Project Number: MH0410

HUMANITY IN SPACE

An Interactive Qualifying Project Report

submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

by

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May 3, 2005

1. asteroid
2. laser
3. space

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Abstract

As a first step this IQP explored ancient cultures, space commercialization, and survival. We found that one of the greatest threats to humanity survival is near earth objects. Various ways were examined to divert these dangerous objects and we determined that the most feasible method is moon based lasers. A program was developed which calculates the amount of thrust required to redirect these asteroids. Based on these results, we propose the placement of four carbon dioxide lasers on the moon.

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Executive Summary

This project is a thorough examination of the complex and ever-changing relationship between humanity and space. This relationship, beginning with our ancestors who looked into the night sky, and progressing to where we are now, has not always taken the form of scientific reality. For example, mythologies of various cultures include references to human beings in flight. The perception of space is now undergoing another change: when we look to the stars we look with apprehension because we know not only of the possibilities that lie beyond, but also of the dangers.

Humanity has only existed for a fraction of earth's history, and survival, it seems, is an ongoing struggle. Throughout our collective history, the human species has come in contact with natural disasters, plagues, and wars that threatened our existence. One of our oldest threats, which is ironically one of the newest discovered, is near earth objects. Asteroids, comets, and meteorites are always passing earth. Most of the time, these objects are burnt up by the earth's atmosphere and cause no real damage to the planet. However, giant craters on the earth's surface give evidence to the danger that they can cause. If a near earth object with sufficient size and velocity were to hit earth, life would be struggling to survive. A large object would not have to collide with the earth to cause incredible damage.

Considering the grave threat that a collision or near miss with an asteroid presents, we decided to tackle this problem and come up with a viable solution. We discovered that there are many variables to consider when judging the threat a near earth object would pose. The primary factors in determining the damage an asteroid can cause are its trajectory, size, composition, and velocity. Methods of diverting an incoming asteroid, including nuclear warheads, solar sails, chemical and electrical thrusters, and lasers were investigated. We determined that the most

feasible method of diversion, given a ten year warning, would be the use of a carbon dioxide laser array. In order to most effectively target a threatening asteroid, we propose to place four nuclear powered lasers on the moon, distributed evenly along its surface. An orbit simulation program was written in MATLAB in order to calculate the affect of a man generated force on the asteroid. It was determined that a laser array with an intensity of 1.5 megawatts would be enough to move a dangerously large asteroid out of the earth's path, preventing collision, over 10 years.

Introduction

Introduction

Our fascination with the heavens dates back thousands of years. Ancient cultures such as the Mayans, the Egyptians, the Sumerians, and the Celts had a great interest and remarkable sophistication in tracking celestial bodies. Even more amazing was that the ideas of flight and exploration of space were commonly dreamed about even though these civilizations were not close to developing a means of achieving these feats.

Today, we are even more curious about space than ever before. Advancements in technology have given us the ability to visit nearby planets and moons. Our technology has evolved such that we can now see neighboring stars and planets clearly. Space is no longer as unreachable as it once was thought to be. Currently there are business-owned satellites orbiting the earth delivering communications and entertainment to millions of customers. Advances in space technology are both scientifically and economically beneficial to our society as a whole.

The Interactive Qualifying Project (IQP) is defined as a project that relates technology with society. This IQP relates the fundamental qualities of our society to space. Such qualities include scientific curiosity, technological ingenuity, economic ambition, and species survival. The main focus of this IQP is examining various ways of deflecting near earth objects and then determining the best possible method of preventing a disastrous asteroid impact.

Drew Copeland-Will

I chose to do this IQP, Humanity in Space, for several reasons. One of the reasons for my interest is that I have always been fascinated by space travel. When I was younger I can remember watching news clips of the space shuttle launches. I used to read science fiction novels and dream about what it would be like to actually be out there. Watching movies like 'Apollo 13' made me realize that it wasn't just the astronauts that were heroes, but also the support crews too.

I feel that there must be many more people like me, people that foster an interest in space travel and exploration. There must be people out there who get excited when they see pictures of distant planets viewed up close for the first time. It is for this reason that I felt that doing a project on the relationship between humanity and space would be important. It was my hope that the work that my project partners and I do would not only encourage interest in space exploration but also to raise awareness about its necessity.

We as a species have always pushed outward. First we pushed out of Africa, and then across the continents. We crossed over every physical barrier on earth, but why should it end there? Space is where we need to go next. Our moon and the nearby planets should be where we set our sights for the near future. It seems that in many cases, expansion is necessary for survival. The more we push out, the more technological advancements we make and the more we know about our universe and ourselves. There are many mysteries of science that we do not yet understand, and to find the answers to these questions we must explore as far as we can reach.

Andrew Bangs

I first became interested in doing an IQP dealing with space when I first learned that it was an acceptable choice. My greatest interest has been in computers, but as a child looking up at night, I've always loved dreaming about being in space. However, since my education has taken me down the path of computer programming, I will be content with studying space and analyzing the bodies that travel through it. As such, when our group decided to look at solutions to preventing near-Earth objects from colliding with the Earth, I felt that it was one of the most interesting and ambitious projects we could do.

Looking ahead, I feel that all the factors of the IQP will have helped me for the future. The entire project has been an exercise in problem solving, which will be an important asset for my career. An ideal scenario would be if I were to use my research and experiences with this IQP as a launching point for acquiring a job as a computer technician at an aerospace corporation.

Shaun Haerinck

As a student of Worcester Polytechnic Institute, I am contributing to this IQP because I truly believe that there is a greater purpose for space and would like to be able to see the day when mankind finds this purpose. Both researching and writing this IQP has opened my view to many new ideas and concepts I had not considered previously. Whether it be to mine an asteroid in space for space travel, construct crystals in zero gravity that cannot be constructed on earth, or use the moon as an observation post to studying asteroids which cannot be seen from Earth due to the Sun's glare; this IQP has broadened my horizon and expanded my knowledge of what can be done as humans.

This IQP plays an important role in my major. As a computer science major, I would be expected to take part in plotting out the orbit of an impeding asteroid. I would also have to plot out how to prevent this asteroid impact by adding a particular force to it. With the knowledge I've gained in this IQP, I hope to be able to one day apply to NASA as a computer programmer and impress them with my prior background in asteroid studies and deflection.

Heather Bolton

The idea of a project involving humanities in space was very appealing to me because I have always been interested in space exploration and space threats. My interest in space started when I was young, hearing my parents talk about watching the first moon landing. Looking up at the stars it was amazing to me that there could be people up there, walking around on the moon. As I got older I started to learn about comets and asteroids and the impact they have on earth, specifically the asteroid that theoretically caused the extinction of the dinosaurs. Having these interests all my life, an Interactive Qualifying Project investigating the threat of asteroid collision with the Earth was a natural choice. I chose to work on this project to get a better understanding of the threat that asteroids and other near earth objects pose to earth, to find out what is being done to protect earth from possible destruction or damage, and to come up with new methods of prevention of near earth object collisions.

Having researched near earth objects and methods of diverting them from earth I understand how complicated it is to come up with feasible solutions. I now have a greater appreciation for all the work that scientists and engineers that work to protect us from these asteroids do as well as all the advancements they make in exploration of space. Also as a result of the preliminary research for this project I have an increased interest in space technology including solar power satellites, GPS, and satellite broadcasting. This project was intended to give a greater understanding of the resources space can provide and most importantly the resources that we have or are able to develop for near earth object collision.

Chapter One:

Background of Ancient Civilizations

Nothing worth doing is completed in our lifetime,
Therefore, we are saved by hope.
-Reinhold Neibuhr

To consider one's history is often to consider the entire society as a series of static moments, frozen in artifacts and captured within textbooks. Such introspection is necessary to capture the spirit with which we as a society view an issue. Looking back upon the ancient cultures of the world it is surprising to find not only such advancement, but such determination and curiosity. For thousands of years human beings have looked up to see the night sky and they have watched, wondered, and observed the stars subtle movements.

Several examples of this are found throughout ancient history. The Mayans of Central America developed a calendar that is extremely accurate even by today's standards with only the help of a rudimentary mathematics system. The Sumerians, who inhabited the Fertile Crescent between the rivers Tigris and Euphrates, were very advanced for their time and possessed knowledge of all but three of the known planets in our solar system. The curiosity and determination necessary to make such discoveries show that they were very interested in space, much like our culture is today.

Other cultures around the world even wove tales and mythologies involving the role of people in space. Even back when the thought of a human in flight was regarded as pure fantasy, there still was a great interest in it. This interest possibly shows the first germ of hope that one day, humans would climb through the skies and to the stars and finally attempt to satisfy our curiosity.

Celtic Astrology

The Celts of early Ireland were not only highly advanced in astronomy, but they were also highly respected by other civilizations. The Greeks respected the Celts for their speculations from the stars and even the Romans paid tribute to their astrology. A Celt, named Mo Chuaróc macc Neth Sémon of Munster, is recorded as having written the first major work on astrological computations[1]. Celts were also noted as having first discussed the relationship of the tides to the phases of the moon.

The Celts can be credited with the same calendar practiced by the Greco-Romans. Celtic scholar Dr. Garrett Olmsted predicted the concepts of the Celtic calendar and found parallels in Vedic cosmology in 1100 B.C[2]. The Celtic culture was also highly innovative in astrological observation, particularly in the construction of calendars. In the 1980s, a letter was found in Padua, written by Colmbanus to Pope Gregory, which supports the Celtic dating of Easter. The calendar covered the years A.D. 438-521, and is one of the most exciting Celtic discoveries of recent years[3].

The Celtic calendar is based around various spirals, which are sacred in their religion because they symbolize creation. On the calendar, the seasons turned and returned each year like points on a giant wheel, and the stars in the heavens appeared to wheel overhead, turning on an axis which was the North Star[4]. The Celts believed that the North Star was the location of heaven, and the apparent movement of the stars around this axis formed a spiral path, or stairway, on which souls ascended to the afterlife.

Mayan Astrology

The ancient Mayans were very interested in astrology, particularly in tracking the sun across the Mayan latitude. Each year, the sun passed over 23 ½ degrees north latitude at its summer solstice allowing Mayan cities south of this point to view the sun directly overhead twice per year, at intervals spaced evenly around the day of the solstice. The Mayans represented the sun's peak position through the god known as the Diving God[5]. On days not marked by the solstice, the sun was tracked on what was known as the Ecliptic. The Ecliptic is the path in the sky, marked by fixed star constellations, which the sun follows[6]. The constellations that marked the Ecliptic path, also known as the zodiac, included a scorpion, a pig, a jaguar, multiple serpents, a bat, a turtle, and a shark. The Ecliptic was represented as a double-headed serpent[7].

As well as observing the Sun, the Mayans made daytime observations of Venus and used the cycles of Venus to plan major events. The Mayans timed some of their wars based on the stationary points of Venus and Jupiter. Human sacrifices took place on the first appearance of Venus when it was at its dimmest. The Mayans viewed the cycle of Venus as one of the most significant celestial bodies. This reverence was because the emergence of Venus as Morningstar happened roughly every 258 days which corresponded to the Mayans' calendar of 260 days. The cycle of Venus also corresponded with the human gestation period and the planting and harvesting of certain crops. Venus was a prominent tool used in the timing of major events in Mayan civilization[8].

During the summer months, the Milky Way could be seen as brilliant star clouds which the Mayans observed and revered. To the Mayans, the Milky Way was known as the World Tree and was represented by a tall flowering tree. The Mayans believed that all life came from the star clouds that made up the Milky Way, just as all life came from the tree of life used to represent it[9]. The Milky Way and stars were important in timing the change of Mayan rulers. Approximately every 20 years, in cycle with the moon, the reign of the current Mayan ruler ended. To celebrate the ending of the period, the ruler would dress in costume which represented the World Tree and carry a rod bent in a circle to represent the double-headed serpent of the Ecliptic. By wearing the World Tree costume, the ruler would link himself to the sky, the gods, and life[10].

Sumerian Astrology

The Sumerians, living in what is now Iraq from 3800 - 2000 B.C., are commonly believed to have invented astrology[11]. They knew of all planets up to Saturn, as well as Pluto, but that was believed to be a moon of Saturn, torn away with the passing of Nibiru. Nibiru, often referred to as Planet X, is said to be an Earth sized planet who's highly elliptical orbit takes 3,600 years, coming as close as the asteroid belt. Such a great object entering our solar system would cause havoc. The Sumerians believed that our moon once belonged to Nibiru. Additionally, they believed that the Biblical Great Flood was caused by Nibiru's passing. The Sumerians had a belief of a 12-celestial body system, which consisted of the Sun, the Moon, and ten planets: the nine we acknowledge today, as well as Nibiru[12].

Sumerians were technologically advanced, giving rise to the 360 degrees of a circle divided into minutes and seconds[13]. They invented Cuneiform, one of the first forms of written language[14]. The Sumerians were even aware of the earth's precession: the speed at which the pole traces a circle. They had even calculated the time it takes the earth's pole to make a full circle. They also had an accurate measure of distances between celestial bodies. How and why a primitive people would know this is unknown. The Sumerians claim they inherited it from "the gods." Whether these may have been extra-terrestrial beings or not is a potential subject of debate.

Aborigine Astrology

The Aborigines were not a specific group of people, but rather it is a name for the broad group of natives who lived throughout Australia prior to the arrival of the English in the late 1700s[15]. As such, they have a broad range of cultures. But most of their way of life was spent on fishing and farming. Like many natives around the world, Aborigines felt that the sky and the earth were connected, and that darkness and night were comforting and familiar. The movement of the heavens was directly likened to the changes in the seasons and the blooming of flowers. Travel and trade would be done at night, perhaps partly because of the extreme heat, but more likely due to their use of the stars as guides[16].

This dependence on the sky meant each tribe would give different names to constellations. Some constellations shared common names, such as the Southern Cross, and the Pleiades, or Seven Sisters. Also, rather than choosing geometric or pictographic constellations, many Aboriginal constellations were either amorphous shapes, or abstract conceptions[17]. Their ‘doctors’ and ‘sorcerers’ often claimed to have visited the ‘Skyworld,’ because they believed their ancestors dwelled there, and could instill great knowledge.

The Aborigines also used the night sky as a visual reminder of their morals. That is, most of their beliefs came from stories or myths passed down through the generations[18]. Most of these myths end up with something becoming a constellation. For instance, the Pleiades are a group of sisters who are chased by an old man (the moon) each night. Therefore, while the stars are observable to everyone, true understanding can only come by initiation into the tribal lore.

Indian Astronomy

The earliest Indian references to astronomy can be found in the Rig Veda, one of several Vedas, or sacred Sanskrit books written about 2000 B.C. These books were a series of hymns composed over several hundred years. In the Vedas, gods were referred to as Devas, meaning ‘bright’ in reference to the sun and stars. The sun, comets, the sky, dawn, and the horizon were all deified based on their attributes[19].

The planetary deities are the Sun (Surya); the Moon (Chandra); Rahu (a demon who is always trying to swallow the Sun or the Moon, explaining solar and lunar eclipses); Venus (Shukra, a divine sage and tutor of the demons); Mars (Mangala, the God of War); Saturn (Shani, the son of Surya); Ketu, (the headless body of the demon Rahu); Mercury (Budha, the son of the Moon and the North Star); and Jupiter (Brihaspati, a divine sage and tutor of the gods)[20].

The Indians based their calendar off of the lunar cycle. A hymn in the Rig Veda refers to a wheel of time comprised of 360 lunar days or 12 lunar months. Daylight time was divided into three, four, five or fifteen equal parts for reasons of ritual. Sacrifices were different lengths of time to accommodate the daily cycle of the sun[21].

Eskimo Folklore

There are many Eskimo tribes which believe in Valkyries and the ability to travel through space. For example, within the Norse mythology, reference is made to the bridge Bifrost. It is referred to as a "burning, trembling arch across the sky, over which the gods could travel from Heaven to Earth[22]." This is similar to when the aurora borealis occurs. In some Eskimo traditions, aurora rays were perceived as lights carried by the Valkyries as they rode the sky. A Valkyrie is a corpse goddess, which is represented by the carrion-eating raven. The word valkyrja literally means "chooser of the slain." The Valkyrie is related to the Celtic worrier-goddess, the Morrigan. Other ancient Eskimo stories often are associated with notions of life after death. Some thought that the aurora was a narrow and dangerous pathway for the departed souls to heaven. Many early believers in this theory tried to use the aurora as a pathway into space.

Eskimo folklore also states that Valkyries carried them to the artic north from Mongolia. Interestingly enough, in the late 1950s, Soviet, American, and Indian scientists concluded that the ancestors of today's Eskimos migrated from Asia very suddenly. Even today, no scientist can accurately explain why such a sudden migration occurred 10,000 years ago[23].

A third piece of Eskimo folklore speaks of the Shamans. A shaman is defined as a "man who has immediate concrete experiences with gods and spirits; he sees them face to face, he talks to them, prays to them, implores them - but he does not 'control' more than a limited number of them[24]." In other words, a shaman's soul can safely abandon his body and roam at vast distances, can penetrate the underworld and rise to the sky. He can go below and above because he has already been there.

Egyptian Mythology

Ancient Egypt was a wealthy land. Its wealth was created by the fertility of the Nile River and the incoming trade goods of both western Africa and the Fertile Crescent. However, it might be said that the Egyptians squandered their wealth upon the vanity of dead kings, but from their point of view they were but only giving the proper farewell of a deserving demigod.

While the main portion of Egyptian mythology is concerning death, the afterlife, and the nearly ubiquitous theme of rebirth, there are a few stories that lend some insight into how they viewed space. One such story is the tale about the daily journey of Ra upon his barque through the waters of the heavens.

Ra, the god of the midday sun, was viewed as benevolent, powerful, and the epitome of all light and goodness. Since the sun was hot, it was the next logical step for the people of ancient Egypt to surmise that Ra must travel through water. This water was the water of the heavens, which was the corporeal body of the goddess Nut, through which all of the gods traveled.

At dawn, Ra would start his journey along the light side of the waters. As the day grew on, his boat would become more powerful until it was midday. After that point, Ra's vessel would grow weaker until the sunset. Fortunately for Ra, he did not have to make this journey alone. In fact, he was accompanied by an entire crew of Egyptian deities.

At the helm was Horus, Ra's owl-headed great-great-grandson, and it was his job to safely navigate the celestial ship through the treacherous waters. Also on board were Thoth and Ma'at, the first and second mate to Horus, the captain. The god Upuaut, known as the 'opener of ways' stayed on the prow at night when the voyage was the most trecherous.

Ra's barque was defended from the forces of darkness by the god Seth. Known as a troublemaker and a bringer of chaos in almost every other Egyptian myth, Seth actually takes on the role of defender when battling Apep, the serpent-like god of darkness. Seth would almost always defeat Apep, but sometimes Apep would win and this would cause bad weather and even a solar eclipse if the defeat were bad enough.

Greek Mythology

Ancient Greek society is often noted for how scientifically advanced it was in relation to the rest of the ancient world. For example geometry, triangulation, classic architecture, and the first stirrings of a helio-centric model of the universe were all Greek innovations. Wisdom and knowledge were prized values in Ancient Greece, particularly in the city-state of Athens.

Athens, the home to great thinkers such as Socrates, Plato, and Aristotle was the scientific and cultural capital of the early Mediterranean. Within the safety of the famous city walls, men were allowed to gather and discuss their latest ideas and philosophies. So proud were the Athenians of their learned citizens that they altered the myth of Daedalus so that he would have an Athenian heritage.

According to the myth, Daedalus was a famous inventor, architect, and craftsman. He was renowned for his fantastical inventions such as a wooden cow (which was used by the queen Pasiphae for deviant purposes) and the infamous labyrinth on the island of Minos. It is of note that within Greek mythology, characters that possess great skill or knowledge are often revered. The Olympian god of fire and metal working Hephaestus was said to be lame and rather homely, yet he was still respected because of his skills. Even knowledge and wisdom itself has its own patron goddess, Athena. Unfortunately for Daedalus, the respect he garnered did not always save him from harm, as he was imprisoned on Minos with no land or sea route available.

With no other choice than to fly away from capture, Daedalus constructed two sets of wings using feathers and wax. One set was for him, and the other set was for his son, Icarus, who was also imprisoned on Minos. Daedalus warned his son not to fly too low, or else risk getting his feathers wet and also not to fly too high, or the sun would melt the wax. Unfortunately, Icarus flew higher and higher into the sky, overcome with the sensation of flight, and the sun eventually burned so hot that the wax melted and his feathers flew off. Icarus then crashed into the sea and drowned.

From this tale, it is clear that the idea of flight was fascinating to the Ancient Greeks. However, it is also a cautionary tale warning of the tragic outcomes of exuberantly treading into the territory of the gods. This story shows both the curiosity and fear that the idea of flight could produce.

The myths of Ancient Greece have many stories about space and the universe. In the Greek story of creation Gaea, the goddess of the earth and the personification of the planet itself, and Uranus, the god of the sky and the heavens, join together to form the first few gods that would rule the planet. Eventually, Gaea tires of Uranus, and they are forcibly separated. In other stories, it is said that the Titan Atlas carries the world (and therefore the known universe) upon his shoulders. Yet another story relates how people were created by Prometheus. According to the story, this higher intelligence engineered people from clay and small flecks of all other life forms. He is also the one responsible for bringing fire, and therefore knowledge, to the common man.

Chapter Two:

Commercialization of Space

A pessimist sees the difficulty in every opportunity; an optimist sees the opportunity in every difficulty. – Sir Winston Churchill

While it may be more noble to pursue space exploration in the interests of pure science and the survival of the human species, it is often much more appealing to realize ways of profiting from new discoveries and technology. In today's earth bound market place, business people and marketers have let their imaginations run wild coming up with new products and services. To take the step into a spaced based paradigm would mean that vast amounts of opportunities would present themselves.

One such opportunity that has yet to be tapped into is the development of a solar power satellite. A solar power satellite would be able to gather sunlight almost all year long because its position is not determined by the earth's rotation. This definitely offers a competitive advantage over conventional earth-based solar panels and would be an excellent source of clean, cheap electricity.

Another way to take advantage of space is one that is already in place today, a Global Positioning System or GPS. The potential offered by GPS is staggering. Map-making and navigation are two obvious applications of the technology, but it could also be adapted to fit the needs of law enforcement and even environmental groups as a means of tracking.

The unique environment of space also offers something that earth cannot: a lack of gravity. In a zero-G environment, there can be many things made more difficult, but also many things that can be done much better. Crystal growth in space is one such thing that can be done better in space than anywhere else. If companies can overcome the difficulty of having an operation in space, there will be great benefit.

Commercial Applications

The commercial potential for space travel, colonization, and development of space based industry is immense. The infinite expanse of space is hazardous, and this limits our commercial opportunities. If we are to send our best and brightest into the furthest reaches of space, we need to recognize the trials and strife that they will face. Hazards such as radiation, cosmic collisions, bone density loss, and psychological problems associated with extreme isolation, are all well documented but not yet entirely solved. In fact, many in the scientific community are certain that there are many hazards involved with space travel that have not even been conceived yet. The terror of the unknown is great, but the driving curiosity and the need to expand trump this primal fear.

Currently, our greatest limitation towards reaching the stars is our technology. We have not developed the necessary components to facilitate a successful manned voyage into deep space. However, we have become increasingly capable of wading out into our own back yard, so to speak. Near earth space missions are now a very common thing. In addition to small excursions into orbit, there have been several unmanned probe launches to several of our neighboring planets. The infrastructure that has been built since the launching of the very first man-made satellite in the 1950's has made many things possible that were only theoretical and even fantastical only a few decades ago.

Thanks to modern satellite technology we are able to share information with people all over the globe. Communication is instantaneous. If someone wishes to speak with someone on the other side of the globe, it will only cost a few dollars. In a way, it has brought the world closer together as people can reach one another at any time and in any place. In addition to communications, global positioning satellites have been created that help with location and guidance throughout the world. With a global positioning system, or GPS, a person can successfully navigate through uncharted territory or even territory that is entirely unfamiliar to him or her. This is only but one application for such a powerful tool. One possibility for a global network of positioning satellites is defense applications.

Since the 1980's, the governments of the world have been toying with the idea of space based military power. Such 'Star Wars' defense programs have been laughed at by the general public and denounced by advocates of peace as merely another means of arms proliferation and brinksmanship. However, it now may seem that the only way to eventually bring more civilians and eventually businessmen into space that there might have to be a military presence there first. After all, the militaries of the world were always sent in first to explore and settle new lands here on earth, they might just be the most prepared to deal with the harsh realities of space.

Currently, military minds are set upon the development of space based missile and laser platforms guided by either a spotter on the ground or through using global positioning satellites to pinpoint an attack upon a target. Although there are many things about such a system that raise ethical issues, something like this is possible to create, and in fact, GPS has been used in recent conflicts to direct munitions to help strike targets.

Growing Crystals in Space

Crystals can be constructed that possess highly desirable thermoelectric and electro-optic properties, but they are nearly impossible to produce on earth, due to gravity. Gravity adversely affects the growth of crystals for two reasons. First, density-driven convection causes irregular formations of molecules, which create imperfections[25]. As the crystal is growing, it absorbs protein molecules from the surrounding solution. This makes the area immediately around the crystal less-dense, and so it rises, due to gravity. These eddies alter the orientation of the crystal, making the next protein molecules not line up[26]. The other problem is due to sedimentation. On earth, as crystals grow in drops of solution, they begin to sink to the bottom of the drops. This results in several separate crystals all growing into one another[27]. Since single crystals are preferred to multiple ones, this becomes a problem.

Since these problems are on a molecular level and the process of growing a crystal takes weeks or months, zero gravity environments are more suited for the growth of near-perfect crystals[28]. Experiments are already under way. In 2000, scientists were able to construct a crystalline alloy of germanium and silicon, something impossible to do on earth, because germanium is three times heavier than silicon[29]. Another benefit of growing crystals in a gravity-free environment is the 'Detached Bridgman Growth' (DBG). DBG occurs when the molten material doesn't press against the container it's housed in. Essentially, the material cools for two weeks in a free-floating environment. This process yield stronger, better crystals[30].

While it is economically infeasible to produce all high-quality crystals in space, scientists are focused on using zero gravity growth to understand the materials science behind the process. Fortunately, scientists have discovered a way to simulate the detached growth on earth[31]. This detachment is influenced by factors such as gravitational force, the materials involved, and pressure forces, among others. However, further analysis is necessary to develop easier ways to be able to mass produce near-perfect crystals. In 2005, a project will go into space to test whether the gas that's trapped between the container wall and where the crystal starts to form is important or not.

Another way that crystals are being produced in space is through the process of reverse diffusion[32]. The Granada Crystallization Facility was used in the International Space Station, and consists of three parts: a gel salt solution at the top, a gel protein solution at the bottom, and a gel buffering solution between the two. As the salt and proteins undergo reverse diffusion, crystals are formed in the buffering solution. Depending on which gels are used, the crystals grow at different rates of super saturation.

Flawless crystals are important because they have many modern uses. Crystals can be used in fields such as astronomy, communication, defense, medicine, at the diagnostic and curative levels, as well as in image production and holograms. Crystals formed by Detached Bridgman Growth, in particular, could lead to improved windows and substrates for infrared sensors, more accurate cosmic-ray detectors, and tiny solid-state lasers for next-generation flat-panel displays[33]. It's also believed that these crystals will produce the means for technology that is yet to be discovered.

Global Positioning Systems

The Global Positioning System (GPS) has been around since the 1960s, when the US Navy set up Transit. Transit was a satellite navigation system with nominal accuracies on the order of 100 to 200 meters, but still much less accurate than the technology today. The Transit service ended on December 31, 1996 due to increases in military technology which could not be incorporated into Transit[34]. The GPS consists of three main parts, known as the Space Segment, the User Segment, and the Control Segment. The Space Segment is a group of satellites, currently 27 orbiting 19,200 nautical miles above the earth's surface[35]. The User Segment is a receiver which receives a transmission from the satellites. The Control Segment then reads in the data and calculates the location of the user on earth.

There are many current uses of the GPS system in today's world. These uses include navigation, grounds keeping, construction, vehicle tracking, surveying, and even archeology[36].

Currently, there are many cars which have come out within the past few years that include a GPS system built into the dashboard. This provides the operator of the car a sense of security because they do not have to look at a map while operating the car. Grounds keeping by using GPS systems has been on the rise in recent years; especially on golf courses[37]. It is much easier to plan a golf course with an exact map of the property than it is to estimate and have to redesign holes later. British and French crews used GPS systems when building the tunnel under the English Channel. This provided a far greater accuracy than it would without the technology, because each country started building on opposite sides of the channel. Companies have begun to install GPS based trackers into their vehicles. This allows the company to know if the driver is leaving a designated area, if the truck is stolen, or how fast the driver was actually driving on the trip. Even wildlife management personnel are using GPS systems[38]. They use the GPS systems to track the migration pattern of the Mojave Desert tortoise to help determine their population distribution patterns and possible sources of disease.

Currently, a person who owns a cell phone can be traced to within a few hundred yards of their current location. Every cell phone currently being made comes with a GPS chip installed directly into it. This is useful for tracking 911 calls when the person is unable to give a useful description of their location[39]. Other safety devices that are potentially feasible are chips installed directly into newborn babies. Right now, there is a miniature button a child can wear which allows a parent to track his or her child in case of an abduction. These buttons may fall off the child in a struggle. If these chips were installed directly into a baby's foot, it would prevent the loss of this device. This device could also be used on inmates. This would limit the number of escaped convicts running from the police because the police would be able to zoom in on the position of the convict and arrest him.

Solar Power Satellites

For years, solar power has been investigated as a clean efficient source of energy here on earth. Solar panels have been constructed and are functional on earth, but a better source of clean power would come from space solar panels. This view is shared by many NASA scientists and US Department of Energy officials. The idea of solar power satellites (SPS) has been around since 1968, but was not implemented then due to the lack of a method of sending the collected energy back to earth[40]. Today the idea has been revisited and technology has advanced. The SPS is becoming an increasingly practical idea for our time.

Placing solar power cells in space would be a more practical method of obtaining solar energy than panels on earth. In space there is more intense sunlight for a longer period of time and weather does not affect the sunlight reaching the panels. In geosynchronous orbit, a SPS would receive sunlight over 99% of the time. The earth's shadow would only block sunlight from the SPS a few days a year during the spring and fall equinoxes. A solar panel on earth, even in the Sahara Desert where the sun is intense, would receive sunlight for less than 50% of the day due to the position of the sun on the horizon[41]. The amount of solar energy obtained by SPSs far surpasses the amount collected by panels located on earth.

The SPS would consist of three major parts. A large solar collector made up of solar cells, a microwave antenna on the satellite to transmit the energy collected back to earth, and a large rectifying antenna on earth to receive the power transmitted from the satellite. The orbiting structure would collect solar energy which would be converted into electricity and then into microwaves. The microwaves would be sent down to the earth's surface via the microwave antenna and would be received by the rectifying antenna. The microwaves would then be converted back into electricity[42]. A 1970s study done by the US Department of Energy and NASA determined that the SPS would have to have a three by six mile solar face and a 0.6 mile diameter transmitting antenna. The rectifying antenna would be an ellipse of six miles by eight miles[43]. These dimensions are so large because at the time, solar cells were very inefficient. Solar cells in the 1970s could only transfer about 17% of the energy collected. Today, solar cells can transmit 50% or more of the power collected[44]. Today's advances in technology would reduce the size of the SPS enough to make it more feasible to launch into space.

The benefit of such a satellite would be worth the size. If the lifetime of an SPS is 20 years and we estimate the price per kilowatt hour of electricity is five cents in the US, an SPS would generate about $250,000 in revenue per hour and over the 20 year lifespan it would generate about $44 billion in revenue. The power available to consumers would be roughly five billion watts which is over five times the power delivered by a conventional power plant today[45]. The SPS would be practical if it was inexpensive to construct or if it could function for a very long period of time. In addition to these factors that hold the SPS back, launching the satellites into orbit can be very costly. Advances in materials may bring the construction cost down making the SPS more feasible, but some still question the safety of the SPS.

The transmission of microwaves down to earth is the most controversial topic concerning the SPS. The microwave beam being transmitted to earth would be far below the lethal level of exposure even for a prolonged time. Even if an airplane were to fly directly through the beam passengers would be protected by the plane's metal shell. Over 95% of the beams will be transmitted directly to the rectifying antenna and the remaining beams would be less concentrated than conventional microwave ovens[46]. In reality there is very little that the microwaves can do to harm any life on earth.

The SPS would be a highly effective way of transmitting clean powerful energy to earth if the initial cost of creating and launching the satellite can be overcome. In 1995 a “fresh look” study was done by NASA on the feasibility of the SPS. NASA determined that the idea is becoming more worthwhile, but despite increased technology in solar cells, size and cost are still major factors in delaying implementation of the SPS[47]. Solar power satellites would be an economical source of energy for the United States and the world if more technology can be focused toward their development and improvement.

Chapter Three:

Satellite Communication

The newest computer can merely compound, at speed, the oldest problem in the relations between human beings, and in the end the communicator will be confronted with the old problem, of what to say and how to say it. – Edward R. Murrow

To communicate is to reach somebody and have an exchange of ideas. Traditionally, this has meant some sort of conversation that happened face to face. However, as technology gets better the medium of the exchange changes from one new thing to the next. From hand carried documents, to signal pyres, to the telegraph, we have always come up with new ways to communicate with one another.

Today, communications also includes the mediums of radio, television, and the internet. These mediums allow for massive amounts of information to be disseminated across millions of channels all over the world. Radio and television have, until a few years ago, always been a grounded technology. Recent developments in space technology have made it possible for satellites to remain in orbit and broadcast television and radio right down to subscribers. This means that the quality of the service is increased because it can operate on a higher frequency, giving the broadcast a much higher fidelity.

Another step in satellite communications was taken with the development of satellite telephones. A satellite phone has the ability to directly link up with a satellite and connect to any other phone in the world. This technology is very useful in areas where there are no land lines, cell towers, or really any other infrastructure. With more effort and research put in to the development of satellite based telecommunications, the technology could become less cost restrictive and allow for anyone to get in contact with anyone they wanted to at anytime.

Satellite Telephones

In today’s world many individuals rely on cellular phones for communication around the globe, but for those customers who travel to remote locations, work on the ocean, or in mines, satellite telephones provide a more reliable source of communication. Many areas located on the oceans or near the poles have little to no cellular phone coverage or landline phone systems. For these areas, satellite phones work well for emergency communication, business communication, and leisure communication and decreases in size of the phones make them easier for everyday use.

Satellite phones rely on a series of satellites to transmit signals to earth receiving stations. The phone's handset transmits signals to the orbiting satellites which then transmit the signal to the land earth stations (LES). The LES then connects to the Public Switched Telephone Network, the telephone backbone system, which transmits the phone call to the dialed number[48]. The process of making a satellite telephone call takes about 1/10 of a second[49]. Satellite telephones require the user to have a clear view of the sky so that the handset can connect to the satellites. Satellites will have an obstructed line of communication to the handset if the user is indoors or around tall buildings. Some satellite phone providers place their satellites in geosynchronous orbit which requires the handsets antenna be pointed directly at the satellites position over the earth, but most providers make phones with omni-directional antennas which do not require the antenna to be directly pointed at the satellite[50]. This feature simplifies the satellite telephone greatly and allows for more versatile use.

Today there are two primary satellite telephone service providers, Globalstar and Iridium. Globalstar's satellite services uses 48 Low-Earth-Orbiting satellites which are located 700 miles from the earth. When a call is placed from a Globalstar satellite phone, it is sent through as many as four satellites to ensure that if one satellite loses the call the others will pick up and the call will not be disturbed[51]. Iridium uses a network of 66 satellites in polar orbit 485 miles above the earth. These satellites are in six orbital planes with eleven satellites in each plane. If an Iridium satellite phone user is placing a call to another Iridium satellite phone user, the call will be transmitted directly across the satellites and will not connect to the land network first[52]. Satellite telephones are highly convenient to those customers who cannot use cellular or ground based telephones.

Satellite telephones are useful, but have a few drawbacks. Currently, making a satellite call within the United States costs between 17 and 99 cents per minute and calling to the United States from another country costs $1.79 per minute with Globalstar[53]. Calling from anywhere to anywhere using an Iridium satellite phone will cost $1.49 per minute, and $1.00 per minute from satellite phone to satellite phone[54]. Although these are the lowest rates to date, satellite phone calls are still far more expensive than cellular phone calls or land line phone calls. The cost of purchasing a satellite phone ranges from $300 to over $1,000. One feature that many customers have commented on is the size of the antenna on satellite telephones. Typical antennas are several inches high and roughly an inch in diameter. The Qualcomm GSP-1600 phone offered by Globalstar is 7.0(H) x 2.2(W) x 1.9(D) inches with the antenna down and weighs 0.82 pounds[55].

The number of satellite telephone subscribers is increasing steadily despite a rough start in the 1990s. Satellite phones opened to the consumer market in the 1990s but did not become a solid industry until 2001[56]. As of August 2004, Iridium had a total of 100,000 satellite phone subscribers and was gaining 2,000 to 3,000 new subscribers per month. In August 2004, Iridium saw a 29% subscriber increase up from a 17% increase earlier in 2004. Globalstar boasted a subscriber base of 110,000 clients in August 2004 and saw similar subscriber increases[57]. The popularity of satellite phones is increasing alongside the decrease in rates and sizes of satellite phones.

Although satellite phones are more expensive and larger than cellular phones, they are the only option for those that live or work in remote areas of the world. For those customers who rely on satellite phones for communication, advances to make the phones smaller and more convenient to use in and out of doors would be beneficial. Satellite telephones are very reliable, and with a decrease in cost and size they are becoming a popular form of communication around the world.

Satellite Broadcasting

In 1992, the Federal Communications Commission (FCC) allocated a spectrum in the "S" band, which operates at 2.3 GHz (a frequency about 20 times higher than standard FM radio), for national broadcasting of digital audio[58]. Only four companies applied for a license and only two were given them. Sirius and XM (formerly CD Radio and American Mobile Radio, respectively) shelled out the $80 million for the licenses in 1997. XM has two satellites in geosynchronous orbit above the United States: one over the east coast and one over the west coast, with a third satellite prepared in case one fails[59]. From Washington D.C, the company transmits the signal to the satellites, which then relay it to receivers in cars and homes. There are also repeaters located near cities to boost the signal in urban areas. There is a delay of about four seconds from broadcast to receiving[60]. Sirius's system is similar, except there are three satellites in elliptical orbit, with each one over the US at least 16 hours per day. Worldspace, an international satellite radio company that owns XM, services Europe, Africa, and Asia, with plans to cover South America soon. They project that they have a potential audience of 4.6 billion people[61].

Commercially, both companies are doing fairly well. Both of them have brokered deals with major car companies: XM has Honda and GM, Sirius has BMW and Ford. Subscription numbers for both companies are doing well. XM has 1.7 million subscribers who pay $10 per month, while Sirius has 261,000 who pay $13 per month. Going at the current monthly rate, this means XM is getting $204 million per year in subscriptions alone ($40 million for Sirius), not counting startup profits[62]. This is enough to put XM into the black since it first started up, and Sirius expects to be there by mid-2005. There also appears to be a huge acceptance for satellite radio. Commercial-free listening seems to be the greatest attraction, and while it's still not universally common, it's certainly gaining ground[63].

Satellite television is achieved in a similar way to radio, except there is no middle man. The consumer purchases a dish which receives the signal directly from the orbiting satellite. An important issue in the beginning of satellite television was users on the ground essentially stealing television by pointing their dish at the correct part of the sky. The FCC decided that users had as much right to receive satellite signals as broadcasters had the right to transmit them. So an intricate method of encryption had to be developed so that only those paying for the service would receive it[64].

Satellite television has also taken off in the last ten years, offering a digital signal rather than analog. Years ago, when an analog signal was broadcast, the receivers had to be many feet in diameter. The signal wasn't even that great, since it was broadcast in the "C" band, which was between 3.5 and 7 GHz. Today, with all digital programming, the signal is sent in the "Ku" frequency range (12 to 14 GHz). This more focused signal also allows the receiving satellite dish to be less than 18 inches. This allows far more consumers to purchase the technology. Currently, DirecTV is the largest satellite TV provider in the United States with about 12 million subscribers paying $35 to $85 per month[65]. They have six satellites scattered throughout the US in geosynchronous orbits. Dish Network is second largest, with 10 million subscribers paying between $25 and $75/month, with nine satellites in geosynchronous orbits around the United States.

Chapter Four:

Survival

It is not the strongest of the species that survives, nor the most intelligent that survives. It is the one that is most adaptable to change. – Charles Darwin

Man can live for about forty days without food, three days without water, about two minutes without air, but only a second without hope. – Anonymous

Survival is seen as one of the basest instincts that living things possess. From the lowest form of bacteria to the most intelligent of our own species, we are all somehow driven by the urge to keep on living. This urge is one that is a shared experience among all human beings. When gathered together, this urge becomes a will that is shared amongst a society to preserve its institutions, traditions, and cultural heritage. The desire for civilizations to last is based upon our desire of leaving something behind after we have passed on and our fear of being forgotten.

Despite our best efforts, the survival of the human species has not always been completely assured, nor is it even today. There are several threats to our continued existence. Among them are contagious diseases that spread to epidemic proportions and kill millions. Such disastrous plagues, like the Black Death in the middle ages, have even changed the course of history. Other natural disasters like earthquakes and floods can take many lives, destroy buildings, and send a society back thousands of years in development. Another concern for our survival is our own irresponsible and reckless waging of war, in which nations clash against one another with the use of deadly new technology. Perhaps the most deadly of all threats to our survival would be an impact by a near earth object. A collision of sufficient force could potential wipe out any life and civilization as we know it. We must pause to consider what steps we must take to ensure our survival.

Biological Warfare

Biological warfare has been around since the sixth century B.C. The earliest reported bioterrorist event occurred when the Assyrians poisoned their enemy wells with rye ergot, a fungus that causes convulsions if digested[66]. What are the reasons why mankind strives to create such terrible weapons which can potentially lead to the demise of mankind? How often do humans create biological weapons, and accidentally release them upon their own people? Is the need for space travel really a biological issue?

In 1346, the end of humanity almost occurred once again through biological warfare. The Black Death pandemic, a lesser known form of the Bubonic Plague, was just starting to make an up rise yet again. During the siege of Kaffa, the plague was tearing through the attacking army of Tartar. Soldiers began to hurl the corpses of plague victims over the city walls, which caused an epidemic and resulted an in the defending city to surrender. Fleeing citizens of Kaffa are said to have inadvertently started the Black Death. A projected 30 million people died from this epidemic alone[67]. In total, approximately 137 million people died from the three major outbreaks of the Bubonic Plague.

The most horrific account of biological warfare resulted in 1979. Even after signing a peace treaty with the United States which agreed to extinguish all biological weapons, the Soviets converted old factories into biological plants. On a secretive military base called "Compound 19," the production of anthrax powder was being churned out[68]. On one morning in April, a very small amount of dust was accidentally released through the ventilation system of Compound 19. This dust was then blown over a nearby town and ceramic factory. By the end of that very day, the sick began pouring into hospitals all around Sverdlovsk. Symptoms included vomiting blood and a burning within the lungs. Within the next 48 hours, a vast majority of the victims died[69]. The cause was still unknown. In the aftermath of the incident, the Soviets lied to their people in order to conceal what was truly occurring behind the walls of their military plants. The cover-up did not last for long as many Soviet civilians and countries across the world began their investigations.

Another well known disease which was speculated to be man-made is the AIDS virus. A well-known theory is that the virus called HIV was originally constructed in a germ laboratory and released as the result of an accident. This theory is notably unlikely because HIV precedes the facilities needed to construct such a virus[70]. Yet, people went on to suggest that the virus had been altered in the laboratory from animal strains. This may result in the virus evolving to the animals' genes; thus, changing the genetic make-up of the virus. Although this scenario is unlikely, what if humans accidentally created and released a virus which caused massive deaths and the probable end of mankind?

Even more recently, the SARS pneumonia virus has been speculated to be a man-made biological weapon. Scientists in Russia made a press release in November 2003 linking their assumptions with known facts about the virus. The head of Moscow's epidemiological services told the press, "there is no vaccine for this virus, its make-up is unclear, it has not been very widespread and the population is not immune to it[71]." The virus is a mixture of mumps and measles, whose mix could never appear in nature. He says these characteristics prove the virus must be man-made. The scientist later goes on to suggest that the virus may have spread because of an "accidental leak" from a lab somewhere in China. Over 100 people have died and 3,000 others have been infected by the SARS virus.

So, what is the importance of space travel when we should be spending more money on preventing biological warfare? The answer is simple and can be summed up in one word: survival. How do you prevent terrorism? As we see in today's society, preventing terrorism is not an easy task. We have spent over two years in a war with Iraq trying to prevent terrorism. Yet, we still have a long way to go. There is no way to ensure that any country is not creating biological weapons. This was proven with the history of the Soviet Union. The United States was under the assumption that all countries who signed the treaty were following it. This was not the case. In order to ensure survival, mankind must explore the universe and find a way to colonize on other planets before it is too late. The sooner we act and start traveling, the better our chances of survival if a biological weapon is released causing vast death amongst our civilization.

Plagues

Disease has always been an ever present hazard for all living things. In earlier more primitive cultures, being struck with a disease was a sign of divine malevolence. It was believed that a person must do something wrong to be stricken with some sort of plague. It wasn't until recently in human history that it was discovered that pathogenic microbes caused infections, fevers, and illnesses. We still have far to go in our understanding of how infectious diseases came about or even why they exist, but our knowledge is expanding every day. Epidemics, pandemics, and plagues have had an enormous impact upon the development of civilization on earth. In fact, the impact of plagues in the past has been so severe that it is conceivable that a plague might one day wipe out the human race.

The Bubonic Plague is a bacterial agent that is spread to humans through the saliva of biting fleas. Thanks to modern hygiene, fleas are no longer a concern to the majority of the population. However, back in the middle ages, even the most fastidious members of the population were only bathing once a month. Fleas were everywhere, and this made it easier to spread the Bubonic Plague.

The symptoms of the Plague were horrific. The victim would be stricken with a high fever often accompanied by weakness and delirium. The lymph nodes would swell and fill with blood, which would appear as dark black nodules on the neck, the armpits, and the groin. It was from these blotches that the plague got the name the 'Black Death'. Currently, the mortality rate for someone stricken with bubonic plague is only 40%, however due to life-long malnutrition and lack of sanitation, getting the plague in the Middle Ages was a certificate of death. Survival rates were extremely low, and Western Europe lost close to 60% of its total population. This loss was devastating and caused many people to flee their homes and some leaders to consider some drastic measures in order to stem the spread of the disease.

Natural Disasters

Landslides, hurricanes, tsunamis and others are all an ever present danger. Most of these are not an overwhelming danger to mankind. They've been happening for thousands of years, but life continues on. Some disasters can become a great danger, however, and have altered the world in the past.

Global warming has been talked about for decades, but the impact of it will be great regardless of when it happens. A multi nation summit was convened to discuss the potential threat. They believe that at the current rate, enough of the Arctic ice will melt that by 2100, polar bears will be wiped out[72]. Global warming will definitely have an impact on humans. If the Arctic ice caps melted, water levels wouldn't rise, as there is no chance in displacement. However, Antarctica and Greenland both have much ice that, if melted, would significantly raise sea level. Since Greenland is closer to the equator than Antarctica, it is at more risk of melting. If all the ice melted off Greenland, it would raise sea levels around the world by 20 feet[73].

That situation is not likely to happen soon, but what is more likely is that global warming will result in water temperature increasing. Thermal expansion of water shows that the density decreases as water is heated, so even if the temperature change is small, the effect is multiplied by all water on earth. This can have a significant impact on earth. While most of Florida and the islands around it will be directly affected first, global sea storms will be exponentially more damaging, as more water at the coast will increase the strength of the storm and deliver more precipitation[74].

Volcanoes are caused by an excess of pressure inside the earth that needs to be released. The eruption of a volcano releases much of this heat, as well as ash, sulphur dioxide, and other chemicals. The result of an eruption directly cools off earth's core, but the dust and ash that is released lingers in the atmosphere, reflecting the sun's rays away from the earth. Also, several cases of airline failure have come as a result of hot ash being sucked into jet intakes. This causes engines to sputter and stop, but so far, all planes have been able to restart, and there have yet to be any injuries as a result[75].

While volcanoes have been erupting since just after the creation of earth, there has been an increasing threat within the past 25 years. Statistically, the number of active volcanoes has been increasing at a steady rate[76]. There are several theories, but the accepted belief is that since global temperature has been increasing, so has the core's temperature. The greenhouse effect is like putting a lid on a boiling pot of water. Scientists don't yet know what the result of the ever increasing number of volcanoes will be. It could be that when hundreds of volcanoes erupt, the amount of ash that gets released will reflect a significant portion of the sun's energy back into space. This could spark another ice age, since the earth would cool off very quickly.

Earthquakes will also be a result of further global warming. In many regions where glaciers cover much of the land mass, the threat of serious earthquakes is increasing. As tectonic plates move about and collide into each other, they begin to form mountains. In the process, they also produce earthquakes. However, heavy glaciers are theorized to help prevent serious catastrophes. Alaska in particular has been faced with this problem. The 7.2 quake in Alaska's St. Elias region in 1979 happened after a period of substantial thinning of the glaciers there over the past 80 years[77].

Natural disasters can be devastating forces, but more often than not, the damage is highly localized. Tsunamis can flood hundreds of miles of coastline, but for one to affect the world on a global scale, the wave would have to be thousands of feet tall. The only feasible way that something of that magnitude would come about would be through an interstellar collision. Earthquakes and volcanoes also cause millions, or even billions of dollars in damage, but the area of damage is unlikely to ever exceed more than 100 miles. Even if all the glaciers on both Greenland and Antarctica melted, sea level would rise only 215 feet[78]. This would cause serious problems for all cities along all the coasts, but wouldn't nearly wipe out humanity.

There are very few theories out there that detail the potential worldwide destruction as a result of global warming. One possibility would be if hundreds of volcanoes erupted within a short span of each other. It would have to cause enough soot and ash to be sent into the atmosphere to produce the same result of the asteroid impact that caused the extinction of the dinosaurs. If enough ash and dust were put into the atmosphere, it could cause the earth to freeze over, causing an ice age. Something of this nature would be impossible to prevent at our current level of technology. Another possibility would be if dozens of these natural disasters occurred shortly after each other. Fortunately, there is no indication that either of these situations is likely, and even the possibility of it happening is very remote.

Near Earth Objects

Near earth objects, asteroids in particular, are constantly being watched by scientists in order to predict their paths relative to earth. Asteroids are believed to be chunks of rock or metal that failed to become part of planets when the solar system was formed. These bodies come in a variety of sizes from dust size particles to rocks several kilometers in diameter[79]. Asteroids become near earth objects when they pass within 0.3 Astronomical Units (the distance between the earth and the sun) of the earth's orbit. They become potentially hazardous when their orbits come within 0.05 AU of the earth's orbit and are at least 150 meters in diameter[80]. Most asteroids are traveling on a known path through space, but some inevitably come in contact with earth. When contact is made, depending on the size of the object, great damage may result.

Asteroids travel between 15 and 30 kilometers per second through space. When an asteroid enters the earth's atmosphere, regardless of whether it touches earth or not, it releases a great amount of energy. This energy release creates massive shock waves and heats both the earth's atmosphere and the object itself. The energy wave causes a blast wave which represents an abrupt change in pressure. This generates high speed winds which carry debris. These winds can be at higher speeds than hurricane winds which max out at about 150 miles per hour[81]. The debris carried by these high speed winds has the potential to damage or destroy forests, vehicles, homes, office buildings, and many other important aspects of human life. An air burst generated by a 50 meter diameter asteroid impact in Siberia in 1908 flattened 2000 square kilometers of forest[82]. Imagine what that impact could have done in a major city. The Chicxulub asteroid is credited with the extinction of the dinosaurs 65 million years ago. It had a diameter of about 10 kilometers and when it landed in Mexico it left a crater with a diameter of 180 kilometers. The blast wave from this asteroid would damage only a small percent of the earth, but the physical damage of the impact would devastate the area of a large country[83]. If this was indeed the cause of the extinction of the dinosaurs, a collision of this magnitude would have the ability to end all life on earth again.

If an asteroid were to hit earth in an ocean, a huge tsunami would form. An asteroid with a diameter of 30 kilometers would reach the bottom of the ocean and cause the water to rush out and back into the hole creating massive waves emanating in all directions surrounding the impact site. Tsunamis travel as fast as air craft and can affect areas around the world[84]. A 1960 earthquake in Chile caused a tsunami in Japan over 17,000 kilometers away, killing over 100 people and causing tremendous damage[85]. Asteroid tsunamis have the potential to do much greater damage especially since a major portion of the world's population live on or near the coast. The Chicxulub asteroid, located in Mexico, caused a tsunami which deposited material in Haiti, Texas, and Florida[86]. A tsunami created by impact of a large asteroid would undoubtedly kill many people and destroy great amounts of land.

Another impact due to asteroid contact is the debris that would fall off the object and remain in the air after impact. Particles that came off an asteroid stay in the air for days. When they fall, their energy is dispersed when cooling and therefore have the potential for starting small fires. These fires would cause damage as well as depositing soot and ash into the air and emit poisonous gasses. The combination of small particles as well as ocean water in the air causes the sun to be blocked from earth. As a result, the water in the air and on the surface will freeze, creating something similar to the nuclear winter effect[87]. The effect of a one kilometer diameter asteroid hitting the earth could devastate all life on earth including human life.

Near earth objects are constantly being monitored in order to predict possible collisions with earth. The orbits of near earth objects are somewhat predictable, but the objects are constantly being hit by smaller particles in space so their paths become harder to forecast. Measurements and observations allow us to know the path of nearly 400 near earth objects of diameter one kilometer or larger. This knowledge allows us to say that none will hit earth within 50 years, but we estimate that over 400 similar sized objects have yet to be discovered which have the possibility to strike earth causing horrific damage[88]. Smaller objects which can do equally horrific damage are harder to find and track. It is estimated that we have found less than 10% of objects with a diameter of 300 meters or below, leaving 90% of objects untracked and unpredictable[89].

One difficulty in tracking objects is determining their size and mass. This relies on knowing the brightness of the asteroid and the proportion of sunlight which it reflects. Density is used to determine the mass of objects. In order to determine their densities, we need to know the chemical composition of the asteroid, something almost impossible to determine from earth[90]. This makes it hard to determine if a large asteroid will cause a global or regional catastrophe.

An asteroid that collided with Jupiter in July of 1994 shows the amount of power a collision can release. Comet Shoemaker–Levy 9 collided with Jupiter in July 1994 sending up fire-balls the size of Earth. The fragments that struck Jupiter had diameters between one and two kilometers. The first fragment struck Jupiter with a kinetic energy equivalent to about 225,000 megatons of TNT creating a plume which rose about 1,000 kilometers above the Jovian cloudtops. The second fragment left little mark, but the third, fourth, and fifth fragments created damage similar to the first fragment. The final fragment struck Jupiter with an estimated energy equivalent to 6,000,000 megatons of TNT (about 600 times the estimated arsenal of the world). The fireball from the final fragment rose about 3,000 kilometers above the Jovian Cloudtops and was documented by many observatories on earth[91].

The damage done by Shoemaker–Levy 9 shows just how powerful a collision can be. If this impact were to have happened on earth, it is doubtful that many people would have survived. It is for this reason that near earth objects should be closely monitored and methods of averting any threatening asteroids should be developed. The survival of earth's population depends on methods of removing potentially hazardous near earth objects. In the month of November 2004 alone, ten asteroids entered the earth's atmosphere[92]. It is only a matter of time until one of these objects creates massive destruction.

Chapter Five:

Background of Near Earth Objects

The idea that asteroids occasionally hit Earth and influence its geology and life remained rejected until the 1980s. Now we suspect that they have influenced the record of humanity. –
Rene Gallant

A near earth object is defined as comets and asteroids that have been moved somehow into an orbit that will bring them close to the earth. It is alarming to think that these objects are coming close to us, but this happens frequently. Smaller objects constantly hit our planet, but are often times reduced to nothing more than a small rock by the time they get through our atmosphere. It is estimated that there are tens of thousands of these kinds of impacts every month! However, these are not threatening to us at all because of their small size and they actually present us with a scientific opportunity to study their composition.

Near earth objects usually fall into the category f being a either an asteroid or a comet. Almost all asteroids in the solar system are located in an asteroid belt. This belt is in between the planets Mars and Jupiter. Scientists believe that the asteroid belt was formed when the solar system was formed and that it is the remains of a planet that tried to form but was held apart by the gravity of Jupiter. Asteroids stay mainly within the asteroid belt, but there are thousands of other ones that are outside of the asteroid belt and may pose a threat to the earth.

Comets are the travelers of the solar system. Composed of frozen water, gases, and dirt, comets come from a region on the tips of the solar system called the Kuiper Belt that is inside the Oort Cloud. Comets are very massive and travel in elliptical orbits that have been known to crash into other planets as we saw with the Shoemaker-Levy comet that crashed into Jupiter.

Asteroids

Near earth objects are celestial bodies that have the potential to come in contact with our planet. When an asteroid enters the earth's atmosphere the object burns up. However, there is a potential for disaster as some of these objects can be incredibly large. The danger of an impact is related to how much force the impact generates. Force is equal to one half the mass of the object multiplied by the velocity of the object squared. $F = \frac{1}{2}mv^2$ Unfortunately, asteroids travel at upwards of seventy kilometers per second. It is very clear that the threat of an impact is both real and dangerous. The first step in avoiding such a disaster is understanding the nature of it.

An asteroid is defined as a celestial body revolving around the sun with an orbit between Mars and Jupiter. It is an object that is too small to be a planet and yet may still have some of the features of a planet. None asteroids are known to (or at least surmised to because of the scientific data) have tiny atmospheres. Many scientists are interested in asteroids because they contain matter that is reminiscent of matter that was created in the birth of our solar system. These fascinating primordial chunks of rock and metal serve as a reminder of our planet's own creation and the ever changing nature of our solar system.

Within our solar system asteroids are located in a belt pattern between the planets Mars and Jupiter. The asteroid belt itself is an interesting celestial phenomenon. There are a couple theories about how the asteroid belt came into existence. Although there is some disagreement over which one is correct, more scientists believe one rather than the other. The first, and least substantiated, theory is that the asteroid belt was created when a planet was obliterated entirely leaving only bits and pieces behind. However, this theory is not as accepted because of the fact that if all of the matter that is believed to be within the asteroid belt were combined together, the resulting planet would be no bigger than half the diameter of our moon. The theory that currently has the most scientific backing is that the asteroid belt was formed not because of the destruction of a planet, but because of the failure to create one. It is surmised that the asteroid belt is the remains of a futile effort to create a planet. This planet was held apart due to the gravitational pull of Jupiter and the Sun. The gravities of the two bodies created a gap that the rock fragments fell into and remained.

Although the asteroid belt is called a belt, it is not necessarily belt shaped in nature. The asteroid belt is not smooth and has gaps in it caused by the Jovian gravitational pull. These gaps caused by the gravity of Jupiter are called Kirkwood gaps. The reason for these gaps existing is that if an asteroid were to be within this gap it would be attracted by Jupiter's gravitational pull and fall into the planet. The belt itself is made up of hundreds of thousands of asteroids, but it is hard to know for sure how many asteroids there truly are. One reason for this is that asteroids are almost always on the move. It is challenging for astronomers to locate small moving object without having to do large amounts of tedious scanning of a small region of space. Another reason for asteroids being hard to keep track of is that they are composed of dark, non-reflective matter that is very hard to see against the absolute blackness of space. Clearly, not being able to track massive chunks of rock that have the potential to slam into the earth is an unfortunate circumstance. However, many new methods are being tried out to attempt to catalog the exact number and location of every asteroid in our solar system, including bombarding the asteroid belt with radar waves and reading the return signal.

What we know of asteroids is limited to the information scientists have gathered and analyzed. This information has been collected from the analysis of meteorites, or asteroids that have passed through the earth's atmosphere and crashed upon the earth's surface. This analysis has shed some light upon the composition of asteroids. According to the results of years of research, asteroids are made up of mostly silica based rock matter (about ninety-two percent). The other eight percent of the matter that asteroids are made of is mostly iron and other trace elements such as iron, iridium, nickel, and iron oxides. It is also projected that many of these asteroids contain heavier elements such as uranium, but it has yet to be seen if it is true. The reason for this thinking is that the asteroid belt is made up of the remains of a planet that could not form, and because planets contain heavier metals on the inside mantel, the asteroids could easily yield such metals without much digging or drilling.

The asteroids within our solar system are comprised of every shape and size imaginable, within certain limitations of course. An asteroid appears as a dark and ashy gray color, due to its composition of mostly silica based rock and iron oxide metals. The color and hue of an asteroid will change based on its composition. It will appear more reddish if the asteroid contains more iron oxide, and it will look to be more of a grayish color if there is more silica rock within. Asteroids are also pock-marked with craters. This is due to the fact that the asteroids within the asteroid belt are constantly within a slow crashing and grinding ballet with one another.

Comets

The main difference between comets and asteroids is that comets are usually made out of ice while asteroids are made out of rock. Comets maintain their ice form due to the cold temperature throughout the solar system. The only times comets melt are either when it gets too close to the Sun, or when it enters the atmosphere of a planet. As a comet approaches the Sun, it begins to evaporate, forming the atmosphere of the comet and a comet tail. The atmosphere, or coma, is approximately 10,000 times thinner than a cloud on earth and therefore, the nucleus can only be seen by reflected lights when frozen[93].

The main populations of comets in our solar system orbit in the far outer regions. Currently scientists know of two main areas that comets inhabit. These are called the “Oort Cloud” and the “Kuiper Belt.” The “Oort Cloud” is an immense spherical shell of comets approximately three light years away from the sun. This is known to be the vast edge of the sun’s gravitational pull[94]. Comets that are contained in the "Oort Cloud" are estimated to be 40 times the total mass of the earth and take 200 million years to orbit the sun. The composition of these comets is very diverse. This is caused by the distances from the sun and how the temperatures affected the comet when originating.

Most comets astronomers study today are from the "Kuiper Belt." This is located just beyond Neptune's orbit. These comets are unique because their orbits lie near the plane of the earth's orbit around the sun[95]. Also, these orbits travel in the same direction as the planets. It is speculated that Pluto is the "Kuiper Belt's" largest member of that region.

In the 1980s, a computer simulation supported the theory of the "Kuiper Belt" and predicted that a disk of debris naturally formed around the center edge of the solar system. This debris was quickly attracted by the gravitational pull of the sun causing planets to form[96]. However, the scenario also suggests that some debris past Neptune was left behind which failed to form planets.

The largest crater in the United States caused by a near earth object is at the mouth of the Chesapeake Bay. This crater is 56 miles wide and was formed approximately 35 million years ago[97]. This does not compare to the biggest crater on earth. This crater is in the Gulf of Mexico and is speculated to have caused the extinction of dinosaurs. The crater, called Chicxulub, is over 112 miles wide and was formed over 65 million years ago. The impact of such an object was so large that it led to fires, tidal waves, and earthquakes near the impact site, as well as a complete change in the global climate.

Although comets are usually not the first topics discussed when considering near earth objects, they deserve to be looked at and have their risks evaluated. It is true that there are many comets which send debris into our atmosphere every day. However, if a large comet were to hit the earth, the impact would be tremendous. Most people think that the atmosphere would melt the comet seeing as though it is made of ice. Although, this not always the case. An article released in June of 2003 talks about a pair of twin comets that plunged just 0.1 solar radii above the sun's atmosphere and continued its journey[98]. The temperature at this level is estimated to be multimillions of degrees. This is not the only recorded case of this occurrence. In June of 1998, a similar incident occurred with a separate pair of comets. If these comets are able to resist the multimillion degree atmosphere of the Sun, then they will definitely plunge through the earth's atmosphere without distinct enough evaporation to save humanity. An impact this large would totally obliterate the world as we know it.

Chapter Six:

Moon Base

Shoot for the moon. Even if you miss, you'll land among the stars. - Les Brown

The moon has always held the attention of humans throughout history. Ancient calendars were created from its cycles, rituals and ceremonies were performed in its honor, and even religions were based upon its phases. It seems inevitable that we would one day set foot upon the moon. It is now thirty years since the Moon's surface has been seen by human eyes up close. Many people now think that it should be a long term goal for us to permanently inhabit the moon.

There are several advantages and opportunities that come along with a permanent moon base. One advantage would be the sheer amount of scientific data that one could gather if on the moon. For example, one main problem with Earth based telescopes is the interference from the atmosphere that occurs. Whether it is just clouds or even the shimmering effect that differences in air pressure create, it is often difficult to create a clear image of space. However, if there was a telescope installation on the moon there would be no atmospheric interference at all. The images that would be captured by such a telescope would be incredibly sharp and would allow us to look even deeper into space.

One of the main drawbacks of creating a permanent moon base is the fact that it would cost a great deal of money. However, considering the great amount of knowledge that would be gained from this, cost should be a secondary concern. Additionally, there are several sources from which funding may be acquired. The budget of the United States contains many ample reserves from which a moon base program could be created. Additionally, an international effort would most likely be the best option for receiving the greatest amount of financial backing.

Observation Post

The last time any American landed on the moon was over 30 years ago. There are many reasons to inhabit the moon. The most prominent of these reasons is protection from future asteroid or comet impacts. Scientists currently know the risk of a cataclysmic impact is far greater than previously imagined. The moon would be an ideal observation post to examine the threats of near earth objects. Yet, so much money is diverted to other programs which prevents the take-off of a program that would develop a moon base observation post.

The advantages of having an observation telescope located on the moon are countless. Not only would it allow scientists to discover and track new asteroids that were previously unnoticed, it will also allow scientists to track the paths of these asteroids[99]. By tracking their paths, scientists will be able to give a fair enough warning to the public if one were to hit the earth. Even tracking an asteroid the size of a modern day house would be worth while because scientists would be able to predict where the asteroid may hit, if at all, and evacuate the area effectively. Another great advantage to the space telescope located on the moon would be studying the composition of asteroids. This could be done in two ways. The first would be reflecting light off of the asteroid and zooming in with the telescope. The second would be sending a probe out from the observation post. The second method would be vastly superior to sending a probe out from earth because the distance to the asteroid is far less which means faster results at a lower cost[100]. By studying the composition of particular asteroids, scientists will be able to figure out the best way to deflect or explode an asteroid if the need shall arise.

All the recent activities make this is a definitive way to help the rising problem of asteroid impact. From September 20 through September 29 of 2003, there were a series of impacts on earth[101]. Fortunately, most of the asteroids which hit earth landed in the Pacific

Ocean. However, many countries including India, Australia, and the United States reported damage. On September 23, a New Orleans couple's recently renovated bathroom was completely destroyed as an asteroid the size of a Volkswagen tore through it. On September 29, many San Francisco residents reported a huge fireball dart across the sky turning the night into day. Luckily, no one was hurt in these instances but 20 people were hurt when an asteroid set a village on fire in India[102]. Two pieces of this asteroid were recovered.

Currently, the moon would be the most ideal place to set up an observation post. The current telescopes we have set up on earth thrive only under perfect circumstances. The ground-based telescopes of today have become limited due to atmospheric turbulence, geographical limitations of telescope location, earth's day/night cycle, poor weather, and the moon getting in the way[103]. However, it is proposed that the moon based telescope would prevent many of these problems. Ironically, the telescope could be located in an asteroid induced crater on the moon. This crater is deep enough that it faces away from the sun at all times due to the moon's 28 day celestial orbit. The crater would block the sunlight out of the observation telescope, so it would be able to broadcast images back to NASA at all times. This 24 hour broadcast would present many new asteroids into the open and allow NASA to plan ahead and track them.

There are only a few drawbacks to the proposed observation telescope. The first of which is power. Every high ranged telescope would need a source of power. In this case, the telescope would need enough power to encapsulate the images it can see and broadcast them back to NASA 24 hours a day. This would require an intricate system to give the telescope enough energy to fulfill these requirements. Even so, the United States must start funding the network by cutting back in other areas. Other drawbacks include the maintenance, servicing, and upgrading of the technology in the post. If research was done more in the area of technology in space, then it may be feasible to better equip the observation post for the future. Also, this technology would help NASA improve their command and data handling services, lunar getaways, and crew and cargo transfer vehicles.

The biggest current drawback to the observation telescope proposal is that in order to get it up and running, there must be a vast improvement in space activity. No American has landed on the moon since 1972 and a lot of space exploration launches are being postponed or cancelled within the past decade. This lack of scientific curiosity and funding will be the death of humanity if we don't change our current course[104]. Any system Americans would like to get up and running, whether it is the observation telescope or another method of their choosing, would require an advanced method of space transportation. The only method of extending the mobility of the program is to fund it properly. The space program is one of the fastest declining programs in the last three decades. Funding is constantly being diverted and stripped. However, the decrease of funding by the government has sparked private organizations to compensate in the space field.

The Lowell Observatory and Discovery Communications Incorporated agreed to build a $30 million telescope that would observe a portion of the sky eight times greater than the current largest telescope on earth[105]. This telescope would be the ideal telescope to place on the moon. The telescope also has real time imaging and can be quickly converted to its alternative optical configuration which is ideal with particularly bright phases of the moon and will block out other solar glaring.

A second telescope will up and running in late 2005. The Large Binocular Telescope is known to be the largest pair of "eyes" ever built to aid search for planets. The telescope has two saucers which make it resemble a human face. The design came out of the theory that, like humans and animals, combining the optical power of two eyes is better to see than just one eye. This telescope is hoped to be the first to capture a direct observation of giant planets around others stars[106]. Scientists currently know of at least 100 stars that have planets orbiting them, just like our sun. But humans did not have the technology to observe these planets prior to this telescope being constructed due to the blinding glare of the stars the planets orbit.

Unlike a human pair of eyes that captures two images of the same thing and combines the two to form one image, the Large Binocular Telescope combines the light waves with each other which creates the effect of canceling each other out. This technique allows scientists to make a star “disappear” from view[107]. The telescope also comes with the ability to magnify images. With the help of two mirrors, each 28 feet in diameter, the telescope has the ability to magnify the image of planets which are currently being overshadowed by the glare of the stars they orbit. Scientists would then be able to use this technology to magnify the image of incoming asteroids. They would be able to calculate size, mass, and orbit using this telescope and its mirrors. This telescope, like the first mentioned, would use its ability to block out solar glare and allow scientists to discover asteroids blocked out by our own sun’s glare. Thus, increasing the total percentage of sky observed while minimizing the potential of danger to the earth.

Even with these drawbacks, more advantages arise every moment which give the observation post a credible means of existence. The observation post could also be used as a station to deflect asteroids. As of this moment, scientists have not had the need to deflect an asteroid on a collision course for earth. If the need were to arise, it would be in NASA’s best interest to have practiced before. The moon based station could be used as the main station to set off missiles aimed at deflecting asteroids. NASA would be able to practice on asteroids which are passing by the moon but do not have a serious threat to earth. They could then critique their techniques and improve among them at will. It is also proposed that lasers could be invented that would also deflect or even heat the asteroid to its breaking point. The moon based station would also be a terrific place to integrate a testing station like this. The experimenting with hypothesis is the only true way to know if a method will work. The more testing the scientists get, the better prepared they are for when the worst circumstances occur.

The Funding Issue

With all the talk of terrorism going on today, why is it so important that we fund NASA and other organizations devoted to the space program? Wouldn't the money proposed for the space program be better used to find and stop a country devoted to terrorism? Why should I care, isn't there someone out there who tracks asteroids and other objects that will hit the earth? Aren't there better things that we could use the money for? These are typical questions standing in the way of the funding NASA needs.

Many Americans today are more scared of terrorism than the threat of an asteroid impact. As September 11th 2001 remains in our minds, it will be hard to analyze the true need for the space program. As of 2003, NASA received $2.8 billion a year, with only a small portion of it devoted to analyzing, tracking, and preventing asteroid impact: approximately $3.5 million. Yet, $4.1 billion is devoted to Homeland Security alone[108]. The need for an increase in funding is imminent if NASA is to track all near earth objects. But how does NASA get an increase in funding if many Americans are speculative of the need for an increase in funding? For example, the Australia space program asked for an increase of merely $1 million to scan the mostly unsurveyed southern skies for killer space rock[109]. Yet, the Science Minister of Australia Peter McGauran gawked at them on television because he did not understand the need for funding. He called the effort to find potentially threatening asteroids "fruitless, unnecessary, self-indulgent" and promised no funds unless researchers provide a more convincing argument for the need[110].

Many people across the world believe all asteroids are being traced and tracked. They believe such asteroids do not pose a threat and thus do not need to be funded. While many asteroids are being tracked, the threat is still great for asteroids that haven't been detected yet. On March 8, 2002, an asteroid the size of an 18-story building passed merely 298,400 miles from the earth[111]. This is just a bit farther out than the moon. What is astonishing is that the asteroid was never detected until four days after it passed its closest approach to earth. The asteroid was in the glare of the sun which prevented astronomers from discovering it until after it passed earth. With an increase in funding, astronomers hope to discover asteroids like this in enough time to prevent them from being lost in the sun's glare.

This is not the only circumstance in 2002 that an asteroid passed by earth without any warning. On January 7, 2002, an asteroid came within two lunar distances of earth but was only discovered the month before. This asteroid was the size of three football fields and would have done major damage to a city if an impact had occurred. One researcher estimates that up to 25 asteroids roughly this size pass by closer to the earth than the moon every year unnoticed[112]. This is astonishing and is a threat that should be recognized by people all across the world. These asteroids all go unnoticed by a limitation in technology, telescope time, and especially funding. By increasing the funding, we can expand upon the current technology enough to allow for better telescope time and a more precise path for future earth pass bys.

Unfortunately, the disaster of September 11th scares politicians and the public more than the threat of an asteroid impact. Scientists understand that only tremendously expensive new telescopes which are placed outside the earth's orbit are needed in order to discover some of the many undiscovered asteroids that are not on the known list before it is too late. The moon based observation telescope previously mentioned is a definitive example of a useful telescope to track known asteroids and discover new ones.

The risk of dying from an asteroid impact is greater than most people realize. From the clues discovered by scientists examining past encounters, the expected risk factor is 1 in 20,000 will die from an asteroid impact[113]. This seems like a low risk but the chances of dying in a plane crash are roughly the same. This risk is far greater than dying from food poisoning, a rattlesnake bite, or a tornado because these chances are roughly 1 in 60,000. Even so, the public is more worried about their fears than they are statistics. These fears are based on personal experience, knowledge, and a sense of the situation. Americans felt the terror of September 11th but do not feel the terror of what may come of an asteroid impact. Unfortunately, the only real way to awaken the public is for an extraordinary event to occur. However, this should not be the case. If such an event occurs, not only will it alter the face of earth as we know it, it may end all humanity. We cannot wait till this day arrives.

Chapter Seven:

Methods of Asteroid Diversion

Civilizations that do not become space-faring become extinct. – Carl Sagan

The threat provided by near earth objects, and particularly asteroids, is considerable. It is big enough to be warranted a problem in need of a solution. The collision between an asteroid and the earth would have catastrophic consequences including massive tectonic disruptions, warping of the Earth's crust, and fallout lasting for decades. There are two ways of avoiding such a collision one is for the asteroid to be destroyed before impact and the other is for the asteroid to be moved to a safer path.

There are several ways to achieve an avoidance of a collision. The best method of destroying an oncoming asteroid would be to somehow detonate a nuclear warhead on or near the asteroid, or even a barrage of nuclear warheads. This method requires a great amount nuclear weapons to pass through space, which in itself is risky. There are many more options along the ways of moving the asteroid out of a dangerous path.

One method of diverting an asteroid would be to attach thrusters of some kind to the asteroid and then push it into a safer orbit. There are several different kinds of thrusters that could be used including traditional liquid fueled rockets, solar sails, and charge ion thrusters. However, the one thing in common that all of these methods have is a level of difficulty for success that is near to impossible.

Another method that may seem rather unconventional is to move an asteroid using light. Specifically, the asteroid would be moved by an intensely focused stream of photons. In other words, a laser could be used to move an asteroid. We have discovered that this option is the most viable because of its readiness of deployment, the availability of technology, and the speed at which it would be able to divert an asteroid.

Chemical and Electrical Propulsion

Rocket thrusters are currently the main propulsion system for spacecraft. These chemical thrusters supply large amounts of power over short amounts of time, providing an excellent method of moving great distances over small time periods. The problem with chemical rockets is they are very inefficient. A much more efficient method of propulsion is the ion engine. The ion engine provides a small amount of thrust over a long period of time, but in the long run, an ion engine will provide ten times more thrust per kilogram of fuel than a traditional chemical thruster. Both of these propulsion systems can be examined for use in diverting an asteroid from impact with earth.

Chemical rocket thrusters, the type typically used to propel spacecraft, operate by heating chemicals to high temperatures and exhausting them from a rocket nozzle. This is most often done by direct heating in which a chemical reaction will provide an extreme temperature that heats a material and makes it expand explosively. This explosion is released from the back of the rocket and provides enough thrust to power a spacecraft[114]. Chemical combustion is the single most common form of rocket propulsion. Chemical thrusters exert megawatts of power but only over seconds at a time. This thrust is typically enough to push small space craft, but would not be nearly enough to propel an asteroid of 200 meters in diameter over a short period.

Ion engines are an alternative spacecraft propulsion mechanism. An ion engine works by ionization of a propellant gas. In this process, electrons are forced into the discharge chamber of the engine where they collide with a propellant gas, such as Xenon, causing electrons to be stripped off the propellant gas creating positively charged ions. These ions are charged with electrostatic pulses and forced to accelerate through a high voltage metal grid at the back of the discharge chamber. As the ions pass through this grid they reach a velocity of 31.5 kilometers per second and are focused into an ion beam which is exhausted from the back of the spacecraft[115]. This beam produces a very low thrust force, approximately 0.09 Newton, but can be operated constantly for over 8,000 hours[116]. While the ion engine only produces a small amount of thrust, it would be effective in diverting an asteroid if years of thrust are applied.

Specific impulse is a measure of efficiency of a propulsion system. Specific impulse can be calculated using the equation:

$$I_{sp} = \frac{v_p}{g_0}$$

where g_0 is the gravitational acceleration constant and v_p is the total impulse of the device. The specific impulse of chemical thrusters maxes out around 500 seconds while ion engines have a specific impulse between 2,500 and 10,000 seconds[117]. This means that an ion engine is much more efficient with propellant fuel than a chemical thruster. Figure 1 shows a comparison of the specific impulse of chemical and electric propulsion devices. An ion engine uses only a few grams of propellant fuel per day but provides ten time as much thrust as a typical chemical thruster[118]. Because ion engines require less fuel than chemical thrusters, launching an ion engine propelled craft toward an asteroid would be much easier and cost much less. The ease in launching is due to the light weight of the ion engine and the small amount of fuel needed.

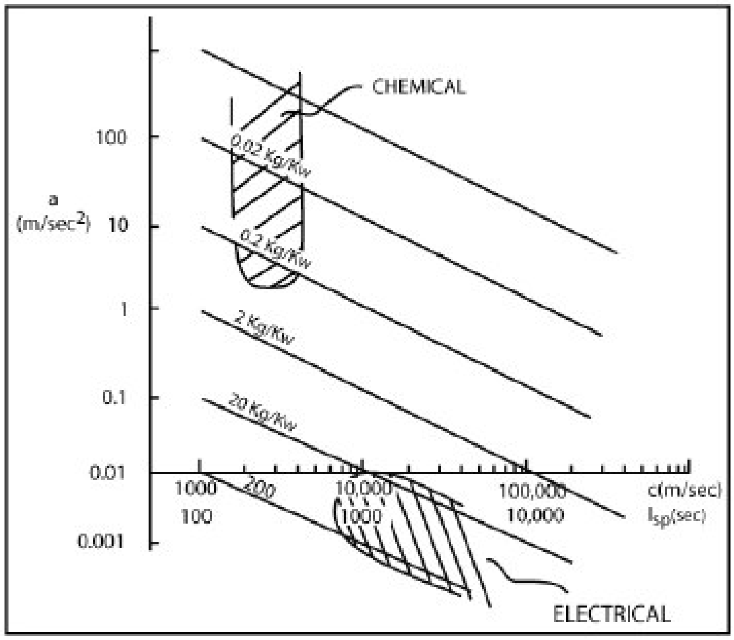

Figure 1: Specific Impulse versus Acceleration of Chemical and Electrical Propulsion Devices[119]

To keep an ion engine running, solar panels would be used to provide enough electricity to power the engine[120]. As long as the asteroid being pushed by the ion engine is within range of the sun, the engine will work given enough propellant gas. A chemical thruster requires thousands of pounds of propellant for its short bursts of propulsion. Although chemical thrusters are common in use for spacecraft, they would be impractical for use in propelling an asteroid with a large mass. The short bursts of thrust provided by a chemical thruster would have to be applied over a long period of time to create enough force to accelerate an asteroid along its path, preventing a collision with earth. If these short bursts were applied over years, an extremely large amount of propellant would be needed since chemical thrusters have very low specific impulse. The better method of propelling an asteroid away from earth over a long period of time would be to use ion engines. Because the ion engine has a higher specific impulse, it is much more fuel efficient than a chemical thruster and would cost much less to operate over a long period of time. The ion engine would be a more efficient and cost effective way to divert an asteroid from earth than a chemical thruster.

NASA's Jet Propulsion Laboratory has tested an ion engine and proved that it indeed is a very efficient and practical propulsion system. NASA ran an ion engine for almost five years constantly in a vacuum. In simulated space conditions the engine had a design life of 8,000 hours but it was kept running and fully functional for almost five years. The engine was shut down prior to failure only due to the need of the analysis data from the test. After inspection, the engine showed wear but nothing that would have caused failure at any time soon if the test had been continued. The sample engine was run on only a few grams of Xenon gas daily, proving that ion engines are very fuel efficient[121]. Taking into consideration the efficiency and the long life of the ion engine, the ion engine appears to be a better option of diverting an asteroid over a long time period than the chemical thruster.

Thrust Calculations Based on NEAR Shoemaker

NASA's Near Earth Asteroid Rendezvous (NEAR) mission is part of the Discovery program. NEAR Shoemaker was the first spacecraft to go into orbit around a near earth object. NEAR Shoemaker was launched into orbit around the sun on February 17, 1996 and used rocket thrusters to catch up to the asteroid Eros. By February 1999, NEAR Shoemaker was in orbit around Eros where it used x-ray devices, cameras, and tracking systems to view the asteroid. Images and data collected by NEAR Shoemaker were sent back to earth[122].

To get a sense of how much thrust would be required to change the path of an asteroid, we have used the amount of thrust used by NEAR Shoemaker in reaching the asteroid Eros to calculate the amount of thrust required to move a sample asteroid. The asteroid 2004 GE2 has a diameter of approximately 180 meters and an estimated mass of 8.0×10^9 kilograms and will be used in the comparison.

The NEAR Shoemaker spacecraft has a mass of 805 kilograms[123]. To propel NEAR Shoemaker to the asteroid Eros where it orbited and took photographs of the asteroids surface and then made a touchdown onto Eros a number of various sized thrusters were used. One 450 Newton large velocity adjuster and 11 fine velocity control thrusters were used on NEAR Shoemaker. Of the 11 fine velocity control thrusters, 4 were 21 Newton thrusters and 7 were 3.5 Newton thrusters. The propulsion thrusters were used as the main driving thrusters and the one main thruster was fired only twice to provide large increases in velocity. To power these thrusters, 340 kilograms of propellant was used. Solar cells were also carried onboard to power the electronic equipment and cameras. NEAR Shoemaker's entire journey took four years to complete[124].

In utilizing the thrust capability of NEAR Shoemaker to determine the thrust needed to propel the 2004 GE2 asteroid, we assumed that the thrust per unit mass of the object would be the same for both NEAR Shoemaker and the asteroid under inspection. Using the ratio of thrusters per unit mass of NEAR Shoemaker we were able to determine the number of large and small thrusters needed to propel the asteroid at the same velocity as NEAR Shoemaker. The asteroid 2004 GE2 has a mass of 8.0×10^9 kilograms, nearly one million times larger than that of NEAR Shoemaker. NEAR Shoemaker has a ratio of one fine velocity control thruster per 73.2 kilograms and one large velocity adjuster per 805 kilograms. Using these ratios, we calculated that asteroid 2004 GE2 would require 109,289,617 fine velocity control thrusters and 9,937,888 large velocity adjusters for a total of over 110,000,000 thrusters. To power these thrusters, a total of 338,081,270 kilograms of fuel propellant would be needed. These numbers are so high that it would be practically impossible for us to produce and attach so many thrusters to an asteroid headed for earth with any reliability.

The feasibility of attaching such a large number of thrusters to an asteroid without serious complications is very low. The mass of the required fuel alone is 4% of the mass of the asteroid. Launching an object with such a mass would be a major feat and would cost large amounts of money. Also, these calculations account only for propelling the asteroid away from the earth's orbit. Fuel calculations were not included for launching the thrusters to the asteroid and landing on it. It is likely that larger thrusters can be used to reduce the amount of thrusters needed on the asteroid, but the amount of thrust needed to budge the asteroid will still be very high. A smaller amount of thrust applied over a long time period would also probably help divert the asteroid's path, but a large amount of time would be needed. To gradually apply thrust to the asteroid, years of time would be needed to launch the thrusters, have them land on the asteroid, and begin accelerating the asteroid. The NEAR Shoemaker mission took four years to complete including time to observe Eros while orbiting it, but a similar time might be expected to reach an asteroid being propelled depending on the position of the asteroid. The method of applying thrusters to an asteroid on a collision course with earth seems very improbable at this point in time.

Solar Sails

A solar sail is a spacecraft with a large, lightweight mirror attached to it that moves by being pushed by light reflecting off of the mirror instead of rockets. The light to push a sail can come from the sun or large lasers we could build. Satellites in orbit around the earth can survive for many years without any maintenance while using only a little bit of rocket propellant to hold their positions. Solar sails can be made to survive in space for many years as well. But, because solar sails use sunlight that never runs out like rocket propellant, during those years the sail can move around as much as you want it to, such as from Earth to Mars and back, possibly several times if the sail remains in good condition. A similarly equipped rocket would either be ridiculously huge because it has to carry the fuel for each trip, or would need to be refueled regularly.

Before anyone ever took a beam of light and measured how much it could push, there were predictions that light could exert a very gentle push on objects it hits. James Clerk Maxwell developed the laws describing electromagnetism and concluded that light is an electromagnetic wave. Maxwell predicted that when light hits an object and is absorbed or reflected, the light wave pushes on electric charges in the surface of the object, which in turn push on the rest of the object. If the light is reflected, the object gets pushed twice as hard, just as if you would be pushed twice as hard by a rubber ball hitting you as a ball of clay. In 1901-1903, the Americans Nichols and Hull and Russian Lebedev were able to measure light pressure as predicted by Maxwell.

Sunlight exerts a very gentle force. The power of sunlight in space at earth's distance from the sun is between 1.3-1.4 kilowatts per square meter. When you divide 1.4 kilowatts by the speed of light, about 300 million meters per second, the result is very small. A square mirror 1 kilometer on a side would only feel about 9 Newton or 2 pounds of force. Fortunately, space is very empty and clean compared to earth, so there is plenty of room for a one kilometer wide sail to maneuver, and there is no noticeable friction to interfere with your 9 Newton thrust. A sailboat on earth wouldn't be going anywhere with that little force because of drag from the water and air. Some rockets can push millions of times harder, but the sail keeps pulling so long as light shines on it. Months or years after the rocket runs out of fuel, the sail is still pulling.

Missiles

One of the most common and intuitive methods for potentially deflecting a dangerous near earth object is to launch at least one tactical missile towards the object. The hope is that the explosion will give off enough energy to adjust the trajectory, keeping it away from the earth. It is a popular idea because, if it were in the interest of global safety, every nation would be willing to send what they had at the asteroid. Also, we already have the missiles produced, many with the capability to exit earth's atmosphere. Given a notice of several years, warheads could deliver a sufficient force to accelerate the asteroid out of earth's path.

If we take a given asteroid with a diameter of 100 meters, and assume its composition will be mostly iron, the density will be 8 g/cm^3. Therefore, the mass will be about 4.189 x 10^6 tons. To work out the power requirements, we use the displacement formula $S = \frac{1}{2}AT^2$. Since we only need to prevent a collision with earth, S = 6370 kilometers which is the radius of the earth, and we can use any arbitrary time for T. Let's assume we have five years, T = 1.5768 x 10^8 seconds. This results in a needed acceleration of 5.124 x 10^{-10} meters per second squared. Next, we determine the force required, using the equation $F = MA$, and we get a necessary force of 2.146 Newtons. Now finally, we can work out the necessary energy needed to apply that kind of force. Using the equation for work, $W = FD$, the total energy needed is 1.367 x 10^7 joules.

A megaton bomb contains approximately 4.18 x 10^{15} joules of energy[125]. Theoretically, this should be more than enough. However, nuclear detonations in space have not been thoroughly tested and analyzed, and it is believed that the explosion would be much different than one on earth. For instance, the shockwave that is a common signature for a large bomb would not be present in the vacuum of space. The characteristic of a bomb that would knock the asteroid off course would be the immense transfer of heat. This would vaporize the surface of the asteroid, propelling it in the opposite direction.

A hypothesized problem with a missile prevention system is if the missile is detonated too far away from the asteroid, not enough energy will be transferred. That which is transferred will just be absorbed by the asteroid, in the same way that the sun's energy doesn't affect the object's trajectory. A proposed solution to this would be to send two missiles together, a small one which detonates very close to the asteroid to transfer a great deal of energy to pass the threshold of the asteroid's energy absorption, then a second, larger warhead to provide the thrust.

All of these calculations are dependent on the missiles approaching the asteroid from behind, so that the missiles and the asteroid are both traveling in the same direction at the same speed. A two missile system wouldn't work for a head on collision, due to the immense relative speed of the asteroid. Therefore, it would be necessary to carry enough fuel on both rockets to get out to the asteroid, pass it, and then come back to it. However, if we were to accelerate the asteroid on an earlier pass around the sun, while it is already traveling away from us, it would be much more feasible.

As far as the current situation, if a threatening asteroid was found to impact within a year, this would likely be the only method of prevention. There are many ways for a rocket mission to fail, such as failing to detonate at the right time, colliding with debris, losing control of the rockets, or other problems. However, for the immediate future, they can be used to deflect asteroids, until solutions that are more reliable and effective are developed.

Nuclear Warheads

In order to deflect a large near earth object, one that has enough mass to potentially threaten life on earth, you need a great amount of thrust. Thrust is created by exerting a force upon an object in a certain direction. Force is defined as mass multiplied by acceleration. Therefore, in an environment such as space the best way to create thrust is to somehow create a 'push'. One idea for creating such a push is to use nuclear warheads.

The idea for nuclear weapons is not new. Einstein and Bohr were convinced of their feasibility in the early part of the 1900's. The way a nuclear weapon works is by forcing an atom to undergo fission. The resulting fission chain reaction releases large amounts of energy in the form of heat, light, and radiation. Fission weapons were developed first. The process of fission was achieved by focusing explosive shockwaves onto plutonium. The plutonium fuel then underwent a fission chain reaction in which the resulting energy from the original nuclear fission set off other fission reactions. More advanced nuclear weapons were developed using the process of fusion.

Nuclear fusion is when two atoms join together. This process is constantly happening on the sun, but on earth it has only happened during test explosions of hydrogen bombs. Fusion weapons, also known as thermonuclear weapons, were made a reality by the idea of encasing a smaller fission bomb within a fusion bomb. The energy produced by the fission bomb would in turn cause the fusion reaction. The energy produced by a thermonuclear weapon is tremendous and it is terrifying to think that these weapons have been developed to be put to use against fellow human beings.

A far more beneficial use for these nuclear weapons, aside from the scientific knowledge gained during their research and development, is to use them to deflect a 'world-killer' near earth object. This idea has been proposed many times. One of the reasons for this is that the plan of causing a massive explosion next to an asteroid or comet is just so simplistic. Common sense dictates that the easiest solution is often the best, however, the logistics involved in placing a nuclear weapon even close to a near earth object is mind boggling.

In order for a nuclear weapon to be placed either on, or even near, a NEO we would have to have a space craft that is capable of escaping the earth's gravity, catching up to a near earth object, and then slowing to its targets speed. This would require either immense amounts of fuel or the use of a propulsion system that we do not yet have access to. Such a craft could be developed within five years or less, but this would not help our plight if a near earth object was only discovered a month before its expected impact. The only way we could get a weapon out there in time is to already have this fantastic new space craft that is capable of such feats.

Another problem with detonating a thermonuclear warhead in space is that the environment in which it is being used is not the same as the environment in which it has been tested. One would think that the same city-leveling explosion that happens on earth would be just as devastating in space. However, in the environment in space, there is no air and very little matter to come in contact with. A nuclear explosion on earth is accompanied by a shockwave created by superheated air and the resulting pressure differential. The shockwave is what accounts for 90% of the immediate damage in a nuclear blast. Winds of hundreds of miles per hour can tear through almost everything. In space, however, there is no air or any other matter to create a shockwave with. The initial vaporization would be the only destruction to take place with little thrust exerted. The only way for thrust to be created from a nuclear blast, on a scale large enough to move the path of an asteroid, would be to detonate one nuclear weapon right after another. This would create a cloud of plasma from the first weapon which would then be used as shockwave fodder for the second weapon.

This possibility does seem to be effective, but it relies on too many factors. The weapon could get to the asteroid, but only if it was developed first. The weapon might create enough thrust, but only if there was another weapon detonated before it. In conclusion, the feasibility of using a nuclear weapon on a near earth object is very small.

Lasers

The use of lasers to prevent an asteroid collision has been discussed by many scientists and astronomers alike. The use of lasers relies on two theories. The first of which is that when a constant pulsing force is applied in one direction, it will change the orbit of the asteroid enough to prevent a collision with earth. The second theory states that when a metal heats up to a certain temperature at an accelerated rate, an explosion will occur. Astronomers hope to use these explosions to thrust an asteroid out of its current orbit, escaping the impending doom left if an impact were to occur.

The use of lasers to prevent asteroid collisions sounds like a good theory. But how does one calculate and test this theory? This question can be answered by looking at the work done by Colonel Jonathan W. Campbell at the center for Strategy and Technology in Air University[126]. Campbell looked into using lasers to remove orbital debris. He then took his equations for removing orbital debris and used them to calculate the deflection of an asteroid.

Colonel Campbell's research into orbital debris removal began with the Orion study. This study considered many laboratory experiments that were conducted with representative materials and found useful models for the coupling of both metals and nonmetals. This study also showed that the optimum intensity is higher for metals than for nonmetals because of the onset of plasma formation above the optimum intensity for nonmetals occurs at lower intensities[127]. Campbell hypothesized that this system would effective for both metals and nonmetals that arc at higher orbital altitudes. From his studies, he demonstrated the useful laser propulsion of orbital debris as the result from placing intensity on the order of 10^8 W/cm^2 on the target. He also calculated the angular beamwidth required to achieve this intensity from the equation:

$$\alpha = \frac{1}{z}\sqrt{\frac{E}{\frac{\pi}{4}It}}$$

where E is the pulse energy, I is the required intensity, t is the pulse duration, and z is the target range. To show this in an example, we will use a pulse energy of 20 kJ, a pulse duration of 5 ns, a range of 1,600 km for debris at an altitude of 800 km, and a zenith angle of 60^{o}. We can conclude the required angular diameter to be 1.4 μrad. This is displayed in Figure 2 below.

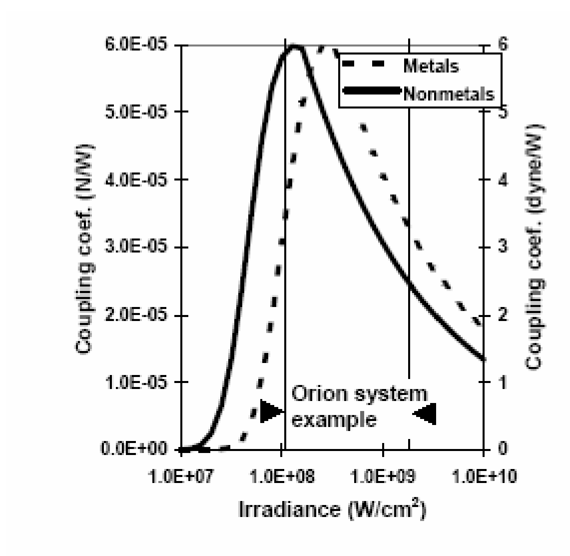

Figure 2: Laser Coupling for 5 ns Pulse Duration[128]

These calculations do not take into account the high-order correction of turbulence which tilts the wavefront, displaces the emerging beam from its intended path, and attenuates the beamwidth. However, high-order correction for atmospheric turbulence has been demonstrated with laser guide stars and active optical corrections. With existing technology, a resolution of one μrad was obtained in an experiment at the USAF Phillips Laboratory Starfire Optical Range in Albuquerque, New Mexico[129].

Scientists plotted out the various times at which to use a ground-based laser on space debris. Their conclusions were all similar and they all concluded that the ideal time to use the ground-based laser would be more beneficial on the apogee, or the point in an orbit most distant from the body being orbited. The effects of the single pulses are small but significant[130]. They are displayed in Figures 3 and 4 below.

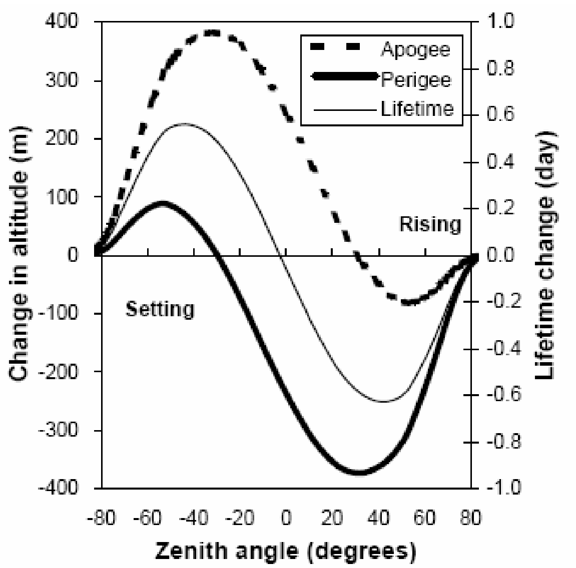

Figure 3: Effect of Single Laser Pulse[131]

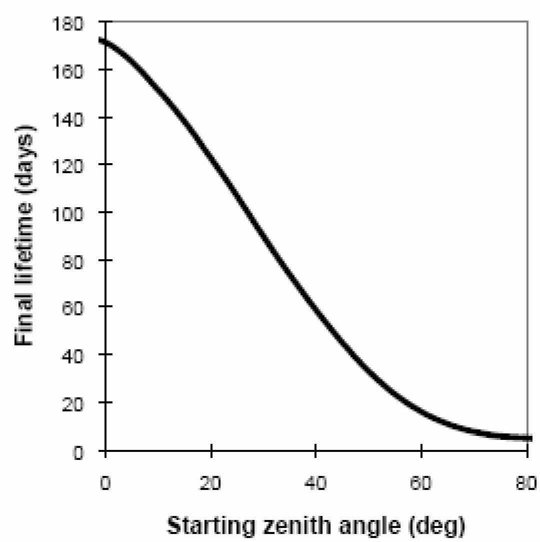

Figure 4: Post-Engagement Lifetime for an Orbital Debris Object With Zero Final Zenith Angle[132]

Figure 3 shows the change in degrees caused by a single pulse for the apogee, the perigee, and the total lifetime of the space debris. Figure 4 shows the reduction in the total amount of days for an orbital debris object with a zero final zenith angle. As you can see, the lifetime was reduced from 171 days to merely 20 days. The significance in this is monumental if scientists invent a laser with enough pulse to divert an asteroid.

Initially, it was thought that reflected light from the moving target would be too far removed for effective tilt sensing on the laser impact position. This is because of the finite light-travel time. This concern has been contradicted by astronomical results at the Stewart Observatory. Another concern that was raised would be the laser's ability to operate at all times of the day because the requirements for adaptive correction during the day are different than at night. It was concluded that atmospheric turbulence increases and makes the adaptive optics more difficult during the day. Therefore, the laser would fire primarily at night.

How do we benefit from the research into space debris removal? The research into the removal of space debris will benefit astronomers and mankind alike. Astronomers will be able to use this information to make a larger scale model of the space debris laser. This laser will produce beams that are large enough, in theory, to deflect an impeding asteroid from colliding with earth. The laser itself would not be enough to prevent an asteroid from colliding without the proper warning time. This is why an observation telescope will accompany the Phased Array Laser Systems (PALS) in orbit.

Project Orion demonstrated the sufficient capability for orbital debris removal for objects in the size range from 1-10 centimeters in diameter. This is not nearly large enough to deflect an asteroid of any large size. However, the laser used was very small and only used a 20 kW pulse. The experiment also showed the average surface pressure that the impulse imparted to the aluminum targets to be 6.5×10^{-4} N/cm^2. This is the same as saying it gave it an acceleration of 1.25×10^{-6} m/s^2. If one was to scale this up for an asteroid of about one kilometer in diameter, it would require a 200 GW power source[133]. An asteroid of about one kilometer in diameter would destroy about 85% of a continent. The power needed for the laser could be obtained from any readily available power source such as nuclear, electric, or solar power.

There are two types of collisions to consider when doing calculations with the asteroid. These two collisions are the "head-on collision" and the "catch-up collision." If we assume that the asteroid is heading directly at earth with a velocity v_0 and an impact parameter R, then we can calculate the closest point of approach R_e:

$$R_e \cong R_E\left[1+2g\left(\frac{R_E}{v_0^2}\right)\right]^{\frac{1}{2}}$$

Where R_E is the radius of the earth, and g is the gravitational acceleration at the surface of the earth. With an initial velocity of 40 km/s, a "head-on collision" would yield the closest point of approach to be 1.04 R_E, while with an initial velocity of 5 km/s, a "catch-up collision" would yield the closest approach of 1.1 R_E. This displays how the "catch-up collision" is a greater danger to mankind than the "head-on collision." Even so, both threats can be calculated the same way but the worst case scenario is for a "catch-up collision[134]." This displayed in Table 1 below.

Table 1: Catch-Up Collision Scenario

Time (in days)	Displacement ΔR	Final Lateral Velocity v_f
1.0	4.9 km	0.11 m/s
10.0	485.0 km	1.08 m/s
36.0	1.00 R_E	4.07 km/s
38.8	1.10 R_E	4.19 km/s
44.0	1.45 R_E	4.75 km/s
46.3	1.56 R_E	5.00 km/s

With all the ideal stipulations met, it would only require 38.8 days of constant pulsing in order to deflect an asteroid of one kilometer. If this theory is correct, then it would take slightly less than 4 days in order to deflect an asteroid of 100 meters. This is an extraordinary finding because new asteroids are being discovered at the last second all over the world. This theory not only cuts down on the warning time needed to deflect the asteroid in time, but it also gives a feasible solution to a problem which has gone ignored for far too long.

Another scenario depicts an asteroid being deflected from its current orbit with one high intensity impulse thrust. Realistically, this is not feasible but it allows us to demonstrate the affects of the deflection.

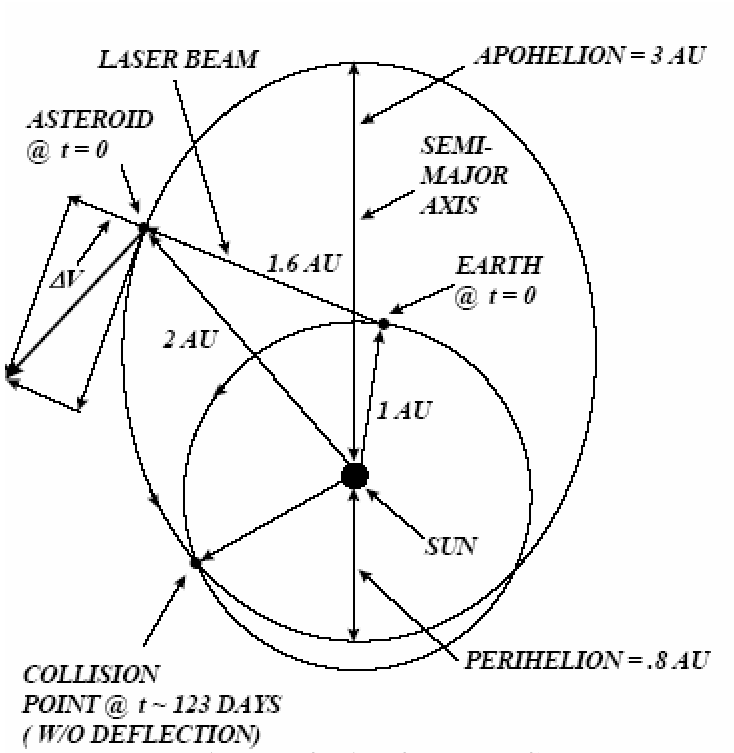

Figure 5: Orbital & Impulse Geometry

In Figure 5, the laser begins the impulse when the asteroid is 2 AU from the sun, where 1 AU is 1.49598×10^{11} meters. This causes the asteroid to descend to the last perihelion before the collision is expected to happen. The laser impulse is directed through the asteroid and the velocity is increased by 5 m/s. As was shown in Table 1, a change in velocity of 5 m/s yields a miss distance and the asteroid passes in front of the earth by 1.25 earth diameters[135]. As was mentioned, this is not a realistic model because in order to deflect an asteroid one would need constant low intensity impulses that would gradually reshape the orbit over an extended period of time.

The use of lasers to prevent an asteroid collision with earth seems the most likely scenario to achieve the goal of deflecting an asteroid away from the earth. This is because our current technology can be modified in order to achieve enough power to supply the laser, the warning time for asteroids can be cut down drastically compared to other methods, and the location of the laser itself can vary if needed. The laser could be located on the moon, floating in orbit around the earth or moon, placed in orbit around the asteroid, or on earth, all of which currently can be done with enough warning time. Given all the factors, we've decided to further analyze lasers as a means to deflect asteroids.

Chapter Eight:

MATLAB Simulation for Divergence of an Asteroid

In order to fully understand the proper thrust needed to deflect an asteroid from colliding with Earth, our group created a program in MATLAB that displays the orbit of an asteroid around the sun. The program, orbit02.m[136], also graphs the distance between the earth and the asteroid. With the help of Professor Mayer Humi, we were able to create a program which can visually display graphs needed to calculate the appropriate thrust. The graphs provided us with the proper information to calculate the amount of thrust that must be applied to the asteroid and in how many days. This information is the basis for this IQP because it allows us to analyze whether using a laser to deflect an asteroid is feasible with our current technology.

Within the program, there are a variety of variables and equations used. Such variables include msun, GG, GM, mobject, R0, vx0, vy0, eps, and nstep. The variable msun stands for the mass of the sun; which is approximately equal to 1.9891×10^{30} kilograms. GG stands for the gravitational constant. This is equal to 1.4756×10^{-34} astronomical units cubed per kilograms days squared. The variable GM is the product of the mass of the sun multiplied by the gravitational constant. R0 is the initial radius of the earth's orbit in astronomical units. The earth's initial x-component of velocity at time 0, vx0, is initialized to -1.715×10^{-2} astronomical units per day while the equation for the initial y-component of velocity of time 0, vy0, is initialized to zero. The point the earth begins its orbit is (0, R0); with x0 and y0 symbolizing these values respectively. The variable nstep is the number of steps the calculations are run for. The initial value of nstep is set to 15,000 days. The variable R1 contains the value of approximately one astronomical unit. This is used to determine how close the asteroid is from hitting the earth in relative terms.

After the values are initialized, the program performs the integration on the equation of motion for earth by calling another program called orbitsys12.m[137]. This program performs this integration on the equation

$$dx = \begin{bmatrix} vx0; vy0; \frac{-GM}{R^3} \times x0; \frac{-GM}{R^3} \times y0; vxa0; vya0; \\ \frac{-GM}{RA^3} \times xa0 - \frac{GME}{REA^3} \times (xa0 - x0); \frac{-GM}{RA^3} \times ya0 - \frac{GME}{REA^3} \times (ya0 - y0); \end{bmatrix}$$

where the distance from the sun to earth is

$$R = \sqrt{x0^2 + y0^2} \text{ ,}$$

the distance from the asteroid to the sun is

$$RA = \sqrt{xa0^2 + ya0^2} \text{ ,}$$

and the distance from earth to the asteroid is

$$REA = \sqrt{(x0 - xa0)^2 + (y0 - ya0)^2} \text{ .}$$

This equation is important because one must add the thrust to dx in both the x and y directions in order to alter the asteroid's orbit. For earth, there is no additional thrust added in order to maintain the earth's orbit. The simulation of the orbit is then plotted as a function of time in days. The program also plots the simulation of the orbit in polar coordinates by changing the x and y coordinates into polar coordinates. This is done with the equation

$$theta(i) = \arccos\left(\frac{xx(i,1)}{R(i)}\right)$$

when y is greater than zero and

$$theta(i) = -\arccos\left(\frac{xx(i,1)}{R(i)}\right)$$

when y is less than or equal to zero. In this equation, i goes through the loop nstep times. To distinguish between the equation for earth and the equation for the asteroid, we call orbitsys12.m on earth and orbitsys12thrust.m[138] on the asteroid.

In order for one to compute the asteroid trajectory, one must use similar equations but with the values of the asteroid inserted instead of the values for earth. For the asteroid in this program, we've chosen a hypothetical asteroid whose mass (masteroid) is $1.6\text{x}10^9$ kilograms. The eccentricity of this asteroid's orbit is 0.25 while the initial radius for the asteroid's orbit is 2.81005 astronomical units. This asteroid also has an initial velocity, vxa0, of 8.05 kilometers per seconds at the initial position (0, 2.81005).

After the asteroid's values have been initialized, the program calls orbitsys12thrust.m. Like orbitsys12.m, orbitsys12thrust.m performs the integration on the equation of motion. This time it does it for the asteroid with thrust rather than the initial asteroid without thrust. The only difference between orbitsys12.m and orbitsys12thrust.m is that the external thrust is being applied to dx. The new equation for dx is

$$dx = \begin{bmatrix} vx0; vy0; \dfrac{-GM}{R^3} \times x0; \dfrac{-GM}{R^3} \times y0; vxa0; vya0; \\ \dfrac{-GM}{RA^3} \times xa0 - \dfrac{GME}{REA^3} \times (xa0 - x0) + ux); \dfrac{-GM}{RA^3} \times ya0 - \dfrac{GME}{REA^3} \times (ya0 - y0) + uy); \end{bmatrix}$$

In this equation, ux and uy are the thrusts in the corresponding directions. ux is found by taking the derivative of the acceleration, which results in

$$ux = laserthrust \times \sin(theta);$$

where

$$laserthrust = \left(\frac{ForceOfLaser \times 6.68458e-12 \times 172800}{masteroid} \right)$$

and

$$ForceOfLaser = \frac{LaserJoules}{(abs(R - RA) \times 150e6 \times 1000)}.$$

In this equation, the LaserJoules is the variable that is modified based on how strong of a laser is available. uy is found similarly by deriving acceleration, yielding

$$uy = -laserthrust \times \cos(theta);.$$

Figures 6 through 9 show the various distances between the earth, the sun, and the asteroid, throughout the course of our simulation. Figures 10 through 12 show these distances with and without the thrust applied to the asteroid. Figures 13 through 15 show the asteroid's orbit if its initial position were (5, 2.81005).

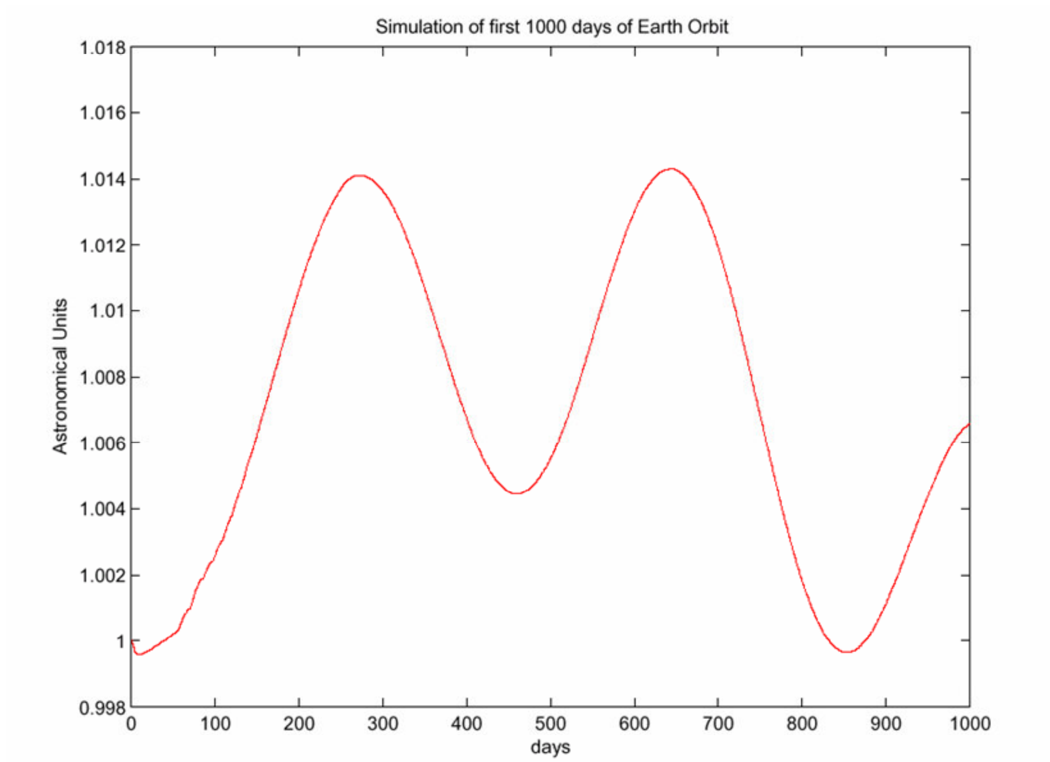

Figure 6: Earth's Distance from the Sun During the First 1,000 days of the Simulation

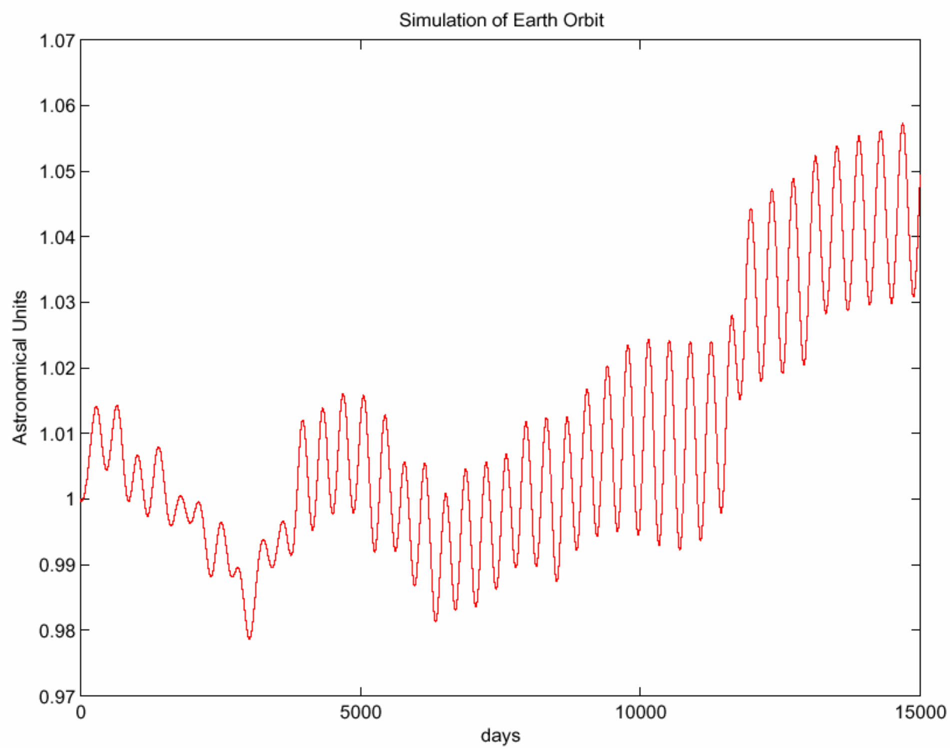

Figure 7: Earth's Distance from the Sun Throughout the Entire Duration of the Simulation

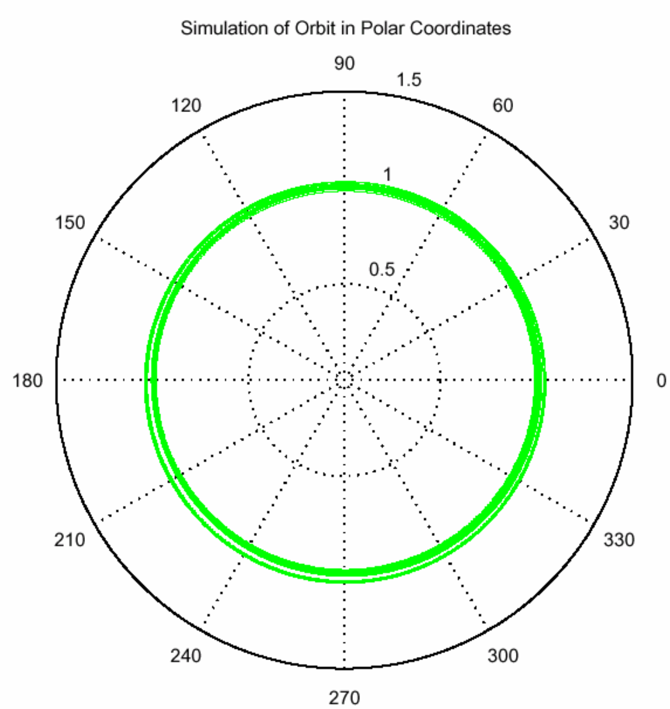

Figure 8: Earth's Orbit Around the Sun Throughout the Entire Duration of the Simulation

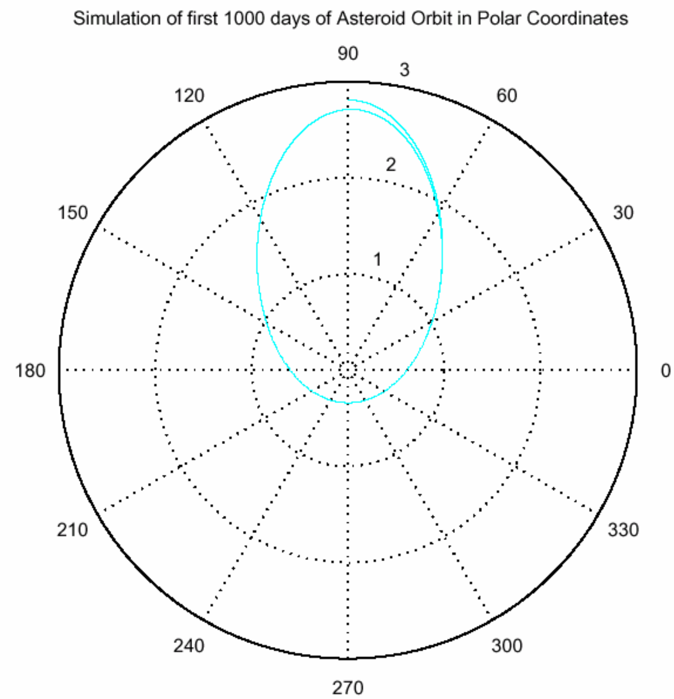

Figure 9: Orbit for the First 1,000 Days of Our Asteroid

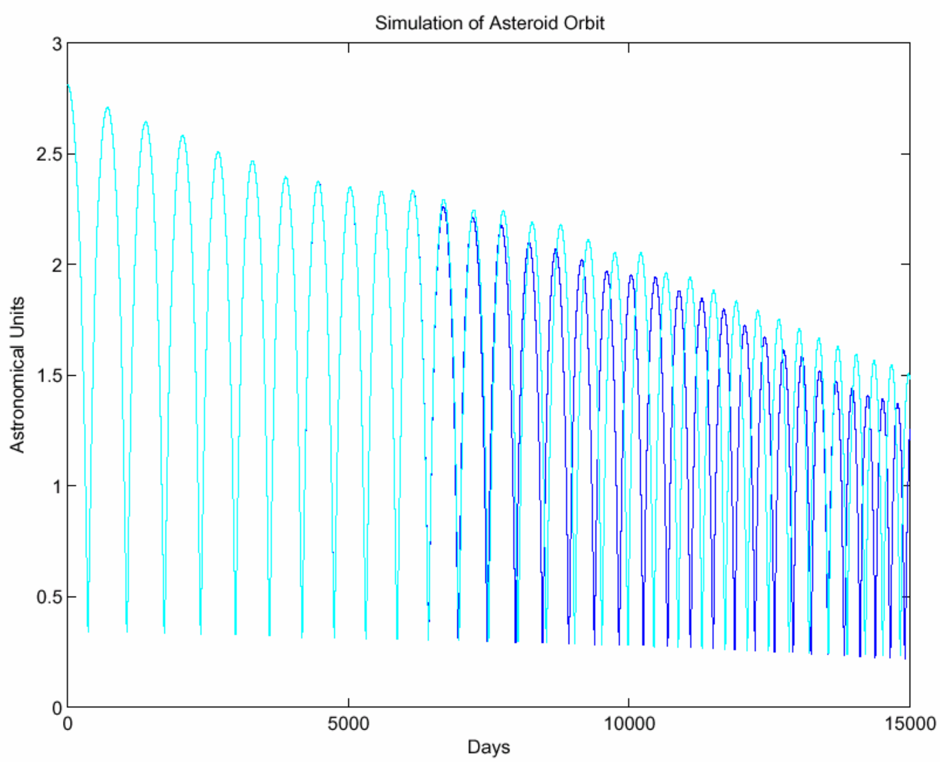

Figure 10: Asteroid's Distance from Sun. Blue line - Without Thrust. Cyan line - With Thrust.

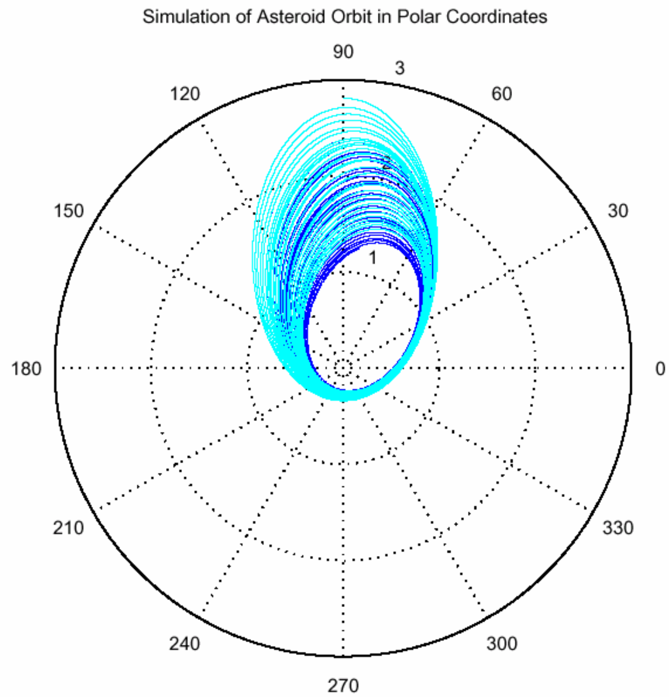

Figure 11: Simulation of the Asteroid's Orbit. Blue line - Without Thrust. Cyan line - With Thrust.

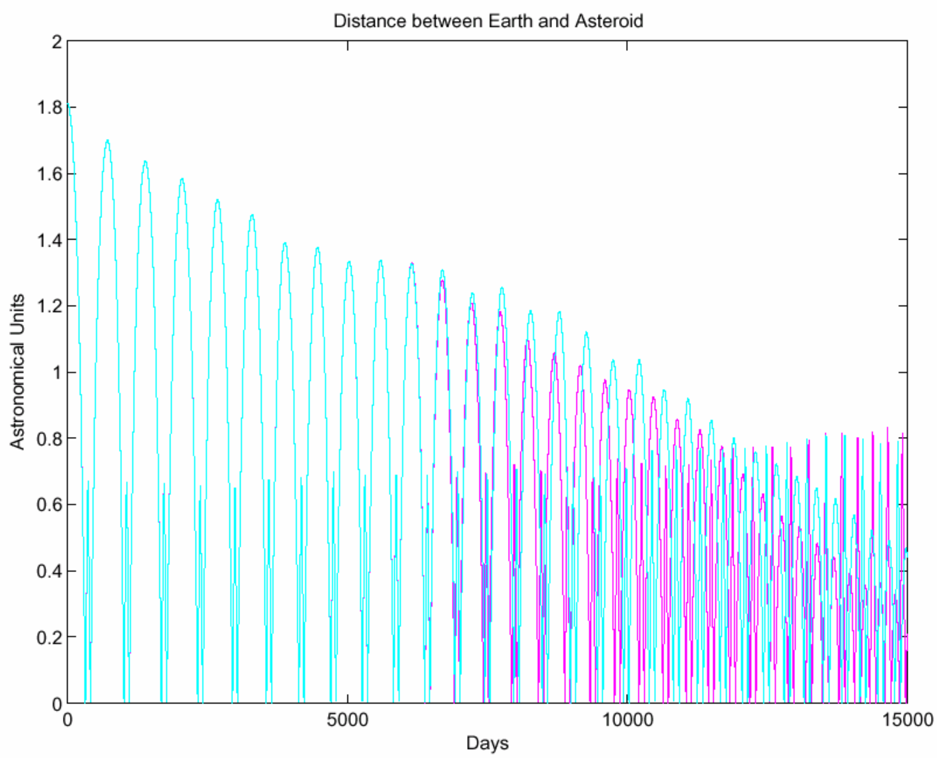

Figure 12: Absolute Distance Between the Asteroid and Earth.
Magenta line - Without Thrust. Cyan line - With Thrust.

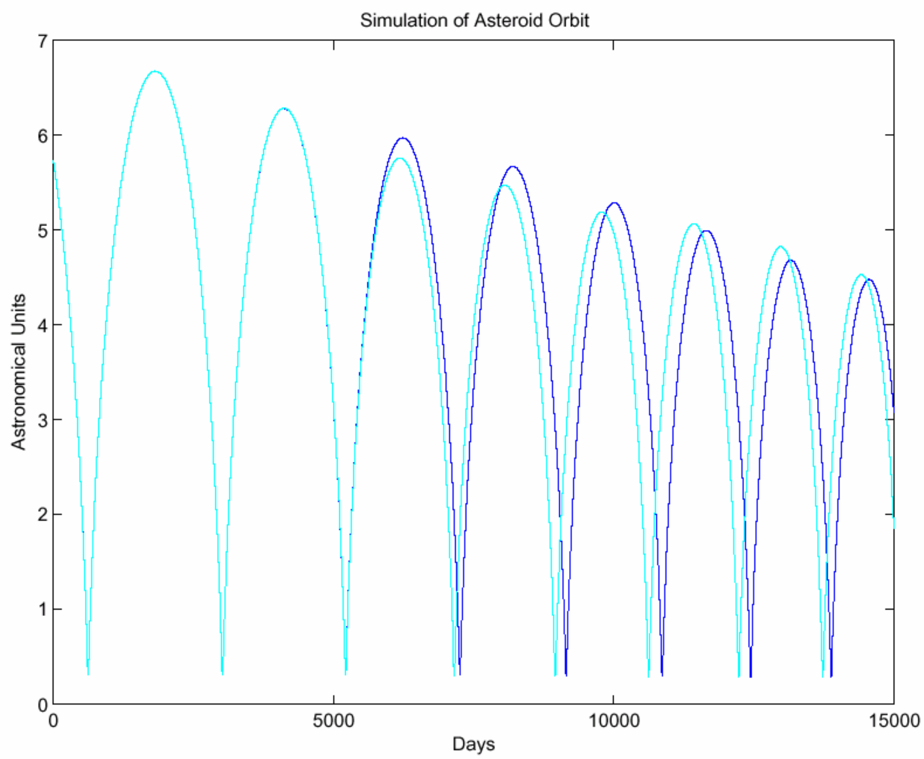

Figure 13: Distance from Sun to Asteroid with Different Starting Position

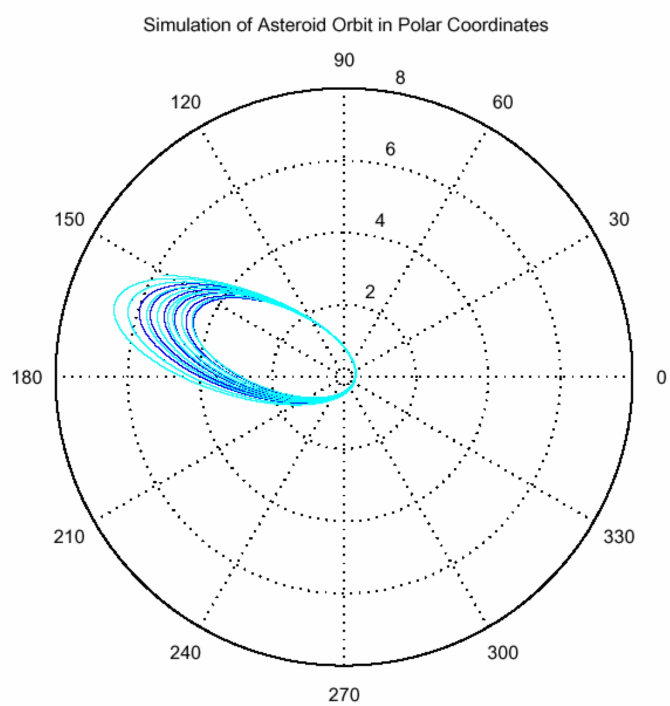

Figure 14: Orbit of Asteroid with Different Starting Position

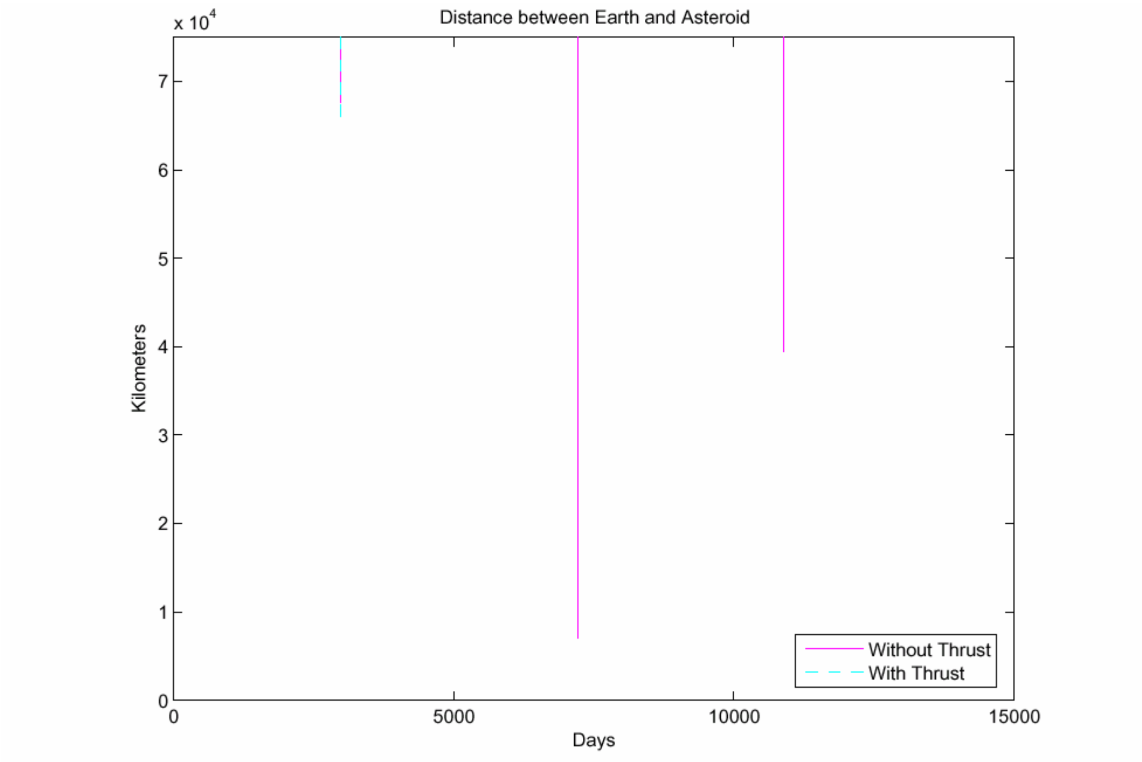

Figure 15: Distance Between the Earth and an Asteroid with Different Starting Position

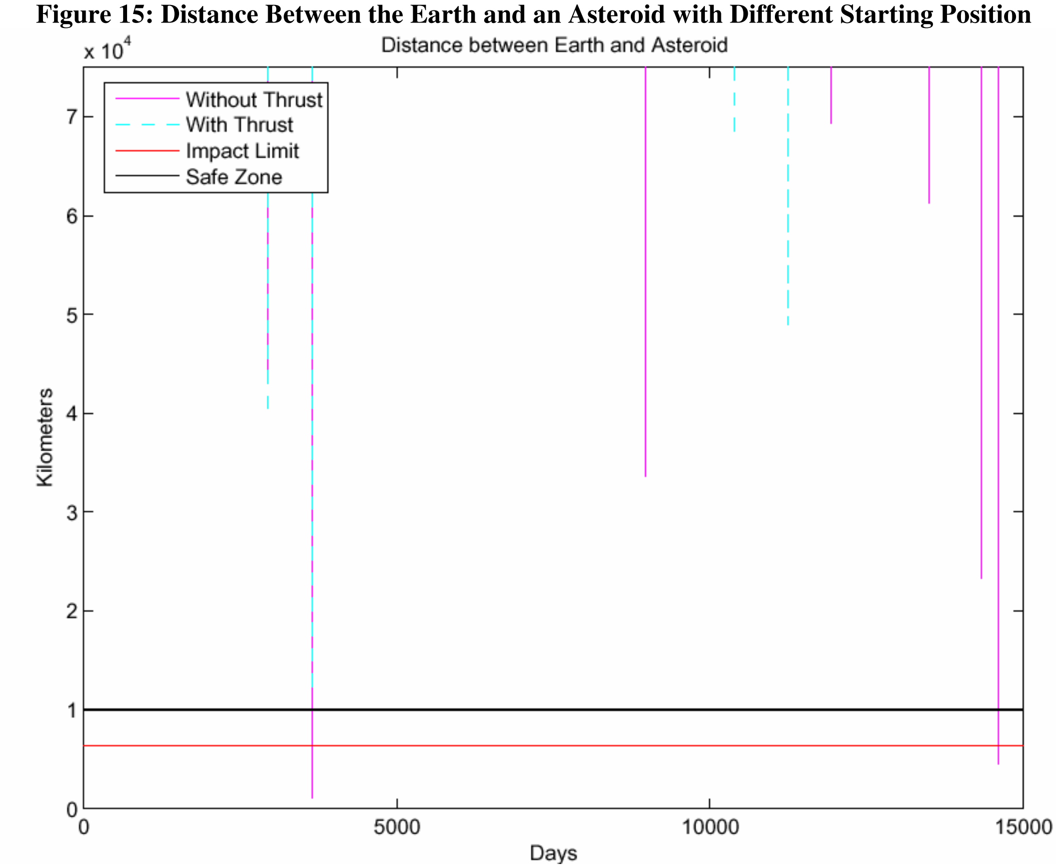

Figure 16: Distance Between the Earth and Our Asteroid

Figure 16 shows how close our asteroid gets to the earth both with and without the thrust from our laser. Since the radius of the earth is 6,300 kilometers, the minimum that the asteroid would have to clear us is by that much, corresponding to the red line on our graph. We've decided that, given the number of approximations and potential rounding errors, clearing the earth by 10,000 kilometers would be a safe assumption. This chart was made assuming 500 trillion joules of energy would be outputted over 10 years, which equates to roughly 1.584 megawatts of continuous output.

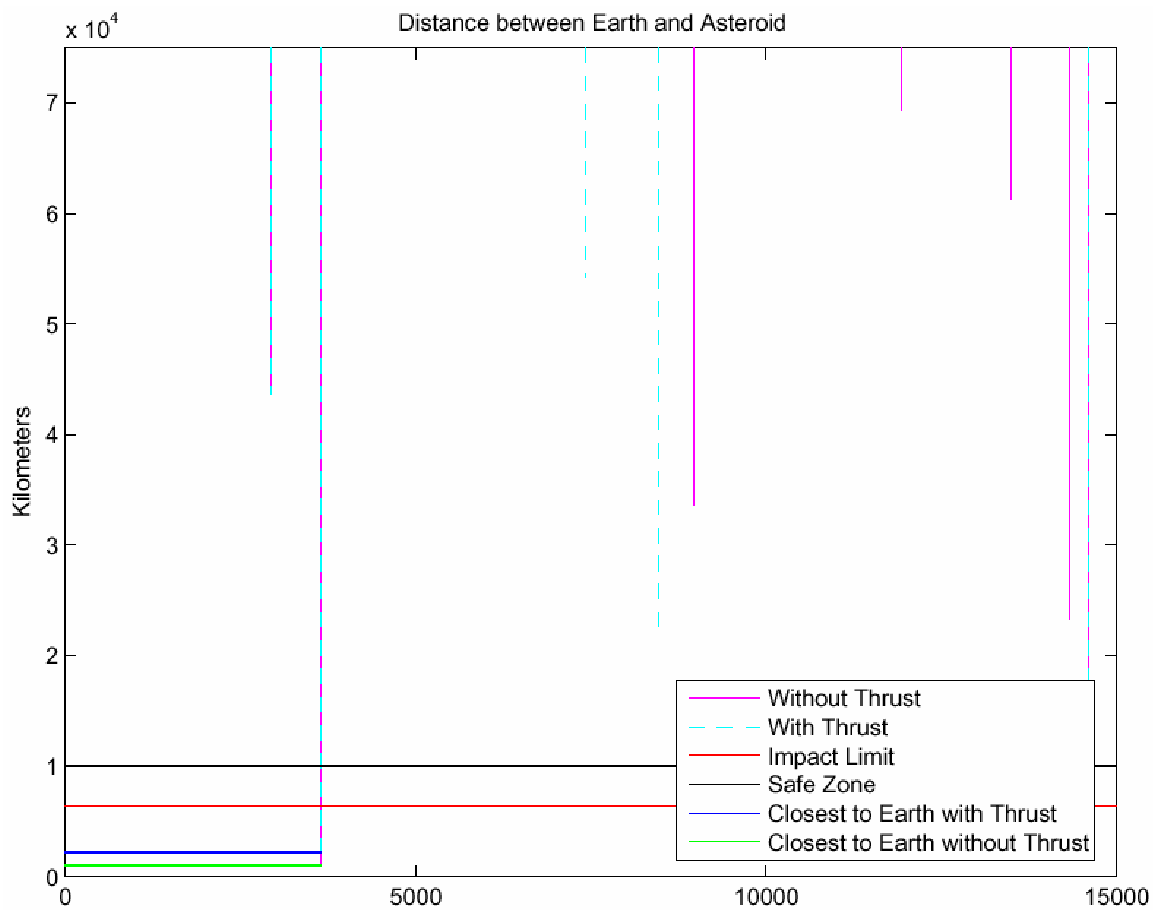

Figure 17: Distance Between the Earth and an Asteroid Ten Times as Massive

Next, we determined how much of a difference the same strength laser over the same amount of time would have on an asteroid 10 times as large. This yields a divergence of only 1,050 kilometers, which would still not be enough to prevent a collision.

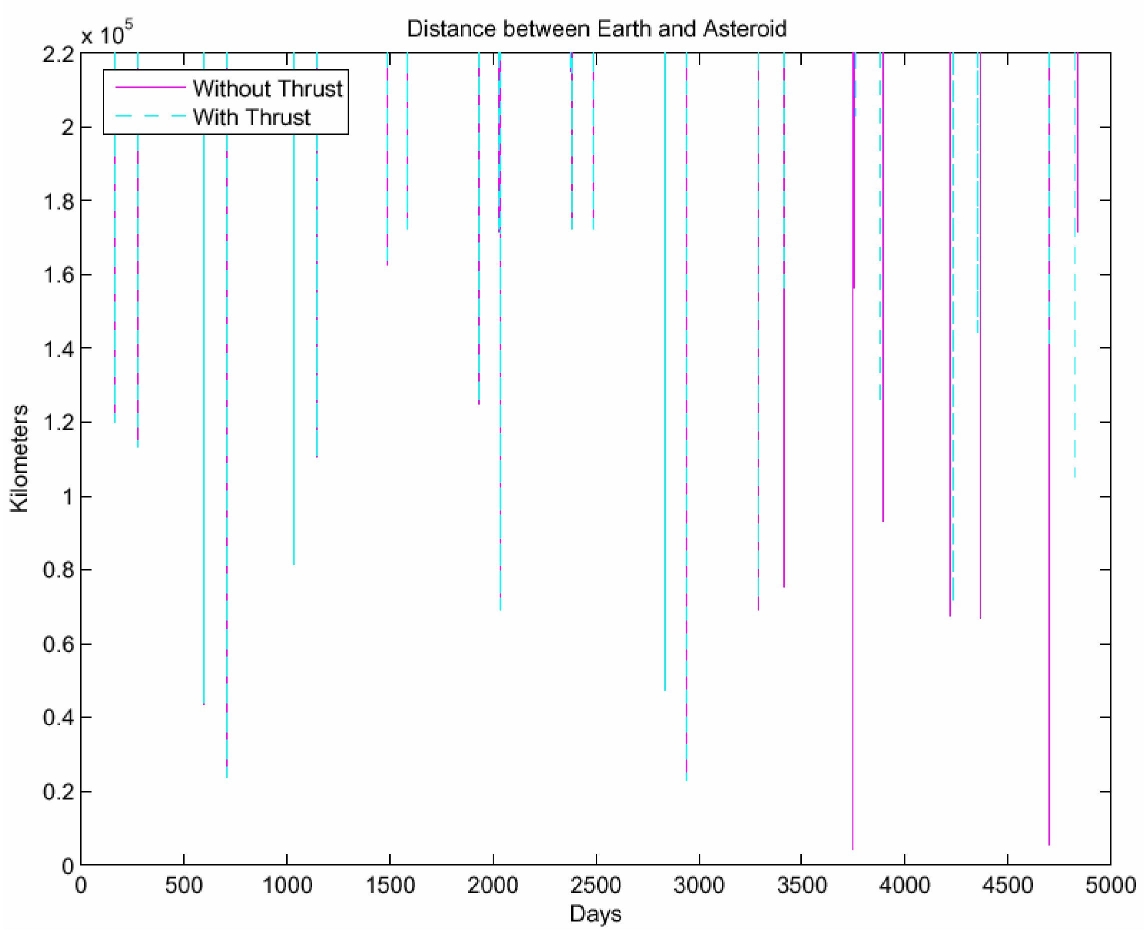

Figure 18: The Effect of Our Thrust on an Asteroid Three Times as Fast

Finally, we looked at the original asteroid, with a different starting position and velocity. Rather than 8.05 km/sec, we tried a value of 23 km/sec, and instead of a starting radius of 2.81005, we used 0.81005. This resulted in an entirely new orbit, as shown above. Using only 161 trillion joules of energy, we were able to divert the first collision with earth by over 18,000 km. These experiments give us two vital pieces of information. First, that the faster an asteroid is moving, the easier it is to alter its course. At 23 km/sec, we used 3 times less energy to move it 10 times farther. Second, the divergence of the asteroid directly corresponds to its mass. The increased factor of 10 in its mass caused the divergence to decrease by the same factor.

There are many advantages and disadvantages to using a program such as this in order to calculate thrust. A major advantage to creating this program is the significance of the information provided by the program's results. This program allows the user to plot out the path of an asteroid and the amount of thrust needed in order to prevent an asteroid from colliding with earth. A disadvantage to using a program to figure out the calculations needed is that the programmers often have to round off numbers for simplification. In this program, for example, we use approximations in many of the numbers. This is more due to rounding calculations that appear throughout the conversions between units. Therefore, the results of this program are an approximation and not an exact model of the results that will occur in a real-life situation. However, these approximations are enough of a basis for an accurate conclusion to be based off of.

Chapter Nine:

Using Lasers to Divert Asteroids

Introduction to Lasers

A laser is a mechanism by which the intensity of light is increased creating a highly directional beam of light with a specific wavelength. “Laser” is an acronym for “light amplification by stimulated emission of radiation.” Stimulated emission occurs when a beam of light excites other atoms to emit light of the same wavelength and amplitude and in the same direction of the original beam.

The light from a laser is coherent, meaning it is emitted at the same wavelength and amplitude and in the same phase. This is different from light beams which are typically incoherent. Incandescent light, for example, is incoherent because it is emitted in wavelengths between 300 and 1,600 nanometers. Incoherent light is emitted in many different phases and is not nearly as directional as laser light. For this reason, laser beams can be focused to much smaller radii than light beams.

A laser typically consists of a gain medium and a mirror arrangement called an optical resonator[139]. Inside the gain medium atoms are excited by a flashlamp or voltage applied between electrodes. The excited atoms release photons of light as their electrons move to lower energy levels. The photons of light bounce between the mirrors positioned at either end of the gain medium. As the light beams bounce back and forth they become highly directional. These light beams are eventually directed out of one end of the medium through one of the mirrors which is only partially reflective. Figure 6 shows a typical laser setup including the gain medium (labeled laser medium), a flashlamp, and the optical resonator.

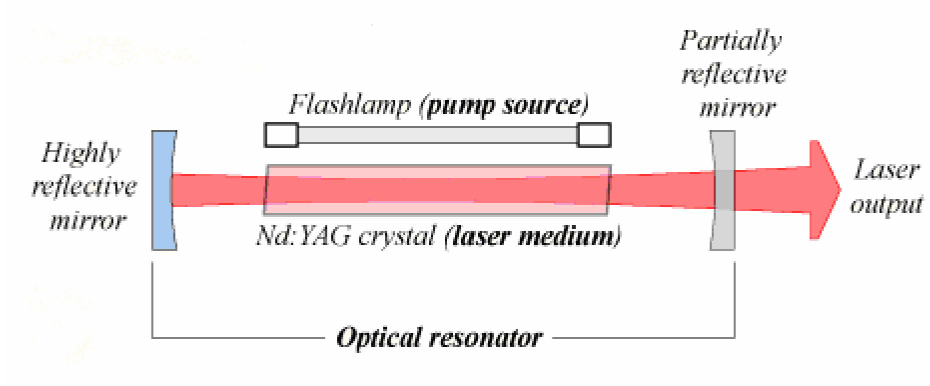

Figure 19: Typical Laser Setup

Lasers are used in many situations including surgical procedures, manufacturing, welding, cutting, surveying, communications, and in grocery store scanners. The tiny beam that can be obtained with a laser allows for highly precise surgical procedures. The high power a laser beam outputs allows for ease in cutting through materials such as steel for manufacturing. The laser has become a very precise and powerful tool used in many situations today.

Laser Choice for Asteroid Diversion

To use lasers as a defense mechanism against asteroids is a very large project. In planning this project you first must investigate the various types of lasers that are available and decide which would be best for such a large scale operation. There are four fundamental types of lasers in use today: solid-state lasers, gas lasers, dye lasers, and semiconductor lasers. The primary difference between the types is the material found in the gain medium. Different gain mediums allow for different power outputs as well as different efficiencies. An investigation into the different types of lasers will help to decide which would be best and most efficient for use in space.

The gain medium of a solid-state laser is a cylindrical transparent glassy or crystalline material. Crystals used in solid-state lasers are typically sapphires, garnets, or rubies[140]. A flashlamp is used with solid-state lasers to excite the electrons inside the solid gain medium. The energy produced by a solid-state laser depends largely on the volume of the gain medium. Gain medium rods range from ¼ inch in diameter and three inches long to ½ inch in diameter and six inches long. The largest solid-state laser systems use rods one inch in diameter and fifteen inches long[141].

The most commonly used type of gas laser is the Neodymium laser[142]. The Neodymium laser consists of neodymium atoms distributed at about 0.7% in yttrium-aluminum-garnet (YAG) crystals[143]. A YAG crystal has a limited growth size; therefore a similar neodymium laser has been developed with a glass host rather than a YAG host. Both glass and YAG neodymium lasers have high thermal conductivity and remove excess heat during operation which allows for high repetitive rates, reaching several pulses per second. Neodymium lasers can be operated to produce 20 joules per pulse at 20 pulses per second[144]. Neodymium lasers are used in military applications and for drilling through solid materials[145].

Gas laser gain mediums consist of a chamber filled with gas. The gas may be carbon dioxide, argon, helium-neon, or several other gases. The chamber has high voltage applied between electrodes. When the voltage is applied, electrons within the gas are excited and bump into other gas atoms. The collision creates more excitement and the emission of photons[146]. Depending on the type of gas used in the gain medium, the size of gas lasers range from 10 centimeters to 200 centimeters in length with varying power outputs. The largest and most powerful gas laser is the carbon dioxide laser which can be built the size of buildings[147]. Gas lasers are used today in surveying, laser printing, and eye and tissue surgery[148].

The carbon dioxide laser functions just like a gas laser except the entire CO_2 molecule bounces back and forth inside the optical resonator instead of just the electrons[149]. Carbon dioxide lasers range from tiny versions producing milli-watts of power to building sized versions producing over 10,000 Joules of energy. As well as being very powerful, carbon dioxide lasers are highly efficient. They typically range between 10% and 15% efficiency, but can reach 30%[150]. Carbon dioxide lasers are typically used for cutting and welding.

Dye lasers contain a liquid gain medium such as alcohol in which dye molecules are dissolved. Different dyes have different colors which creates laser beams of different wavelengths. Excitation of electrons in the liquid gain medium is typically achieved through the use of additional lasers or flashlamps. These pumping sources are very inefficient and require a great amount of input power. Prisms are often used in the optical resonator to tune dye lasers over a very broad spectrum of wavelengths. Using several dyes allows the dye laser to be tuned over the entire visible light spectrum[151]. The dye laser's ability to be tuned makes it an optimal laser for medical procedures and spectroscopy[152].

Semiconductor lasers are made up of an elongated gain region typically made of a gallium-arsenide crystal. Inside this semiconductor gain region, basic p-n junctions are formed. In a p-n junction, free electrons in n-type diffuse into p-type under forward bias. In the p-region they meet a majority of holes & recombine. Excess energy after the combination is emitted as light[153]. The light reflects off parallel faces of the crystal and gathers to be emitted as a laser beam. Semiconductor lasers are the smallest lasers in use today at about the size of a grain of salt. Semiconductor lasers output a very small power and run at very short wavelengths. Semiconductor lasers are primarily used in communications and in range finders[154].

To deflect an asteroid headed toward earth, a laser has to have a high energy output to provide a push against the surface of the asteroid. A laser that is used for cutting or drilling would be beneficial if it bore away at the asteroid while heating up the surface to extreme temperatures, resulting in small explosions that propel the asteroid away. While providing a push against the asteroid, the cutting of the laser would take mass off the asteroid, even if it is just grams of rock, over the course of many years, this will make the asteroid easier to accelerate away from earth.

The divergence of the laser beam will not be a factor in space. With no dust or particles in space, the laser beam will not have any material to bounce off of. This means that along the infinite path of the laser, the beam will not increase in diameter. The smaller diameter means that the energy of the laser will be focused on a single small area, rather than a large area. The same amount of energy acting over a larger area would mean less of a force pushing on the asteroid. In effect this would mean that the laser will have enough power to bore a hole in the asteroid rather than just heating up the surface.

Taking into account the efficiency as well as the overall power output of each type of laser, the gas lasers, in particular the carbon dioxide laser, seems to be the most likely choice for asteroid diversion. The carbon dioxide laser currently has the most power output of all lasers in use. The carbon dioxide laser, being a gas laser, is also more durable than a solid-state laser containing a crystal. This is important for transportation of the laser to the moon where it will be in operation. There is little risk of the gas laser being damaged like a crystal based laser might. The carbon dioxide laser can be built on a very large scale which will be needed to move or bore away at an asteroid of one kilometer in diameter. The carbon dioxide laser is also the most efficient laser in use at this time which is important for use in space. Only a limited supply of power can be generated while on the moon so the more efficient the laser during operation, the less input power will be needed. The carbon dioxide laser is a good choice for using in asteroid diversion because it has the capability to provide large energy outputs, it is very efficient for use on a moon base, and it is capable of cutting into materials such as iron, a major component of typical asteroids.

Laser Specifics

By using the program we created, orbit02.m, it was determined that the minimum amount of energy we need to divert an asteroid of $1.6x10^9$ kilograms would be 500 trillion joules. Since $Watts = \frac{Joules}{\sec}$, this results in an average of 1.584 megawatts of continuous output applied over ten years. A typical carbon dioxide laser has a 15 to 20 percent efficiency ratio of input to output. Therefore, between eight and ten megawatts of input energy is needed to provide the necessary output of the laser. Carbon dioxide lasers can reach power outputs of 10 kilowatts per meter[155]. To achieve the required 1.584 megawatts of continuous output, we would need a total of 158.4 meters of gain medium. This produces the light intensity which becomes the laser beam.

The size of the laser being used will not be a problem because the gain medium can be folded back upon itself reducing the overall length of the laser. Transportation of the laser to the moon may be difficult if the laser is built on earth and transported as a whole. To alleviate this problem, multiple smaller lasers can be built and combined through one lens to form one laser beam. In doing this, the overall length of the laser will be greatly reduced, while the diameter of the laser is increased. The laser will then be easier to transport and operate once in place on the moon.

The main problems with the use of lasers on earth are divergence and diffraction. The divergence of a laser beam is the increase in beam diameter from the opening of the lens from which the beam emerges to the final destination[156]. Divergence occurs on earth because of the atmosphere and what is contained within it. For this reason, divergence of the laser beam will not occur in space because there is no atmosphere. Like divergence, diffraction is caused by minute collisions between the laser beam and the earth's atmosphere. Diffraction is the apparent bending of the laser beam due to the obstacles it encounters. In space, the only obstacle that will be encountered will be the asteroid itself. Therefore, both divergence and diffraction do not need to be taken into account when building and calculating the lasers proposed to be put on the moon in order to deflect and asteroid.

In order to achieve the most optimal defense grid with the carbon dioxide lasers on the moon, a specific placement of the lasers is required. We propose four groups of lasers should be placed on the moon. One group would be placed on either pole and two on opposite sides of the equator. In placing a group of lasers on each pole, we will be able to adequately aim at and focus on an incoming asteroid regardless of where it is in the solar system. Placing additional groups of lasers along the equator will also benefit us because they will provide a backup to the primary lasers in defending against incoming asteroids from all directions.

To obtain the 1.584 megawatts of continuous output, we propose that each of the lasers located at the poles be able to output 1.5 megawatts. This would provide more than enough output to divert an asteroid of $1.6x10^9$ kilograms over ten years. We also propose that the lasers on the equator be able to output at 0.75 megawatts each. This is because these lasers are primarily used for backup and each laser would only be able to target the asteroid for about 50 percent of the time due to the moon's orbit around the earth.

To power the groups of lasers, we would suggest using the recently developed small, sealed, transportable, autonomous reactor (SSTAR) system. The US is developing these reactors to provide powerful, reliable energy to developing countries, with the hope that the fissile material would be unable to be extracted by rogue factions[157]. A 10 megawatts version has been planned, at a size of approximately 6 meters tall and weighing 200 tons. Currently, our most powerful earth-to-space launcher is the Space Shuttle, which can only transport 30 tons at a time. Given that we would have to provide one SSTAR system per group of lasers, this means we would have to make 28 trips to get all the materials into space.

Conclusion

Humankind has always been inquisitive about the sky. Astrology is a common theme among past civilizations. Heavenly bodies have been identified as gods in Mayan, Eskimo, Indian, Greek, Egyptian, and Celtic cultures, among others. Their interest has passed down to us today through things such as our calendar, understanding of the cycles of the moon, and constellations. Our interest in space has always thriven, and with the development of recent technology, we possess the ability to now travel there.

Our ancestor's curiosity of space has been passed down through the generations. On the cusp of a new frontier, new opportunities are being developed that are profitable only in space. The technology of today allows entrepreneurs to expand their reach. Such opportunities include solar power satellites, crystal growth, and global positioning systems, as well as satellite broadcasting and personal communication. These advancements in technology allow mankind to tap into the previously untouched resources in space.

As technology advances, so does our need to expand. One of the reasons for our interest in space exploration is the survival of the human race. Wars, biological attacks, plagues, global warming, natural disasters, and near earth objects all have the potential to wipe out most human life on earth in a very short period of time. By being a space-faring society, we can use satellites for monitoring the earth for changes in climates, for tracking countries in possession of weapons of mass destruction, and for observation of near earth objects. Additionally, we could seek out a new planet to inhabit, should the worst-case scenario happen to earth.

One such scenario involves near earth objects. Astrologers have studied objects in our solar system through the use of telescopes for many years. They study comets and asteroids alike, then track their paths and ensure that there is no immediate threat to earth. Occasionally, Astrologers examine an asteroid which has crossed the earth's path but was never previously documented. This unawareness of an asteroid's path leads many to wonder about what defense system is in place, in the event that an asteroid threatens a collision with earth.

As a defense system, it is proposed that the moon be a center location for an observation post. The post would be able to monitor asteroids previously unseen from earth and would be located in a crater previously induced by an asteroid. Boundaries which currently prohibit the best telescopes on earth from being able to monitor an asteroid become obsolete. For instance, the solar glare of the sun which blocks out many asteroids during the day on earth would be nullified from the crater surrounding the observation post. Also, different methods could be put into practice to divert an asteroid. The base could be used as a launching point for experimenting in the deflection of near earth objects.

Scientists have been discussing how to prevent an asteroid collision with earth for many years. The most feasible theory to date is deflecting the asteroid by using some type of continuous thrust to move it over a period of time. Typical theories involving thrust are the use of solar sails, missiles, chemical or electrical propulsion, and the use of lasers. The idea behind solar sails is that a sail could be attached to the asteroid to collect solar winds. The winds would then propel the asteroid in the given direction to disrupt its orbit. Scientists who hope to deflect asteroids through explosions theorize about missiles. Missiles would be launched into the asteroid causing an explosion which would knock it off course. The concept behind chemical or electrical propulsion is that they attempt to accelerate the asteroid by attaching thrusters to the asteroid itself. Thus, applying enough force to give the asteroid a new orbit. The theory behind lasers uses a similar approach to diverting the asteroid. Both methods use continuous propulsion as a means of deflection. Lasers, on the other hand, send a pulsating beam with enough force to gradually alter the path of the asteroid. The force applied is due to the laser superheating a small area of rock, causing it to explode, which provides a force away from earth.

In order to find out which theory is most feasible, we designed a program that would determined the amount of thrust needed to adequately divert an asteroid from a collision with earth. We took into account the sun's gravitational pull, the earth's orbit, the asteroid's orbit, and many other factors when designing the program. It was concluded that 500 trillion joules is needed. With this conclusion, it is apparent that some of the methods of diversion would not be feasible with our current technology. One method that remained feasible is the use of lasers to divert the asteroid.

The program designed for this project allowed us to conclude that lasers would be the only applicable method of diversion with our current technology. A pulsating laser beam would be sent to the asteroid. This beam would heat up the surface of the asteroid to the point where the asteroid's surface would have many explosions. The explosions would gradually thrust the asteroid in the opposite direction, altering the path. To adequately divert the asteroid it would require 1.584 megawatts of continuous output to produce the 500 trillion joules needed. Instead of one massive laser, we intend to use four lasers. Two large lasers supplying 1.5 megawatts, placed at either pole of the moon, and two smaller lasers, placed on both sides of the equator of the moon, would supply 0.7 megawatts as a backup to the main lasers. This is a fully redundant system, in case of system failure while on the moon. To power this, we propose that one nuclear power plant be constructed for each laser. Each nuclear power plant outputs 10 megawatts of power. This is more than enough to supply our lasers.

Researching for this IQP, we have discovered many intriguing ideas of how to deflect an asteroid. We even constructed a program calculating the amount of thrust needed to deflect a given asteroid. The program takes into account many factors, but due to time constraints, leaves out others. In order for other groups to benefit from this IQP, we propose that other hard working individuals take upon the task of finishing the program for us. In order to do so, the group would add in other factors which may alter the trajectory of the asteroid. Such factors which need to be resolved include the moon and other planets' gravitational pull on the asteroid, modifying the program to take into account an actual asteroid and its trajectory, using the actual statistics of real lasers rather than the hypothetical one listed, calculating the minimum amount of energy needed to divert an asteroid, and other such factors. We hope that someday, our efforts are put to good use.

Chapter One Resources:

Celtic/Eskimos Resources

The Celtic Cosmos. (1999). Retrieved November 2, 2004, from The Sacred Fire Web site: http://www.geocities.com/~huathe/cosmology.html

Ellis, P.B. (2001). *Early Irish Astrology: An Historical Argument*. Retrieved November 2, 2004, from Centre Universitaire de Recherche en Astrologie Web site: http://cura.free.fr/xv/11ellis1.html

Ilyin, V. (2004). *Mysteries of lost civilizations.* Retrieved November 3, 2004, from PRAVDA.Ru Web site: http://english.pravda.ru/printed.html?news_id=11888

Rasinkangas, R. (1995). *Auroral folklore.* Retrieved November 3, 2004, from the Space Physics Group of Oulu Web site: http://www.oulu.fi/~spaceweb/textbook/ aurora/folklore.html

Shand, R. (n.d.). *Shamanism A Master of Ecstasy.* Retrieved November 2, 2004, from Illuminations Web site: http://www.mystae.com/restricted/streams/scripts/ shamanism.html

Mayan/Indian Resources

Berger, M. (2004). *The Maya Astronomy Page.* Retrieved November 2, 2004, Web site: http://www.michielb.nl/maya/astro.html

Crystal, E. (2004). *Ancient India-Astronomy.* Retrieved November 3, 2004, from Ellie Crystal's Metaphysical and Science Website Web site: http://www.crystalinks .com/indiastronomy.html

Crystal, E. (2004). *Mayan Astronomy.* Retrieved November 2, 2004, from Ellie Crystal's Metaphysical and Science Website Web site: http://www.crystalinks .com/mayanastronomy.html

Major-Jenkins, J. (1994). *Tzolkin: Visionary Perspectives and Calendar Studies.* Borderland Sciences Research Foundation.

Prabhupada, A.C.B.S. (n.d.) *Planetary Deities & Zodiac.* Retrieved November 3, 2004, from The Black Peacock Art Gallery Web site: http://www.goloka.com/docs/ gallery/zodiac/planetary-deities.html

Saunders, C. & Ramsey, P. (2004). *Mayan Mythology: WORLD-TREE.* Retrieved November 2, 2004, from www.godchecker.com Web site: http://www.godchecker.com/pantheon/mayan-mythology.php?deity=WORLD-TREE

Sumerian/Aborigines Resources

About Astrology: Fascinating Facts. (2004). Retrieved November 1, 2004, Web site: http://www.star4cast.com/index2f.asp?page=aboutastrology%2Easp

Ancient Mesopotamia. (1998). Retrieved November 2, 2004, from Federal Research Division of the Library of Congress Web site: http://countrystudies.us/iraq/12.htm

Curnow, P. (n.d.). *Aboriginal Skies.* Retrieved November 1, 2004, from the Astronomical Society of South Australia Web site: http://ching.apana.org.au/%7Epaulc/loreaussie.html

d'Arc, J. (n.d.). Retrieved November 2, 2004, from The Eye's Behind Web site: http://www.subversiveelement.com/Planet_X.html

Mountford, C.P. (1956). Arnhem Land: art, myth and symbolism. *Records of the American-Australian Scientific Expedition to Arnhem Land,*1.

Mountford, C.P. (1958). *The Tiwi, Their Art, Myth and Ceremony*. London: Phoenix House.

Smith,A. (n.d.). *Australian Aborigines.* Retrieved November 3, 2004, Web site: http://www.astronomy.pomona.edu/archeo/Other%20student%20web%20sites/Alex%20N%20Smith/aborigines/index.htm

Egyptian/Greek Resources

Graves, R. (1981). *Greek Myths.* Garden City, NY: Doubleday.

Hare, T. (1995). *Remembering Osiris: number, gender, and the word in ancient Egyptian representational systems.* Stanford, CA: Stanford University Press.

Vernant, J. P. (1993). *Myth and society in ancient Greece*. Cambridge, MA: Zone Books.

Chapter Two Resources:

Commercial Application Resources

Dunsmore, B. (2000). *Telecommunications technologies reference : a comprehensive guide to North American and international telecommunications standards.* Indianapolis, IN: Cisco Systems, Inc.

Spencer, J. (2003). *Global Positioning System : a field guide for the social sciences*. Malden, MA: Blackwell Publishers.

Space Crystals Resources

Barry, P.L. (2001). *Conjuring Crystals.* Retrieved November 15, 2004, from Science@NASA Web site: http://science.nasa.gov/headlines/y2001/ast11dec_1.htm

Human Spaceflight: Life Sciences.(n.d.) Retrieved November 15, 2004, from the European Space Agency Web site: http://www.spaceflight.esa.int/users/file.cfm?filename=sxs-life#top

Kloeppel, J. (2000, March 1). Scientists propose growing better semiconductor crystals in space. *University of Illinois at Urbaba-Champaign News Bureau,* Web site: http://www.sciencedaily.com/releases/2000/06/000602074630.htm

Szofran, F. (2004). *Crystal Growth Descriptions and Definitions.* Retrieved November 16, 2004, from Reduction of Defects in Germanium Silicon Web site: http://science.nasa.gov/ssl/msad/rdgs/Descriptions.html

Why Grow Crystals in Microgravity? (n.d.). Retrieved November 15, 2004, from Biological Crystal Growth in Space Web site: http://crystal.nasa.gov/general/why_grow_crystals.html

GPS Resources

Brian, M. & Harris, T. (n.d.). *How GPS Receivers Work.* Retrieved November 14, 2004, from howstuffworks.com Web site: http://electronics.howstuffworks.com/ gps1.htm

Dana, P.H. (1994). *Global Positioning System Overview.* Retrieved November 15, 2004, from the Department of Geography, The University of Colorado at Boulder Web site: http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html

Kincaid, S. (2002, November 1). Reliable GPS is here. *Grounds Maintenance,* Web site: http://grounds-mag.com/mag/grounds_maintenance_reliable_gps/

Uses for GPS. (n.d.). Retrieved November 14, 2004, from GIS Lounge Web site: http://gislounge.com/features/aa050901a.shtml

Solar Power Satellites Resources

Levine, R. (2001). *Space Solar Power: Objectives & Goals.* Retrieved November 13, 2004, from NASA: Space Solar Power Web site: http://spacesolarpower.nasa.gov/

Mankins, J.C. (n.d.). *A Fresh Look at Apace Solar Power: New Architectures, Concepts and Technologies.* Retrieved November 15, 2004, from the International Astronautical Federation Web site: http://spacefuture.com/archive/a_fresh_look_at_space_solar_power_new_architectures_concepts_and_technologies.shtml

Potter, S. (1998). *Solar Power Satellites: An Idea Whose Time Has Come.* Retrieved November 15, 2004, Web site: http://www.freemars.org/history/sps.html

Solar Power Satellites. (2003). Retrieved November 15, 2004, from US Department of Energy: Energy Efficiency and Renewable Energy Web site: http://www.eere.energy.gov/consumerinfo/factsheets/l123.html

Solar Power Satellites (SPS). (n.d.). Retrieved November 15, 2004, from Sol Company Web site: http://members.nova.org/~sol/station/sps.htm

Wie, B. & Roithmayr, C.M. (2001). *Integrated Orbit, Attitude, and Structural Control Systems Design for Space Solar Power Satellites.* Retrieved March 20, 2005, from NASA tech reports Web site: http://techreports.larc.nasa.gov/ltrs/PDF/2001/tm/NASA-2001-tm210854.pdf

Chapter Three Resources:

Satellite Telephone Resources

Globalstar Satellite Phones and More at Globalcom. (n.d.). Retrieved November 29, 2004, from Globalcom Web site: http://www.globalcomsatphone.com

Iridium Announces Subscriber And Revenue Growth Rates. (2004, November 30). *SpaceDaily Your Portal To Space* Web site: http://www.spacedaily.com/news/ satellite-biz-04zzzzzzzzx.html

Iridium Satellite one system, globally. (2005). Retrieved February 25, 2005, from Iridium Satellite LLC Web site: http://www.iridium.com

Satellite Telephone Information. (n.d.). Retrieved November 29, 2004, from InsideAirports.com Web site: http://www.insideairports.com/telephone/Satellite/

Satellite Broadcasting Resources

Bonsor, K. (n.d.). *How Satellite Radio Work.* Retrieved November 30, 2004, from howstuffworks.com Web site: http://www.howstuffworks.com/satellite-radio.htm

DirecTV. (n.d.) Retrieved February 28, 2005, from Wikipedia The Free Encyclopedia Wed site: http://en.wikipedia.org/wiki/Directv

Kingsbury, K. (2004, August 4). Satellite radio captures ears of millions. *CNN.com*, Web site: http://www.cnn.com/2004/TECH/science/07/30/satellite.radio/

Satellite-TV-Mania. (2003). Retrieved November 30, 2004, from Dish Network Web site: http://www.satellitetvmania.com/briefhistory.htm

Soong, R. (2004). *Satellite Radio.* Retrieved November 30, 2004 from Zona Latina: Latin American Media & Marketing Web site: http://www.zonalatina.com/ Zldata355.htm

Walczak, J. (2004). *Facts About Satellite Radio's History and Future.* Retrieved November 29, 2004, from About.com Web site: http://4wheeldrive.about.comod/ autoparts4x4accessories/a/satelliteradio_5.htm

Chapter Four Resources:

Biological Warfare Resources

Dixon, P. (1995). *The Genetic Revolution: Chapter 7: Takes a virus to catch a virus.* Retrieved November 8, 2004, Web site: http://www.globalchange.com/books/Genes7.htm

History of Biological Warfare. (2001). Retrieved November 8, 2004, from NPR Web site: http://www.npr.org/news/specials/response/anthrax/features/2001/oct/011018.bioterrorism.history.html

Red Lies. (n.p.) *cbc.ca* Web site: http://www.tv.cbc.ca/national/pgminfo/redlies/index.html

Sars biological weapon? (2003, November 4) *News 24* Web site: http://www .news24.com/News24/World/News/0,,2-10-1462_1346560,00.html

Silverman, S. (n.d.). *Bubonic Plague.* Retrieved November 9, 2004, from Useless Information Web site: http://home.nycap.rr.com/useless/bubonic_plague/

Plagues

Nohl, J. (1974). *The Black Death; A Chronicle of the Plague Compiled from Contemporary Sources.* New York, NY: Harper & Row.

Natural Disaster Resources

Cowen, R.C. (2004, August 19). Global warming's surprising fallout. *The Christian Science Monitor,* Web site: http://www.christiansciencemonitor.com/2004/0819/p16s01-sten.html

Dewitt, S. (2004). *Retreating Glaciers Spur Alaskan Earthquakes.* Retrieved November 9, 2004, from NASA Web site: http://www.nasa.gov/vision/earth/environment/glacier_quakes.html

Nelson, S.A. (2004). *Natural Disasters.* Retrieved November 8, 2004, from Professor Stephen Nelson's Earth & Environmental Science website Web site: http://www.tulane.edu/~sanelson/geol204/

Siebert, L. (n.d.). *Global Volcanism Program: Frequently Asked Questions.* Retrieved November 10, 2004, from Smithsonian Global Volacnism Program Web site: http://www.volcano.si.edu/faq/answer.cfm?faq=06

Study: Arctic warming threatens people, wildlife. (2004, November 8). *MSNBC News,* Web site: http://www.msnbc.msn.com/id/6433717

Volcanic Ash: Effects on Transportation and Mitigation Strategies.(2004). Retrieved November 9, 2004, from the US Department of the Interior, US Geological Survey Web site: http://volcanoes.usgs.gov/ash/trans/#aircraft

Williams, J. (2004, November 21). Answers: How much would sea level rise if polar ice melted. *USA Today,* Web site: http://www.usatoday.com/weather/resources/askjack/2004-11-21-melting-polar-ice_x.htm

Near Earth Objects Resources

Atkinson, H., Tickell, C., & William, D. (2000). *Report of the Task Force on potentially hazardous Near Earth Objects.* Retrieved November 9, 2004, from the Task Force on potentially hazardous Near Earth Objects Web site: http://www.nearearthobjects.co.uk/report/pdf/full_report.pdf

Bruton, D. (1996). *Frequently Asked Questions about the Collision of Comet Shoemaker- Levy 9 with Jupiter.* Retrieved November 9, 2004, Web site: http://www.isc.tamu .edu/~astro/sl9/cometfaq2.html#Q3.1

Chesley, S. (2004). *NEO Earth Close Approaches.* Retrieved November 8, 2004, from NASA Jet Propulsion Laboratory Web site: http://neo.jpl.nasa.gov/ca/

Chapter Five Resources:

Asteroids

Gehrels, T. (1979). *Asteroids: A Collection of Research Edited by Tom Gehrels*. Tucson, AZ: University of Arizona Press.

Comet Resources

Bergman, J. (2004). *The Comet Nucleus.* Retrieved November 30, 2004, from Window to the Universe Web site: http://www.windows.ucar.edu/tour/link=/comets/comet_nucleus.html

Chodas, P., Chesley, S., Giorgini, J., & Yeomans, D. (2005). *Radar Observations Refine the Future Motion of Asteroid 2004 MN4.* Retrieved February 20, 2005, from NASA Jet Propulsion Laboratory Web site: http://neo.jpl.nasa.gov/

Hale, A. (n.d.). *What are Comets?* Retrieved November 30, 2004, from Field Guide to Comet Hale-Bopp Web site: http://www.sipe.com/halebopp/whatare2.htm

Hamilton, C.J. (2001). *The Kuiper Belt.* Retrieved November 30, 2004, from Views of the Solar System Web site: http://www.solarviews.com/eng/kuiper.htm

Hamilton, R.L. (1999). *The Oort Cloud.* Retrieved Novmeber 30, 2004, from Views of the Solar System Web site: http://www.solarviews.com/eng/oort.htm

Chapter Six Resources:

Moon Base

Britt, R.R. (2003, October 1). The Sky Isn't Falling, But Pieces Sure Are. *Space.com,* Web site: http://www.space.com/scienceastronomy/chicken_little_031001.html

Chodas, P. & Yeomans, D. (2004). *Hayabusa Spacecraft Founds Earth and Heads for Near-Earth Asteroid.* Retrieved December 28, 2004, from NASA Near Earth Object Program Web site:http://neo.jpl.nasa.gov/news/news143.html

David, L. (2001, December 12). Moon Base Would Scan The Sky, And Deflect Threats To Earth. *Space.com,* Web site: http://www.space.com/businesstechnology/ technology/lunar_caps_011212-1.html

Jackson, R. (2003, November 19). Largest pair of 'eyes' ever built to aid search for planets. *NASA Jet Propulsion Laboratory PlanetQuest News,* Web site: http://planetquest.jpl.nasa.gov/news/lbti_update.html

Wotkyns, S. (2003). *Lowell Observatory and Discovery Communications, Inc., Announce Partnership to Build Innovative Telescope Technology.* Retrieved December 29, 2004, from Lowell Observatory Web site: http://www.lowell.edu/press_room /releases/recent_releases/dct_rls.html

The Funding Issue

Britt, R.R. (2002, March 26). Why We Fear Ourselves More than Asteroids. *Space.com,* Web site: http://www.space.com/scienceastronomy/solarsystem /asteroid_fears_020326-1.html

Leath, A.T. (2001, November 14). VA/HUD Conference Report: NASA Funding Increased by 3.8%. *FYI: The AIP Bulletin of Science Policy News,* 138. Web site: http://www.aip.org/fyi/2001/138.html

Somers, E. & Thaniel, R. (2004, October 18). Congress Approves FY 2005 Homeland Security Funding. *The United States Conference of Mayors,* Web site: http://www.usmayors.org/uscm/us_mayor_newspaper/documents/10_18_04/home landfunding.asp

Chapter Seven Resources:

Chemical and Electrical Propulsion

Balakrishnan, J. & Boyd, I.D. (n.d.). *Ion Propulsion.* Retrieved January 29, 2005, from NASA Lewis Research Center and the Air Force Office of Scientific Research Web site: http://eccentric.mae.cornell.edu/Boydgroup/jbala/temp.html

Brophy, J.R. (2001). *NASA's Deep Space 1 Ion Engine.* Retrieved March 20, 2005, from NASA Jet Propulsion Laboratory Web site: http://techreports.jpl.nasa.gov/2001/ 01-1942.pdf

The Ion Engine. (n.d.). Retrieved January 31, 2005 from TheSpaceSite.com Web site: http://www.thespacesite.com/space/future/electric.php

Ion Engine to Open Up the Solar System. (2002). Retrieved on January 30, 2005, from NASA Jet Propulsion Laboratory Web site: http://www.jpl.nasa.gov/news/ features.cfm?feature=494

Lovato, N. & Amatore, D. (2003). *NASA's Ion Engine Records No Tune-Ups, No Problems.* Retrieved January 30, 2005, from National Aeronautics and Space Administration Web site: http://www.inspacepropulsion.com/news/JPionenginemilestone.pdf

Martinez-Sanchez, M. (1998). *Lecture 1b: Review of Rocket Propulsion.* Retrieved January 29, 2005, from the American Institute of Aeronautics and Astonautics, Inc. Web site: http://ocw.mit.edu/NR/rdonlyres/Aeronautics-and-Astronautics/16-522Spring2004/6D8C8325-437D-4962-99BF-081E9F6F7DC9/0/lecture1b.pdf

Rocket. (n.d.). Retrieved February 27, 2005, from Encarta Web site: http://encarta.msn.com/encyclopedia_761577900_1____45/Rocket.html#s45

Thrust Calculations Based on NEAR Shoemaker

Anderson, D., Gallet, D., Wiley, S., & Lucas, K. (1998). *The Near Earth Asteroid Rendezvous (NEAR) Spacecraft and Aerojet.* Retrieved January 30, 2005, from Aerojet Web site: http://control.aerojet.com/Propulsion/spacecraft_propulsion/near/

Chesley, S. (n.d.). *Impact Risk.* Retrieved January 29, 2005, from NASA Jet Propulsion Laboratory Web site: http://neo.jpl.nasa.gov/risk

Williams, D.R. (2005). *NEAR Shoemaker.* Retrieved January 30, 2005, from NSSDC Web site: http://nssdc.gsfc.nasa.gov/planetary/near.html

Williams, D.R. (2003). *NEAR Shoemaker.* Retrieved February 1, 2004, from NSSDC Web site: http://nssdc.gsfc.nasa.gov/database/MasterCatalog?sc=1996-008A

Solar Sails

Friedman, L. (1998). *Starsailing: Solar Sails and Interstellar Space Travel.* New York, NY: Wiley.

Missiles

Energy. (2001). Retrieved February 13, 2004, from www.Matter-AntiMatter.com Web site: http://www.matter-antimatter.com/energy.htm

Lenz, G.H. (1997). *The Sky is Falling.* Retrieved February 12, 2004, from Sweet Briar College Web site: http://www.dean.sbc.edu/lenz.html

Shults, C.W. (n.d.). *Deflecting an Earth-Impactor.* Retrieved February 13, 2004, from Xenotech Research Web site: http://xenotechresearch.com/spa07.htm

Nuclear Warheads

Feiveson, H. A. (2001). *The Nuclear Turning Point : A Blueprint for Deep Cuts and De-alerting of Nuclear Weapons.* Washington, DC: Brookings Institution.

Woolsey, R. J. (1999). *Nuclear Arms: Ethics, Strategy, Politics.* San Francisco, CA: ICS Press

Lasers

Campbell, J.W. (2000, December). Using Lasers in Space: Laser Orbital Debris Removal and Asteroid Deflection. *Center for Strategy and Technology Air War College,* Occasional Paper No. 20. Web site: http://www.au.af.mil/au/awc/awcgate/cst/csat20.pdf

Cascio, J. (2004, March 13). Life in the Shooting Gallery. *World Changing: another world is here* Web site: http://www.worldchanging.com/archives/000464.html

Divis, D.A. (2002, October 18). NASA eyes lasers to divert asteroids. *United Press International,* Web site: http://www.upi.com/view.cfm?StoryID=20021017-104159-2644r

Ponniah, L. (1998). *It's a Bird, It's a Plane, It's… Oh No!* Retrieved February 11, 2005, from 21st, the VXM Network Web site: http://www.vxm.com/ ponniah.comets.html

Chapter Eight Resources:

See Appendices

Chapter Nine Resources:

About Carbon Dioxide (CO2) Lasers. (2005). Retrieved on April 6, 2005, from GlobalSpec Web site http://co2-lasers.globalspec.com/LearnMore/Optical_Components_Optics/Lasers/Carbon_Dioxide_Lasers

Chryssolouris, G. (1991). *Laser Machining Theory and Practice.*New York, NY: Springer-Verlag.

DeYoung, R.J., Walberg, G.D., and Conway, E.J. (1983). *A NASA High-Power Space-Based Laser Research and Applications Program,* SP-464.

Diffraction. (n.d.). Retrieved on April 7, 2005, from Labor Law Talk Web site http://encyclopedia.laborlawtalk.com/Diffraction

Humes, D.H. (1982). Preliminary Study on the Use of Lasers for the Transmission of Power. *Space Laser Power Transmission Studies,* 2214, 15-32.

Laser Applications.(1991). Waco, TX: Cord Communication.

Laser Technology. (1988). Waco, TX: Cord Communication.

Silfvast, W.T. (1991). Lasers. In *Encyclopedia of Lasers and Optical Technology* (pp. 209-226). San Diego, CA: Academic Press, Inc.

Smith, C. (2004). *S&TR | July/August 2004: Nuclear Energy to Go: A Self-Contained, Portable Reactor*. Retrieved April 12, 2005, from Lawrence Livermore National Laboratory's Science & Technology Review Web site http://www.llnl.gov/str/JulAug04/Smith.html

Watson, J. (1997). *Lasers.* Retrieved March 31, 2005, from the University of Aberdeen Engineering Department Web site: http://vcs.abdn.ac.uk/ENGINEERING/lasers/

Appendix A

```
%file orbit02.m -main program
% to invoke matlab use 'matlab5.3'
%to get out of matlab type 'quit' and return.
% help command prints help on the command

% define some global constants that will be valid
% when you call a function or a subroutine.

%program to compute the orbit of the earth and an asteroid around the sun
% msun=mass of the sun
%G=gravity constant
%R0=initial distance of object from the sun.
%vx0=x-component of velocity at time 0
%vy0=y-component of velocity at time 0
%eps-eccentricity of orbit
%nstep=number of integration steps
%UNITS: time=one day;distance:150*10^6km)
%request high accuracy
format long

% give values to the global constants
global msun GG GM GME mearth masteroid R0 vx0 vy0 eps
msun=1.9891e+30;
GG=1.4756e-34;
GM=GG*msun

%Earth data
mearth=5.97e+24;
GME=GG*mearth
R1=150*10^6;
R0=1.;
vx0=(-29.778202*3600*24)/(150*10^6);
vy0=0;
%Earth position at time 0
x0=0;
y0=R0;

%Asteroid Data
masteroid=1.6e+9;
eps=.25;
RA0=2.81005;
vxa00=8.05*sqrt(1+eps^2);
```

```
vxa0=(vxa00*3600*24)/(150*10^6);
vya0=0;
% Asteroid position at time 0
xa0=0;
ya0=RA0;


%Number of days for the simulation.
nstep=15000;

% set error tolerance and method for the numerical
%integrator of the differential equations.
odeset('maxstep',0.0001,'reltol',1.e-10,'bdf','on')

%perform the integration. 'orbitsys12' is a file that defines
%the equations of motion for the combined system.
% compute the earth and asteroid trajectory.

for i=1:nstep
tt(i)=i;
end
%[x0,y0,vx0,vy0,xa0,ya0,vxa0,vya0] define the initial conditions
[t,xx]=ode15s('orbitsys12',tt,[x0,y0,vx0,vy0,xa0,ya0,vxa0,vya0]);

%R=earth distance from the sun. theta=angle form x-axis
%plot R=sqrt(x^2,y^2) as a function of time
for i=1:nstep
R(i)=sqrt(xx(i,1)^2+xx(i,2)^2);
if xx(i,2) >= 0;
theta(i)=acos(xx(i,1)/R(i));
else
theta(i)=-acos(xx(i,1)/R(i));
end
end
plot(tt,R,'r')

%title and axes labels for the plot
title('Simulation of Earth Orbit')
xlabel('days')
ylabel('Astronomical Units')
print -dpsc2 -r600 orbit02.ps

%Plot the same for the first 1000 days only
plot(tt(1:1000),R(1:1000),'r')
title('Simulation of first 1000 days of Earth Orbit')
xlabel('days')
```

```
ylabel('Astronomical Units')

%save the plot to a postscript file
print -dpsc2 -r600 -append orbit02.ps

%plot the same in polar coordinates
polar(theta,R,'g')
%title and axes labels for the plot
title('Simulation of Orbit in Polar Coordinates')

%append the plot to a postscript file
print -dpsc2 -r600 -append orbit02.ps

%plot RA=sqrt(x^2+y^2) [asteroid distance from the sun]
% as a function of time

for i=1:nstep
RA(i)=sqrt(xx(i,5)^2+xx(i,6)^2);
if xx(i,6) >= 0;
phi(i)=acos(xx(i,5)/RA(i));
else
phi(i)=-acos(xx(i,5)/RA(i));
end
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%% Added to overlay the modified thrust onto the original graph
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%perform the integration. 'orbitsys12' is a file that defines
%the equations of motion for the combined system.
% compute the earth and asteroid trajectory.

for i=1:nstep
ss(i)=i;
end
%[x0,y0,vx0,vy0,xa0,ya0,vxa0,vya0] define the initial conditions
[s,zz]=ode15s('orbitsys12thrust',ss,[x0,y0,vx0,vy0,xa0,ya0,vxa0,vya0]);

%R2=earth distance from the sun. theta2=angle form x-axis
%plot R=sqrt(x^2,y^2) as a function of time
% Probably don't need this
for i=1:nstep
R2(i)=sqrt(zz(i,1)^2+zz(i,2)^2);
if zz(i,2) >= 0;
theta2(i)=acos(zz(i,1)/R2(i));
```

```
else
theta2(i)=-acos(zz(i,1)/R2(i));
end
end

for i=1:nstep
RA2(i)=sqrt(zz(i,5)^2+zz(i,6)^2);
if zz(i,6) >= 0;
phi2(i)=acos(zz(i,5)/RA2(i));
else
phi2(i)=-acos(zz(i,5)/RA2(i));
end
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%% End addition
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%



plot(tt,RA,'b')
hold on;
plot(ss,RA2,'c')
title('Simulation of Asteroid Orbit')
xlabel('Days')
ylabel('Astronomical Units')
hold off;

%save the plot to a postscript file
print -dpsc2 -r600 -append orbit02.ps

%plot the same in polar coordinates
polar(phi,RA,'b')
hold on;
polar(phi2,RA2, 'c')
%title and axes labels for the plot
title('Simulation of Asteroid Orbit in Polar Coordinates')
hold off;

%append the plot to a postscript file
print -dpsc2 -r600 -append orbit02.ps

polar(phi(1:1000),RA(1:1000),'b')
hold on;
polar(phi2(1:1000),RA2(1:1000),'c')
```

```
title('Simulation of first 1000 days of Asteroid Orbit in Polar Coordinates')
hold off;
print -dpsc2 -r600 -append orbit02.ps

%plot distance between earth and asteroid
plot(tt,abs(R-RA),'m')
hold on;
plot(ss,abs(R2-RA2),'c')
title('Distance between Earth and Asteroid')
xlabel('Days')
ylabel('Astronomical Units')
hold off;
print -dpsc2 -r600 -append orbit02.ps

%plot distance between earth and asteroid
plot(tt,abs(R-RA)*R1,'m')
hold on;
plot(ss,abs(R2-RA2)*R1,'c--')

% Add horizontal lines at the critical values
% Commented out due to extensive processing
for i=1:3642
bb(i)=i;
end

%plot(tt,6378.1,'-r')
%plot(tt,10000,'--k')
%plot(bb,2154.1275,'b')
%plot(bb,1045.657,'g')
legend('Without Thrust', 'With Thrust', 'Impact Limit', 'Safe Zone', 'Closest to Earth with Thrust',
'Closest to Earth without Thrust', 4);
hold off;
v=[0 15000 0 0.0005*R1]
axis(v)
title('Distance between Earth and Asteroid')
xlabel('Days')
ylabel('Kilometers')

print -dpsc2 -r600 -append orbit02.ps
```

Appendix B

```
%file orbitsys12.m -diff eqs.
function dx =orbitsys12(t,x)
global msun GG GM GME mearth masteroid R0 vx0 vy0 eps
R=sqrt(x(1)^2+x(2)^2);
RA=sqrt(x(5)^2+x(6)^2);
REA=sqrt((x(1)-x(5))^2+(x(2)-x(6))^2);
%this is the system of differential equations WITHOUT
%the earth gravational field
%dx=[x(3);x(4);-GM/R^3*x(1);-GM/R^3*x(2);x(7)+ux;x(8)+uy;-GM/RA^3*x(5);-
GM/RA^3*x(6)];

%this is the system of differential equations WITH
%the earth gravational field
dx=[x(3);x(4);-GM/R^3*x(1);-GM/R^3*x(2);x(7);x(8);-GM/RA^3*x(5)-GME/REA^3*(x(5)-
x(1));-GM/RA^3*x(6)-GME/REA^3*(x(6)-x(2))];
```

Appendix C

```
%file orbitsys12.m -diff eqs.
function dx =orbitsys12(t,x)
global msun GG GM GME mearth masteroid R0 vx0 vy0 eps
R=sqrt(x(1)^2+x(2)^2);
RA=sqrt(x(5)^2+x(6)^2);
REA=sqrt((x(1)-x(5))^2+(x(2)-x(6))^2);
theta = atan(x(6)/(x(5)+1e-30));  %The addition is to prevent division by 0

% Converting Newtons (meters * kg * s^-2) to our units (AU * kg * days^-2)
% we do the following:
% Multiply by 1 m / AU, or 6.68458e-12
% Multiply by 1 s^2 / day^2 or 172800

LaserJoules = 500000000000000; % The energy needed to move the asteroid, in Joules
%LaserJoules = 161000000000000;
%This is equal to ~1.584 megawatts for 10 years
ForceOfLaser = LaserJoules / (abs(R-RA)*150*10e6*1000); % Joules (Newton-meters) divided
by distance = Newtons
laserthrust = ForceOfLaser * 6.68458e-12 * 172800; % Converting Newtons to our units
laserthrust = laserthrust / masteroid; % Dividing the force by mass to yield acceleration
ax = laserthrust *cos(theta); % Determining the acceleration in the X direction
ux = laserthrust *sin(theta); % Velocity in x at time 't' for the asteroid, given thrust 'laserthrust'
ay = laserthrust *sin(theta); % Determining the acceleration in the Y direction
uy = -laserthrust *cos(theta); % Velocity in y at time 't' for the asteroid, given thrust 'laserthrust'

%this is the system of differential equations WITHOUT
%the earth gravational field
%dx=[x(3);x(4);-GM/R^3*x(1);-GM/R^3*x(2);x(7);x(8);-GM/RA^3*x(5);-GM/RA^3*x(6)];

%this is the system of differential equations WITH
%the earth gravational field
dx=[x(3);x(4);-GM/R^3*x(1);-GM/R^3*x(2);x(7);x(8);-GM/RA^3*x(5)-GME/REA^3*(x(5)-
x(1))+ux;-GM/RA^3*x(6)-GME/REA^3*(x(6)-x(2))+uy];
```

[1] Ellis, P.B.
[2] Ibid.
[3] Ibid.
[4] *The Celtic Cosmos.*
[5] Crystal, E. (2004). *Mayan Astronomy.*
[6] Berger, M.
[7] Crystal, E. (2004). *Mayan Astronomy.*
[8] Berger, M.
[9] Crystal, E. (2004). *Mayan Astronomy.*
[10] Berger, M.
[11] *About Astrology: Fascinating Facts.*
[12] d'Arc, J.
[13] *Ancient Mesopotamia.*
[14] Ibid.
[15] Curnow, P.
[16] Ibid.
[17] Smith,A.
[18] *The Living Australia*, Issue 70, Bay Books Pty Ltd, Sydney, 1986.
[19] Crystal, E. (2004). *Ancient India-Astronomy*
[20] Prabhupada, A.C.B.S.
[21] Crystal, E. (2004). *Ancient India-Astronomy*
[22] Rasinkangas, R
[23] Ilyin, V.
[24] Shand, R.
[25] *Why Grow Crystals in Microgravity?*
[26] Ibid.
[27] Ibid.
[28] Szofran, F.
[29] Kloeppel, J.
[30] Ibid.
[31] Barry, P.L.
[32] *Human Spaceflight: Life Sciences*
[33] Barry, P.L.
[34] Dana, P.H.
[35] Brian, M. & Harris, T.
[36] *Uses for GPS.*
[37] Kincaid, S.
[38] *Uses for GPS.*
[39] Ibid.
[40] *Solar Power Satellites (SPS).*
[41] Ibid.
[42] *Solar Power Satellites.*
[43] Potter, S.
[44] Ibid.
[45] Ibid.
[46] Ibid.
[47]Mankins, J.C.
[48] *Satellite Telephone Information.*
[49] Ibid.
[50] Ibid.
[51] *Globalstar Satellite Phones and More at Globalcom.*
[52] Ibid.
[53] Ibid.

[54] Ibid.
[55] Ibid.
[56] Iridium Announces Subscriber And Revenue Growth Rates.
[57] Ibid.
[58] Walczak, J.
[59] Ibid.
[60] Ibid.
[61] Bonsor, K.
[62] Soong, R.
[63] Ibid.
[64] *Satellite-TV-Mania.*
[65] *DirecTV.*
[66] *History of Biological Warfare.*
[67] Silverman, S.
[68] Red Lies.
[69] Ibid.
[70] Dixon, P.
[71] Sars biological weapon?
[72] Study: Arctic warming threatens people, wildlife.
[73] Ibid.
[74] Ibid.
[75] *Volcanic Ash: Effects on Transportation and Mitigation Strategies*
[76] Siebert, L.
[77] Dewitt, S.
[78] Williams, J.
[79] Atkinson, H., Tickell, C., & William, D., 9.
[80] Ibid., 11.
[81] Ibid., 15.
[82] Ibid., 17.
[83] Ibid.
[84] Ibid.
[85] Ibid., 18.
[86] Ibid.
[87] Ibid., 19-20.
[88] Ibid., 20.
[89] Ibid.
[90] Ibid., 23.
[91] Bruton, D.
[92] Chesley, S.
[93] Bergman, J.
[94] Hamilton, R.L. (1999).
[95] Hamilton, C.J. (2001).
[96] Ibid.
[97] Hale, A.
[98] Chodas, P., Chesley, S., Giorgini, J., & Yeomans, D.
[99] David, L.
[100] Ibid.
[101] Britt, R.R.
[102] Ibid.
[103] Jackson, R.
[104] David, L.
[105] Wotkyns, S.
[106] Jackson, R.
[107] Ibid.

[108] Leath, A.T.
[109] Britt, R.R.
[110] Somers, E. & Thaniel, R.
[111] Britt, R.R.
[112] Ibid.
[113] Ibid.
[114] *Rocket.*
[115] *The Ion Engine.*
[116] Ibid.
[117] Balakrishnan, J. & Boyd, I.D.
[118] *Ion Engine to Open Up the Solar System.*
[119] Martinez-Sanchez, M.
[120] *The Ion Engine.*
[121] Brophy, J.R.
[122] Williams, D.R. (2005).
[123] Anderson, D., Gallet, D., Wiley, S., & Lucas, K.
[124] Williams, D.R. (2003).
[125] *Energy.*
[126] Divis, D.A.
[127] Ibid
[128] Ibid.
[129] Ibid.
[130] Ibid.
[131] Ibid.
[132] Ibid.
[133] Ibid.
[134] Ibid.
[135] Ibid.
[136] For code, see Appendix A.
[137] For code, see Appendix B.
[138] For code, see Appendix C.
[139] Silfvast, 209.
[140] Ibid., 221.
[141] Laser Technology, 93.
[142] Watson.
[143] Ibid.
[144] Laser Technology, 101.
[145] Silfvast, 221.
[146] Ibid., 218-219.
[147] Ibid., 219.
[148] Ibid.
[149] Watson.
[150] Silfvast, 219.
[151] Laser Technology, 213.
[152] Ibid., 222.
[153] Watson.
[154] Silfvast, 222.
[155] *About Carbon Dioxide (CO2) Lasers.*
[156] *Diffraction.*
[157] Smith, C