able to both process and store information at once, computers will be able to learn and adapt as if they have emotional motivation and reasoning abilities, "without the constraint that they are actually aware of these feelings, thoughts, and motivations" [136]. Computers with such capabilities are known as animats, and will have endless applications. The first of these applications will likely be for military use since DARPA is the primary funding, however, space travel will not be far behind.

Despite organizations like DARPA and Boston University taking huge strides in the field of Artificial Intelligence, the progress is not without challenge. One of the largest roadblocks in the aforementioned advances is the issue of power supply. For example, "brains can operate at around 100 millivolts" [136] whereas their electrical counterparts require around 10 times that. Memristors are making it a possibility to lower the necessary power supply in the future because they require no power to remember their previous state. Another major challenge that arises is the state memory ability of memristors decays over time. After the technology is refined, this will behave much cells dying in a biological brain—as cells die, the brain gradually slows down in functionality, rather than crashing like a computer. However, current technology is not yet able to facilitate the memristor decay so gracefully.

While Boston University is working on recreating a version of the brain to power robots, scientists at the University in Reading, such as Professor Kevin Warwick and Doctor Ben Whalley, are creating a new generation of robots that are powered by none other than a living biological brain. The brain cells are first cultured in the lab, and a suspension of these cultured neurons are then put into a device called a multi electrode array. The specially designed multi electrode array is used as a container for the brain cells whose surface is comprised of upwards of sixty electrodes. The electrodes are able to pick up the electrical signals from the firing of the neurons and the voltage output of each electrode is determined by the following equation [133]:

$$V_{pad} = V_{overlap} \times \frac{A_{overlap}}{A_{electrode}} \qquad \text{(Eq. 1)}$$

Ultimately, the voltage outputted to the control the robot is determined by the voltage of the overlapping region of the cells and the electrodes multiplied by the area of the overlap divided by the area of the electrodes. These signals are then wired to the wheel motors of a small, simple robot, and various sensors on the body of the robot which allow it to know its whereabouts. Through this process, the brain is able to control the movement of the robot [133]. This new technology is fully autonomous; in fact, there is almost no way to control the brain. These little robots drive around at their own accord and are nearly impossible to control without overriding the brain's choices with exterior control.

Figure 8. A brain powered robot with multi electrode array shown. (Robot Powered by Rat's Brain, Mail Online)

This is perhaps the greatest stride for AI to date. These groundbreaking robots are able to store memories and learn from their past experiences. For example when and obstacle was places in the way, perhaps at first they would run into it, but the next time they would remember its presence and stop and go around it [133]. Although this may seem like a small step, it is the first sign of any robot that can actively learn from its mistakes without being told so. Upon further developments, such robots will be capable of learning from and adapting to their environments.

Regrettably, the intelligence of the robot is heavily tied to the sophistication of the brain. Although the first generation of brain-powered robots were made with the brain cells of a mouse, plans are being set in motion at the University of Reading to being culturing human brain cells for use of controlling robots. Although these robots would only be run with a small number of cells and not a full sized brain, heavy social implications will begin to come into play. Although studying these robots will allow scientists a glimpse of how memories are stored and created—thus enabling them to improve artificial brain structures like MoNETA—there are also many other factors that come along with utilizing human biology power for the purpose of technology.

For example, as the technology improves, and the brains controlling the robots become more sophisticated and humanlike, they will also begin to deserve more rights. Furthermore, since it is so difficult to control these robots without exterior limitations that are able to override the brain—such as constant monitoring and a backup control system that can disable the brain, it is unlikely that future generations of this technology will be capable of strictly adhering to Asimov's laws of robotics. To complicate matters even more, since the brains are human, and the more powerful generations will deserve rights, it may be considered unethical to monitor them and place exterior control restrictions on their behavior.

Although these robots are currently being studied to learn more about the brain, this technology can also be thought of as the original definition of a cyborg. Although people traditionally consider cyborgs to be humans that are adapted into partially robotic forms, the technology developed at University of Reading could eventually lead to robots that have been adapted into partially human forms. Once humanoid robotics can reach a level that is on par with the movement capabilities of the human body, paired with a lab-developed human brain, the result would essentially be a human in a robot body. The reason this is so exciting for the future of space travel, is that on planets such as Mars or even Titan, where the atmosphere and temperatures pose a threat to the human body, having instead a robot body with a human brain may prove to be extremely valuable to the success of space civilization. Furthermore, since brain cells take time to be grown, it is possible that they could be cultured on the long trip to Mars, and be fully functioning by the time of landing. This technology could eventually eliminate the problem of long space travel times, as well as many environmental concerns once the destination is reached. This plan, of course, is not without complication. The human brain could not survive in this form without prior adaptation. For example, the areas of the brain that register hunger and pain, would have to be readapted to be perceived instead as feelings of low battery charge and need of robotic repairs. It is unknown yet if it is possible to modify the brain in such ways while it is in the process of being grown, however, these issues among others, such as power supply and nourishment of the brain, will need to be dealt with.

Despite numerous challenges that still need to be overcome, true AI is more feasible at present than ever in the past. Advances such as MoNETA and the memristor are allowing researchers to combine brain-like software with a design that is physically similar in layout to the biological brain. Such a combination will lead to animats that are able to live among humans, replace soldiers, care for elders, and even man spacecrafts. Perhaps with these advances, Artificial Intelligence becoming part of everyday life in the near future will be a reality and not just a bold claim.

Future robotic technology will enable humans to flourish in many space locations, especially the Moon and Mars. Although autonomous robots such as Moonraker, and the rovers and the rise of AI is perhaps the most critical for the beginning stages of colonizing the moon, human assistive devices such as HUCL will also be valuable assets to cut down manpower when developing a habitat. As the technology develops, robots developed for medical, military, and personal use can be adapted for lunar use. Such technology will enable humans to develop not only suitable, but enjoyable habitats away from the earth.

3. SPACECRAFTS

3.1 SOLAR SYSTEM MECHANICS AND NAVIGATION

In order to navigate the solar system the basic mechanics of the solar system need to be understood. The sphere of influence of planets and other bodies, planetary flyby techniques, orbit transfers, and the effects of atmospheric drag are critical in understanding spacecraft flight. To begin, the sphere of influence, or SOI, is the area that a celestial body has a greater gravitational influence than the parent star it orbits, such as the Earth when compared to the Sun. This definition is explained mathematically by

$$Gm_em_v/r_{ev}^2 > Gm_sm_v/r_{sv}^2 \qquad \text{(Eq. 2)}$$

which essentially states that the relation between the mass of the Earth (m_e), mass of a vehicle (spacecraft, m_v), and the radius (distance, r_{ev}) between the Earth and the vehicle must be greater than the relation between the mass of the Sun (m_s), the mass of the vehicle (m_v), and the radius between the Sun and the vehicle (r_{sv}), with the gravitational constant (G) acting on both sides [107]. Once the Sun's influence overtakes that of the body in question the sphere of influence of the celestial body essentially ends. The radius of the sphere of influence can be calculated by

$$r_{SOI} \approx (m_p/m_s)^{2/5} \times r_{sp} \qquad \text{(Eq. 3)}$$

with r_{SOI} as the radius for the sphere of influence, m_p as the mass of the planet, m_s as the mass of the sun or star of the system, and r_{sp} as the radius from the sun to the planet [107]. The interesting thing to note about the SOI is that one must consider the double-think phenomenon, which essentially holds that contradicting points of view must be considered and that both points are true. When applied to the SOI, one doubly views it as both extremely large and extremely small; the discerning factor is the reference frame [107]. When viewed on a planetary scale the sphere of influence is seen to be immeasurably large, extending far beyond the planetary body's radius. However, when viewed on the solar scale, or considering the solar system as a whole, the SOI is extremely small when mapped on the ecliptic plane of the solar system. The sphere of influence concerning Earth, or another planet, is only notable when stationing an artificial satellite in orbit around it or when leaving its gravitational influence. Once a spacecraft has left the gravitational influence of a planet, it must work against the gravitational influence of the Sun; this is only important when performing planetary flyby missions or orbit transfers.

The velocity necessitated by a spacecraft relative to the planet for exiting the SOI on an escape hyperbola is called the hyperbolic excess velocity vector, which is equivalent to the escape velocity for Earth, except in relation to the sphere of influence. The heliocentric velocity, on the other hand, is comparable to the hyperbolic excess velocity vector, except with the Sun as the focus rather than the Earth. When this hyperbolic excess velocity vector is added to the planet's heliocentric velocity, the spacecraft's heliocentric velocity is acquired for the interplanetary transfer orbit through the solar system. A flyby trajectory, also known as a gravity-assist maneuver or a swingby trajectory, is critical when performing interplanetary missions with the goal of preserving fuel [107]. When fuel is preserved, less needs to be contributed to the mission and a more massive payload can be allowed. To find the change in velocity due to the flyby, one can follow either equation:

$$\Delta v_{FB} = v_{svO} - v_{svI} = v_{\infty O} - v_{\infty I} \qquad \text{(Eq. 4)}$$

$$\Delta v_{FB} = 2\ v_{\infty}\sin(\delta/2) \qquad \text{(Eq. 5)}$$

With Δv_{FB} as the change in the velocity of the spacecraft due to flyby, v_{svO} and v_{svI} as the outbound and inbound heliocentric velocity vectors, $v_{\infty O}$ and $v_{\infty I}$ as the outbound and inbound hyperbolic excess velocity vectors relative to the planet, v_{∞} as the common magnitude of both the inbound and outbound hyperbolic excess velocity vectors, and δ representing the angle between $v_{\infty O}$ and $v_{\infty I}$ [107].

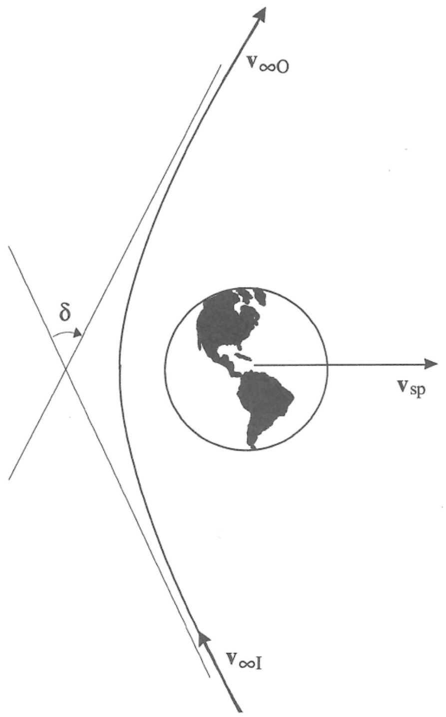


Fig. 7.7 Flyby Trajectory

Figure 9. Diagram depicting standard flyby trajectory, showing inbound and outbound hyperbolic excess velocity vectors, $v_{\infty I}$ and $v_{\infty O}$, with angle δ. (Prussing, p.131)

For a flyby following a Hohmann transfer, which will be discussed in length in a later article, the aim is to either decrease or increase the heliocentric outbound velocity vector of the spacecraft, depending on how the flyby is performed and following a Hohmann orbit transfer, as viewed below:

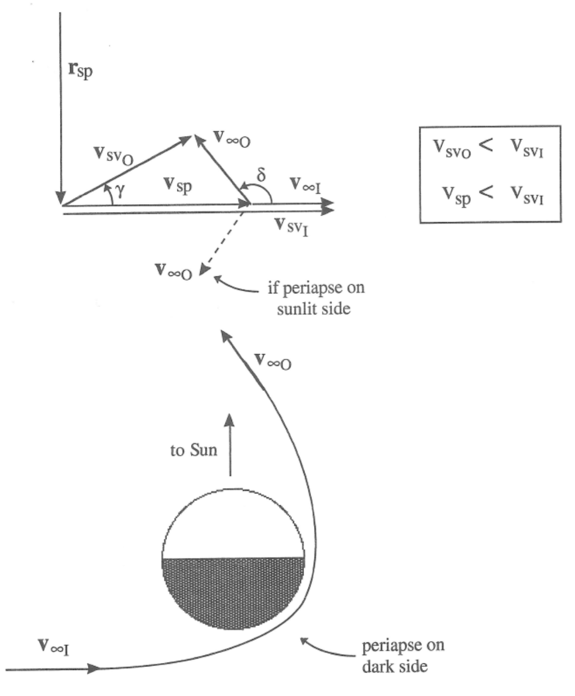


Fig. 7.10 Flyby Following Hohmann Transfer to Inner Planet

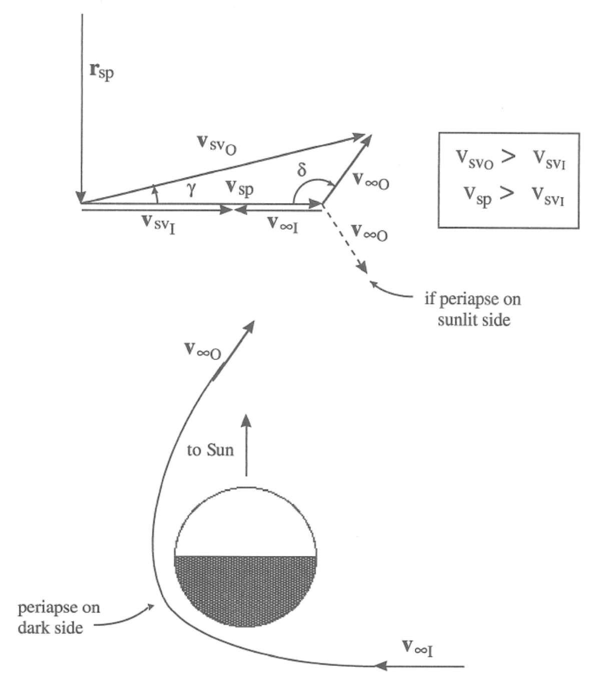


Fig. 7.11 Flyby Following Hohmann Transfer to Outer Planet

Figure 10. Diagram (to the left) depicting a flyby trajectory following a Hohmann orbit transfer, destination is for an inner planet due to a decrease in heliocentric velocity of the vehicle. (Prussing, p.135)

Figure 11. Diagram (to the right) depicting a flyby trajectory following a Hohmann orbit transfer, destination is for an outer planet due to an increase in heliocentric velocity of the vehicle. (Prussing, p.136)

These views are in reference to the planet in a non-moving reference frame. However, if this flyby were to be put in motion in a celestial model, it would show that for a transfer to an inner planet (Figure 10) the outbound velocity relative to the planet, $v_{\infty O}$, is appearing to proceed to the planet's left, yet also seems to eventually proceed to the Sun's left. This is false, though, because while the velocity relative to the planet puts the spacecraft to the planet's left, the velocity relative to the Sun, v_{svO}, does not place the craft to the star's left since it is moving in an inwardly spiraling motion. This is because the objects within the reference frame are in motion radially with the Sun as the focus. Similarly, for transfer to an outer planet (Figure 11), the velocity of the craft relative to the planet is greater, though the inbound heliocentric velocity is not [107]. Due to this, the craft is able to overtake the planet, regarding relative velocity, the planet then gives the craft a boost in heliocentric velocity, and the spacecraft is able to migrate outwards towards an outer planet. The main note to keep in mind for the movement of bodies on the solar plane is that the difference in reference frames will provide different results, such as relative planetary velocity v_∞ and heliocentric velocity, v_{sv}.

Furthermore, the mechanics of orbit transfer and the effects of atmospheric drag on reentry influence spacecraft performance. The three types of standard orbit transfer are the Two-Impulse transfer orbit, the Hohmann transfer, and the Bi-elliptic transfer. The Two-Impulse transfer orbit is essentially a basic elliptic with the focus, or gravitational center, the same as the focus of the destination, known as the terminal [107]. This would be such that the focus in a two-impulse orbit transfer from Earth to Mars would be the Sun; since Mars orbits the Sun the spacecraft would likewise have a similar gravitational center. The reason for being called a "two-impulse" orbit transfer is that the spacecraft would require two impulses, or velocity boosts, in order to first initialize the transfer orbit and then to circularize the spacecraft into the final elliptical orbit. Calculating for the radius of the periapse (r_p), or the closest point in the orbit to the focus, and the apoapse (r_a), or the farthest point in the orbit to the focus is as follows

$$r_p = \leq r_1 \qquad \text{(Eq. 6)}$$

$$r_a = \geq r_2 \qquad \text{(Eq. 7)}$$

with p representing the parameter of the orbit, e representing eccentricity, or how much the orbit deviates from being circular, r_1 representing the inner orbit of a celestial body such as the Earth, and r_2 representing the outer orbit of a body such as Mars [107]. Parameter is derived from the aforementioned equations concerning the inner and outer radials, and is as follows

$$p \leq r_1(1+e) \qquad \text{(Eq. 8)}$$

$$p \geq r_2(1+e) \qquad \text{(Eq. 9)}$$

Subsequently, these equations are expressed in Figure 12 below.

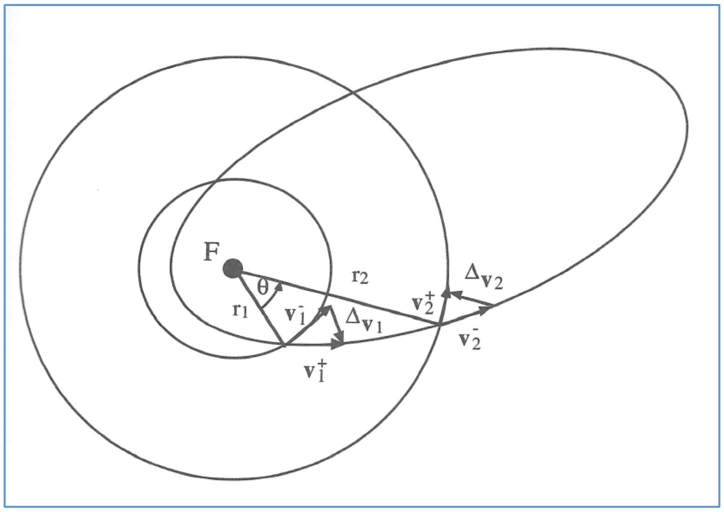


Figure 12. Diagram depicting standard Two-Impulse transfer orbit. The focus, in this instance, would be the Sun for an Earth-Mars transfer, the periapse lying within the inner radial and the apoapse lying without the outer radial. (Prussing, p.103)

To further elaborate on the eccentricity, e, of orbits, an ellipse maintains that $0 < e < 1$, a parabola $e = 1$, and a hyperbola $e > 1$ [107]. These characteristics are important when considering and differentiating flybys, which are typically hyperbolas, two-impulse and Hohmann transfers, which are nominally elliptic, and bi-elliptic transfers, which can extend to become parabolas. A Hohmann transfer is a notable transfer orbit because it is the least eccentric, the most circular, of all the transfer orbits and the most fuel-efficient for direct interplanetary travel. Calculation of the semi-major axis, a_H, and the eccentricity, e_H, is relatively simple and is shown below

$$a_H = (r_1+r_2)/2 \qquad \text{(Eq. 10)}$$

$$e_H = (r_2-r_1)/(r_2+r_1) \qquad \text{(Eq. 11)}$$

with r_1 being the inner radial orbit and r_2 representing the outer. For eccentricity of a Hohmann transfer, the periapse is always r_1 and the apoapse is always r_2 [107], as illustrated in Figure 14. For clarification, the semi-major axis is half of the longest diameter of an ellipse; one can think of this as the longest "radius", though this would be misleading for an ellipse. The semi-minor axis, on the other hand, is the half of the shortest diameter of an ellipse. Both are illustrated in Figure 13.

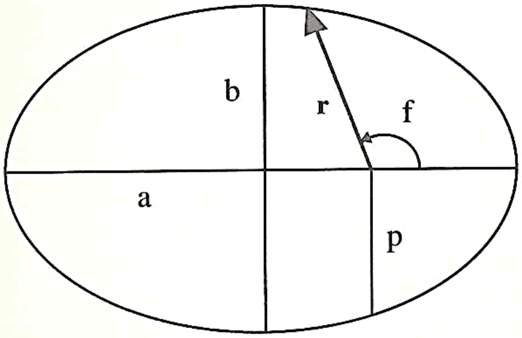


Fig. 1.4. Geometry of the Elliptic Orbit

Figure 13. Diagram depicting a basic two-dimensional ellipse with the semi-major axis, a, lying along the x-axis and the semi-minor axis, b, lying along the y-axis. The symbols f,r and p denote the angle in radians along the x-axis, the separation distance according to the angle, and the parameter when $f = \pi/2$, respectively. (Prussing, p.16)

Finally, the transfer time, t_H, can be calculated via the equation

$$t_H = \pi((ah^3)/\mu)^{1/2} = \pi((r_1+r_2)^3/8\mu)^{1/2} \qquad \text{(Eq. 12)}$$

with a_H representing the semi-major axis of the Hohmann transfer, r_1 for the inner radial, r_2 for the outer radial, and μ for the gravitational constant of the central body [107], known as the focus and represented by the **F** in figures 12, 14 and 15. In effect, the Hohmann transfer is as shown on the following page.

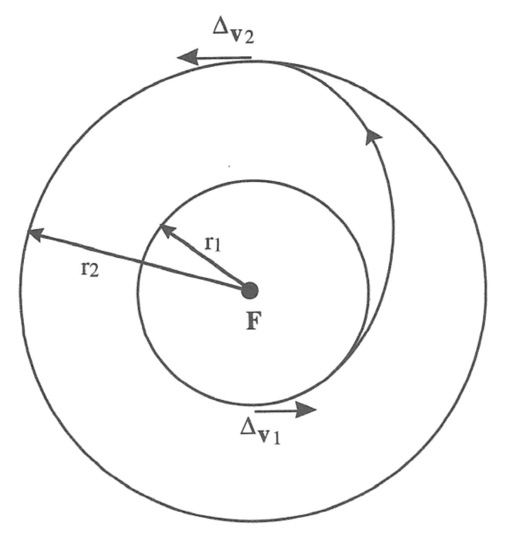


Figure 14. Diagram depicting standard Hohmann transfer orbit. The focus, in this instance, would be the Sun for an Earth-Mars transfer, the periapse lying on the inner radial and the apoapse lying on the outer radial, since both radials are equivalent to their respective apses. (Prussing, p.105)

The third and final orbit transfer is the bi-elliptic transfer. This, in effect, is a manipulation of the Hohmann transfer, which itself is a manipulation on the two-impulse transfer, in that its midcourse radius, r_i, lies outside the outer radial in contrast to the Hohmann transfer, as can be seen in Figure 15. However, r_i cannot be considered the apoapse since the orbit eventually decays as the spacecraft modulates its orbit parameter. Furthermore, the bi-elliptic is so named because it contains two ellipses and it is considered separate from both the two-impulse and the Hohmann transfer because the bi-elliptic utilizes three impulses during its course: one for orbit initialization, one for midcourse tangential velocity increase, Δv_i , and one for interception or orbit stabilization [107]. If the midcourse tangential velocity boost did not occur, than the bi-elliptic would degrade into a standard two-impulse orbit transfer.

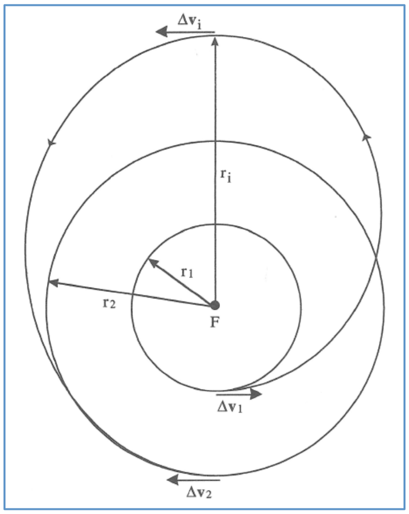


Figure 15. Diagram depicting bi-elliptic transfer orbit. The focus, in this instance, would be the Sun for an Earth-Mars transfer. The midcourse velocity boost allows the orbit to evolve into a bi-elliptic from a two-impulse orbit. (Prussing, p.109)

A variation on the bi-elliptic is the bi-parabolic, which essentially is just the case where r_i approaches infinity, $r_i \to \infty$, and the midcourse velocity boost approaches 0 for Δv [107]. The ellipse then evolves into a parabola, as the name suggests.

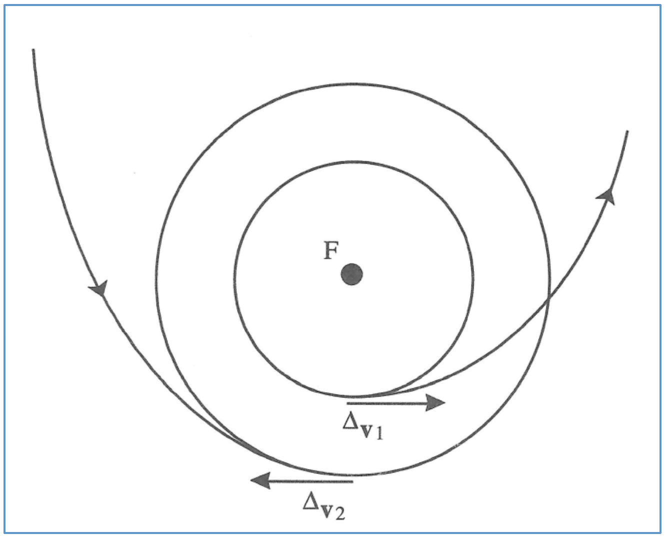


Figure 16. Diagram depicting bi-parabolic transfer orbit. The focus, in this instance, would be the Sun for an Earth-Mars transfer. The midcourse velocity boost approaches 0 as r_i approaches infinity, which causes the orbit to evolve into a bi-parabolic from a bi-elliptic orbit. (Prussing, p.110)

The most economical, considering both fuel-efficiency and transfer time, would be the Hohmann transfer since it is the most direct. The only stipulation with a Hohmann transfer is that it would need to be timed impeccably for optimal orbit insertion and planetary interception, unlike a two-impulse transfer which simply puts a spacecraft into perpetual orbit around a focal point, such as the Sun, until further action takes place. When planetary interception and atmospheric reentry takes place, the primary force to consider is atmospheric drag, aside from gravity. This is also relatively easy to compute, with the equation

$$T = -\tfrac{1}{2}\rho C_D A v^2/m \qquad \text{(Eq. 13)}$$

With T representing the drag force, ρ for atmospheric density, A for cross-sectional exposed area of the spacecraft to the atmosphere, m as the mass of the spacecraft, v for the velocity of the craft, and C_D as the drag coefficient, contrived from the surface area of the object [107]. Fuel efficiency is important in all forms of transportation, especially considering space and the extreme scarcity of refueling opportunities.

3.2 PROPULSION

In order to travel to any location in space, one must utilize a form of spacecraft propulsion. Currently, the most reliable and well-known type of spacecraft propulsion is the standard chemical rocket. This type of propulsion mechanism uses an internal chemical reaction between two fuel types, usually liquid hydrogen and liquid oxygen, which react upon mixture and ignition in the combustion chamber of the rocket. In a solid fuel rocket, the oxidizer (liquid oxygen) and the fuel (liquid hydrogen) are premixed but unreacted, requiring ignition to catalyze the reaction [123]. For monopropellant rockets the fuel is usually not ignited but rather undergoes a self-maintained chemical reaction, usually of decomposition to a hot gas, and includes hydrazine, hydrogen peroxide, and nitrous oxide [123]. Hybrid rockets use both liquid and solid state fuels. Standard chemical rockets, however, have low specific impulse. Specific impulse is the propellant flow rate required for a given thrust, so if the propellant flow rate is high over a short period of time, such as for chemical rockets, then the specific impulse is low

[123]. Other terms of note include the actual exhaust velocity, which is the average speed that the exhaust jet leaves the vehicle, and the effective exhaust velocity, which is the speed that the propellant burned per second would need to exit the vehicle to be able to give an equivalent amount of thrust [124]. Current chemical rockets are adequate enough to be able to bring humanity to the Moon, but if human beings want to go further or take a more direct route, thereby requiring more fuel consumption, then other options will need to be researched.

The current viable sources of energy that can be used for spacecraft propulsion are chemical, solar, electric, and nuclear (fission). As stated previously, chemical rockets have high thrust, but low specific impulse, so they would be able to enable a spacecraft to exit Earth's gravitational influence, but not travel to any great lengths in space. Solar energy applications would revolve mostly around the solar sail, which is already in use for research space probes. A solar sail would definitely not enable a spacecraft to exit the Earth's gravitational influence since the technology is based on gaining what little momentum it can from the photons and particles ejected from the sun as well as from the heat it radiates after absorbing solar energy. Since a solar sail does not consume fuel and only gains energy from surrounding solar influences, it can travel indefinitely [123]. However, this will lead to relatively slow space travel since there is extremely little thrust involved; the importance of this technology is its availability and its high specific impulse, which is good for space probes.

Electric propulsion would involve the various forms of ion or plasma technology. The three most eligible technologies are the electrostatic ion thruster, the Hall Effect thruster, and the pulsed plasma thruster; all electric propulsion mechanisms have low thrust, yet extremely high specific impulse [123]. An electrostatic ion thruster uses electrodes and the resulting electric field from these electrodes to accelerate ions it produces by firing electrons within the vehicle to produce thrust [38]. A Hall Effect thruster (HET) uses a magnetic field to direct electrons to ionize propellant, which the mechanism then accelerates out of the vehicle with an electric field [47]. The difference between the electric field and magnetic field is that the electric field results from the strength of charge on a particle without involving movement of the particle while the magnetic field relies on the motion of the charge, or the current. This difference illustrates how a

Hall Effect thruster is identified as an active thruster while the electrostatic ion thruster can be considered passive. Pulsed plasma thrusters are significantly different in that they use an electric arc to cause solid propellant to turn into plasma, a state of matter in which most of the particles are ionized and are in an energetic state, which then exits the vehicle [105]. These thrusters can provide continuous acceleration by firing the electric arc hundreds of times per second with energy provided via solar panels, allowing for high velocities to be attained within the solar system. A benefit of this system is that a large amount of electric energy is not necessarily required, and thereby being able to run off of solar panels. However, the major drawback is that pulsed plasma thrusters are extremely inefficient in handling fuel.

Of special note is the magnetoplasmadynamic thruster, also known as an MPD, which uses an electromagnetic field to accelerate the ions of a gaseous fuel to produce thrust. Why this is of special merit is that it has one of the highest specific impulses of ion thrusters, which are among the highest for all types of propulsion methods overall, and also has relatively high thrust at 200 Newtons, near to that of small chemical rockets [74]. All the electric propulsion technologies, both ion and plasma, are able to provide high specific impulse, though low thrust; they may be able to last for a long time, up to weeks or months, but they will not be used for exiting the Earth's gravitational influence which is currently still monopolized by chemical rockets. Electric and plasma propulsion is mainly relegated to orbital spacecraft attitude control [140]. Nuclear fission shows itself in the nuclear thermal rocket, which utilizes a nuclear reactor to produce high temperatures so that a liquid fuel, like hydrogen, can be exposed to it and rapidly expand and exit the launch vehicle, producing thrust. The effective exhaust velocity is approximately twice as efficient as chemical rockets and with equivalent thrust [123]. The dangers, though, with nuclear thermal rockets and nuclear fission technology in general is the fear of a nuclear catastrophe occurring if the rocket malfunctions. If a malfunction does occur, the radioactive material could be spread over a large area, especially if the rocket achieves high altitude before the time of malfunction. If nuclear fission technology were to be utilized, great precautions would need to be made to ensure public safety. However, we can be secure in the knowledge that humanity has already developed several dozens of different propulsion technologies, with new theoretical models being developed and tested regularly.

3.3 ROCKETRY AND SPECIFIC IMPULSE

As noted previously, chemical rockets currently monopolize most of the field of propulsion and rocketry, with other propulsion technologies being delegated the task of orbital attitude control. Chemical rockets are the most prevalent and widely used, and are presently the only forms of spacecraft propulsion able to propel a body into space and out of the Earth's gravitational influence. The design of a rocket currently resides in two broad categories: single-stage and multistage. Single-stage rockets only consist of one engine to produce thrust with one or more tanks for fuel; depending on the fuel type it could either be one tank for a solid-fuel rocket or multiple tanks for rockets requiring a chemical mixture, such as that of a hydrogen-oxygen rocket [91]. Currently, single-stage rockets are relegated to being used for missiles, which generally do not leave the atmosphere and have significantly less mass than a typical rocket intended for delivering a payload to space. Multistage rockets, however, are able to attain greater acceleration due to a significant, periodic decrease in mass during flight time [91]. The decrease in mass is not due to the expulsion of fuel during flight, which single-stage rockets experience as well, but due to the ejection of multiple "stages" of the rocket in flight [92]. These stages, whether serial or parallel, meaning they are either stacked on top of each other or attached alongside each other, each separately house their own set of fuel tanks and engines. Each stage is ejected from the overall rocket when the stage attains burnout, or when the fuel can no longer sustain proper thrust and runs out of fuel. This is the most efficient multistage technique, by firing the successive stage at the previous stage's burnout, compared to firing the successive stage at the previous stage's peak altitude because firing at the burnout allows the rocket to maintain velocity and further accelerate due to the decrease in mass [92]. This is depicted in the figure below from Vashon Industries Valkyrie Report No. 5105:

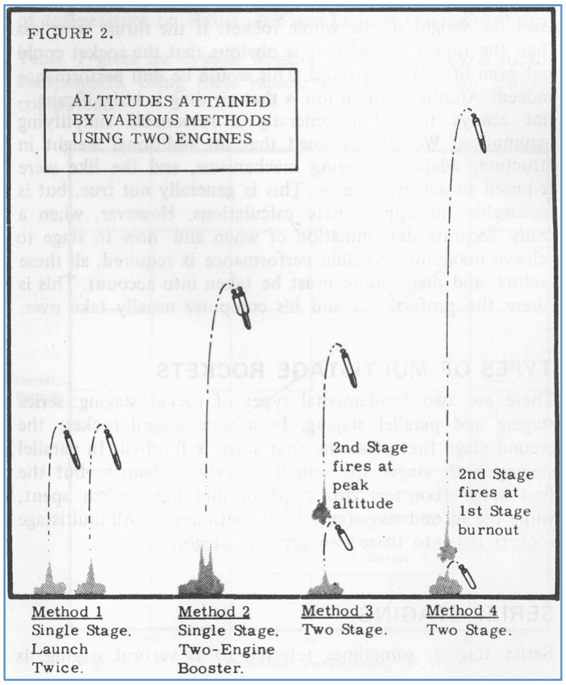


Figure 17. Schematic detailing the altitudes able to be attained by differing rocket propulsion methods using two engines. ("Multi-Stage Rockets: Valkyrie Report No. 5105", Vashon Industries, Inc.)

To mathematically explain the reason behind preference for multistage rockets, we shall consider the work needing to be done to propel a spacecraft out of the Earth's gravitational influence. The minimum amount of work, W_{min} in Newton-meters (Nm), needing to be done by the rocket can be explained by [132]

$$W_{min} = hP_R + W' \qquad \text{(Eq. 14)}$$

$$P_R = g\rho V \qquad \text{(Eq. 15)}$$

With h representing height to be attained, P_R representing the weight of the hull and non-fuel components of the rocket, and W' representing the work needing to be done to compensate for the fuel. In the second equation, which explains hull weight, g represent acceleration due to gravity, ρ represents density of the material, and V represents volume the material is occupying. W' is explained by [132]

$$W' = g(m_{fuel,h} - m_{fuel,0})(z)dz' \qquad \text{(Eq. 16)}$$

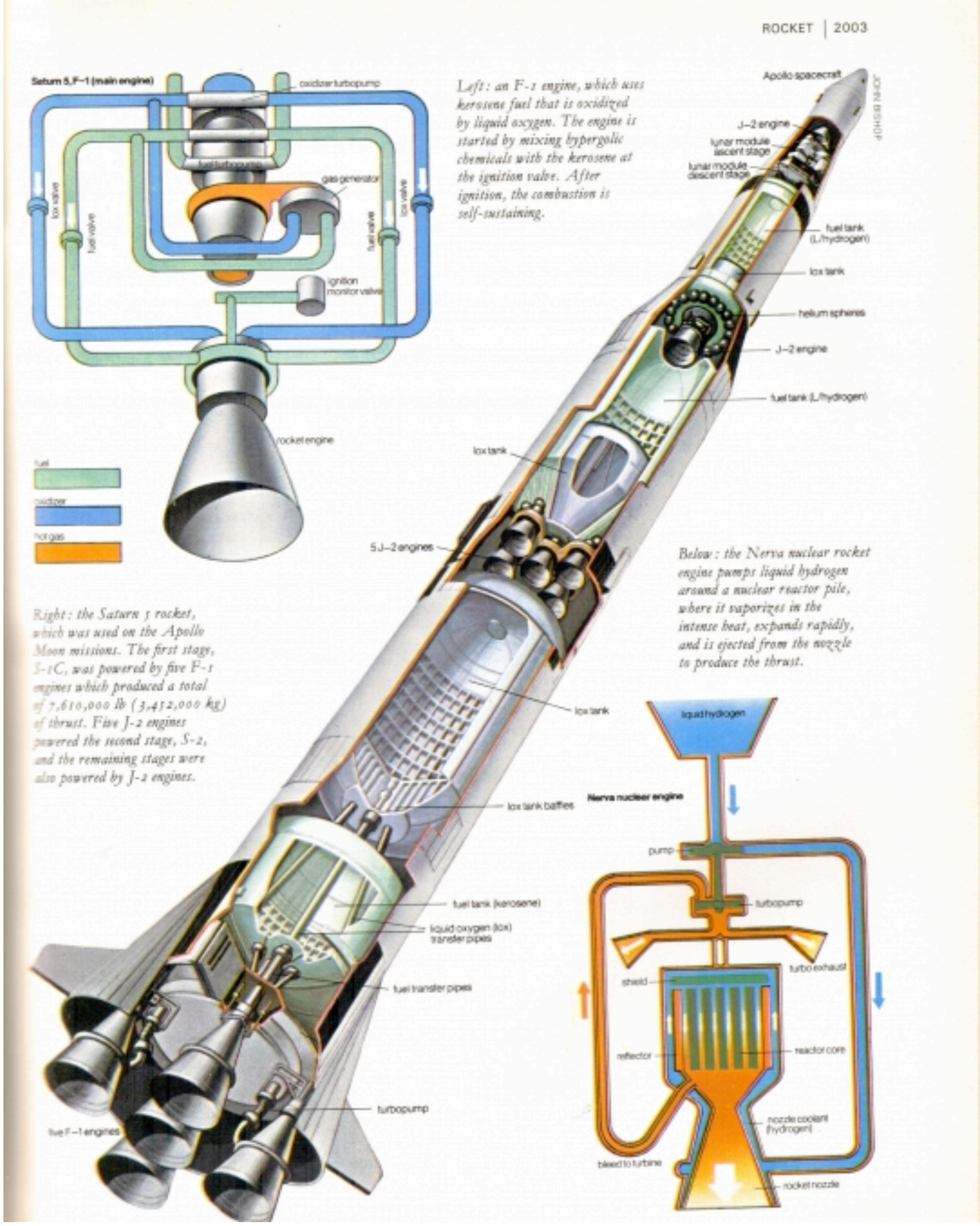
With m_{fuel} representing the mass of the fuel and being integrated over position due to the mass of fuel being expelled over time. Finally, the minimum work needing to be done for a two-stage, or multistage, rocket, W_{min2}, is shown below [132]:

$$W_{min2} = (h/2)(P_R+p_E) + (h/2)(P_R-p_t) + W'_2 = hP_R + W'_2 - (h/2)(p_t-p_E) \qquad \text{(Eq. 17)}$$

With h representing the height the given stage will be ejected, being the first stage in this case, p_E representing the weight of the engine in the stage, and p_t representing the weight of the stage to be ejected. W'_2 can be made smaller than W' if the fuel is slightly reduced for the multistage rocket, which would inevitably happen since efficiency would increase given multiple stages and less fuel would be needed anyway. Thus, if calculated, W_{min2} for a multistage rocket will be shown to be less than W' needed for a single-stage rocket [132].

In essence, a multistage rocket is beneficial because it is able to attain higher rates of acceleration when it ejects a spent stage from the overall rocket. The decrease in mass enables this increase in acceleration so that the escape velocity of 11.2 km/s can be reached.

The following is the basic design for a multistage rocket, consisting of three stages (Saturn V rocket):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Left: an F-1 engine, which uses kerosene fuel that is oxidized by liquid oxygen. The engine is started by mixing hypergolic chemicals with the kerosene at the ignition valve. After ignition, the combustion is self-sustaining.

Right: the Saturn 5 rocket, which was used on the Apollo Moon missions. The first stage, S-1C, was powered by five F-1 engines which produced a total of 7,610,000 lb (3,452,000 kg) of thrust. Five J-2 engines powered the second stage, S-2, and the remaining stages were also powered by J-2 engines.

Below: the Nerva nuclear rocket engine pumps liquid hydrogen around a nuclear reactor pile, where it vaporizes in the intense heat, expands rapidly, and is ejected from the nozzle to produce the thrust.

Figure 18. Schematic detailing the structure of a multistage rocket, specifically the Saturn V rocket that is composed of three stages. ("Eric: Spaceships Rockets", SpaceCollective)

The physics of a rocket is vital to consider if one were to be built. The basic physics include thrust, impulse, and specific impulse. Thrust is the force that propels a body, such as a spacecraft, forward due to expelled mass in the opposite direction. This derives from Newton's second and third law: acceleration of a body is directly proportional to the net force, F, and indirectly proportional to the mass, m, given by F=ma; and that action and reaction forces between two bodies are equal and opposite. Thrust, *T,* is given by

$$T = (dm/dt)v \qquad \text{(Eq. 18)}$$

Where *dm* is the change in mass with respect to *dt*, the change in time, multiplied by the velocity, *v*, of the ejected mass relative to the rocket. More specifically, thrust, in Newtons, is given by [106]

$$T = \dot{m}V_e + (p_e - p_a)\, A_e \qquad \text{(Eq. 19)}$$

$$\dot{m} = f_e V_e A_e \qquad \text{(Eq. 20)}$$

Where $\dot{m}$ is the mass flow rate, V_e is the exhaust velocity at the nozzle exit, f_e is the fluid density at the nozzle exit, A_e is the nozzle exit area, p_e is the exhaust pressure at the nozzle exit, and p_a is the ambient pressure.

Thrust is the primary force enabling a rocket to escape Earth's gravitational pull and mainly acts against drag and weight, or the force on the object due to gravity, during atmospheric flight.

Impulse, on the other hand, is affected by thrust and is the integral of force with respect to time, or simply the change in momentum. When a force is applied to a body, the momentum of the body changes; impulse is equal to this change of momentum. A small force for a long time will give the same amount of impulse as a large force for a short time, all other forces excluded. Impulse, in Newton-seconds (Ns), is given by the equation

$$I = (F_{tmax} - F_{tmin})dt = F\Delta t = ((dp/dt)_{tmax} - (dp/dt)_{tmin})dt = \Delta p \qquad \text{(Eq. 21)}$$

With *F* as force in newtons, *dt* and Δt as the change in time, and *dp* and Δp as the change in momentum.

Specific Impulse, furthermore, is the derivative of impulse with respect to the amount of propellant used, or thrust divided by the amount of propellant used per unit time. To explain this, iteration on thrust is shown here [124]

$$F_{thrust} = I_{sp}\dot{m}g_0 \qquad \text{(Eq. 22)}$$

With F_{thrust} being equivalent to T, or thrust, $\mathrm{I_{sp}}$ for specific impulse (in seconds), $\dot{m}$ for mass flow rate (kg/s), and g_0 being the value of the acceleration due to gravity at the Earth's surface ($\mathrm{m/s^2}$).

Specific impulse may be measured in seconds or meters per second, depending on what is being referenced. When it is measured in seconds it is referring to the duration of time the propellant would last if the engine's thrust were to be adjusted to equal the initial weight of the propellant. When measured in meters per second it is denoting the effective exhaust velocity. Specific impulse ($\mathrm{I_{sp}}$) in seconds is given as [124]

$$I_{sp} = v_e/g_0 \qquad \text{(Eq. 23)}$$

With V_e as the effective exhaust velocity in meters per second. V_e is related for equation 10 by the formula [124]

$$F_{thrust} = V_e\dot{m} \qquad \text{(Eq. 24)}$$

And specific impulse in meters per second is given by [124]

$$V_e = I_{sp}g_0 \qquad \text{(Eq. 25)}$$

Which, in essence, is a simple algebraic manipulation of equation 23, with V_e representing specific impulse measured in meters per second, effectually the effective exhaust velocity.

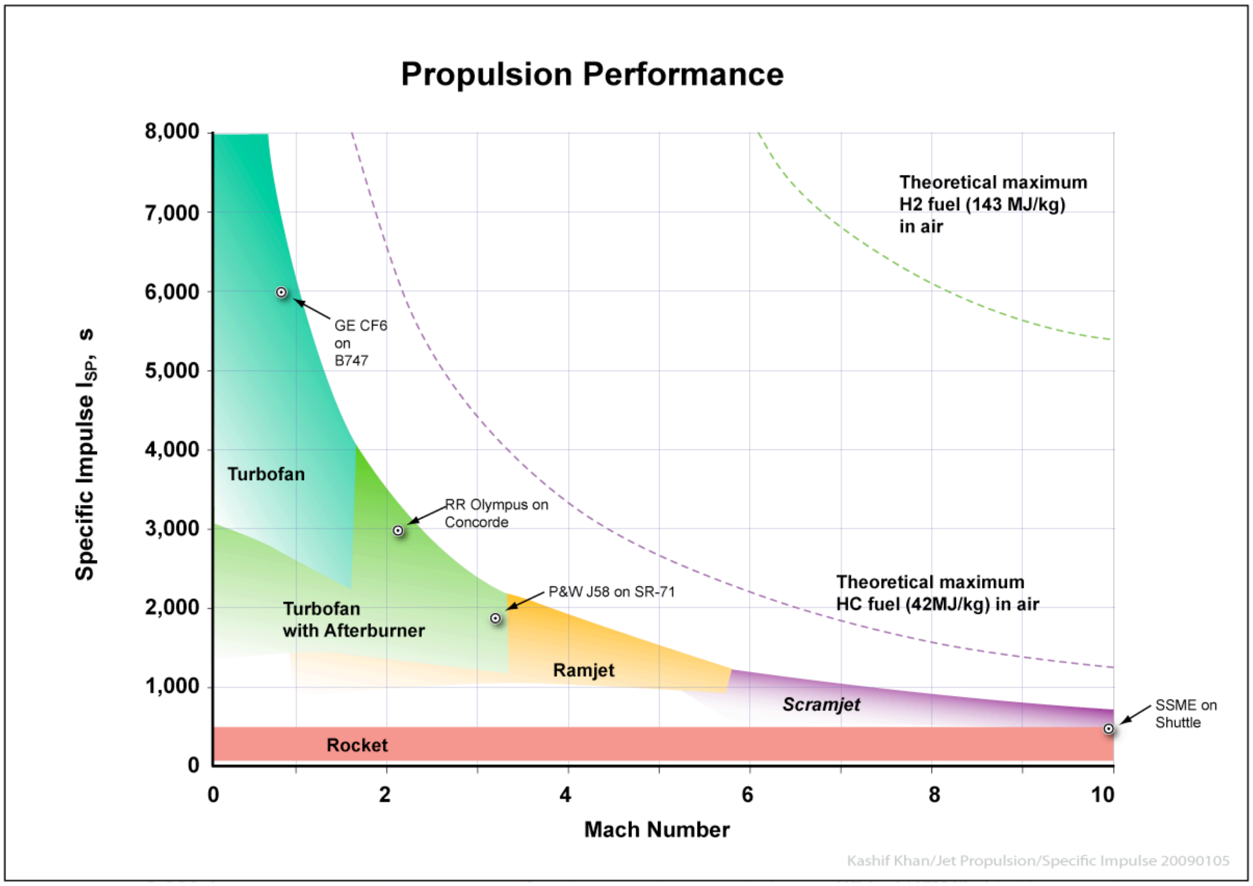


Figure 19. Graph detailing propulsion performance of various propulsion methods, comparing Mach speed to specific impulse (I_{sp}) in seconds. ("Specific Impulse", Wikimedia Foundation)

Yet propulsion and rocketry would have little importance in spaceflight if ground controllers could not communicate with the flight engineers aboard the spacecraft to enable safe and secure handling of the astronautical vehicle.

3.4 CELESTIAL COMMUNICATION

When man ventures back out to space, methods of communication will be vital to ensure that any mission will be carried out properly and that the crew's wellbeing is optimal. Some methods already exist, such as those used for the Apollo missions and the Mars Exploration Rovers, however improvements can be made. Currently there are only ground-based antenna towers and communications satellites (COMSATs) in orbit around Earth [67]. The uses for

COMSATs are mainly relegated to commercial/domestic and military needs. All astronomic communications so far have been wireless, and will likely remain so since incorporating an extremely long tether for wired communications would be highly impractical and most likely dangerous when considering velocity of the craft and tension involved in the tether. For instance, the Apollo missions have incorporated a high-gain S-band antenna for Earth-to-craft communication, which has appeared to be the mainstay for near-Earth communication in the years since first sending a man to the moon, such as that for commercial communication broadcasts [137]. To note, the S-band covers the 2-4GHz range within the microwave band of the electromagnetic spectrum.

What is used more commonly in recent years, however, is the use of the X-band, which covers the 7 – 11.2GHz range within the microwave-radio region of the electromagnetic spectrum; this is relegated primarily to deep space telecommunications [78]. An example of the X-band in use is in the Mars Exploration Rover missions, used for both the spacecraft that ferried the rovers and the rovers themselves. The primary advantage of using the X-band over the S-band is the ability for smaller antennas that run on less power, yet they still deliver optimal data rates [78]. When near to Earth, the Mars rover spacecraft utilized a low-gain omnidirectional X-band antenna for Earth-to-craft communication, but as the spacecraft traveled farther from Earth it had to switch to a medium-gain X-band antenna with a tighter beam focus toward Earth to boost transmission power and avoid extraneous radio interference from the Sun [78]. The Mars mission rovers also utilize the Mars Reconnaissance Orbiter to relay data communications to Earth. This setup can be beneficial in future space exploration aspects in that the high power technology can be relegated to a safe orbit rather than subjecting it to planetary weather patterns.

Most cosmic communication from Earth has been kept on the ground with use of large antennas and radio and radar telemetry, such as that of the Deep Space Network, DSN, of the United States. This network of spatial communications and observation equipment is located in Goldstone, California, Madrid, Spain, and Canberra, Australia to give 360 degree communication ability to any point in the solar system for interplanetary spacecraft (the only impedances would be if a craft or rover were on the far side of a planet or the sun) [85].

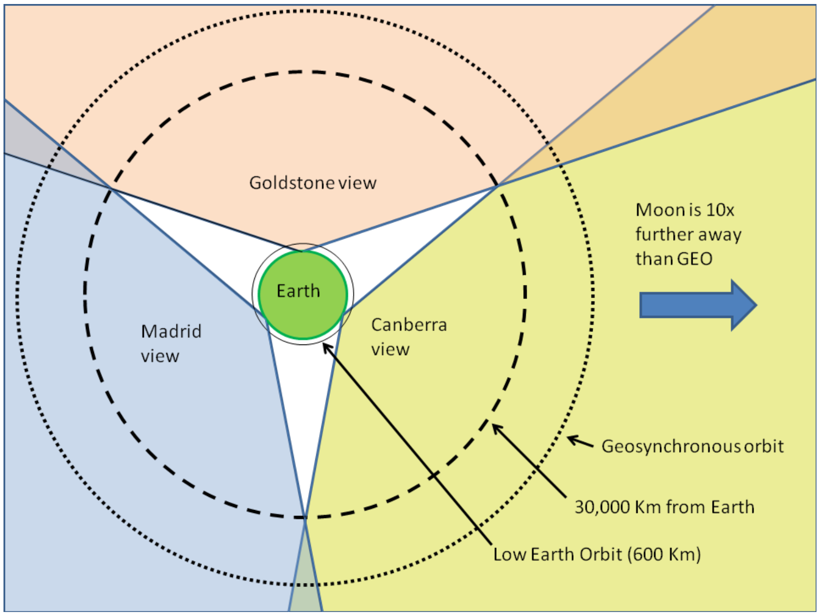


Figure 20. Area of communication ability for each DSN location, each with 120 degree view. ("Deep Space Network", Wikimedia Foundation)

Space communication technology can still improve, however. Currently, use of the X-band for interplanetary communication seems adequate, especially since most of the infrastructure has already been set up for such communication, like the DSN. So, in response to this, an undertaking that could occur is to launch multiple communications satellites meant for Deep Space communications for orbit around the Moon and Mars, and other celestial bodies within the solar system that humanity plans to explore in the near future. For an Earth-to-Mars communication scenario a signal would be transmitted from a ground station to a satellite in geosynchronous orbit around Earth, to a satellite in lunar orbit or a ground-based communications outpost, to a satellite orbiting Mars, then finally to the receiver on the Martian surface. This would enable a more secure method of transmitting data between two points in the solar system since the data could be checked for errors at each transmission/reception point. A string of satellite communication outposts would prove to be extremely robust for signal integrity when considering the interference from the Sun or other irradiative bodies in the solar system.

The only issue that faces current communications technology stationed in space is the possibility of radiation exposure and the ionization it causes to computer systems which, in turn, causes corruption or loss of data in standard, non-hardened equipment. A burst of radiation, whether from high energy neutrons in cosmic radiation or from alpha particles, can cause a single-event upset (SEU) that will defect hardware or erase data [145]. Forms of radiation hardening already exist, and usually follow the role of replacing semi-conductor materials with insulating ones, such as by replacing silicon with silicon oxide, using magnetoresistive random access memory, MRAM, which uses magnetic storage elements instead of electrically capacitive ones since electrons can be physically knocked out of a circuit by certain types of radiation, by physically shielding the electrical components, or by using depleted boron (Boron-11) to protect the computational chips since boron-10 readily decays when exposed to radiation, but boron-11 resists radioactive decay [108]. These radiation hardening techniques are already in use in nuclear power plants, and would perform excellently in a space environment. Such protection is vital when considering habitable structures in space, such as that of the International Space Station.

3.5 RAILGUNS AND MASS DRIVERS

The United States Navy has recently expanded upon the theory of a rail gun and is using it as a new method for shooting artillery [60]. A railgun consists of two conductive rails running parallel to each other and a conductive projectile that lies between the two rails. When power is supplied to the gun, electric current runs up the positive rail, across the projectile, and down the negative rail. Both rails are connected to the positive and negative terminals of the power supply respectively, and the conductive projectile completes the circuit [12]. The current, force, and magnetic vectors that act upon a rail gun can be seen in Figure 21 on the following page.

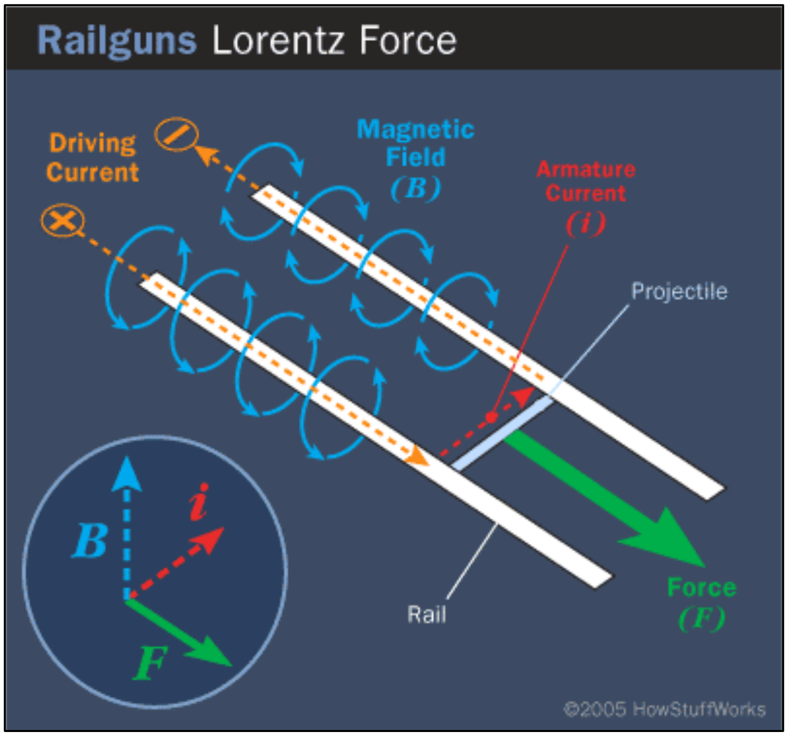


Figure 21. Railguns & the Lorentz Force. (Harris)

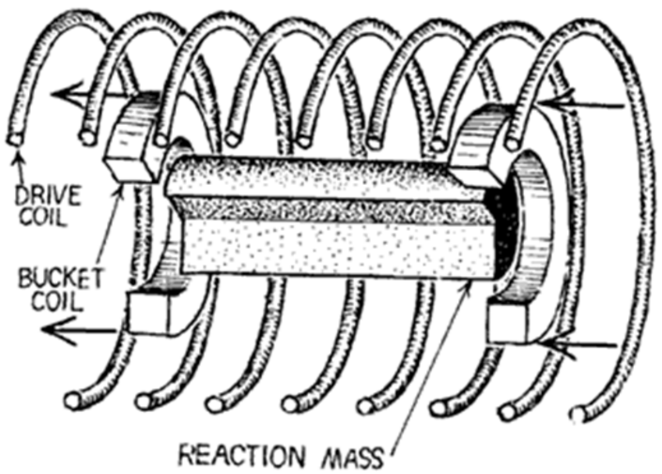
Since current is flowing in opposite directions along the rails, a magnetic field forms around the projectile and the net field is directed vertically. The projectile then experiences the Lorentz force, named after a Dutch physicist, which runs perpendicular to the magnetic field and away from the power supply. This force acts upon the projectile, and accelerates it forward at a very high speed. The following equation describes the mathematical relationship between the Lorentz force, F, the vector of electric current, **I**, the vector of the magnetic field, **B**, and the length of the rails, *l* [46].

$$\mathbf{F} = \mathbf{BI}l \qquad \text{(Eq. 26)}$$

The force can be boosted by either increasing the length of the rails or the amount of current supplied to the system. In Phase I of the U.S. Navy's railgun experiments, a 32 M-Joule prototype was demonstrated, and has been launched at speeds that range from 4,500 mph to 5,600 mph. Phase II of the design began in early 2012, and will focus on achieving a 10-rounds-per-minute firing rate [60]. Resistive heating and melting are the main drawback to railguns, and thermal management techniques must be considered when improving the design and functionality of the system. The high velocity and friction of the projectile along the rails causes resistive heating, and can damage the surface of the rails. Since the currents flowing through the rails are running in opposite directions, a repulsive force is also created and attempts to push the rails apart. With such large currents that railguns require, on the order of amperes, the repulsion between the rails is significant and they must be very firmly mounted to withstand this force [49]. These problems, as well as the fact that the projectile must be conductive for the system to work, are the main downfalls of railguns and many break after just a few uses. A pulsing, alternating current (AC power supply) provides energy to the railguns and is another problem in their design. A huge amount of power is necessary to create the millions of amps required to launch a projectile, and it is difficult to find or create a supply that can do this for an extended amount of time. Large capacitors, cubic meters in size, are the only current device that can store the sufficient amount of power [12].

In the future, railguns could be a practical application for lunar launching. The Moon's escape velocity is 2.4 kilometers per second, which is equivalent to 5,368 miles per hour and is within the perfect railgun velocity firing rate. The United States Navy plans on introducing a railgun that can precisely hit a target from a 50- to 100-nautical mile range; such precision and distance make railguns an ideal mechanism for launching payloads into outer space from the Moon without rocketry. To escape the Moon, a velocity of 2.4 kilometers per second must be achieved. This is equivalent to 5,368 miles per hour, which lies within the firing rate of railguns. Railguns have also been proposed to help aid the cause of the Strategic Defense Initiative, a U.S. government "Star Wars" program that is responsible for the research and development of a space-based defense system. Railguns would be able to fire projectiles at incoming ballistic missiles that are following a sub-orbital predestinated path [60]. In space, railguns could be used to interject incoming NEOs; an asteroid could either be destroyed or its trajectory altered with the projectile.

Another device that is being considered for lunar launching and possibly spacial defense are mass drivers. These are electromagnetic launchers that use a linear motor and recirculating buckets surrounded by superconducting magnetic (drive) coils to accelerate and catapult payloads, or projectiles, at very high velocities. Once electricity is supplied to the linear motor, which guides and drives the launch, current begins to flow through the bucket and drive coils, creating a magnetic field that levitates the buckets and sends them down the motor [12].



Cutaway of a mass driver model: the current in the drive coils makdes a magnetic field which pushes on currents in the bucket coils, producing acceleration.

Figure 22. Mass Driver Mode. (Kolm)

The first mass driver to be built, Mass Driver I, arose in 1977, under the expertise of Dr. Gerard K. O'Neill, founder of the Space Studies Institute (SSI), and Dr. Harry Kolm [63]. The SSI continues to support the research and implementation of mass drivers and produced Mass Driver II and Mass Driver III in later years. The second Mass Driver operates in a vacuumed, four-inch caliber tube that incorporates the superconducting bucket and an oscillating, push-pull coil system. This mass driver reached 500 G's and demonstrated the feasibility of the circuitry that is necessary to store and supply power to the drivers. Mass Driver III improved the coupling between the drive coils and buckets and reached over 1,800 G's [116]. In this design, the payload does not have to be conductive to be launched, as a railgun requires. However, it is possible to include a conductive armature in between the rails of a railgun, making it just as applicable to all types of payloads as a mass driver. This armature can be in the form of a solid conductive metal, a sabot that encases the projectile and then breaks off once the projectile is in flight, or, in more advanced designs, the armature is plasma. In this design a thin piece of metal foil is attached to the back of the non-conducting projectile and when power is supplied to the system, the plasma vaporizes through the foil and carries the current across the rails [49].

With this improvement, and military research and progress already in process, railguns seem to be the correct choice for future space applications and technologies. Current railgun designs are capable of hitting a target 250 miles away in just six minutes. Lower gravity in space, or on the Moon, will only effect the vertical component of launching, but the decreased, and non-existent air resistance will affect the horizontal distance that can be achieved, making the projectile's capable distance longer than that on Earth. This is convenient because on a space-based scale, launches or missiles will need to cover quite a large distance compared to that on Earth. To reduce friction on the rails, and the wear and tear that accompanies frictional force, Argonne National Laboratory has developed a Superhard and Slick Coating (SSC) that reduces friction by 80%. Argonne researchers developed a crystal-chemical nanocomposite coating model that was able to help them predict what possible materials can be used for the coating and the correct chemical combination of those materials. Due to their high combined ionic potentials, the most promising candidates that the model predicted were molybdenum and copper. Other possibilities include molybdenum-silver, molybdenum-tin, molybdenumantimony, and molybdenum-mixed alloys of copper, silver, tin, and antimony. With this improvement in coating mechanical systems, performance accelerates and the amount of energy needed to operate the system is reduced [134]. Such future developments will continue to increase the potential of railguns both on Earth, and in space.

3.6 LIFE SUPPORT SYSTEM

For further exploration and colonization of the planets, a life support system that can sustain life for long periods of time is a necessity. Constantly reshipping water and oxygen supplies are far too expensive to consider. A more permanent life support system has been developed by Paragon Space Development Corporation, and may serve as an initial life support system for life on Mars in 2023.

Paragon is a company that specializes in life support systems that works alongside with NASA, which recently completed their Commercial Crew Transport-Air Revitalization System (CCT-ARS). The CCT-ARS was challenged to exceed NASA human flight safety standards. It was completed with less than $1.5 million of government investment, took less than 10 months to complete, and was able to meet all technical requirements specified by the Commercial Crew Development Space Act Agreement with NASA [100]. The CCT-ARS is able to provide seven crucial life support functions when running: carbon dioxide removal, humidity removal, trace contaminant removal, post-fire atmospheric recovery, air filtration, cabin air circulation, and temperature control [100].

Mars-one, a company that plans on establishing the first human settlement on Mars by April of 2023, plans on incorporating Paragon's CCT-ARS into their Mars lander. The life support system is calculated to yield 1500 liters (396.26 gallons) of water and 120 kilograms (264.55 pounds) of oxygen in 500 days [129]. Mars-one intends to have two of these life support units actively set-up on Mars with production of water and oxygen completed by the time the four astronauts are scheduled to land in 2023. With the arrival of humans, the CCT-ARS will then be able to utilize its additional functions of water purification and removal of harmful gases from the living space. This life support system would not be able to produce enough water on a daily basis to keep four astronauts alive without the function of recycling used water. As a result, the life support system will continue to create water as a reserve for when water is lost to surroundings or when water consumption exceeds the water recycle rate [129]. At first, the water will be collected from the soil of Mars. Approximately 60 kilograms of soil will be loaded into the life support system [129]. Once inside, the soil will be heated to melt and then evaporate the frozen water stuck within the soil. The water is then condensed and the soil is dumped back onto the planet. The water can then be stored and some of it will be used to produce oxygen by means of electrolysis [129]. The CCT-ARS is also designed to be able to filter out any nitrogen and argon that enters from Mars' atmosphere and release them into the habitat as an inert gas [100].

Not only is the CCT-ARS cost effective and productive, but it is also easily maintained. The high cost and difficulty of having to ship additional supplies of water and oxygen are significantly diminished by this life support system. This particular life support system could potentially provide permanent life on Mars for humans, and should be used as a stepping-stone for further development of life support systems.

3.7 LIFE SUPPORT FEATURES

Environmental control on the ISS is vital and includes such aspects as airflow, air quality and humidity, and thermal control. The main component in charge of environmental control is the ECLSS, or the Environmental Control and Life Support System. The ECLSS maintains and manages the atmosphere and water/waste distribution by capturing and recycling used water and air, maintaining habitable humidity and air composition levels, venting unusable environmental products overboard such as H_2 and by reducing generated waste [96]. One notable mention of ECLSS use is in Iraq since April 2006, where potable water is produced at 4 gallons a minute for 2 cents a gallon to Iraqi villages from contaminated groundwater [96]. The oxygen levels are maintained by storing gaseous oxygen in tanks on the ISS and releasing it when needed for regulation. Other methods include perchlorate “candles” that, when ignited in the environmental reactor, produces enough oxygen for one person for one day and electrolysis, which produces molecular oxygen and hydrogen by inducing an electrical current in water, with the hydrogen being vented overboard [69]. Humidity is maintained in the air by utilization of the Temperature and Humidity Control (THC) system, which filters out excess humidity and cabin heat by use of an air-to-water heat exchanger [17]. Air circulation is accomplished by use of standard ventilation fans.

For filtering out contaminants, the main processes are using zeolite, a common naturally-occurring mineral that is used as a commercial absorbent, activated charcoal, and sorbent beds [95] [17]. The zeolite is used to remove carbon dioxide from the air while the activated charcoal is used to remove most hazardous contaminant gases caused by scientific research. An interesting fact to note is that 1 gram of activated charcoal has 500m^2 of surface area due to microporosity [2].

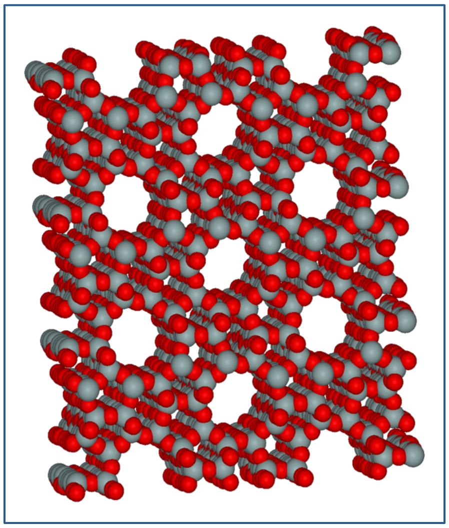


Figure 23. Zeolite lattice structure. The microporosity, seen at this level, allows for extremely high surface area for small masses. ("Zeolite", Wikimedia Foundation)

The sorbent beds also trap carbon dioxide produced by the crew, and are able to be reused once exposed to heat and the vacuum of space, essentially the outside of the ISS on the Sun side [17]. The hazardous contaminant gases also include methane, ammonia, acetone, carbon monoxide, urea, and methyl alcohol which are produced by humans via their urine, sweat, or breath that accumulate due to the zero gravity environment [17].

The Trace Contaminant Control System, which itself is part of the Atmospheric Revitalization System, scans for 200 trace chemical contaminants from research off-gassing and crew metabolic processes by using a mass spectrometer [17]. The Air Revitalization System is located on the Tranquility US module, while the Oxygen Generating System is located on the Destiny US module [58]. There is also integration for life support with the Russian module Zvezda for the Elektron, Vika, and Vozdukh systems. The Elektron system utilizes electrolysis to separate oxygen from water, the Vika utilizes solid lithium perchlorate for oxygen production, and the Vozdukh system scrubs carbon dioxide from the air [58]. NASA engineers are looking into combining carbon dioxide with excess hydrogen to produce water and methane, with the methane then being vented overboard instead of the hydrogen it replaced. NASA has also been looking into plant-based environmental recycling systems, though they are too labor-intensive and the chemical/mechanical systems take up much less space currently. Long term space travel would need to look beyond the artificial environmental systems since they are prone to failure. One example of this is the spontaneous 2004 Elektron failure, which persisted until November 2006; much too long for repairs to take place to ensure survivability [58]. If water was not extracted from the air of the ISS cabins or purified from the urine excretions of the crew, approximately 10,000 pounds of water would need to be retrieved from Earth which would be used for drinking, hand/body washing, air humidity, et cetera [69].

Due to the physics in space, there is no circulation in the ISS similar to that on Earth. Because of this, forced air systems are necessary to bring temperatures on differing sides of the ISS to equilibrium. Still, the solar side of the ISS could soar to approximately 121 °C and the dark side could plummet to -157 °C if insulation were not applied [69]. Therefore, the ISS uses a highly reflective covering called Multi-Layer Insulation (MLI) composed of Mylar, also known as BoPET or Biaxially-oriented PolyEthylene Terephthalate, and Dacron, or polyethylene terephthalate [69]. The sheets of Mylar are aluminized to prevent solar radiation from transferring through, yet are extremely thin at 0.3mm thick and reinforced by Kapton material, which is a polyimide film used in such things as printed circuit boards [69]. Due to air circulation and solar insulation, the station produces more heat internally than it receives externally, and therefore must shed waste heat externally by use of heat exchangers in conjunction with an internal cold water circulation system which utilizes a 17,000rpm impeller the size of a quarter for water flow [69]. These extensive and intricate technologies are indeed necessary for the ISS, and spacecraft in general, to function optimally and continue to explore the vast regions of space.

3.8 INTERNATIONAL SPACE STATION

Next to the first manned mission to the Moon, the International Space Station is the greatest human space achievement of scientific nature. Composed of mostly American and Russian parts, called modules, the International Space Station, otherwise known as the ISS, is a joint international effort by the United States, Russia, Japan, Canada, and the European Space Agency, ESA [138]. The European Space Agency is composed of Belgium, Denmark, France, Germany, Italy, The Netherlands, Norway, Spain, Sweden, Switzerland, and the United Kingdom. All the cooperating nations have contributed to the ISS except for the United Kingdom [138]. The original ISS was a combined effort between the US and Russia with their respective SS Freedom and Mir-2 projects joined into one single space vehicle and is the ninth habitable space station [138]. The cost for the overall ISS endeavor for its 14 years of service so far is approximately US$150 billion, split into the shuttle flights and the individual budgets of the participatory countries, with the US covering the majority at $72.4 billion [56].

As of the time of this writing the ISS has been continuously inhabited since November 2, 2000, with a total of 4959 days in Earth orbit, 161 spacewalks totaling 1,015 hours, and 1.5 billion miles traveled over the course of 57,361 Earth orbits, equivalent to 8 round trips to the Sun [57]. The ISS retains a mass of 450,000kg, a solar array 73 meters long that produces 84 kilowatts from 8 panels, a habitable volume of 388m^3, and 2.3 million lines of computer code [57]. Comparable for size, the ISS is approximately as large as a five-bedroom house which, considering it is a space station, is not relatively large, though it is the largest object in orbit. Boeing is the primary contractor for both hardware and software aboard the ISS, and, for example, developed the Starboard-6 truss segment of solar arrays for the last component of the US core of the station [29].

The primary means of transporting people and goods to the ISS was by NASA’s Space Shuttle program and by Russian Proton and Soyuz rockets; however the US has largely backed off flight operations since the 2003 Columbia Space Shuttle accident and fully ended Shuttle support with the retirement of the Space Shuttle program in 2011. Currently NASA is looking toward Space Exploration Technologies Corporation, commonly known as SpaceX, for providing shuttle service to the ISS. The first and only shuttle trip so far was carried out by the SpaceX Dragon in May 2012, the first commercial venture to do so. Payload volume varies between $10m^3$ for pressurized and $14m^3$ for unpressurized contents, with a 6,000kg up-mass and a 3,000kg down-mass and the ability to support 7 crew members [37]. The up-mass refers to the amount of mass that the shuttle can handle on its route to the ISS and toward space while the down-mass refers to the amount of mass that can be handled for atmospheric reentry and braking. The shuttle retains two solar arrays for power and utilizes 18 Draco thrusters for orbital maneuvering and attitude control (this includes system redundancy). The fuel that it uses are nitrogen tetroxide and monomethylhydrazine (NTO/MMH) propellants that provide 400N of thrust for orbital maneuvering, de-orbit burns, and re-entry attitude [37]. The shuttle is designed to be carried into orbit by SpaceX's Falcon 9 rocket. The shuttle, for re-entry, experiences lift to enable a smoother deceleration, lower g-forces, and has the ability to land in the water with parachutes. A vital element of the ISS that is constantly maintained by the researchers aboard the station and by goods supplied by the shuttle service is life support.

4. MOON

4.1 LUNAR BENEFITS

There are many reasons for colonizing the Moon. One such reason would be for the sake of economics. Currently, all spacecrafts produced on Earth are custom-designed for their missions and require years of both designing and testing before their launch into outer-space. The estimated cost of launching a space payload from Earth is $10,000 per pound. By moving spacecraft manufacturing to the Moon, time and money will be saved. The launching of the same payload previously described from the Moon would cost no greater than $0.01 to $0.10 per pound [115]. The launching task would be completed by either a mass driver or railgun (section 3.5) from a lunar base and is the reason for the excessive drop in price per pound of a unit being launched. Launching payloads from Earth is extremely expensive because over 90% of the launch vehicle is made up of chemical fuel and rocket components. In space, the use of rocket components would be completely eliminated and replaced by the mass driver/railgun system. The ability to test and produce these products on the Moon will also save both time and money immensely, since mass-production techniques can be put to use on the base. The products will also already be in the perfect testing conditions due to the vacuum of space that exists on the Moon. Mass-production will speed up the process of making spacecrafts by simultaneously creating them. When testing these vehicles on Earth, complicated simulations must be made and put to use, while by testing on the Moon, in the actual environment that the spacecrafts are meant to function in, more accurate results will be obtained and the process will be less expensive and time consuming.

Besides large spacecrafts, thousands of very small, single function probes can also be manufactured and launched from the Moon. These tiny probes can be launched at very high accelerations (100 to 1,000-G force or higher) at velocities 10 to 100 times greater than what is currently possible through rocket propulsion. These probes could perform high-velocity fly-by missions to any area of interest in the solar system, such as Pluto, Mercury, or comets at the aphelion of their orbit. Larger spacecrafts can then be associated with these fly-bys to the point of interest, where they can be maneuvered to fall into a desired orbit or surface on certain locations. The probes will first provide information from the points of interest, so that larger spacecraft can then be tailored to the mission.

Mass drivers or railguns can be beneficial yet again while recovering spacecrafts on the Moon; mass drivers have the ability to run “in reverse” that allows both manned and unmanned spacecrafts to de-orbit and land on the Moon without the use of chemical rockets. Being able to eliminate our dependence on rocket components is a great beneficiary aspect in space production. Rockets that are launched from Earth present many environmental and safety risks that will be avoided on the Moon and it will cost much less, for example, to place a satellite into Earth’s orbit using mass drivers than by launching them with rockets from Earth. Launching systems from the Moon require much less energy than at Earth’s surface, and there is no atmosphere on the Moon to block or delay launches. Although the initial investment in industrializing the Moon will be large, benefits will soon be apparent. As time continues, the use of the Moon as an industrial base will allow all the hardware necessary in the physical exploration of space to be produced at a fraction of the cost of the current production and launching of space entities from Earth. Using mass-production techniques and micro-/nano-technologies, components of all manned and unmanned spacecrafts will be able to be produced and applied in space [115].

4.2 Supplies and Personnel

Sometime, within the next generation, humanity will venture again to the moon and start building a permanent base there. While this will be, no doubt, a hefty endeavor with costs in the billions, it will mark the first step in space colonization. Two major aspects to consider for the colonization effort on the moon are the initial crew required for setup and testing and the supplies needed as well as how to transport both. The four main positions on a space mission are Pilot, Flight Engineer, Mission Commander, and Mission Specialist [102]. These positions are filled by crew members who usually have other distinctions as well; that is, the crew members are not usually solely dedicated to one of the four positions. The position of Pilot for an astronautical vehicle is the same as for an aeronautical vehicle; they are dedicated to flying the spacecraft and controlling its navigation. There may be co-pilots on the spacecraft; however, they are given the same distinction of Pilot.

A Flight Engineer has the task of monitoring and controlling the various spacecraft mechanisms, though this position is being phased out in recent years due to the advent of high precision microelectronics and computing devices. In continuance from the Artificial Intelligence section, an AI could eventually retain the role of Pilot and Flight Engineer due to the ability to handle multiple complex tasks simultaneously with efficient speed and no human error. However, a human standby will be necessary in case there is hardware failure or a software glitch that causes the spacecraft AI to become inoperable.

There is the position of Mission Commander which, as the name implies, handles the direction of the mission and heads the exploration or colonization team. The Mission Commander is not a specific designation based on academic qualifications. Finally, there is the Mission Specialist, which most crew fall under for designation, which has an assigned task to perform during the mission. Payload Specialist is a variant of the Mission Specialist position that, while a Mission Specialist was selected as an astronaut first and assigned a task, a payload specialist was selected for a mission then assigned as an astronaut [102]. The bulk of the crew will be assigned as Mission/Payload Specialists all coming from various academic backgrounds.

The actual composition of the types of experts to commence startup of a moon colony would be quite diverse. Of primary concern is the necessity of a medical doctor or physician for treatment of the crew in extraterrestrial conditions and maintenance of their overall health. The doctor would have to be well-versed in psychology as well to diagnose mental health disorders arising from being confronted with the vast emptiness of space, limited freedom and pursuant dangers close at hand, and tensions arising from living and working with the same small number of people for an extended period of time.

A structural engineer would be prescient to oversee and perform quality checks on the progress of the lunar habitat and research facilities. This would be vital considering a structural weakness of the habitat would mean death for the colonists. A chemist, or better yet a biochemist, would be beneficial for academic research on the chemical feasibility of the Moon, specifically the presence of Helium-3 fuel. Developing a process for mining and refinement of Helium-3 would help to make the colony profitable and self-sustaining, the hope being that the lunar habitat would be able to support itself financially and not be strongly dependent on the Earth for financial assistance. A mechanical engineer, with a focus in material science, would be advantageous to help with the manufacture of materials, use of In-Situ Resource Utilization (ISRU) mechanisms, maintenance of a solar panel installation, and analysis of Helium-3 fuel deposits and acquisition. The mechanical engineer would work in tandem with both the structural engineer for types of building materials to use for optimum structural strength and the biochemist for handling machines to mine the Helium-3 deposits in the vacuum of space.

A biologist with a specialization in botany would be necessary for cultivation of a hydroponics or aquaponics station to supply food to the lunar base. Napoleon Bonaparte famously said that an army marches on its stomach; this idea further extends to the critical importance of the supply line [4]. This is especially so when considering that a lunar base would be isolated, vulnerable to the vacuum of space lest a structural defect occurs, and response time to aid the lunar colonists would be long. A biologist would be one of the most important citizens of a blossoming lunar habitant since everyone would depend on the biologist’s efficiency and field of expertise in order to simply have food on the table.

An electrical and computer engineer focused in integrated circuits and power systems would be optimal for maintenance of the computer and electrical systems of the lunar outpost. The electrical engineer would be useful since the biologist would not be able to grow vegetation without a source of light and heat, which would be supplied by fluorescent lights simulating sunlight and standard heaters to maintain an Earth-normal growth habitat. A robotics engineer or specialist with a concentration in computer science would be necessary for working with the electrical engineer on the lunar colony circuit systems, working with the mechanical engineer on the machines to be used for Helium-3 acquisition, as well as programming and debugging the programs used for base operations. Finally, a physicist and an astronomer would be beneficial for academic research purposes since the lunar outpost will most definitely have an astronomical observatory. The reason for maintaining an astronomical observatory is that there are superior environmental conditions for viewing deep space for scientific research, since the absence of an atmosphere will not cause visual interference dissimilar to Earth, and to provide an early warning system against NEOs for Earth and the lunar colony.

This team of nine or so crew members would work together to initially create a large and sustainable enough lunar habitat that even more researchers would be able to live simultaneously to produce valuable data. Originally only essential, scientifically aligned people would be necessary due to the startup nature of the operation and to prepare the habitat for further expansion for non-essential personnel to start to inhabit the colony, thus paving the way for a fully functioning community with all types of professions and peoples. Perhaps a community of thirty, potentially even fifty, may inhabit one lunar base fit with an astronomical observatory, launchpad, solar panel installation, research laboratories, hydroponics lab, and general living quarters. This extraterrestrial installation would then enable further and loftier goals of human spaceflight, exploration and colonization.

4.3 BASE BUILDING

In order to construct a durable and safe Moon base, a few hazards must be considered. The biggest issues that face construction are lower gravity, varying temperatures, and meteorites. If all of these factors can be accounted for, a long lasting Moon base can be made. In addition to the hazards that will be faced during construction, location and building materials need to be established first.

The ideal location for placement of a Moon base would be in a pre-made crater [98]. A crater provides a great dug out space that already has walls, and a floor. Making it a great spot for an initial base. Of course the floor would need to be flattened out or covered to make a suitable living space. Once that is complete all that is left to complete an adequate living space would be a ceiling.

With a location in mind, the next step is to identify the best building material for the base. The best material to be used for the creation of a Moon base would be regolith. Regolith is the blanket of soil, broken rocks, dust, and other tiny objects that makes up the Moon [98]. If the building were to be made out of the regolith that is on the Moon, a couple benefits are produced. Using materials for building that are already on the Moon make it so that additional trips will not have to be made. Since regolith is resilient to erosion by lunar dust, struggling to find a material that can withstand lunar dust is no longer a factor [98]. Using regolith also eliminates the issue of having to shield from meteorites. One of the Moon's functions is to serve as a shield to Earth from meteorites. Therefore, using the regolith on the Moon makes for an excellent meteorite shield.

Since the Moon's atmosphere is not as protective as Earth's, heat is easily lost to space during the night. Any place on the surface of the Moon experiences about 13 days of sunlight, followed by 13 days of darkness [21]. As a result the Moon can reach temperatures as low as -153°C (-243.4°F) at night, and temperatures as high as 107°C (224.6°F) during the day [21]. Therefore, heavy insulation will be needed for any building constructed on the Moon. Constructing a thick ceiling of regolith for the Moon base would do just that, and more. In addition to providing great temperature control to the Moon base, the thick ceiling would also provide a great shield from meteorite strikes and cosmic radiation [18].

For the actual construction of the Moon base, a combination of regolith brick and bags filled with loose regolith would make a formidable structure [18]. The bricks would serve as a great building block for the general shape of the ceiling. The bags would then be loaded on top and a layer of raw regolith would be layed across. Since the bags would be nearly exposed to the hazards of the surface of the Moon, a strong material, such as Kevlar, would be needed to keep the bags from splitting open from either lunar dust or meteorite strikes [18].

By using the materials that are already present on the Moon, creating a base seems more and more plausible. Also, with the gravity of the Moon being one-sixth of that on Earth, it is possible to create a durable base that is also structurally sound. With a Moon base, the potential for spaceports and additional launch sites would make space exploration much more attainable. It is highly recommended that a Moon base should be created.

4.4 WATER LOCATION

In order to colonize on the Moon one of the key components for human survival is water. Without water, life on the Moon will not be possible. The main issue is that transporting water from Earth to the Moon would cost a large sum of money. As a result, the only way around this issue would be to already have water on the Moon, which fortunately there is.

The Lunar Crater Observation and Sensing Satellite (LCROSS) mission successfully uncovered water on October 9th, 2009 [35]. After a year of analysis NASA announced that the LCROSS lunar-impact probe mission found up to a billion gallons of ice in the floor of a crater near the south pole of the Moon. That's enough to fill 1,500 Olympic size swimming pools [104]. NASA was also able to conclude that water is not only located near the north and south poles of the Moon. Water is distributed in pockets around the Moon, and it is not limited to the shadowed regions [73]. With the main sources of water being at both poles of the Moon, it is still possible to mine the valuable mineral thorium, which is mostly buried on the nearside of the Moon.

The ice in these craters is mostly in the form of pure ice crystals. However, there is more than just water in the craters. About 20% of what LCROSS analyzed on the Moon was a volatile component. Materials such as methane, ammonia, hydrogen gas, carbon dioxide, and carbon monoxide were all found. Light metals like sodium, mercury, and even silver were found too [73]. Since mercury is toxic, astronauts would not be able to just melt all the ice for use. A process to filter out the mercury and other materials would be needed to use the water for valuable life support resources.

The average person uses about 100 gallons of water every day [54]. Assuming that astronauts will eventually live in similar conditions to that on Earth, it would be easy to have more than 100 people on the Moon for a long period of time. Considering that NASA has found about one billion gallons of water already and people use 100 gallons of water a day, 100 people could live on the Moon for 10,000 days. Being able to utilize that many people on the Moon would greatly increase our ability to further colonize the Moon.

Overall, having water on the Moon makes the need to colonize on the Moon even more relevant. The ice in the craters could be melted and purified for drinking and cooling of spacecraft systems. It could also be broken down further to use the hydrogen as fuel, and the oxygen for breathing. In addition to there being water on the Moon, an abundance of hydrogen gas, ammonia and methane were found that could potentially be used to produce fuel as well. With building materials like regolith that can block out cosmic radiation, sources of energy like thorium, and essential living supplies like water, the Moon is a great first location for colonization.

4.5 HELIUM-3

In the future, humanity will exhaust its terrestrial energy sources and will need to look for alternative, extraterrestrial sources of energy. This source of energy will most likely present itself in the form of Helium-3 fuel. Also known as He-3, ^{3}He, or tralphium, this non-radioactive isotope of helium is composed of two protons and one neutron and is extremely rare in the Earth's geosphere [13]. The geosphere itself includes the pedosphere and lithosphere, which are, respectively, the biologically active layer of topsoil and the outermost shell of the planet that contains the crust and upper mantle. However, Helium-3 is prevalent in the lunar soil of the Moon, especially in the lunar maria, or the large, dark basaltic plains on the Moon. Helium-3 is, and has been, ejected by the Sun and absorbed by the Moon's regolith over the millennia, up to an estimate of 1,100,000 metric tonnes according to some sources [10] or 20-30 ppb on an atomic basis [65].

Helium-3 is the major player behind nuclear fusion research and energy, next to deuterium, D, and tritium. However, Helium-3 is the most promising nuclear fusion fuel since it provides essentially direct electric energy, as opposed to using tritium, which expends vast amounts of radiation as byproduct, or deuterium, which disburses moderate amounts of radiation. This is analogous to heat given off in an energy generation system, which constitutes as thermal energy that cannot be captured for electrical energy production. The only current problem is that Helium-3 is extremely rare on Earth, with the only sufficient sources residing on the Moon. Thus nuclear fusion research relies mostly on deuterium since it is relatively easy to capture from the Earth's oceans and is in greater abundance (≈156.25 ppm), yet Helium-3 is still a tantalizing prospect for extremely efficient nuclear fusion ventures [120].

Another issue that presents itself is that Helium-3 will not be found in any specific deposits on the Moon, rather He-3 is distributed throughout the regolith, or the dusty lunar topsoil. The regolith would have to be heated to 600 degrees Celsius to extract the Helium-3 [10], and a further temperature increase to 900 degrees Celsius to extract oxygen for use in lunar habitats or rocket fuel, though this extraction technique is fully feasible [13]. Once extracted, the Helium-3 could be stored in regular pressurized tanks and loaded aboard a space shuttle for transport back to earth; the current NASA space shuttle has a potential volume capacity of approximately 25 tonnes [10]. The mined Helium-3 can then be used in a fusion reactor to generate electrical energy.

The process followed by a Helium-3 reactor would involve either a ^{3}He-^{3}He or a D-^{3}He reaction, respectively known as ^{3}Helium-^{3}Helium and Deuterium-^{3}Helium reactions. These two reactions attain the highest electrical energy efficiency and produce the least amount of radiation in the form of neutrons [65] compared to Deuterium-Deuterium, D-D, or Deuterium-Tritium, D-T, reactions. While deuterium may be the most abundant fusion reactant, Helium-3 is the most potent and allows for direct conversion to electrical energy in a fusion reaction using either Helium-3 solely or in conjunction with deuterium [65]. Fusion utilizing Helium-3 has also been known to produce very little high-level radioactive waste compared to tritium or deuterium reactors [65]. Direct conversion implies that electrical energy can be generated directly from the reactor, either from electrostatic conversion or through electromagnetic conversion. Electrostatic conversion involves dielectric plates that would have induced vibration from the fusion reactants, thereby converting mechanical energy into electrical energy. Electromagnetic conversion involves a rectenna, or an antenna that absorbs wave or particle energy to convert to direct current electricity, absorbing photons given off by the fusion reaction to generate electricity.

The actual process for a fusion reaction of D-^{3}He or ^{3}He-^{3}He involves either an electromagnetic confinement field (ECF) or Inertial Electrostatic Confinement (IEC) [42]. Electromagnetic confinement fields are utilized in magnetic confinement fusion employed by the toroidal reactors known as tokamaks for high-energy, high-temperature fusion reactions. The Joint European Torus, otherwise known as JET, that resides in Culham, United Kingdom is an example of this technology. A tokamak generator is more suitable for large-scale applications, like widespread power generation, while an IEC generator is used for controlled, moderated reactions currently. The main difference between these two technologies, besides scale, is that an ECF reactor utilizes electric and magnetic fields to maintain and contain a fusion reaction while an IEC reactor utilizes laser or ion beams to fuse the reactants together [42]. A tokamak generator initializes a fusion reaction by heating the gas inside its toroid by targeting it with microwave radiation and neutral particle beams until it reaches a plasma state, when the gas becomes highly ionized and the electrons of the corresponding atoms are in an extremely energetic state [42]. The electromagnets of the generator are initialized to contain and further compress the plasma to initiate the fusion reaction, utilizing both the high levels of pressure and heat within the toroidal magnetic confinement field. The hot plasma then generates electricity through direct conversion, or though heat exchange to produce steam.

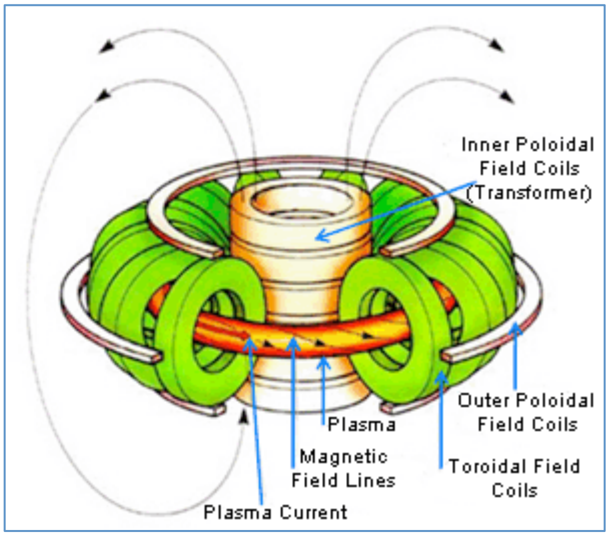


Figure 24. The standard layout of a tokamak toroidal electromagnetic fusion generator. The vertical inner magnets produce the toroidal magnetic field while the circular magnets forming the donut shape contain the plasma stream and compress it to initiate fusion. (Battery and Energy Technologies, Woodbank Communications, Ltd.)

The Inertial Electrostatic Confinement method, while less common, is certainly more exotic. The best working example of the IEC method resides in the National Ignition Facility at Lawrence Livermore Laboratory and induces fusion by firing 192 lasers at a pea-sized pellet containing a deuterium-tritium mix [42].

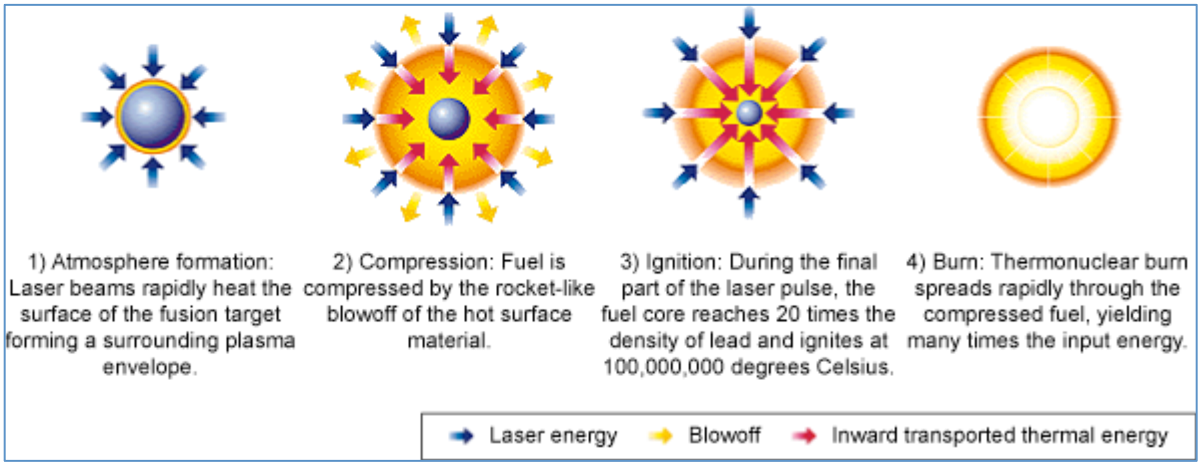


Figure 25. The various phases of the Inertial Electrostatic Confinement fusion process. First, laser radiation impacts the target pellet which leads to heating and compression. Fusion occurs after the target has been adequately heated and pressurized, leading to the thermonuclear output of heat and radiation. (IFT Concept, General Atomics)

The laser excitation lasts only a millionth of a second, but the explosive energy released by the IEC lasers causes the deuterium-tritium mixture to experience fusion due to the immense heat and pressure applied. The heat produced by this reaction would then be applied to a heat exchanger to produce steam in order to drive turbines for electrical energy production, similar to how a nuclear fission power plant works.

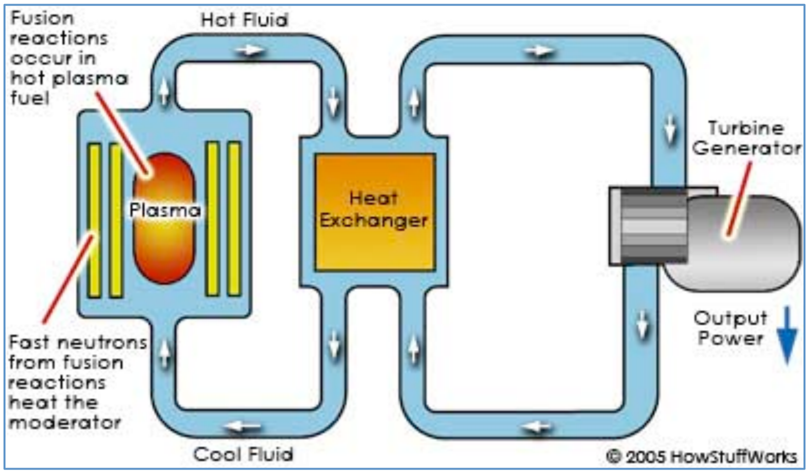


Figure 26. Standard process for electricity generation following heat exchange from a fusion reactor. (How Nuclear Fusion Reactors Work, HowStuffWorks, Inc.)

The US, it is estimated, would only require 25 tonnes of Helium-3 to power the energy grid for one year, with all other energy sources supplanted while Helium-3 is being used. The world at large would be estimated to require 100 tonnes, with the price resting at $3 billion per tonne for the global economy [13], and the lunar reserves lasting for approximately 11,000 years. One source examines the previous price of He-3 at $150 per liter and the recent increase to $5,000 per liter [99], thus demonstrating that the price of $3 billion per tonne could decrease dramatically given a secure supply and remediation of the shortage situation. If the US were to solely control Helium-3 output from the Moon, it could produce approximately $300 billion per tonne in net revenue, if the US were to sell to the rest of the world. The output of the one million or so metric tonnes of Helium-3 on the Moon would amount to approximately 20,000 terawatt-years of thermal energy, or ten times the amount of energy able to be harvested from all the fossil fuels on Earth [13]. Helium-3, as can be seen, is extremely energy dense as a fusion reactant.

Additionally, Helium-3, due to the ever-present solar wind, is relatively abundant throughout the solar system and is even supposed to be in the thick atmospheres of the gas giants, leading to thoughts of harvesting Helium-3 from locations such as the upper cloud layers of Saturn and establishing outposts on the asteroids in its rings [65]. The initial prospecting would also be made easier with the use of teleoperated mining robots; the technology for these already exist and, compared to many locales and terrain types on Earth, the lunar landscape would be relatively easy to traverse and sieve (the only issue is that they couldn't operate on the far side of the Moon due to radio signal unable to reach that side, unless satellites were to be stationed in orbit around the Moon). The establishment of a lunar base would streamline the extraction process, since refinement, storage, and transport would all be able to be carried out at the base. However, China and Russia are both looking into establishing Helium-3 endeavors on the Moon as well, thus hopefully stimulating political interest in the US for another lunar space race to occur [66]. In any event, Helium-3 will eventually be recognized for its pivotal use as a clean, potent source of energy in nuclear fusion and will be sought after by a multitude of nations in the future.

4.6 THORIUM

Thorium was discovered in 1828 by the Swedish chemist Jons Jakob Berzelius, who named it after Thor, the Norse god of thunder [131]. Thorium is a naturally occurring element on Earth that is mildly radioactive [119]. It has a low level of waste, its waste is not very harmful to the environment, it is very abundant, and it also serves as an alternative fuel for nuclear fuel supply. It would also be a great replacement fuel for reactors because it releases a large amount of energy, and could be used as a sustainable energy source. Thorium research continues to find many benefits over uranium as a reactor fuel, and should be used.

The theory behind thorium is actually quite simple. When thorium absorbs neutrons, it turns into an isotope of uranium (U-233). When U-233 absorbs another neutron it releases 2-3 neutrons and a great deal of heat. The thorium can then absorb those 2 neutrons and release its energy again, making it theoretically possible to indefinitely sustain energy [119]. Further, as thorium decays in a reactor core, its byproducts produce more neutrons per collision than conventional fuel. When more neutrons collide, more energy is created, less fuel is consumed, and less radioactive material is left behind [82].

On average, the Earth's soil contains about 6 parts per million of thorium, which means that it is not rare [131]. Thorium is roughly 4 times more abundant than uranium in the Earth's crust, and that it can be found almost anywhere. There are areas in Idaho as big as football fields that have enough thorium to power the world each year. There's a lot of thorium on the Moon as well, it's very common and easy to find. There are large deposits on the lunar farside where Apollo 11, 12, and 14-17 landed [130]. This makes building a community on the Moon entirely possible. A liquid thorium reactor would produce enough energy to power a lunar community over the 2-week dark period on the Moon [130].

Thorium is also a very portable energy source, and the facility to house its reactor would be compact. "It's so energy dense that you can hold a lifetime supply of thorium energy in the palm of your hand," said Kirk Sorensen [130]. With its portability and potential to shrink reactor size, thorium could replace other forms of energy and eliminate the need for large nuclear reactors, or large long distance power transmission towers.

Research into the use of thorium as a nuclear fuel has been ongoing for over 40 years now. Work has been done all over the world in areas like Germany, Japan, India, China, the USA, and more [131]. However, thorium research has not had as much time commitment as it has for research on uranium fuels. Unfortunately a lot of research into thorium came to a halt in the '60s. The US government was more interested in building uranium-fueled reactors instead because they produce plutonium, which can be refined into weapons-grade material [82]. Although interests were more aimed towards weapon making ability, times have changed and now an energy source that does not proliferate is more desirable. Thorium has almost no ability to proliferate too. The byproducts that are given off by a thorium-fueled reactor would be nearly impossible to be used for the fabrication of nuclear weapons. An experiment at Oak Ridge National Laboratory in Tennessee showed that when making liquid-fueled reactors, using liquid fluoride salts as a fuel base was most likely the best method. The reactors could operate at high temperatures without the need of a high-pressure chamber. Uranium and thorium could dissolve in the fluoride-salt mixture, which became impervious to radiation damage because of the strong ionic bonds. The only waste from the reaction was heat and small amounts of barely radioactive material [119]. The small amount of waste given off by a thorium reactor would only need to be stored for a few hundred years, whereas a uranium reactor's byproducts need to be stored for a few hundred thousand years [82]. As a result, liquid thorium reactors would not need to use large quantities of water as a coolant. Since liquid fluoride occurs at a relatively low temperature, reactor vessels do not need to be as large and reactor cooling happens more easily and without the need of a coolant. Thorium-fueled reactors like this yield one gigawatt of energy for every one ton of raw thorium. However, a uranium-fueled reactor is only able to yield one gigawatt of energy for every 250 tons of raw uranium [82].

Not only is thorium a potential source of clean nuclear energy, but it is also abundant, portable, efficient, and could kick start our ability to colonize on the Moon. One large draw back for implementing thorium currently is its high start-up cost. Having more thorium-fueled reactors built for testing is costly and would require a lot of initial funding to get more attention. Estimates for building even one thorium reactor can cost more than $250 million [82]. Using Thorium as a fuel for nuclear reactors could potentially eliminate its uranium counterpart as a fuel, as well as other non-clean energy sources like coal and oil. However, this is where another large obstacle for thorium lies. Using a new energy source that could eliminate the use of non-clean energy sources is a huge limiting factor. Large oil and coal-based companies will not be so willing to let thorium put them out of business. Thorium is abundant and energy efficient enough to power our world and keep it clean. Using thorium could help our planet, as well as help regain interest in space exploration.

5. MARS

5.1 MARTIAN ATMOSPHERE

Concerning the livability of Mars, the Martian atmosphere is of prime interest. To begin, the Martian atmosphere is split up into four levels: the Lower Atmosphere, the Middle Atmosphere, the Upper Atmosphere, also known as the Thermosphere, and the Exosphere. The Martian atmosphere has a scale height of 11km compared to Earth's 7km, while the actual height is approximately 200km compared to Earth's actual of 500km [8]. The scale height of a planet's atmosphere is the relation between the mean planetary temperature and the molecular mass of the air, given by the equation

$$H = \frac{kT}{gM} \qquad \text{(Eq. 27)}$$

Where k is the Boltzmann constant of 1.38 x 10^{-23} J·K^{-1}, g is the constant acceleration due to gravity, T is the mean planetary surface temperature in Kelvins, M is the mean molecular mass of dry air in units of kilograms, and H is the scale height value in meters [142]. The Lower atmosphere can be compared to Earth's troposphere, though dissimilar weather occurs on Mars than on the Earth. The Middle atmosphere of Mars, with the Martian analogue of the terrestrial jet stream, can be compared to the upper part of the troposphere and the stratosphere since this is where Earth's jet stream circulates [8]. The Martian and terrestrial thermosphere are synonymous since both exhibit heating directly from solar influence, and the exospheres are identical as well since it denotes the boundary between the atmosphere and space for both planets.

Compared to the vacuum of the Moon, though, Mars is a better candidate for space exploration or colonization considering the presence of an atmosphere. The Martian atmosphere is extremely thin compared to Earth's atmosphere, at approximately 0.59% the average surface level pressure as Earth's averaging 600 Pascals to Earth's 101,300 Pascals [25]. The total mass of the atmosphere is also a fraction of Earth's, with 25 teratonnes, or 25,000,000,000,000 tonnes for perspective, compared to Earth's 5148 teratonnes [7]. The average temperature of the atmosphere is -62.77 °C, with a range from -73.33 °C to 23.88 °C [19]. This is dissimilar to Earth's average temperature of 14.4 °C, yet comparable in that it lies above the Antarctic temperature of -89°C and below Libya's 57.8°C [19]. Also in contrast to the Earth, the Martian atmosphere is mostly carbon dioxide at 95.3%, with 2.7% nitrogen, 1.6% argon, 0.13% oxygen, and trace amounts of water vapor and other gases [28]. The Earth's atmosphere meanwhile rests at 78.1% nitrogen, 20.9% oxygen, 0.9% argon, 0.1% carbon dioxide, and other trace gases [19]. The Martian atmosphere, with this contrasting data, is seen to be unfit for most biochemical reactions to take place to support life, since it has a lack of oxygen and, specifically, nitrogen.

However, it is thought that vast amounts of water, nitrogen, and carbon dioxide are trapped in the frozen polar ice caps of Mars and, if reclaimed, could help spur a thicker and more livable atmosphere closer to terrestrial norms. The oxygen trapped within the frozen and gaseous carbon dioxide could be freed and help attain a more terrestrial atmosphere if Mars had an existing carbon and oxygen cycle within its biosphere. In addition, there is an abnormally large amount of ferric oxide, also known as hematite or rust with chemical formula Fe_2O_3, going so far as to almost completely cover the Martian surface [83]. Iron and steel, vital materials needed for building any sort of structure, could be produced in factories by using the widely available Martian ferric oxide soil as a reactant in a carbothermal reduction reaction with carbon as the other reactant to produce iron and carbon dioxide ($2\ Fe_2O_3 + 3\ C \rightarrow 4\ Fe + 3\ CO_2$) under high temperatures (1000 °C to smelt the ore, 1535 °C to initiate the reduction reaction) [23]. From there the carbon dioxide can enter the carbon/oxygen cycle of Mars, such as by being consumed by plant life for conversion to oxygen. This sort of endeavor involving hematite in factory smelting reactions would be to great extremes if dealing with a small initial outpost on Mars, though an integrated society with many industrial cities could probably succeed producing oxygen as a simple byproduct of industrialism.

However, even with all conditions met for a livable atmosphere with nitrogen and oxygen being the most prevalent gases in a terraformed Martian atmosphere, the atmosphere would slowly dissipate over a few hundred or thousand years due to the lack of an ozone layer and, more importantly, a magnetosphere. Scientists believe the current nonexistence of a Martian magnetosphere is the leading cause of a lack of a Martian atmosphere [25]. Earth has an active magnetosphere that protects it from bombardment by the solar wind; however, Mars, with its lack of a magnetosphere, is continuously bombarded by the solar wind at the level of the ionosphere and therefore can only retain a thin layer of atmosphere. Further concerns include the presence of extremely fine Martian regolith, with an approximate grain size of 30 micrometers [83]. This Martian dust could cause environmental problems for exploring humans in the future similar to how the lunar regolith caused issues for astronauts, especially since both regolith types are of the same size. Of interesting note is the presence of methane and ammonia in the Martian atmosphere, both of which persist in trace amounts, approximately 10 ppb for methane and less for ammonia [28]. Methane decays from ultraviolet radiation within a few hundred years, and ammonia does so within a few hours [28]. While possibly indicative of life, the main reason scientists believe this occurs is outgassing from the Martian soil of methane and ammonia, specifically that the hydrogen within the soil combines with the carbon present to form methane, which outgasses from the top layer of Martian regolith to later decay under ultraviolet radiation in the atmosphere.

The conclusion for space exploration is that while the atmosphere cannot directly support life or habitation, the similar atmospheric mechanics and relatively agreeable temperatures, along with the possibility to eventually reintroduce oxygen and nitrogen into the atmosphere, may allow for limited, protected habitation in airtight outposts.

These graphs are generated from formulas acquired from "Mars Atmosphere Model – Imperial Units" and show the trend for the temperature, pressure, and air density of the Martian atmosphere.

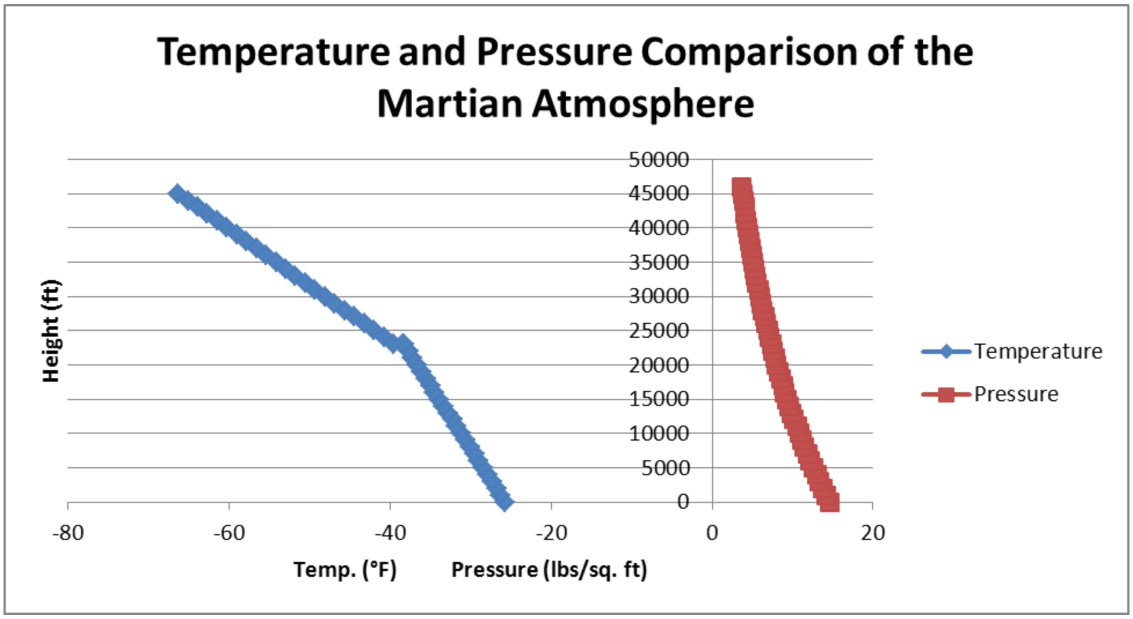


*Figure 27. Temperature, in blue, was calculated using T = -25.68-0.000548h for temperatures occurring below a height of 22960ft and T = -10.34-0.001217h for temperatures occurring above a height of 22960ft. Pressure, in red, was calculated using the equation P = 14.62*E$^{-0.00003h}$ for all heights. (Martian Atmosphere Characteristics, Self-produced)*

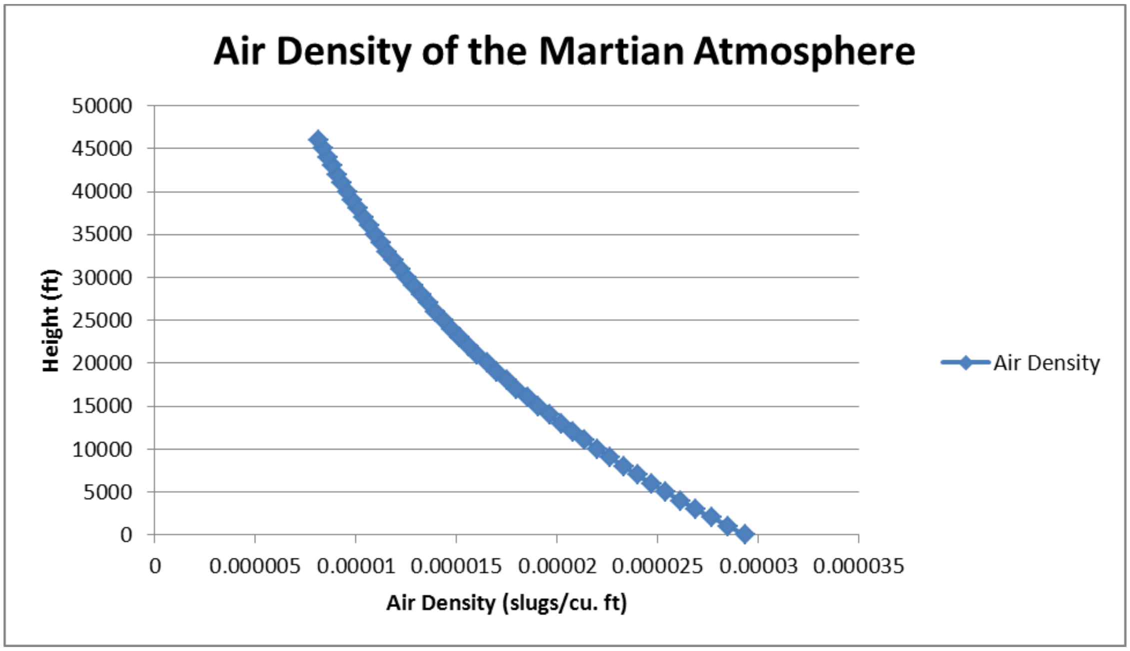


Figure 28. Air Density, in blue, was calculated from pressure and temperature using the formula ρ = P/(1149(T +459.7)). (Martian Atmosphere Characteristics, Self-produced)*

5.2 HAZARDS OF HABITATION AND EXPLORATION

The journey to Mars is a long one, and there are many possible problems that may arise when entering the Martian atmosphere, including landing and exploring its surface. A favorable period for launching a spacecraft from Earth is known as a launch window. When chosen correctly, a launch window can save energy and reduce the spacecraft's total payload by taking advantage of the Earth's solar orbit and daily rotation. Based on Mars's and Earth's orbits, a launch window to reach Mars is created every 25-26 months. This allows for a straight shot to the planet and no worries about whether the spacecraft will miss its destination or not. Entering the Martian atmosphere is a difficult task to complete, due to the density of the atmosphere, sandstorms and outcrops of rock on the surface of the planet, issues with the speed of the spacecraft, a faulty trajectory, lack of fuel, or an electronic glitch. Due to these and other complications, 60% of the missions to Mars have failed. Humans have not yet been transported to Mars, so even the landing methods that have already been put to use must be tweaked if people were to walk the planet. Usually, inflatable landing cushions, parachutes, and thrusters bring a robot safely to the Martian surface at a speed of 15 G's—robots can survive this impact, but humans cannot. Another simple problem is the amount of time it would take to reach Mars and explore it. With the correct launching window it would take a spacecraft 7 months to reach Mars, and then another 18 months would have to pass before the astronauts could begin their 7 month journey back, amounting to an entire 2 and a half years of space voyage. Astronauts would be far from family, home, or anything familiar for this long stretch of time, which could easily cause mental instabilities [22].

Deep space is filled with protons from solar flares, gamma rays from newborn black holes, and cosmic rays from exploding stars—all variations of the increased radiation that is present in outer space. In a 2001 study of people exposed to large doses of radiation (subjects were Hiroshima atomic bomb survivors and cancer patients who have undergone extreme radiation therapy) scientists figured that there is somewhere between a 1% to 19% increase in cancer risk from radiation. In space, they suppose the increase will be about 3.4%, but there are no human subjects available to prove this accuracy. A healthy, non-smoking American has about a 20% risk of developing cancer, and if the increase is only 3.4%, the astronauts could definitely bare it. However, it is possible that the increase is as high as 19%, making the overall risk of cancer 39% for a healthy human, which is unreasonable and not worth the risk [122].

The greatest threat to astronauts is galactic cosmic rays, or GCRs. These are particles that have been accelerated to practically the speed of light by distant supernova explosions which contain heavily ionized nuclei such as Fe^{+26}. GCRs will barrel through the skin of spaceships and people like tiny cannonballs, ripping strands of DNA molecules apart, damaging genes and killing cells. Astronauts have rarely experienced full doses of deep space GCRs, but they are a major problem that must be addressed before sending humans as far as Mars. Overexposure to such space radiation can burn skin, cause cataracts in the lens of an eye, and immediately deplete blood cells, besides the risk of an increase in cancer [122].

To measure radiation doses of astronauts performing Extra Vehicular Activity (EVA), which is when an astronaut is spacewalking outside of the shielded walls of a spacecraft and only protected by a spacesuit, NASA and the Canadian Space Agency (CSA) developed the EVARM experiment. EVARM, short for Extra Vehicular Activity Radiation Monitoring, is the first device to measure the radiation dosages encountered by the eyes, internal organs, and skin during spacewalks while relating it to the type of activity performed and the location of the astronaut. EVARM consists of a storage/badge reader unit and 12 badges, 3 for each crew member with 4 crew members in all, which are attached to 3 different key locations on the body: the head, torso, and leg. Each badge contains a silicon MOSFET chip (metal-oxide silicon field effect transistor) that continuously measures the total radiation dosage experienced by the astronaut. This can then be plugged into the badge reader after a spacewalk, and data will be transferred to the Human Research Facility laptop in the International Space Station then finally transmitted to the payload team on Earth which will analyze the data obtained in space. When a MOSFET is exposed to ionizing radiation, a positive charge builds up on the silicon surface, creating a negative shift in the threshold voltage of the chip. Measurements are taken by comparing threshold voltage changes with a radiation dose, which is recorded using a photodiode. Factors that must be considered when analyzing the badges are the time and place of the EVA, and the orbit and altitude of the International Space Station (ISS). This experiment was implemented throughout 2001 and 2002, and results have shown that although EVA doses are elevated compared to those within the ISS, the difference is not very significant. More work on the deflection and dosages of space radiation should be in progress, and the torso badge must also be improved because it was not sufficient enough to accurately determine the radiation delivered to internal organs [22].

5.3 RADIATION PROTECTION

Mars maybe a potential planet to colonize because of its many similarities to Earth. A day on Mars is about the same length as on Earth, and the surface temperature (-113°C to 0°C) is relatively close to Earth's compared to other planets [77]. However, a significant obstacle still remains. The atmosphere on Mars has drifted away because of its low gravity (1/3 of Earth) [77]. As a result there is no o-zone, and therefore no protection from ultraviolet (UV) radiation. Astronauts will need to be protected from all types of radiation to insure that their risk of cancer or other serious illnesses does not increase.

Radiation is usually physically blocked like thick concrete walls on a reactor. A renewed idea to shield radiation with a force field instead has been in the works for a few years now. The theory is that since most of the dangerous radiation in space consists of electricly charged particles, if the base on Mars were to be covered with an electric field with the same charge as the radiation, the radiation would get deflected. "Using electric fields to repel radiation was one of the first ideas back in the 1950s…They quickly dropped the idea, though, because it seemed like the high voltages needed and the awkward designs that they thought would be necessary would make such an electric shield impractical," said Charles Buhler of ASRC Aerospace Corporation [11].

The concept design for the force field would contain several inflatable spheres with a 5m diameter mounted above the base site, where the astronauts cannot come in contact with them. The spheres would need to be made of strong fibers like Vectran and coated with conductive metal. The spheres would inflate by charging them with 100 megavolts. A small current would then flow through to maintain the charge and save energy [11]. The like charges of the electrons in the conductive metal would repel each other, causing the sphere to expand and inflate.

The problem with the spheres is that radiation can be either positively or negatively charged. So the spheres would need to be arranged in the right way to repel both positive and negative charges, and make sure that there is no impact on the health of astronauts or equipment from the electric fields. Fortunately there are some designs that managed to have a calculated net electric field of zero at ground level [11].

Colonizing on Mars seems to be within research with our current technology. If the issue of radiation protection can be solved with this method or one like it, our ability to put humans on Mars becomes somewhat easier. With its many similarities to Earth, Mars does not have as many variables for base building as the Moon. Mars has a good surface temperature, and its gravity is not too low. Mars is the better option for where to build a base, but it still may not be the best to colonize.

5.4 RESOURCES

Despite Mars's toxic atmosphere and radical temperatures, because of its size and proximity to the earth, it is an interesting place to research as a possible future habitat for humans. Although Mars is less than half the size of the earth, it is a candidate worth considering for future inhabitation due to the prevalence of water on its surface, mineral rich soil, and abundance of caves below the surface that could be made suitable to support human life.

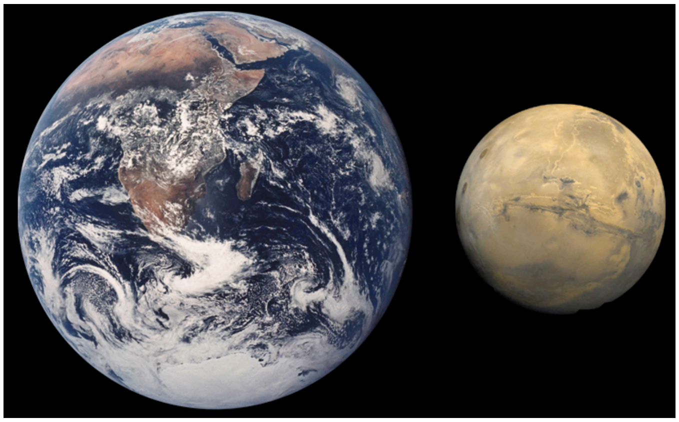


Figure 29. Size comparison of the earth and Mars. (Lunar and Planetary Institute)

Although the thin atmosphere and low temperature of Mars cause exposed water to quickly evaporate or freeze, there is evidence in recent years that in certain gullies and low altitude locations, water does flow for short periods of time.

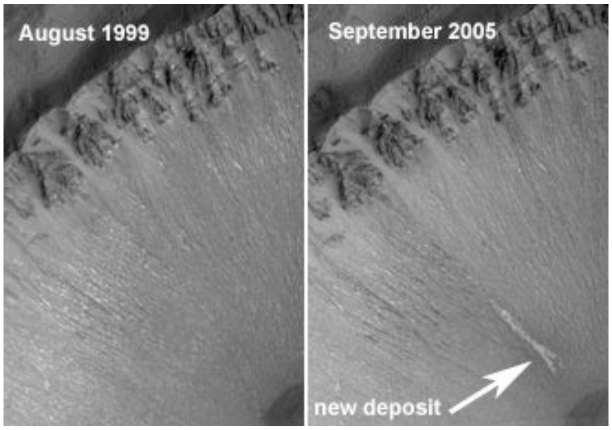


Figure 30. Mineral deposit Mars. (NY Times)

In Figure 30, it can be seen based on new mineral deposits in a Martian gully, that water has flowed in brief spurts in the recent past, sourced from melting subterranean permafrost. Additionally, vast icecaps cover both poles. It is estimated that the southern icecap alone contains enough water to cover the entire surface in a layer of water eleven meters thick. NASA claims that the southern icecap is larger than the state of Texas, and both icecaps range between two and three kilometers thick. If melted, these icecaps could prove to be a valuable resource, providing enough water to sustain human life [81].

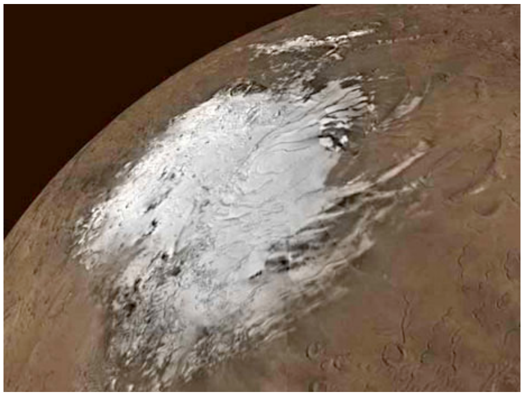


Figure 31. Mars's southern polar icecap. (Mars Melting, standeyo.com)

Because Mars lost its magnetosphere more than four billion years ago, the solar winds can interact directly with Mars's ionosphere, the top layer of the atmosphere. This causes the atmosphere to be exceptionally thin by removing layers of atoms [118]. Although the atmosphere is quite dusty, because it is so thin, and comprised of 95% carbon dioxide—a powerful greenhouse gas—solar power could be a viable option as an energy source. However, because of its distance from the sun, Mars receives only 43% as much sunlight as earth. Because of the lack of any powerful sunlight reaching Mars, solar power would only be a supplemental power source, much like it is on earth. A more suitable candidate for providing energy to future human settlements on Mars would be wind power. Mars is home to some of the strongest winds in the entire solar system, often creating dust storms capable of swallowing up the entire planet [103].

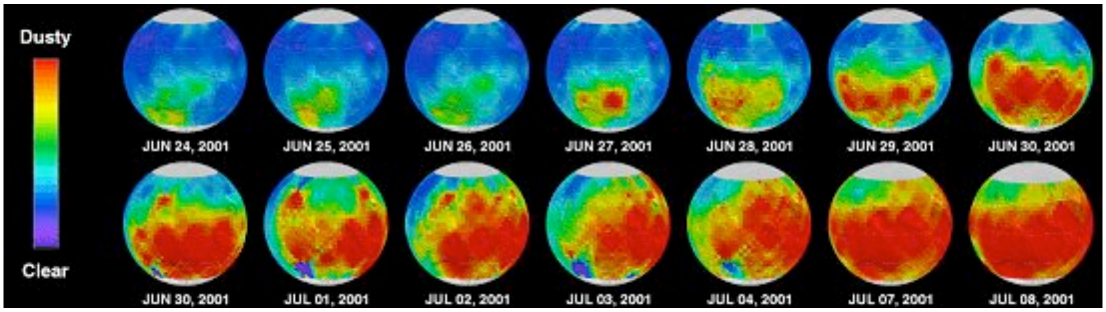


Figure 32. The increase of dust storms on Mars. (Mars, solstation.com)

The average wind speed on Mars is 20 miles per hour, and during storms, can exceed 60 miles per hour [94]. These are ideal conditions for harnessing wind energy. The average large wind turbine can produce around to 700 kilowatts per hour. The average wind speed on earth is only 7 miles per hour, so in under 20 mile per hour wind conditions, one turbine would be able to power a whole community—somewhere around 8000 kilowatts per hour [52].

Martian topsoil has been found to be much less acidic than was otherwise thought. It contains essential minerals such as magnesium, sodium, and potassium. These are essential elements for plant growth, so the surface of Mars is estimated to be surprisingly suitable for agriculture. This was determined by the probe Phoenix in 2008, which collected a small sample of Martian soil and heated it with earth water for analytical purposes [84]. In addition to suitable conditions for plant growth, Mars is also home to a multitude of subterranean caverns. Seven caverns have been documented in the vicinity of a volcano in the southern hemisphere of Mars, however, the structural makeup of these caverns suggests an abundance of such caves may exist globally on Mars. Not only will these caves provide suitable living spaces for settlers, they are also of great interest to the investigation of past life on Mars [27].

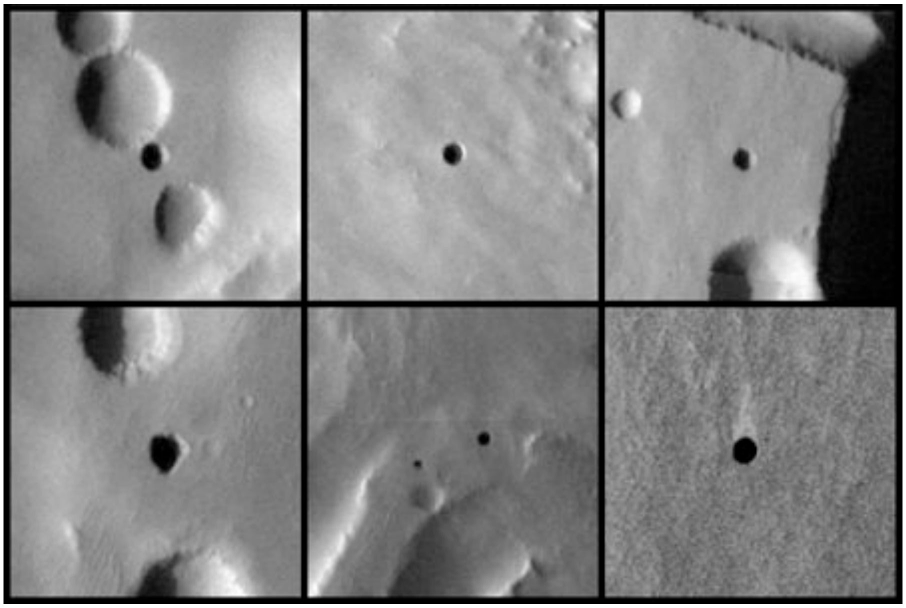


Figure 33. Cavern openings on the surface of Mars. (Universe Today)

Although Mars has a toxic atmosphere, and a number of other hazards to humans, it is becoming a viable option for future space colonization. Its Abundance of water, and caves for shelter make it possible for supporting human life. Additionally, its soil proves to be suitable for plant growth, an essential part of sustainable human life. Although there may not be enough sunlight for solar power, Mars's windy conditions make wind power a realistic option for providing energy to future human colonies. Although many breakthroughs are still needed to contend with the toxic atmosphere and many other hazards, Mars is likely capable of supporting human habitation.

5.5 TERRAFORMING

Terraforming is the process of transforming an environment into one suitable to sustain human life. Since Mars is the most Earth-like planet in our solar system, it is the most viable candidate for terraforming. Even though it seems like Mars is a cold, dry planet, it has all the necessary ingredients for life already. It is widely believed that it is currently technologically possible to create enough global change on Mars to support human life. Greatly increasing the atmospheric pressure and surface temperature on Mars is theoretically possible within a decade, and would be the first step towards terraforming.

The surface temperature on Mars is too low for human life currently because Mars is farther from the sun and outside the habitual zone, and has much less of an atmosphere to keep in its warmth. The atmosphere on Mars has only about 1% the pressure of the Earth's at sea level [146]. Since moving a planet towards a warmer orbit is out of reach, an alternative method to heat up the planet is needed. Another way to do so would be to artificially induce the greenhouse effect on Mars to trap the Sun's heat within the atmosphere. Several ways to accomplish this include using orbital mirrors to warm certain areas of the surface, set up factories on Mars that produce artificial greenhouse gases, or collide asteroids containing volatile components into Mars [146]. Whichever method is used, the main goal is to warm the planet and thicken the atmosphere enough to make a suitable living environment for humans. This artificial greenhouse effect may be able to do that if enough greenhouse gases are released. Carbon dioxide, which is a greenhouse gas, can be found in large quantities on Mars. Most of which is absorbed within the soil, but some of it is frozen in the south polar cap [146]. The only way to reach the carbon dioxide is to heat the planet enough so that it can be released as a gas.

It is estimated that there is enough carbon dioxide frozen in the south polar cap of Mars to initially kick-start the greenhouse gas effect [146]. Once the greenhouse effect begins it enters a runaway process, continuously warming and making it a more life-sustaining planet. The warmer Mars gets, the thicker its atmosphere will become [146]. The thicker the atmosphere becomes, the warmer it gets. Therefore, once the greenhouse effect is started it cannot be stopped. Today, the atmosphere of Mars is roughly 6 millibars of pressure compared to Earth's approximate pressure of 1013 millibars [146]. If the estimated amount of frozen carbon dioxide at the south pole were to be released to the atmosphere, it could add anywhere between 50 to 100 millibars to the atmosphere's pressure, and would take only about 10 years for the process to be completed [146]. That may not seem like enough, but if the estimated amount of carbon dioxide also trapped in the soil of Mars was to be released the atmospheric pressure could eventually reach about 400 millibars [146].

Once the surface temperature on Mars rises above the freezing point of water, the frozen water in the soil would begin to melt. The melted water could then start to refill the dried up riverbeds, and would eventually allow natural ecosystems to begin on the surface. In addition to the development of ecosystems, the melting of water has another major benefit. Water vapor is considered to be a greenhouse gas. When the water melts on the surface it can also evaporate and add to the runaway greenhouse effect, further accelerating the warming process of Mars [146].

The total amount of carbon dioxide available to be used will be unknown until human explorers travel to Mars, and therefore the exact final conditions to occur after terraforming on Mars are unknown. However, there is a significant enough amount of carbon dioxide to make Mars a more suitable planet for living. It is technologically possible to begin the process of terraforming by inducing a greenhouse effect into the atmosphere of Mars.

5.6 MAGNETOSPHERE

Terraforming Mars for colonization is a great idea, but there is one particular problem that has yet to be solved for this task to be complete. This is the lack of a magnetosphere on Mars, or, scientifically, the lack of an active geothermal core with strong magnetic poles [141]. A magnetosphere, such as the one we have on Earth, protects the planet from solar activity and radiation, and confines the atmosphere so that it doesn't escape into space. NASA's Mariner 4 was the fourth spacecraft in a series of planetary exploration flyby missions to Mars and was the first deemed successful because it provided the first pictures of the Martian surface to ever be seen [136]. The spacecraft came within 3.9 Mars radii and found no indication of an Earth-like dipole magnetic field [402]. It is hypothesized that Mars had a thick atmosphere consisting of mostly carbon dioxide billions of years ago, but without a strong magnetic field the carbon dioxide was stripped from the atmosphere by the ions of solar wind and the Martian atmosphere slowly began to decompose. Earth is protected from solar wind by its magnetic field; a stream of very energetic particles make up solar wind, and these particles would strip away the ozone layer that is protecting Earth from harmful ultraviolet (UV) rays if the magnetosphere weakened or was nonexistent.

Solar and space activity have detrimental effects on humans when they are directly exposed to such weather, but the magnetic field and Van Allen Belt that surrounds Earth help to deflect this radiation and keep us safe. The Van Allen Belt consists of two radiation belts, an inner and outer belt, that are made of high-energy particles (10-50 MeV), mostly protons and electrons, that are held captive by the Earth's magnetic field. These belts also deflect radiation when the plasma of the solar wind interacts with the plasma of the Van Allen Belts. Without a magnetosphere, no Van Allen Belts are present, making it even more impossible for humans to live naturally on Mars.

The rate of change of temperature that corresponds with the depth of a planet is called the geothermal gradient. Earth's inner and outer cores have much higher temperatures (4,300 degrees Celsius at the inner core, 5,200 km deep) than those at the surface. Gravity from the Moon creates "tides" on Earth that don't just affect the ocean, but the crust as well. The Moon's gravity pulls on the bulge of the Earth that is created by these tides, and causes the Earth's rotation to slow down. However, it is only the crust that is affected by these tides, while Earth's inner core continues to rotate at a faster pace. This has been proven by scientists' findings when measuring changes in the speed of earthquake-generated seismic waves that pass through the inner core. A significant amount of this research was completed by Xiaodong Song and Paul G. Richards, seismologists at Lamon-Doherty of Columbia University [110]. They say this new information will provide a jumping point for more advanced planetary understanding and will help explain the pattern of changes in Earth's magnetic field. Earth has a solid inner core, made solely of iron, and lies within the outer core, which is also made of iron, but is molten. The combination of these electrically conducting cores and the naturally occurring dynamo effect creates the planet's magnetism. The dynamo effect can be explained in relatively simple physics, using a metal disc, of radius a, that is spinning with angular velocity, *w*. When a magnetic field is present, there is an induced emf, E, across the disc that is proportional to the magnetic flux, Φ, times w. This can be shown through the integration of the Lorentz force (Eq. 26, section 3.5), which produces our final equation for induced emf [31]:

$$E = (w\ \Phi)/(2\pi) \qquad \text{(Eq. 28)}$$

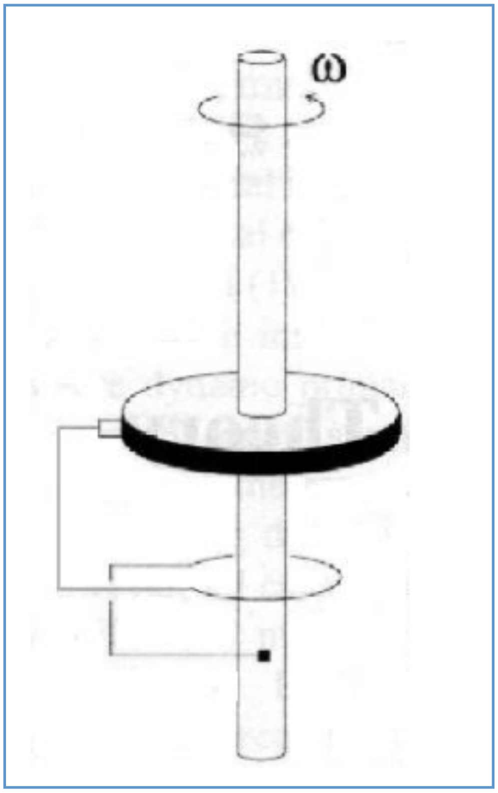


Figure 34. Single Disc Dynamo. (Merrill)

A non-rotating wire electrically connected to the disk and wound about the axle completes the circuit and creates the magnetic field. This can be applied in planetary terms by the solid inner core being the axle, and the outer liquid core being the disk. The "wire" isn't necessary since the cores are so large and therefore have a great enough influence to produce this effect themselves, naturally.

Mars has both inner and outer liquid cores, but does not have a magnetosphere. Andrew Stewart, a planetary geochemist at the Swiss Federal Institute of Technology, suggests that cooling the core might restore magnetism to the planet [90]. If a solid inner core was created, stationed inside the liquid outer core, a natural dynamo effect might be possible. However, this could not be achieved through humanity's technology, and would have to happen on Mars naturally, in the next thousands, or millions, of years.

If we would like to colonize Mars, we must develop some sort of spatial technology that will create an artificial magnetosphere around the planet, or at least something that could protect a small, developing city. Scientists do not have any official plans on how to do this, but a few ideas have been tossed around [97]. One such idea would be to launch electromagnetic satellite generators into orbit around Mars. The generator could be built to fire off electrons, acting as a cathode, towards the next generator in orbit, which would retrieve the stream of electrons through an anode. Each generator would have both anode and cathode portals, and when a continuous stream of electrons were fired, a complete circuit would be achieved. The magnetic field would run perpendicularly to the current between each generator, pointing straight up and then curving towards the North and South Poles of the planet. An electromagnetic generator works similarly to the design of a mass driver, but rather than launching payloads these generators would be launching electrons. A conductive coil runs through the generator, and when voltage is applied, current is created, and a magnetic field begins to form inside the generator. To achieve the flow of electrons through the cathodes and anodes of the generators, we can apply Faraday's Law of Induction. This Law states that a moving magnetic field, such as the one created within a generator, will cause current to flow without applying voltage. A copper wire could run between the cathode and anode of each generator, and once a magnetic field is present within the generator, electrons would begin to flow through this copper wire. The wire would direct electrons out the cathode of one generator, and towards the anode of another. This electron flow would create a magnetic field around the path of the generators.

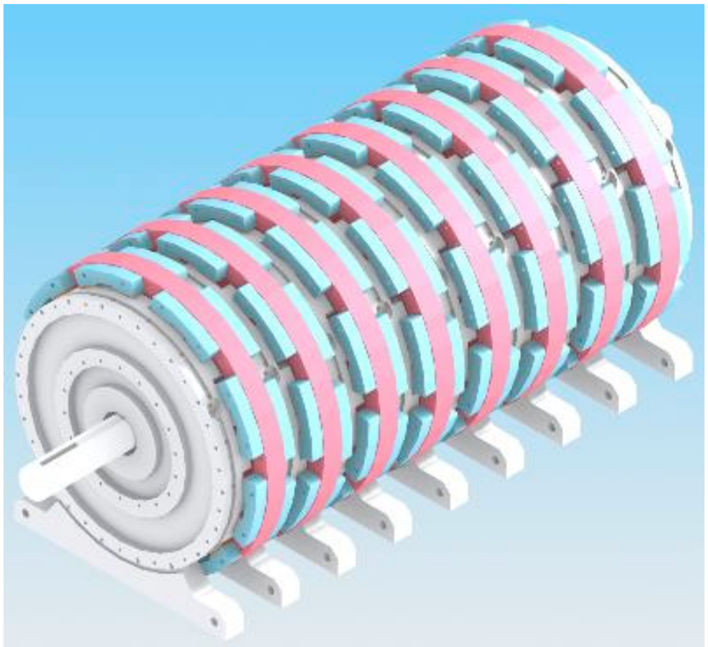


Figure 35. Variable Input Electrical Generator (VIEG). (ExRo Technologies)

The electromagnetic generator pictured above is made by ExRo technologies and has been designed using a series of coils configured into "balanced stages" [112]. The use of magnetic balancing allows permanent magnets to be used in the generators design, which is ideal for the idea of the artificial Martian magnetosphere previously described. Once placed into orbit, the generators would not need to be constantly maintained due to the permanent magnets and the fact that the generator uses wind power for energy. The Variable Input Electrical Generator (VIEG) is able to cycle up and down without hesitation or mechanical friction, eliminating the need for a gearbox and making it much more efficient than competing electromagnetic generators.

If an effective magnetic field was to be made around Mars, the magnetic flux of the field would need to be significantly large in order to cover the correct amount of area above the planet. Magnetic flux can be defined as the product of the average magnetic field and the perpendicular area that it penetrates. Mathematically, it is defined as

$$\Phi = BA \qquad \text{(Eq. 29)}$$

B representing the magnetic field and A being the area perpendicular to the field. In order to increase the field lines of magnetic flux, the electromagnetic generator design could incorporate conductors connected in parallel between each of the generators. The conductors would retrieve the stream of electrons from the cathode of a generator and send them through their own unique circuit, until they are then projected to the anode of another generator. A magnetic field would be created by the current running through these parallel conductors, strengthening the overall magnetic field of the system. The summation of each of the fields created between and through the generators would result in one whole, very large, magnetic field [31].

5.7 Colliding Enceladus with Mars

While terraforming on Mars seems like an approachable idea, there may be another way to do it. Colliding an object, like Enceladus, with Mars could help move it more towards Earth's orbit, and could give it the materials it needs to induce the greenhouse effect still and create a life sustainable planet. The main issues to consider for such a process include cost, time, and technological ability.

It may seem ridiculous to collide a moon of Saturn with Mars, but many other planets/moons have collided before. In fact, the Earth and the Moon could be a result of two planets colliding according to the giant impactor theory. The giant impactor theory suggests that a small planet, about the size of Mars, hit what was once Earth. The result of this collision ejected large volumes of heated materials from the outer layers of both objects into orbit. The debris that was left over in orbit around the Earth eventually stuck together and formed what is now our Moon [30].

Enceladus is a small ice moon located in the E ring orbiting Saturn. Its surface composition is mostly ice, with traces of carbon dioxide, and small amounts of ammonia and hydrogen peroxide. Gases being released by plumes on Enceladus by volume mostly erupt with water (90%), carbon dioxide (5%), methane (0.9%), ammonia (0.8%), and trace amounts of several hydrocarbons and other substances [125]. This presence of organic molecules makes Enceladus appealing for collision with Mars because it may be able to help induce the greenhouse effect on Mars, which could eventually make it a life-sustaining planet. Enceladus also reflects about 80% of the sunlight it receives making it the brightest object in our solar system, and therefore has the highest reflection coefficient of any known solar system object [125]. This may also be beneficial to making Mars a life sustainable planet because of its inability to deflect radiation currently.

In order to move even a small planet such as Enceladus it would take an enormous amount of time and energy. Methods to move a planet include using antimatter or fusion rocket engines have been considered. However, operating a rocket through our atmosphere would be very difficult as well as slow and very costly. Another idea of using just solar sails or orbital mirrors would work technologically, but would take around 40 million years to move Venus into Earth's orbit [14]. Comparatively the distance between Venus and Earth is far less than that between Enceladus and Mars; therefore this method would not have a realistic timeframe. The best current proposal is to establish an accelerating force by transferring momentum and energy to the desired planet to be moved by high-velocity mass-streams. The accelerated mass-stream would loop energy around a nearby planet with the assistance of solar sails and then project it back to be captured by the equatorial track mounted on the moving planet. In essence, the energy being catapulted back to the moving planet would cause it to rotate faster and push it further away from its orbit and the planet the energy came from. It is predicted that this process could work on moving Venus out into Earth's in around 30 years [14].

In summary, if Enceladus were to collide with Mars, it may be able to transfer some of its traits and materials necessary to induce the greenhouse effect on Mars. However, the new proposal for moving planets would not be time or cost effective. The distance from Venus to Earth is far less than that of Enceladus to Mars so the amount of time needed to collide the two would be much greater. Also, the impact of such a large object could destroy or alter the surface of Mars, and make future missions there more difficult. The debris launched into space after the collision could litter the solar system, rather than collect into a moon, since there is very little atmosphere around Mars. Overall, the idea of colliding a large object with Mars to create a life sustainable planet may be possible, but it is neither cost nor time effective.

5.8 CHANGING MARS' ORBIT

Currently, Mars is just outside of the habitable zone in our solar system at an average of 1.52 AU (228 million kilometers) from the Sun [14]. In order for it to be considered within the habitable zone, Mars would need to be 1.33 AU (199 million kilometers) form the Sun [14]. To achieve this, Mars' angular velocity would need to temporarily decrease so that it could slip into an orbit closer to the sun.

Angular momentum measures an object's tendency to continue to spin. For a circular orbit, angular momentum is defined by the equation [41]:

$$L = mvr \qquad \text{(Eq. 30)}$$

Where m is the mass of the object, v is its velocity, and r is its distance from the object it is spinning around or its orbital radius. The mass and orbital radius of any given planet can be easily obtained, but the velocity must be calculated first. In most cases, velocity can be defined by a simple equation [41]:

$$v = d/t \qquad \text{(Eq. 31)}$$

Where d is a measure of linear distance, and t is time. Since we are looking at a circular system, the distance is calculated by finding the circumference of the planet's orbit [41]:

$$d_C = 2\pi r \qquad \text{(Eq. 32)}$$

With r being the distance from the planet to the Sun. So the equation for the velocity of a planet becomes [41]:

$$v = (2\pi\ r)/t \qquad \text{(Eq. 33)}$$

Where t is the orbital period. Therefore, the equation for angular momentum can be stated as:

$$L = mr^2(2\pi/t) \qquad \text{(Eq. 34)}$$

An important factor to note is that angular momentum is conserved [126]. If a planet were to lose some of its angular momentum in order to change its orbit, another planet's angular momentum must increase. However, for this scenario the angular momentum for Mars will be held constant, assuming that the angular momentum that was lost to change its orbit would be returned when it is in its final position.

With Mars' current orbital radius of 228 million kilometers (km), an orbital period of 686.98 days, and total mass at $6.42e^{23}$ kilograms (kg), its angular momentum would equal $3.5e^{39}$ kilogram-meters squared per second ((kg-m^2)/s) [75]. If Enceladus, with a mass of $7.30e^{19}$ kg, were to combine with Mars while its angular momentum is held constant, the combined mass would have a decreased orbital radius and orbital period [75]. If the orbital radius were set to the desired habitable distance of 199 million km, then the orbital period would be 528.31 days.

While it seems to be that a planet with the combined masses of Mars and Enceladus could exist in the habitable zone in our solar system, getting Enceladus to collide with Mars and end up in the right orbit would be a great challenge. The technology and funding for a project of such proportions is most likely out of reach at this current time. It is recommended that an alternative path to creating another habitable planet should be approached.

5.9 POSSIBILITY OF LIFE FORMS IN SPACE

The possibility of life beyond Earth has been a subject of heated debate for thousands of years. Theories and arguments range from the prospect of super advanced civilizations, to abductions from Earth, to a vast science-fiction subculture of imaginings. Although talk of highly developed life forms is interesting and popular, it is more prudent to start the search on a smaller scale: bacteria.

On Mars, evidence of past bodies of water leads NASA scientists to believe that life did thrive on a bacteria level—millions of years ago. More significantly, the discovery of methane in the Martian atmosphere suggests that life may still be in existence on Mars, hibernating below its surface. Here on Earth, there are few areas too hostile for bacteria to survive. Even when conditions become too harsh to support bacteria life, many types of bacteria are capable of degenerating into a dormant state—during which they are called a spore—and reviving themselves when their surroundings again become livable. Such single celled organisms are able to remain in such a state nearly indefinitely [32].

Because over ninety percent of all methane found on Earth is the result of living creatures, NASA's findings suggest strongly that the methane found in the Martian atmosphere was created by bacterial spores living below the permafrost level. Although it will be difficult for such bacteria to regenerate in the current conditions on Mars, without further testing, there is no way to know whether or not there are additional strains of bacteria which have evolved to survive in the harsh Martian environment. Researchers claim that detecting bacteria on the surface of mars will be so difficult that "even future rovers will have a tough time identifying the Martian equivalent of dormant bacterial spores [20]." Because unknown and unidentifiable types of bacteria on Mars could pose a potential threat to settlers, it may be judicious to design future rovers with the ability to send soil samples back to Earth to be tested for bacteria in a contained environment before exposing large groups of settlers to this potential hazard.

In a much more distant part of the solar system, Saturn's largest moon, Titan, is a rich possibility of life beyond Earth. Titan, although too low in temperature to support Earthly life forms, is rich in hydrocarbons such as methane. Although most scientists are more quick to speculate that Titan is simply an example of what a planet looks like before biological growth takes place, it should be considered that Titan could support methanogenic life forms where liquid methane takes on the role that water plays on Earth. Although this possibility seems remote, fluctuations in gasses such as hydrogen and ethane, suggest that conditions on Titan are consistent with the possibility of life. Although the temperature on Titan is still too cold to support human life, it is a bright example of what is to be discovered in the future of space exploration [68].

Although concrete evidence of life beyond Earth is yet to be found, it is an important area of study to consider. It is possible that bacteria on Mars may pose a threat to humans, and it should be studied further before settlers are sent there. Titan on the other hand, is merely an interesting example, not suitable for future habitation. This being said, as the sun expands over millions of years, the temperature of Titan will increase, and perhaps life will bloom and Titan will become comparable to Earth.

5.10 Mirrors in Space

Although technology is growing more and more rapidly to make colonization of Mars a more realistic possibility for the near future, one of the most difficult technological issues to tackle concerns energy sources to power such a colony. Because Mars only receives 43% as much sunlight as the Earth, solar power is a less than viable option. Similarly, because the atmosphere is so thin, wind power is problematic as well. Scientists are left to turn to an option that is just recently being considered as a long-term solution for Earth's climate change issues: reflective surfaces in orbit.

Such surfaces placed in Earth's orbit would be intended to reflect sunlight back out into space, thus diverting the excess heat that would increase the Earth's overall temperature and ultimately get trapped in the atmosphere, contributing to global warming even more. Senior staff scientist, Lowell Wood, at Lawrence Livermore National Laboratory estimates that a mirror of roughly 600,000 square miles in area—or several smaller mirrors equaling that total area—would be able to reduce the Earth's received sunlight by one percent. This, he estimates, would be enough to return the Earth's climate to stability. Although the concept is simple in theory, Woods abandoned the idea after almost ten years or research for its unfeasibility [51].

While maintaining—or even producing—a conventional mirror of such size would be out of the realm of possibilities, it is possible that several installations of smaller sized highly reflective surfaces could get the job done under careful supervision. Using technology similar to solar sails, this engineering feat could be achieved. Solar sails are a type of space propulsion technology that uses radiation pressure and the force of absorbing and reflecting light to gain momentum in space. Because the mirrors have to be so cumbersome, and the payloads so small solar sails are not necessarily practical for modern space travel. This being said, the reflective technology may be of use for both cooling down the Earth, in addition to heating up Mars.

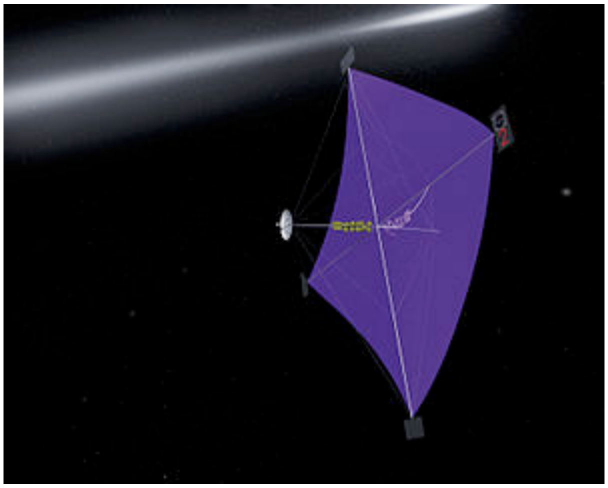


Figure 36. NASA's solar sail concept. (NASA)

Figure 36 shows a sketch by NASA of a potential solar sail design. On this particular design, the reflective surface is only a half of a kilometer wide. Because to make any real difference on earth, the surface would need to be at least 32 million times larger, it is obvious that the technology is still in its developmental days. If the mirrors were placed in a properly calculated orbit of around or above 800 kilometers due to atmospheric drag, the propulsion aspect of the solar sails would not be necessary. However, it is the material used to create the sails that is of interest. The sails are currently being made of either ultra-thin aluminum film, around a tenth of a micrometer in total or aluminized Kapton film around 2 micrometers thick which can withstand high temperatures with ease. The Kapton film is deposited in a vapor form which then hardens into a solid to form the mirror surface when in space. This would be ideal for weathering the long trip to Mars, and once there, could be used to reflect sunlight towards the surface instead of away. Not only would this ultimately heat the planet up, but it would also cause more sunlight to reach the surface, possibly making solar power a more viable option [113].

Despite the fact that the technology is still in its infancy, and as Woods presumed, is not particularly feasible at the time being, it is still a great option to keep open. Mars suffers from the opposite problem as the Earth, in the sense that it is too cold to be convenient for humans, whereas the Earth is gradually heating up. Nonetheless, the same technology hopefully will be able to be used in the future to solve both problems. Although the technology has a long way to go, Mars's temperature is a problem that needs to be dealt with, so the technology is worth developing.

CONCLUSION

Humanity has come far with its knowledge regarding extraterrestrial matters and technological advancements. When people first started studying the stars, a great curiosity blossomed within their collective consciousness. However, the capability of colonizing space seemed dauntingly out of reach. Our team has taken it upon ourselves to advance our personal pursuit of knowledge and further the research available concerning spatial exploration. Furthermore, we have developed this archive of current space colonization and projects for future generations of students.

While our opportunities to explore and colonize space are accessible, one drawback is that international politics and cooperation is not mature enough to support these endeavors. However, it is imperative that nations continue to explore and collaborate on homeworld protection from extraterrestrial dangers; otherwise humankind could be wiped out. Biology will be a limiting factor in the push for space colonization; humanity must develop methods to be adaptable to space or prevent unwanted abnormalities. With continued perseverance and the rise of the private space sector, accomplishments will be made within the next few decades.

Robots will help achieve these accomplishments in areas that humans could not otherwise perform. Current examples are Curiosity, the newest Mars rover successor for the exploration of the Martian environment. The technologies included in this rover are the most advanced in its field and can deliver new information beneficial to a colonization effort on Mars. Terrestrial robots are mainly relegated to industrial applications, such as manufacturing, but autonomous robots are in development. Applied Artificial Intelligence is already being established, however strong AI is still a far beyond our current capacity. The human mind must first be understood in order to cultivate a form of synthetic computer platform that emulates this biological phenomenon.

Through our research, we have discovered that the Moon is rich with various energy reserves. The most prevalent resources on the Moon are thorium and helium-3; however, thorium is a much more realistic option for future energy production. Water is also found in abundance in the lunar regolith in a frozen state. These resources will make the development of a productive lunar outpost a greater possibility for mankind. Our lunar base concept will consist of a solar panel installation for energy capture, a launch pad for low cost rocket propulsion, and a railgun for Near Earth Object defense and investigation. This lunar base is proposed as an outpost rather than a permanent settlement such as a Martian colony.

Mars is a more suitable candidate for colonization efforts than the Moon. The environment is relatively dangerous compared to that on Earth, with the constant bombardment from solar radiation being a prime example. This radiation is a prevalent risk concerning a Martian colony because the planet lacks a magnetosphere. There have been few feasible proposals to date concerning a recreation of the Martian magnetosphere, but it may be possible in the future with developing technology. It would benefit the Martian colonization effort to terraform the planet prior to arrival to better suit terrestrial life. While there are multiple dangers currently on Mars, these can be wholly resolved by terraforming the planet. Once the planet is repurposed, it will be fully capable of sustaining a robust civilization. Humanity will then be able to gain a foothold in further space efforts.

In order for further space exploration to occur, international cooperation must be put at the forefront of the space debate. Current international political relations do not favor a coordinated space effort, as seen with the situation between the United States and China. Still, there are a multitude of reasons to look deeper into space. Eventually, Earth’s natural resources will be exhausted and mankind will require a secondary homeworld to further thrive. Hazards of space will prevent long-term voyages from occurring without extreme technological advancements for protecting human biology. Once humanity has the ability to undertake long-term voyages, we can be sure that humanity’s accumulated knowledge will persist outside of Earth’s realm. Thus the human aspect will continue to proliferate.

Our recommendations for future IQP groups extend to speculating the process of colonizing the target planet, which would realize the formation of an operational settlement on Mars following the timeline of this project. A further recommendation is to investigate the operation and society of an extraterrestrial city, keeping in mind sociological structures and the comparison between such a structure on Mars to that on Earth. Additionally, exploring the technology and infrastructure necessary in the new city would be an inquiry into extraterrestrial habitation. Also, researching how a new planet might affect a human's biology or health is of keen interest if humanity desires to spread out amongst the stars. A future IQP group could also theorize how early settlers would cope with isolation, thereby being a study in psychology compared to a study in sociology about a city. Moreover, a group could analyze the need for traveling to another world due to humanity's effects on Earth. Finally, a group could expand on how solar system economics would be affected with the introduction of a secondary homeworld, thereby being a progressive study in macroeconomics.

Our IQP group has demonstrated the initiative for expanding our knowledge regarding space and technology. We have enhanced our professional group dynamics and cooperative abilities over the course of this project. We have determined the economic and mineral potential of other celestial bodies, especially concerning colonization efforts. Furthermore, we have gained an understanding of real world situations, the influencing factors regarding space travel and applied our engineering backgrounds to measurable data within our fields of study. Conclusively, we have developed an overall proposal for space exploration and colonization with regards to technology.

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