Humanity and Space
Deep Space Habitation Module

An Interactive Qualifying Project Report

submitted to the faculty of

Worcester Polytechnic Institute

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

by

Joshua Fuller

and

Zachary Chester

Submitted to: Professor Mayer Humi

July 01, 2016

Abstract

This project introduces the SAGON spacecraft, a deep space habitable environment using technology available today to address areas NASA considers deficient. This design was submitted to the NASA NextSTEP-2 proposal solicitation. The craft is capable of integrating newer technologies, providing a longer lifespan for the design. Additionally, this project highlights the steps in colonizing Mars using the craft. In accordance with NASA's Mars Exploration program's goals, SAGON can help NASA launch a manned mission to Mars by the 2030's.

Executive Summary

Mars offers an attractive first step for expansion into the Solar System and beyond. This offers a range of possibilities; from mining and refueling, to science centers, to an additional home, to ensure the future of humanity, Mars plays a vital role in our future. Humans have not ventured into the extreme deep space environment. This environment, filled with radiation and great expanses, proves difficult to overcome.

The proposed spacecraft, Solar Adaptive Gathering/Observation Nautilus (SAGON), is a vessel designed for manned deep space exploration. The initial purpose of the craft is for a mission to the planet Mars, however it designed to be capable of traveling deeper into the solar system. It is a modular design, capable of performing multiple missions before needing to be retired. The ship is designed majorly off of existing technologies, therefore there are less costs associated with the ship and less room for error from technologies that are not yet matured.

This craft fulfills each of the goals presented in the NASA Next Space Technologies for Exploration Partnerships, NextSTEP, release. This was for the broad agency announcement release number NNHZCQ001K-HABITAT. The release detailed six specific subcategories that that were key for the design to solve. These subcategories are life support, environmental monitoring, crew health, EVA, fire, and radiation protection.

Life support is currently at a 42% recovery of oxygen on the international space station, along with a water recovery of around 90%. The goals of the proposal are a larger than 75% oxygen recovery and a water recovery of more than 98%. To meet this, existing water recycling systems are implemented along with a miniaturization of the Micro-Ecological Life Support System Alternative, MELiSSA, project research, which has created a self-sustaining ecosystem.

Environmental monitoring will be used to assess the habitability of the modules during extended missions in deep space. This will be done using spectrometers and other forms of sampling for air and water contaminants. It is important to not only identify if there a health risk, but quickly locate its origin. Monitoring equipment is also vital to assessment of crew health and planetary environments. Fast, on site testing is to be incorporated to deliver as much information as possible to both NASA and the crew.

Crew health is a very unique issue, as there are many troubles currently faced in sustaining a manned mission. The question of food was already partially answered with the intention to incorporate the MELiSSA research, as the byproducts are all edible. However, that is not enough to sustain a multi man crew, so the incorporation of other plants like potatoes with limited amounts of processed food is anticipated.

The capsule designed for this proposal incorporates an artificial gravity of approximately .4 g's, which would both limit the mass of the equipment needed and allow for different equipment to be incorporated. In the main crew living area it is anticipated that there would be a bike and some mats. In the central part of the ship, there would be an adaptive resistance exercise device, which works in zero gravity. This is in case the gravity system fails.

Medical supplies are another interesting issue, on a potentially multi-month mission to the surface Mars there are a lot of injuries that could happen. However, in space these injuries are less likely. If a preliminary pod were shipped to the surface, this could contain excess medical supplies and other materials.

EVA goals are to design a newer spacesuit capable of greater mobility, reliability, and enhanced life support. The design of the suit itself is anticipated to be contracted to an outside company, however it is anticipated that the design will incorporate an exoskeleton. This will allow for enhanced carrying capacity of astronauts, as well as ease of movement on missions, hopefully reducing the chances of injury with increased protection.

Fire protection, is a more defined, less dynamic issue. The main goals are to create a unified approach, capable of working in almost any function. This would be done by incorporating fire sensors into potentially fire prone devices, and allowing water vapor and CO2 extinguishers to autonomously target fires if an anomaly is detected by the sensors.

Radiation protection is a very important subject matter, as many people would not volunteer for a mission that does not offer adequate shielding, or where they are likely to encounter hazards later in life as a result of going into space. For this craft, there is an anticipated safe compartment where astronauts can stay safely when there are severe radiation warnings. This shield will be comprised of the water supply, which is an excellent radiation shield. The rest of the ship will be shielded using polyethylene and hydrogenated boron nitride nanotubes (hydrogenated BNNT's).

While a spacecraft is a very important part of the journey to another planet, there are other things that need to be considered. These are things like the landing location, what the astronauts will do, and the potential impact on future missions. Each of these has a very unique impact on the mission, capable of completely changing it or even rendering the proposed craft useless.

There were also technologies left intentionally out of the proposal, as they have not been tested enough to be implemented on a manned mission. Surprisingly, many of these could be tested on the first mission of the SAGON craft to be adapted in the future. A simple space test should help to prove the validity of these technologies and show that they could be implemented in future crafts. Overall, the SAGON craft can provide NASA with a first step to Mars colonization. There are many things that may be learned not only scientifically, but for future advancements in exploring our solar system. With this technology we take the next step forward in utilizing all that is available in our celestial backyard.

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Introduction

Understanding the thoughts behind a project as just as important as understanding the subject matter. In order to identify bias, credibility, and future opportunities, this information is vital.

About the Project

This project examines the human journey to the planet Mars, transforming our species from Terrestrial to interplanetary. While this advance might seem like science fiction, it is a vital step for humanity to explore and expand into the galaxy and beyond. The possibilities with Mars are immense, so this project will focus on habitation of Mars and what this might offer the human race. Additionally, NASA released a solicitation for deep space habitation system designs that coincided with this project. As a result, this project explores the next steps, as of 2016, for a manned mission to Mars, the first interplanetary human mission.

Qualification as Interactive Qualifying Project (IQP)

Worcester Polytechnic Institute requires multiple projects be completed as graduation requirements, the IQP is one such requirement. An IQP is a project that connects science and technology with a social issues or human need [1]. This project embodies the spirit of an IQP with its context of deep space exploration, colonization of other planets, U.S. space policy, and the economics connected with the aerospace industry.

Many great minds today are voicing the need they see for humanity to expand to other planets, to see first-hand what our solar system holds, and to provide additional resources to a dwindling planet. Solving the problems of deep space habitation opens up a rich cosmos to feed our growing population's needs, while providing new technology that will change the future.

The benefits of the space industry can be felt today too. Large manufacturing projects bring local work, higher education jobs open up, new research pours in, allowing breakthroughs in every field of science and new products go on the market for consumers.

Funding a space program is a challenge, and the U.S. government needs to see more than scientific results. Commercialization of Low Earth Orbit (LEO) has been of great interest since telecommunication companies started launching satellites. Large projects through NASA allows other companies to expand to fulfill their contracts, and the economy sees a boost.

However, the project goes deeper into human social interactions as well, it examines what is required for a human to thrive. Beyond the physical needs, how do you alleviate boredom, loneliness, and loss of motivation? How do you ensure the happiness of someone so far from a familiar environment and the comforts of home? What are the potential ramifications of living on a planet other than Earth for years on end?

This project examines much more than new technology, but how technology can be used to create a new home, no matter where that might lead us.

Project Motivation

Zachary:

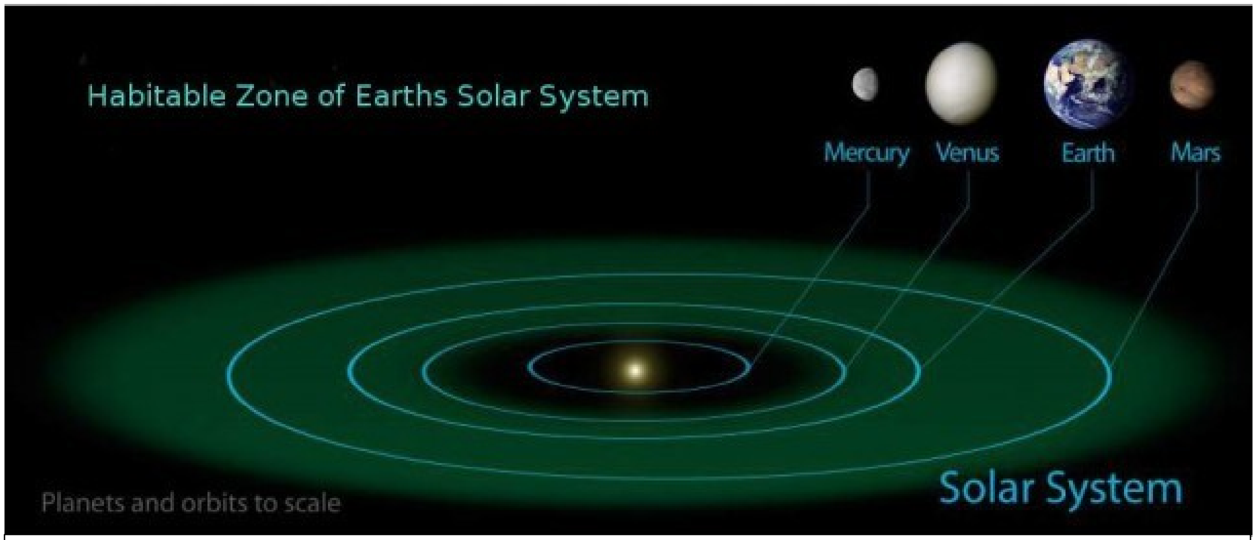
I have been interested in space travel all of my life, and I began to focus my interest in high school, where I took my first class on our solar system. This has continued on through college where I entered school as a physics major with a focus on astrophysics. The IQP is a degree requirement for graduating with a bachelor's degree at WPI. As I began researching an IQP to fulfil this requirement, I was put into contact with Professor Humi, who helped introduce Josh and myself to each other. Originally the project was to focus on the longevity of a manned space mission, however, as Josh will note, we found that a NASA proposal correlated exceedingly well with the goals for our IQP. Working on this proposal for me is a superb opportunity because it allows me to gather experience in creating proposals, as well as working in a competitive business environment, where it is not about the design working, but how well it works.

Joshua:

It fascinates me how we can apply science and technology to inhabit even the most hostile of environments. I have always been interested in space, fascinated with the infinite possibilities, eager to explore the unknown, and always entertained by the newest ideas on how to tame it. As a mechanical engineering major with an aerospace engineering minor, a project about living in deep space instantly drew my attention, but soon the project became more. Through some networking, Zack and I found out our project very closely overlapped with a NASA open proposal. The timing could not have been better, and it would be impossible for me to pass up such an opportunity. Not only is this an amazing opportunity to immerse myself in the subject matter I love, but it became a tactical career move, increasing my exposure the industry, getting my name on the next big thing in space exploration, and of course the networking opportunities. Overall, this project was the best opportunity to complete course requirements while advancing my personal goals, pursuing my interests, and doing something I can be proud of.

Why Mars?

Mars is the fourth planet from our Sun, it is the second smallest planet inside of our solar system at 0.53 times the radius of our Earth. It is also the only other planet near the habitable zone, a region produced around a Sun where the formation of life is considered viable, aside from Earth [2]. This has helped lead to the rise of the popularity not only for research but also for conspiracy theories and the push to be the second planet man-kind sets foot on.



Inner Planets in Relation to the Habitable Zone [3]

In recent years more and more probes have been sent towards the atmosphere and surface of Mars to learn as much as possible about the planet. But robots have never been enough for mankind, firsthand exposure has always been necessary, and that is part of why a manned mission to the surface is so popular. However that is not the only reason that the ‘next big space race’ is happening. There is an immense amount that can be learned from Mars, including helping to answer if liquid water exists on or below the surface of any planets other than Earth, if we are the only intelligence in this solar system, and even if what we think we know about the formation of life is anywhere near correct.

As of now, Mars is considered the most viable planet in our solar system to have life other than Earth, in the past potentially even a more viable planet according to some experts [4]. This makes it ideal to send a manned mission to, as a final answer could be made if life ever existed on Mars, or even if liquid water can be found on the surface or just below the surface of the planet.

Besides unlocking the secrets of life, Mars provides a significant advantage to future space missions. Mars provides closer access to the giants of the solar system, possibly providing insight that is lost to the vast distances from Earth. Additionally, Mars provides a much closer staging area for mining operations in the asteroid belt. Companies like Planetary Resources aim to harvest fuel from water trapped in asteroids, providing a greater area of operation for spacecraft; someday maybe even going as far as to bring rare materials back to Earth [5].

Perhaps most importantly, Mars provides insurance that the human race, and the only intelligent life known in the universe survives should the worst happen to the Earth. Geological events, climate change, large impacts, and more threaten to end life on the planet [6]. While the changes are incredibly low, there is no greater assurance than a second planet fit to call home.

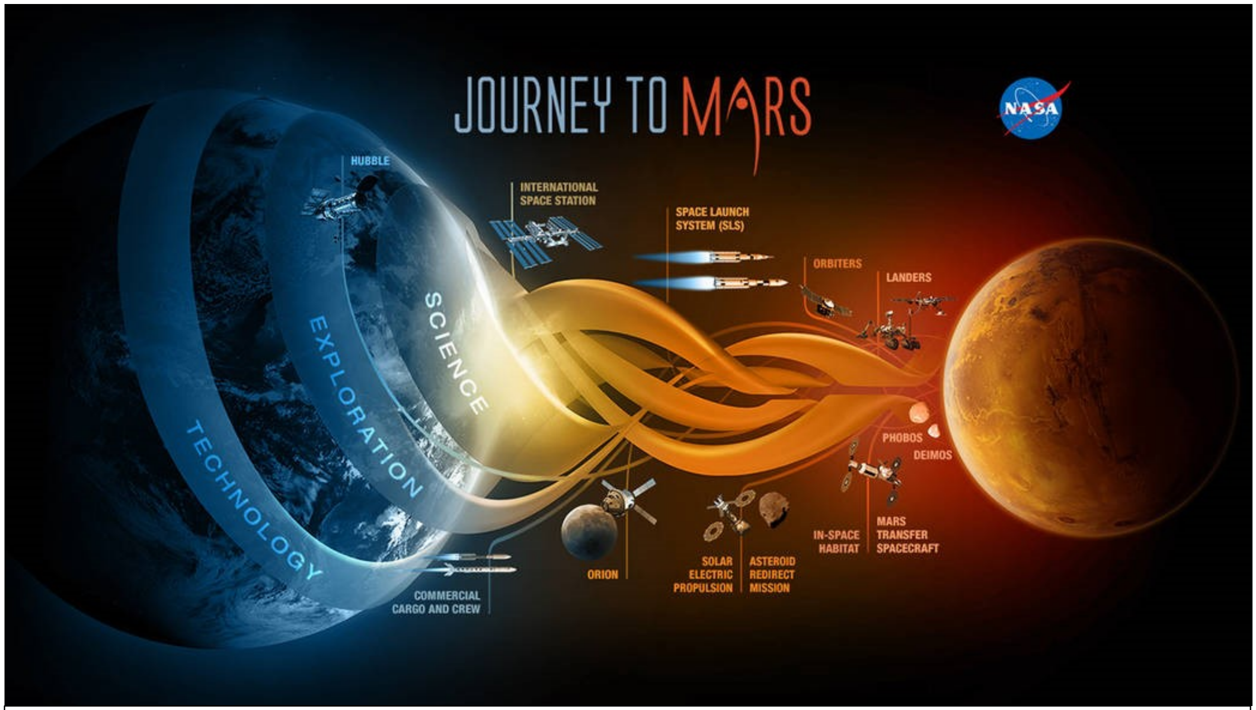
NASA's Journey to Mars

In 1948, the first semi-realistic mission to Mars was planned. Wernher von Braun wrote a book on how humans could colonize Mars, entitled The Mars Project [7]. After World War 2, von Braun moved to the United States, and set the stage for NASA's obsession with the red planet.

At the dawn of the space age, Mars became an early target for unmanned missions. Three years after the launch of the first man-made satellite in 1957, Sputnik, missions to send probes to Mars were already underway. In 1965, the U.S. Mariner 4 was the first spacecraft to reach Mars. In 1971, Mariner 9 became the first spacecraft to orbit another planet. During this time, the USSR Mars 2 became the first man-made object on the Martian surface [8].

In 1976, the U.S. Viking 1 & 2 missions began the search for life on Mars [9]. Since then several probes and rovers have been sent to further our understanding of the planet, with plans for many more unmanned missions in the future.

After years of fantasy, NASA has set a clear path to Martian colonization. Best summarized by their newest poster, NASA plans to leverage all resources for a manned mission by late 2030's. The Mars Exploration Program has outlined a clear, 4 goal approach to getting a Martian Outpost set up. The plan states that rovers and probes will continue to assess the history of life on Mars, the climate of Mars, and the Martian geology. From this, they hope to have enough information to plan the best location for the first manned mission to land by 2030 [10].

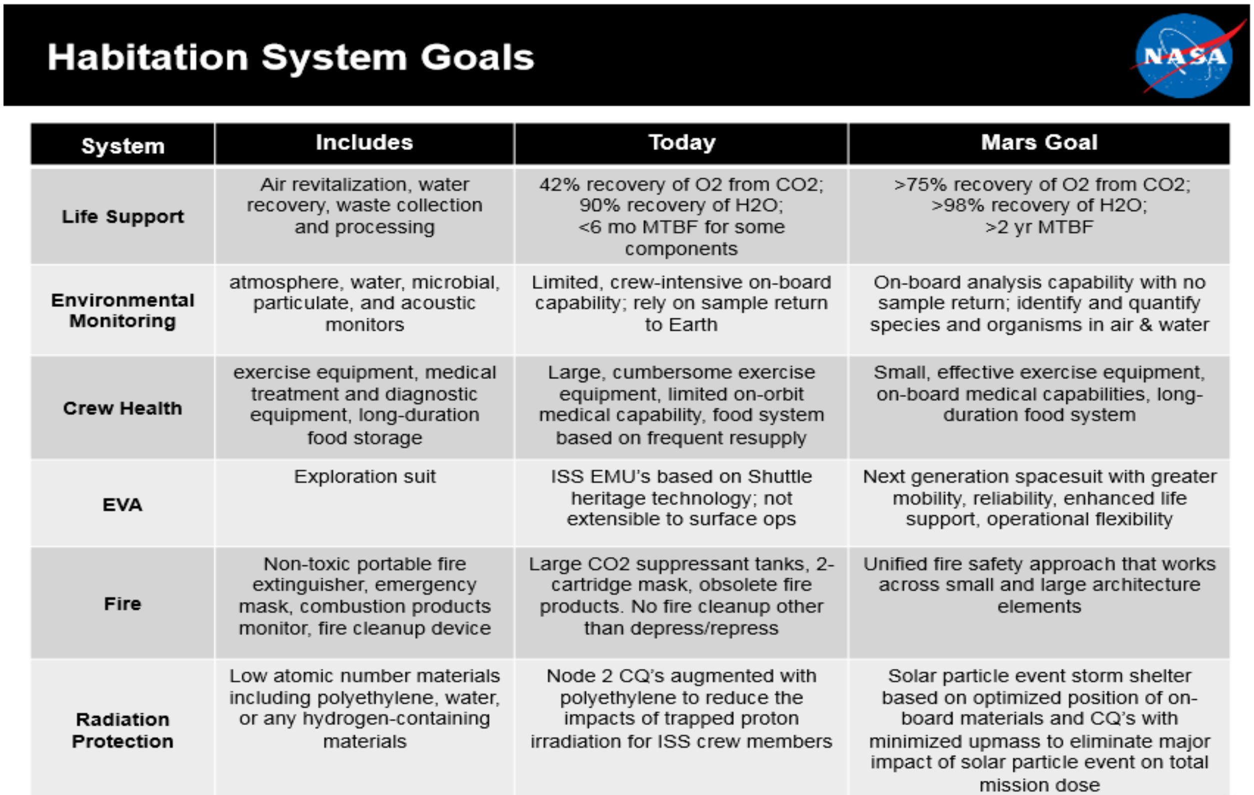


NASA's Journey to Mars Poster [11]

Taking the NextSTEP

As of 2016, NASA is attempting to work with the aerospace industry to develop the needed technology to make a manned Mars mission possible. To do this, NASA posts open proposal solicitations through their Broad Agency Announcements (BAAs) [12]. All qualified organizations may submit a proposed design or research project to further NASA's goals, and in exchange, NASA provides significant funding for development.

As educational institutions are permitted to submit proposals, and this project coincided with the announcement of the NextSTEP-2 Deep Space Habitation Module design request, the project involved an in depth design and cost analysis which was proposed to NASA on June 15th, 2016. This project is hoped to provide a feasible design for the NASA NextSTEP-2 open proposal looking for a deep space habitation system. There are six key design aspects that have been laid out by NASA in order to guide the proposals. These systems are; life support systems, environmental monitoring, crew health, EVA (extravehicular assignments), fire detection and suppression, and radiation protection. Through combination of advanced research and technology, this design provides a reliable system that meets or exceeds the expectations that NASA has laid out in Appendix A. Upon completion of the design, a mock mission was planned to showcase the features of the spacecraft as well as to assess other factors. Such factors include crew mental health, inter-social interactions, contamination of the Martian surface, failure cases, and preparations and research to be done to advance further Martian missions. The overall goal of this project is to prove the feasibility of a manned mission to Mars using technology that is known today and to identify areas requiring further development [13].



Habitation System Goals

System	Includes	Today	Mars Goal
Life Support	Air revitalization, water recovery, waste collection and processing	42% recovery of O2 from CO2; 90% recovery of H2O; <6 mo MTBF for some components	>75% recovery of O2 from CO2; >98% recovery of H2O; >2 yr MTBF
Environmental Monitoring	atmosphere, water, microbial, particulate, and acoustic monitors	Limited, crew-intensive on-board capability; rely on sample return to Earth	On-board analysis capability with no sample return; identify and quantify species and organisms in air & water
Crew Health	exercise equipment, medical treatment and diagnostic equipment, long-duration food storage	Large, cumbersome exercise equipment, limited on-orbit medical capability, food system based on frequent resupply	Small, effective exercise equipment, on-board medical capabilities, long-duration food system
EVA	Exploration suit	ISS EMU's based on Shuttle heritage technology; not extensible to surface ops	Next generation spacesuit with greater mobility, reliability, enhanced life support, operational flexibility
Fire	Non-toxic portable fire extinguisher, emergency mask, combustion products monitor, fire cleanup device	Large CO2 suppressant tanks, 2-cartridge mask, obsolete fire products. No fire cleanup other than depress/repress	Unified fire safety approach that works across small and large architecture elements
Radiation Protection	Low atomic number materials including polyethylene, water, or any hydrogen-containing materials	Node 2 CQ's augmented with polyethylene to reduce the impacts of trapped proton irradiation for ISS crew members	Solar particle event storm shelter based on optimized position of on-board materials and CQ's with minimized upmass to eliminate major impact of solar particle event on total mission dose

Goals of the Deep Space habitation System Proposal Solicitation [14]

Primary Design Concerns

With NASA highlighting six key areas they want technological advancement, the focus was to fully address these goals before moving too deep into the design process. The intent was to identify why these areas were most important to the mission, where the technology was lacking, and what could be done to improve their status.

Life Support

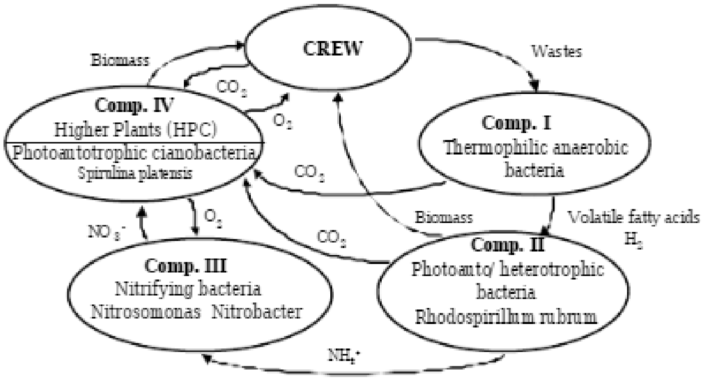
Life support is a broad topic, it encompasses all systems that allow for the habitation of the spacecraft. NASA's expectation was to retain or recover over 75% of the oxygen converted to carbon dioxide, recover more than 98% of water used, and assure a larger than two year mean time between failure of electronic parts [14]. The initial design intent was to implement mechanical systems to cover life support needs, similar to current systems on the International Space Station (ISS). These systems would scrub the air and water, convert carbon dioxide to oxygen, and remove moisture from human waste; however, it seemed there was a better way.

On Earth, organisms specialize in performing these actions in a symbiotic relationship, allowing the great biodiversity that exists in every biome. These organisms are not churning out a human friendly environment, they are living and maintaining an ecosystem. As a result, a biological system is greatly more adaptable, hardier, and can be of more comfort than the latest version of chemical or mechanical life support.

Plants as a means of food is a clear solution to the mass and volume concerns from traditional supplies. The seed take up less space than conventional food, and the plants give the astronauts something to do while in space. There would ideally be three main types of food plants: radishes, beets, potatoes, and potentially a plant that each astronaut choses to grow. Radishes grow exceedingly fast, as quickly as three weeks, but provide little sustenance compared to the other plants. Potatoes are much slower to grow taking beyond seventy days to be edible, however they provide a very large amount of sustenance. Beets are the middle ground of the two, averaging a growth between fifty and seventy days and providing a moderate to large amount of sustenance [15]. Protein would be lacking on this diet, but could easily be solved through use of protein supplements in water. Dietary variety is important to crew health, both physically and mentally. By using fresh, versatile crops, food will be less mundane than the current military rations, improving moral and other aspects of the crew's daily life.

Plants are a clear candidate for oxygen production, however, this introduces an additional water requirement, requiring more supplies be brought onboard. Issues with water recovery are slightly more complicated. Currently on the ISS, there is an approximate 90% recovery, which seems adequate but when the thought of a potentially year long trip, with no chance of an in-space resupply, a 98% recovery sounds more reasonable. However, in research on water recovery methods, an article released by NASA suggests that only a 95% recovery would be necessary [16]. Also, including a hydrogen fuel cell on the craft and growing crops allows only a minimal need to convert carbon dioxide, if any, and the current technologies may provide enough water recovery.

The Micro-Ecological Life Support System Alternative (MELiSSA) project is an attempt at an artificial ecosystem for regenerative life support on a long term manned mission, headed by the European Space Agency. While this project is very promising, it has yet to be tested in space.



MELiSSA Project Ecological Interactions [17]

In this design, there are four compartments, each with specific goals in mind. Compartment one uses bacteria to convert crew waste into carbon dioxide, along with volatile fatty acids and molecular hydrogen. The fatty acids and molecular hydrogen go to compartment two, where a different bacteria transforms them into biomass. The excess of this is ammonium and carbon dioxide, which are passed onto the next compartments. The third compartment uses two bacteria to convert the ammonium to nitrate. Compartment four, the final compartment, uses microalgae, and potentially a plant compartment, to generate oxygen and biomass from the carbon dioxide and nitrate from the other compartments.

There are two main areas of concerns with this technology is that the bacteria and algae have never been grown in space, so there is potential that something may be altered in their growing. However, other plants grown in space have not altered habits drastically, so it is unlikely that these cultures would. Another concerns is the incorporation or plants into the design, with this system, there is no way to remove uneaten/processed parts. That means if something like carrots are grown, it is necessary to eat the tops or store it somewhere, which could cause a storage issue. Although, something like potatoes, which is a great vegetable to eat, does not have waste to worry about, so there are alternative solutions [17].

Environmental Monitoring

Environmental monitoring seeks to quantify on-board organics and particulates with an analysis capable of operating with no sample return. For this there are two parts, water and air analysis systems. Within the water recycling system, there should be onboard filters to detect contaminants. Air is a much more difficult question, especially with plants onboard. Ideally, for the portion containing plants there would be a limited or more relaxed filtration system allowing slightly more contaminants to be detected. For the portion of the capsule not containing plants, that is a much more difficult issue. Ideally there would be a detector capable of registering if a large percentage of carbon dioxide or harmful contaminant was detected. This could potentially be autonomously done with a spectrometer taking samples every hour, responding to changes by releasing more or less oxygen.

Another thing that would be included on the ship would be spectrometers in every subsection. These spectrometers would be used to take samples at a given interval of time from the ambient atmosphere. Each capable of being calibrated for different tolerances; the spectrometer in the plant room being much less sensitive than the spectrometer in the area with sensitive equipment. If a spectrometer detects a composition outside of its specific tolerances, it should trigger an adjustment of the oxygen/carbon dioxide output to that section.

Crew Health

For crew health, the overarching goals were to have small but effective exercise equipment, on board medical capabilities, and long duration food systems. The exercise equipment is of great importance for a long duration mission, as astronauts would need to be able to adjust from having no gravity for months, to gravity and needing to walk again as opposed to floating. Currently there is extensive research being done on the subject, from analyzing astronauts when they return from space to paying volunteers to stay in a sedentary environment for months on end in attempt to analyze the effects on the body [18]. This is a very difficult keep crew healthy in a zero gravity environment, so our proposal seeks to include a simulated gravity component.

For medical capabilities, there are several simple answers, such as first aid kits. For a more traumatic accident that may occur, like a broken limb or a seizure, a ban-aid would not be enough. This creates many issues to address, namely, what is the furthest you are ready to prepare for. For the space flight itself, even a broken bone seems far-fetched, so there should be minimal risk for anything beyond what a first aid kit or something of that caliber can provide. However, reaching Mars is a very different story, where broken bones and more severe injuries are much more likely, not to mention a potential need to relearn how to walk. To accommodate this, and save room on the capsule for the astronauts, it would be ideal to send a preliminary test capsule containing excess equipment and is also capable of monitoring to make sure everything is fully functional.

Long duration food is a problem that has been touched on in a previous portion of this paper, plants are a very simple answer but they are not enough. Radishes grow immensely fast, in as little as five weeks, and would be a great addition to a standard food supply [15]. The main issue with food is that it takes up space, and storing up to a year’s worth of food would take up a significant amount of volume. Ideally, with a preliminary test capsule being sent first, extra food would be stored for the duration of the flight there. Adding a one month contingency is important in case there are any hiccups with the trip.

Exercise for astronauts is also an important thing to look at, not only do they need to exercise while in space, the equipment needs to be rather small. Most muscle groups can be kept in shape with just a mat and some gravity. However cardiovascular health is slightly more difficult. For this, something like a treadmill or bike is ideal, allowing astronauts to work out their legs for a long duration without too much mass being added to the ship. There is also resistance exercise gear, which is used on the ISS, but it not as practical for simulated gravity. The benefits to a bike are that it provides excellent cardiovascular exercises, while weighing a very limited amount. A treadmill also provides a good cardiovascular workout, but weighs slightly more. The main benefit to it, is that it may be designed for potential failure of artificial gravity, where a bike would not be able to provide the same functions. Ideally, though a form of resistance devices, in case of an issue with simulated gravity, and a bike would be incorporated with mats. The treadmill weighs a very large amount due to all of the gear within it that is needed to quell vibrations to the rest of the ship, whereas the bike and resistance gear need much less to prevent vibrations [19].

Extravehicular Activity (EVA)

The EVA sub portion of the proposal had only one goal, to redesign the space suit to have greater mobility, reliability, life support, and operational flexibility. This is calling for a total redesign of the suit, one which would most likely be handled by an outside contractor. The main constraints to focus on are adaptable to different sizes/shapes of astronauts, capable of performing well on both surface and space missions, and ideally ease of access for equipping.

Another idea to increase crew safety was to create a new EVA suit with a built in exoskeleton. This would allow mechanical support for the crew in times of extreme physical stress, such as landing and takeoff. This would also mitigate injuries on the planet's surface, such as broken limbs or stress failures due to bone and muscle deterioration. Furthermore, having better reinforced suits provide a sense of comfort and safety in an environment that is very alien and hostile.

MIT proposed a bio-suit to replace the bulky spacesuits of today. This suit uses mechanical counter pressure as a passive means to deal with the lack of pressure in space. This suit allows for increased flexibility and range of motion. The current limitations with this technology include integration with a pressurized helmet and protection from impacts [20].

NASA's method has involved continuing the design of the spacesuit with improved materials. The NASA Z-2 suit is their latest design for deep space missions. The suit provides outstanding protection from radiation, impacts and the lack of pressure in space, however is limited in mobility similar to previous designs. Most attractive of these features include its design for on planet missions, its ability to dock with the MMSEV, and the custom fitting of the design [21].

Exoskeletons have been explored for many years, with primary focus being military use. Raytheon currently has the most developed exoskeleton for this application. The skeleton can be scaled up or down, and provides an amazing amount of flexibility [22]. With integration of an exoskeleton, astronauts will withstand greater physical stress and reduce the risk of injury.

Other designs have looked into exoskeleton integration, however, these designs generally involve a single layer of protection, the "skin" of the exoskeleton [23]. By combining this suit with the MIT passive pressure suit prototype under the exoskeleton, and the NASA Z-2 prototype's protection outside the exoskeleton, the result is a suit that provides many layers of operational use.

Fire

Fire is a huge safety concern for both the crew and the craft's onboard systems. Detection and prevention are generally the best methods to minimize risk. For fire protection, there are many things to consider, with a goal of ultimately designing an approach that works both in space and on the surface of a planet along with functionality across various size architectures. To start, each capsule and the subcomponents inside the capsules should have sensors capable of detecting excess heat areas, as well as being able to autonomously target and suppress these fires with carbon dioxide suppression. This is a system that could be proven in a test capsule, and then tested with astronauts aboard. The main issue is sheltering the crew, which may be accomplished in a multipart capsule, as the fire is combated in one section the astronauts must move to a separate, sealed, part of the ship.

One of the best options for autonomous fire detection is wide spectrum fire detection cameras. These camera look for IR, UV and CO_2 outputs that are unique to fire signatures. A central computer compares input from the cameras to known fire signatures and triggers an alarm if there is a signature match [24]. The alarm, in turn, could activate a suppression system localized to the section the camera detected the fire in. Since these cameras are continually gaining further resolution, it is becoming easier to detect the exact are the fire is likely to spread to. With these detection and suppression technologies coupled, fire risk should be nearly eliminated.

Suppression can be accomplished by any of many proven methods. Carbon dioxide suppression is most common on spacecraft, as the gas is light, has a high separation temperature, and is non-hazardous to the crew and electronics onboard [25]. Additionally, cleanup is not a concern as it would be with foams or liquids. While fire on Earth has developed the majority of our technology in this field, fires in space require some special considerations. They burn at lower temperatures, and can continue to cause chemical reactions even when the flame is fully extinguished [26]. For these reasons, a suppression method should encapsulate all of the possibly afflicted areas.

Even with these systems, a manual firefighting system should be put in place for redundancy and safety of the crew. A new type of in-space fire extinguisher has been recently patented that relies on non-pressurized water vapor [27].

Radiation Protection

Radiation is a unique issue. On Earth we are protected by the magnetosphere and atmosphere, while in deep space there is no such protection. Shielding from deep space particle bombardment and from solar particle bombardment is vital for the health of the crew and electronic components onboard. For this portion, NASA would like a solar particle event storm shelter, using onboard materials. Additionally, they would like minimal mass crew quarters to help eliminate impact. Current radiation shielding is augmented with polyethylene to help protect astronauts. However, new materials are being developed, like hydrogenated boron nitride nanotubes (hydrogenated BNNT's), which are found to be more effective than polyethylene, and would take up less space [28].

The multi-compartment capsule design also helps with the radiation shelter. One of the compartments could be housed in the ship's water supply which could act as a secondary shelter to protect from radiation. Water provides exceptional protection from all types of radiation [29]. In deep space, radiation poses the greatest health risk. Currently NASA and the University of New Hampshire are conducting separate studies on the effects of radiation in space on the human body [30, 31]. However, we can use the research done by the U.S. Navy, during the Cold War, to assess how much radiation exposure can be permitted, and address this through various shielding methods. While new technology is the most promising avenue for light radiation protection, more developed technology, such as that seen on nuclear submarines and other spacecraft, might provide a greater basis for future designs.

Other Considerations

Once all of the preliminary concerns were addressed, more detail could be put into the other aspects of the design. Many of these concerns apply to all spacecraft and are not unique to this proposal, thus, will not have as much detailed justification.

Manufacturing

In order to reduce mass and costs, a LEO assembly is most attractive. This would entail components being launched as secondary payloads and assembled while in space, similar to how the ISS modules were added on. The appeal with this method resides in the reduction of launch requirements. A completed system would have to be built to withstand the harsh launch environment, adding unnecessary strength to components that would experience little stress in space [32]. Additionally, dedicated launches are expensive and difficult with complex geometry payloads. With gradual assembly in space, the design can also be modified much more easily with mission changes, as the craft will need to be modular. The obvious exception to this would be the main pressure vessels which would likely need to be assembled on Earth due to the advanced testing required [33]. Each module would require a dedicated launch, however, all other parts could be secondary payloads.

Something that was touched on in the previous section was the idea to send a preliminary capsule to Mars. As part of the proposal, the plan dictates that a preliminary test capsule be built. For this specific design, a test capsule containing excess equipment would be sent to the planet ahead of the crew so that when they arrive, there is usable equipment on the planet. This allows for more space on the habited craft, as well as extra supplies for a worst case scenario.

Power

Power will be vital to the spacecraft's mission, and needs to be a large design consideration. While solar panels are commonly used for near Earth applications, their efficiency diminishes significantly as distance to the sun increases. Regardless of this, the spacecraft must use some level of solar cell technology. Nuclear based technology has been tested in the form of radio isotope generators, but has failed in the form of nuclear reactors [34]. Additionally, thermal electric generators could be attached to the sun facing side of the craft in order to generate a small amount of power from pure radiated heat. In the case of an emergency, or high demand for power, hydrogen batteries will be used to store energy. This would work via electrolysis of water to store hydrogen, which could be combusted and reform water. This no-waste system allows for great chemical energy to be released in times of need, without sacrificing valuable space and mass.

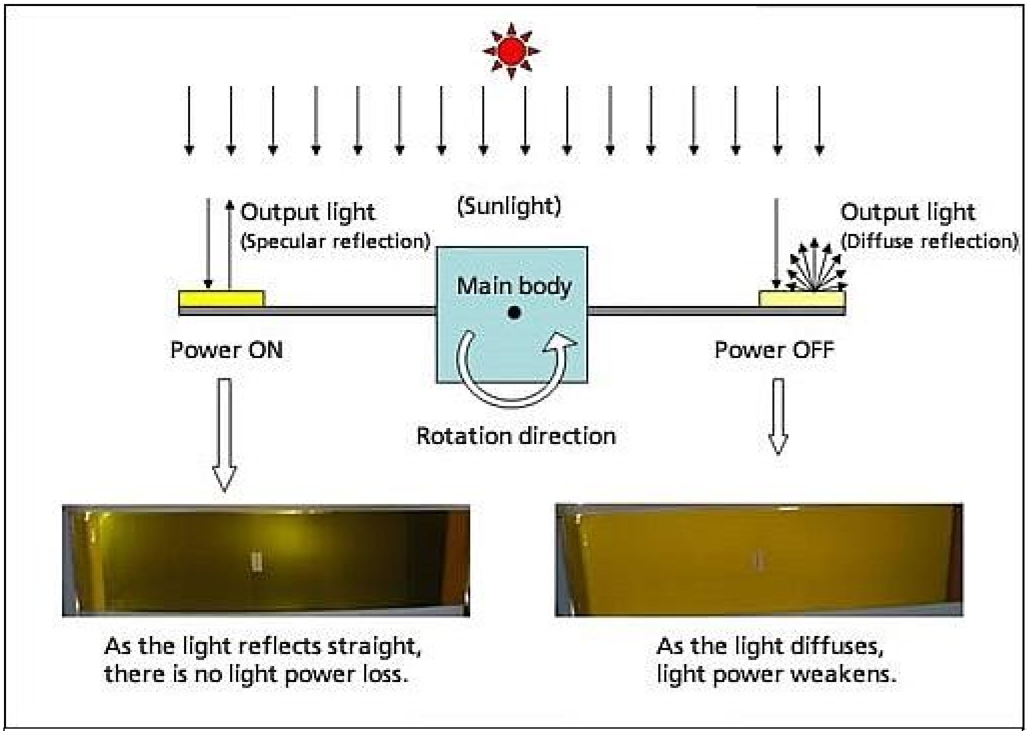
The promising new technology in the field of in-space power collection is solar wind power generation. With this system, electrically charged particles pass through a large wire, producing electricity similar to how spinning a magnet in a coil of wire does. This large wire would be inexpensive and easily deployable in space. The solar wind generator technology is a very interesting concept originating in the 1960's. It was largely abandoned due to the impracticality of supplying the captured energy to Earth [35]. In order to examine its cost and benefits, we examined the theoretical power provided by the generator. Using data from the NASA Genesis mission, it was found that 95% of solar wind particles are ionized hydrogen with a density at Earth of about 9 particles per square centimeter per second [36]. Using this information, it is possible to calculate induced current and voltage potential for an area. For there, the length of a 1mm thick wire with mass of 2000kg was calculated. This resulted in about 5 Watts. Using a calculator designed for Worcester Polytechnic Institute's Spacecraft and Mission Design, a 2000 kg solar array was inputted, with a calculated yield of 15000 Watts. This was using a reinforced array structure and low end silicon cell technology, the worst choice for solar power systems. With every attempt made to validate the use of the solar wind generator, it failed to compare in anything but price.

When choosing solar cells for the array, there are more options every year. The newest of them, quantum flux solar cell technology, is very interesting and may be useful for this spacecraft, however the TRL (technology readiness level) is very low, barely breaking 5. This seems like a considerable investment and risk when there is already similarly efficient Gallium Arsenide cell technology with a TRL of 8 that can be employed.

Propulsion

The solar sail was compared to a traditional solar electric propulsion system, namely the high power ion thruster. It was found to be marginally more efficient for only slightly more mass and with a significantly lower complexity. Mass is a driving factor in every space system design, however, with the spacecraft being constructed in space, this becomes less of a concern. This is due to the fact that components can be launched as secondary payloads, reducing cost of launch. The shorter time of flight (ToF) due to the solar sail also saves on the cost of supplies on board the spacecraft. Our calculated ToF with a .25 km^2 sail is about 170 days. The most attractive aspect of the solar sail, however, is its lack of complexity and thus, reliability. Gridded ion thrusters have a host of potential issues associated with their operation [37]. A failure of a propulsion system could compromise the mission to Mars, or worse, lead to crew being stranded in a Martian orbit. Even in a worst case scenario, a return mission to Earth could be accomplished similar to how sailors sail upwind on a sailboat. The major limit in this technology is that it cannot be efficiently used to return to Earth. For this, solar electric propulsion will be most feasible.

Attitude control is possible the largest problem facing solar sail technology acceptance. A test of the Ikaros vessel from the Japanese Space Agency showed using liquid crystal panels as a sail material allows electric control over whether the material is reflective or not [38]. Since this would work on a gridded system, similar to LED strings, it is possible to rotate the sail while controlling the turning in a heliocentric inertial frame of reference.



Explanation of LED Attitude Control [39]

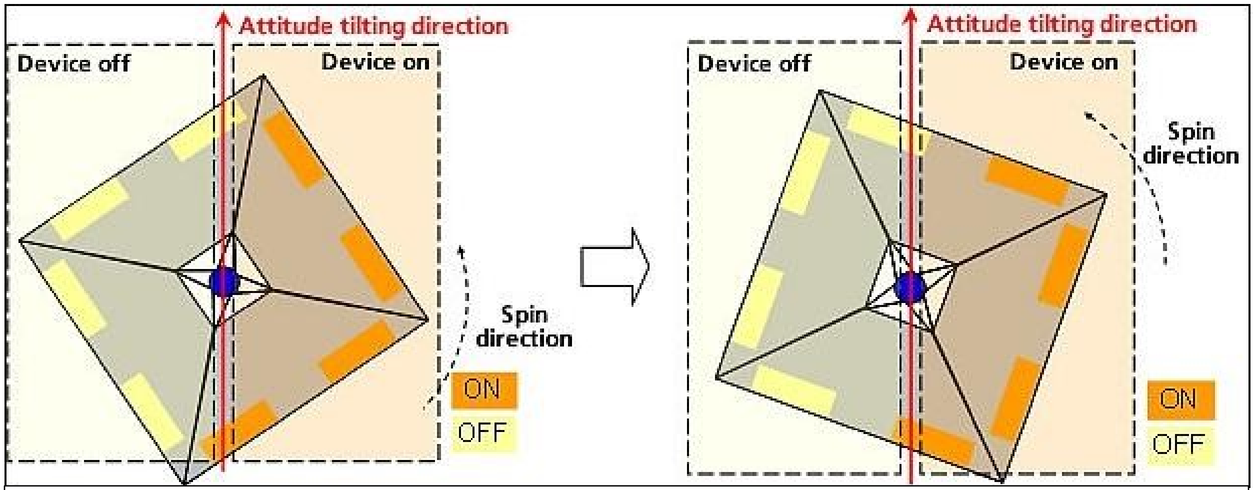


Diagram of Spinning Maneuver Using Solar Sail [40]

For the return trip, a solar electric propulsion system will be used. The most likely candidate is the high yield gridded electrostatic ion thruster. This thruster is the preferred electric thruster for NASA missions, ensuring a high TRL and infrastructure for its most effective use. This thruster uses 3000+ Watts while in use and consumes propellant (most commonly xenon) [41]. The complex thruster is known to have critical failures, although they are rare. We have decided to limit our use of this technology mainly due to the energy requirements, extra space and mass required for propellant, and potential risk posed by a possible failure. However, this technology is needed in order to make the return trip to Earth reasonable. The calculated ToF for this thruster is about 215 days.

Impacts are of large concern to the spacecraft's hull. Research done into micrometeorites showed a focal point of these micrometeorites around a diameter of 200 micrometers. The occurrence of these entering Earth's upper atmosphere was found to be approximately 30,000 +- 20,000 impacts every year. For micrometeorites, there would be approximately 1.08x10-8 occurrences per day per square meter. For the intermediate size meteorites, there is not as much published research on the topic. However, it is known that the distribution of these micrometeorites follows a right, positive, skewed distribution. So, treating the potential for impacts like a linear trend line, would provide an overestimate of the potential for impacts [42]. This is acceptable, since limited data is available on the subject, so an overestimate would be better because it helps provide a buffer in case the limited information provides an underestimate.

From this data, it is predicted that on a 200 day trip, for a circular sail of 250 meter radius, there would be an approximate chance of 1.25 occurrences. For a 500 meter square sail, there would be an approximate chance 1.6 occurrences. The reason that the word occurrences is used here, as opposed to impacts, is because of the known habits of micrometeorite and meteorite impacts. It is known that when these impacts occur, they often occur as storms. When the impacts are calculated, they are calculated as single occurrences, but the probability of occurrence is treated as an event, as multiple are likely to impact the sail during the time.

Since impact rate research has been so neglected, and "storms" of micrometeoroids may occur, an impact detector will be mounted on the forward section of the solar sail. This will help to further our understanding of impact rates in deep space as well as give crucial information of when the sail is safe to deploy. Research suggests that LEO and GEO orbits have an incredibly high chance of impacts damaging the solar sail. Past GEO, these impact rates die down significantly [42]. If the sail is assembled on Earth, attached in GEO, and deployed as the spacecraft left GEO, the sail should see no measurable damage. The Solar Electric Propulsion system can be used to guide the craft out of GEO before switching to the solar sail as the primary propulsion system.

Thermal Regulation

Thermal fluctuations in space are large, causing unique design challenges in order to combat them. The primary thermal regulation technology used in space is radiators. Radiators work on the principle of radiative heat loss, that is, any object hotter than its environment gives off heat, even through a vacuum. Using this principal, large panels are mounted to the hull of a spacecraft, facing into the dark of space, radiating their heat. When the craft is too cold, electric resistance heaters are used to warm up the crew and vital components. These work similar to a toaster, and only require power to operate.

Communications

The communications systems are a vital part of any mission in space. For this mission, Delay Tolerant Networks (DTN) protocol is vital, as communications will take an average of 15 minutes to reach Earth. Any failed communications would take another 15 minutes to learn of the failure, leading to over 45 minutes of lost time per communication [43]. DTN is slower than traditional communication protocols, however it is capable of sending fragmented data and having the receiver patch the information together [44]. Similar to how one may read a letter out loud, and if you missed a word, there is no way to know what that word is, DTN gets all the words multiple times and then arranges them to form the letter. If a few words are lost in the transfer, the copies of them will take their place. This allows data upload and download, but stream becomes difficult due to the delay time for communication and slow rate of data transfer.

As for communication hardware, a small, 5 to 8 meter dish array will be used to communicate with the Marian ground station. This will use an S and X band radio, in order to ensure the signal isn't lost due to interference. For communication from Earth to the orbiter, a larger, 15 meter dish will be mounted. This too will use S and X band radio communication, and will use the Deep Space Network (DSN) to communicate. The DSN is owned and operated by NASA and has current infrastructure to communicate in both S and X band radio, among others, as far as past Pluto [45]. The fact that laser communication may need new types of receivers makes it expensive to pursuit.

In order to prevent blackout periods between the orbiter and Martian ground station, the orbiter will be in a stationary orbit. This would mean a roughly 80 minute black out period between the orbiter and Earth each Sol [46]. This should not be an issue, as the crew will be well prepared and the craft will be mostly autonomous.

Due to rotation of the craft, a rear-mounted array will be used, with the possibility of a stationary tow satellite used to communicate with the ground station. With this design, all axes are covered for attitude control, and the craft has the ability to dock with a retractable arm, allowing resupply missions with the ISS.

Computer Systems

Computer systems are vital to the autonomous nature of this spacecraft. Between deployment of an unmanned, preliminary craft on Mars and the possibility of long durations without crew to monitor onboard systems, the spacecraft must be able to operate without user input. This is commonly done already, with examples ranging from probes to orbiters to landers that do nothing more than send back data.

Radiation poses the greatest risk to electronic systems, and could prove fatal to a computer system. Between shielding on the craft and added radiation hardening in electronics. Radiation hardening is protection from radiation by design or material choice. In the realm of electronics, circuit boards are infused with Silicon Germanium provide extremely lower changes of board failure by scattering the incoming high energy particles to less vital parts of the board. Other methods of radiation hardening include inclusion of self-reconfiguring electronics, or replacing delicate systems with fault tolerant ones [47]. One example of fault tolerant electronics is transistors, and by use of transistor to transistor logic, there is no risk of failure or data corruption from radiation exposure [48].

Besides electronic hardware failures, radiation poses a threat in the form of data loss and corruption. High energy particles can alter data as it is stored, transferred, or processed, leading to software failures [49]. While switching to fault tolerant systems is ideal, these systems often lack the speed, power, and abilities of other systems. To help protect vulnerable data, watchdog timers can be installed. Watchdog timers are bits of hardware that confirm data is in the correct format and can perform the desired function. If the watchdog timer is not fed correct data, it resets or disables the system [50].

Regardless of the steps taken to protect it, sometimes electronics fail. Therefore, all computer systems must have redundancies. Computers can networked in parallel to provide information to one another, and take the role of their failed counterparts. This configuration is commonly known as master/slave interfacing. With this network configuration, all computers process data, however the master computer gives the output that will be used for a system on the spacecraft. Should the master computer show signs of failure or fail to respond, the next computer in the hierarchy will take the place as master computer [51, 52]. The network also allows for data to be processed and compared via different electronics to easily identify failing components.

Hull Design

The habitation modules were sized based on a .5 meter thick bulkhead reference and for equipment while considering the fact that artificial gravity will require walking space, a consideration not employed by the ISS design. OSHA standards were then employed to define how much clearance and work space is required as a basis for comfortable work and habitation environments for the crew. These standards have been created from decades of research and should provide a great basis for refining the scale. The outer habitation modules will be primarily focused on crew and gear space while the inner module will contain the heavier radiation shield “panic room” as well as most of the bulkier life support equipment. It is also planned that most of the electronic equipment will be housed here, as the water for the radiation shield is a great thermal store and radiators will be easier to affix to the middle modules. The modules will all have the same external structure to reduce cost and time to manufacture.

Whipple shields have been used since the 1950’s and have provided great protections in high impact environments such as LEO and GEO. Whipple shielding works off of the idea of conservation of energy. An external “sacrificial layer” or aluminum, or other material, takes the direct impact, transferring energy from the projectile and softening the impact for the main, thicker hull. In turn, this protects the craft from ruptures caused by impacts [53]. External structures will be similarly hardened. The solar sail will be attached with a thick, carbon fiber mount, capable of taking direct impacts without much deformation. The communication dishes will use a mesh that is malleable, and the driving hardware will be housed in the same material as the craft’s hull.

Currently, new materials are being examined to increase functionality, decrease cost, and trim off mass in order to stay competitive with our design. If new materials, such as the self-healing, self-alerting, and compounded material prototypes, do not show promise for being mission ready by 2020, we will proceed with tried and true materials. The MISSE experiment has shed a lot of light on what materials are nearing mission ready status, but it is a lot of data to sift through, so nothing specific has been identified as of yet [54].

There are a multitude of options when it comes to aerospace materials. Aluminum 2219 is the conventional option for aerospace construction [55]. From preliminary calculations, the modules’ masses were unacceptably high. Upon reducing the thickness of the bulkheads and other forms of trimming, the modules became significantly more feasible. Using the OSHA standards, it was found that ladders need a 30 inch diameter “cage” in order to ensure comfort when moving with tools [56]. This caused a reduction in the size of the module connectors.

With the reduced material, a SolidWorks simulation showed a support truss was needed so that gravity gradients did not compromise the structure when in Earth or Mars orbits. These modifications allowed the mass to be reduced significantly. Further reduce mass reductions are possible by thinning bulkheads through use of polyurethane shielding, Whipple Shields, and Kevlar coatings. With this combination, it is possible to reduce the bulkheads to as little as 10 centimeters. Advanced analysis with pressure loading will be necessary, however ⅓ atmospheres is all that is required to sustain life. As a student project, accurate analysis of the complex optimization of hull protection systems was not capable, however recommendations were made based off of conventions from similar projects.

Docking and Resupply Systems

In order to ensure our design stays relevant, we are proposing the docking ports be made to the International Docking System Standard (IDSS) established just last year. This standard will soon be seen on all ships to ensure proper response for all spacecraft. This includes rescues, resupplies, repairs, and other vital changes in missions. This docking standard states our entry pathway be .8 meters wide, with a 1.2 meter wide mount [57]. This is significantly smaller than the 3 meter wide pathway we had arbitrarily chosen before, yielding much more reasonable size for the craft.

Integration with Planned Technology

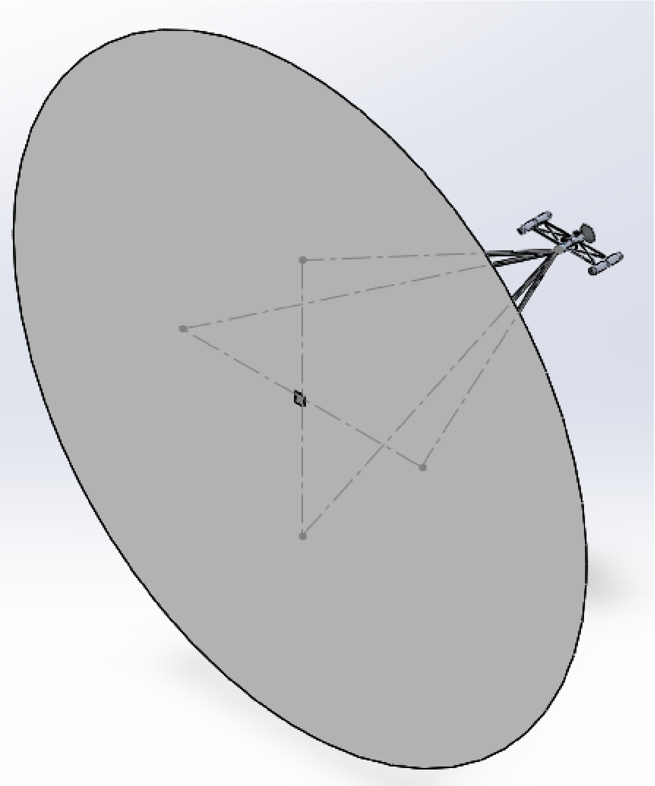
Using the established International Docking System Standard (IDSS), all future systems should be easy to interface with. Chief among these are the NASA Orion Multi-Purpose Crew Vehicle (MPCV) and the International Space Station (ISS). The Orion MPCV will be vital to transportation of crew between planets’ surfaces and the orbital habitation system. For assembly, resupply, and repair the craft must be able to dock with the ISS, allowing safe spacewalks to assess damage. NASA Multi-Mission Space Exploration Vehicle (MMSEV), is also vital for planned Martian exploration activities. The MMSEV will be able to be sent as an attachment with the preliminary habitation system, allowing for immediate shelter in case of failure of the preliminary module.

Repair and Risk Mitigation

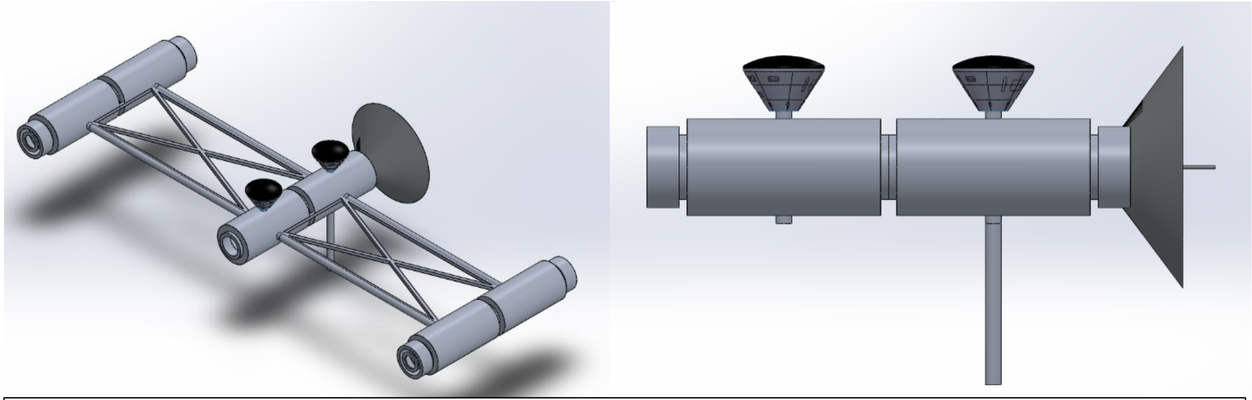
Being able to repair components on a long period in deep space is vital. Currently, 3D printers are being tested for space, but even a simple soldering job is much more complicated in space [58]. Lack of gravity may cause repair of electronics to be nearly impossible, however, with artificial gravity it is expected to be very similar to how it is done on Earth. Tools must be stored onboard to ensure the crew has all available means to fix any problems that may arise. The main issue is how do you fix a destroyed part? In many cases you cannot, which is why it is vital that it can either be printed, or a replacement is taken along. Several replaceable parts will be stored onboard in case of failures, as well as filament for a 3D printer and tools for repairs.

Overall Design and Proposed Name

With the design completed, the last step in any NASA based project is to add a cool name that simplifies into an acronym. Introducing the S.A.G.O.N., the name arises from a description of the craft. Spelled out, it is the Solar Adaptive Gathering/Observation Nautilus. Each part of the name highlights a key feature of the craft. The Solar portion of the craft is highlighted to describe, not the reliance on solar panels of the craft but how it actually uses multiple forms of solar energy to propel the craft towards its destination. Adaptive indicates just how modular the design for the craft is. Any part may be blocked off should damage to it, or breach to the hull occur. Also, the craft is not designed purely for Martian exploration, but rather for deep space exploration, needing little to no alterations from a mission to Mars to a mission to Europa. The Gathering/Observation portion of the craft also helps to display its versatility, it is not a craft necessary to travel to the surface of the planet or one necessary to stay in space. Depending on the mission criteria, it may be used as an orbiter or a surface exploration vehicle. Nautilus is a literary and historically significant name for pioneering vessels. Owning heritage largely to the name of Captain Nemo's vessel in *20,000 Leagues Under the Sea*, as well as being the name of the first nuclear powered submarine created by the United States Navy [59]. This is an ideal portion for the name of the craft as it not only helps to describe the proposed mission of the craft, as the first to take humans to Mars, but to hopefully foreshadow a tremendous arsenal of craft designed after it.



The SAGON craft with solar sail deployed



The SAGON body with Orion capsules docked

Budgeting

For the budget and mass, there are rather loose limits set forward by NASA. These limits are a mass of less than four to six metric tonnes for a SLS launch along with a budget of potentially up to $65 million. Multiple, larger launches will reduce the possible budget significantly. Due to our plan of gradual assembly in space, we can use multiple secondary launches to avoid the mass limit. As the majority of the technologies that are being used are relatively tested, so they are not very expensive one-offs. Cost, however, is an issue that will most likely be faced for the development of the exo-suit, which would have to be an original design and likely more expensive to develop.

There are some assumptions that are made in the cost and mass, to help account for this, the results are intentionally overgeneralized. An example of this would be the fire extinguishers, which do not have a declared mass. Even though the mass is most likely around ten kilograms, it is assumed to be around twelve to fifteen kilograms per unit. This acts as a buffer in case there is an error in the calculations that makes them inaccurate. The overall anticipated budget and cost for this project is a ship weighing approximately six tonnes with a cost under $60 million.

The goals for the mass of the ship are to design a capsule with a final mass of less than 100 metric tonnes. This is a difficult goal to achieve given all that is anticipated to be incorporated inside the capsule, and the fact that the hull needs to be radiation proof. This design has an anticipated mass of under 300 metric tonnes, compared to the 420 metric tonnes of the International Space Station [60]. The majority of the hull should be comprised of aluminum which has a mass of approximately 2.2 grams per cubic centimeter. The radiation shielding is about half that, between 1.3 and 1.5 grams per cubic centimeter depending on the shielding. Taking into account the volume of these materials needed, thousands of cubic meters, the mass begins to pile up very fast.

The monetary cost of the ship is in almost no cases the limiting factor, there is a strict budget of $65 million as a maximum, ideal spread out over multiple proposals. Ideally the design for this would cost less than $60 million, which the proposed design should fulfill. The main costs of the ship would be more unique designs like the oxygen filtration and spacesuits, which actually constitute the majority of the costs of the design.

Expected Mission

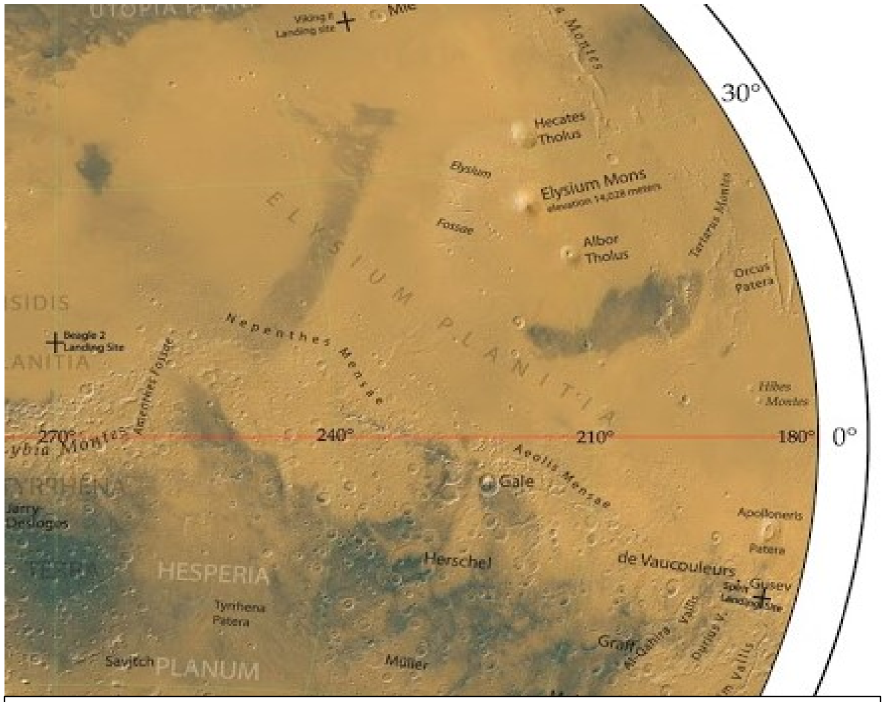
In order to fully analyze the impact of this technology and explore possible scenarios, imagine the following mock mission describing the intended use of this spacecraft and the impacts it will have.

Mission Considerations

One of the biggest questions of space travel, especially for a potentially multi-year long mission is, what the crew will do? Without well-defined objectives and things to keep the astronauts busy the whole time, not only is the mission a waste of resources, it can mentally harm the astronauts which could jeopardize the entire mission. It is ideally proposed that there would be a crew of four to six people, depending on where the craft would land and goals of the mission.

Despite where the craft is landing, there are some missions that would be conducted anywhere. These would be things like materials testing to be done by the crew in space. Also, on the surface of Mars tests would be conducted on the composition of the surroundings, as well as searching to see if there is any liquid water on or under the surface near where the craft lands.

Assuming the craft lands on relatively flat land, or inside of a shallow impact crater, an incorporation of the Multi-Mission Space Exploration Vehicle (MMSEV) would be ideal, as it allows for large amounts of terrain to be covered in a very short amount of time. However, if it is planned to land somewhere like Valles Marineris, sending the MMSEV is worthless. This is because the terrain there is too steep for the vehicle to be used. For this mission design, it is assumed that the ship will land in an impact crater near Elysium Planitia in the Southern Hemisphere. The ideal spot would be something like 29.35 degrees South and 322.63 degrees East on Mars.



Mar’s Elysium Planitia Region [61]

This area, designated ‘Luki’ after a Ukrainian town, is ideal because it is inside an impact crater that is moderately small on the intersection of two water bodies reminiscent of the connection between the Gulf of Aqaba and Suez. The impact crater is a good place to land because it helps to protect the crew and craft from dust storms. It is also only around 25 kilometers wide, with the center point being approximately 30 kilometers from the intersection of the two bodies [62].

To help navigate this, it has already been proposed to use the already designed MMSEV. This is essentially a bus designed for deep space travel, capable of traveling up to ten kilometers per hour and traversing forty degree inclines. This makes it ideal for landing inside smaller impact craters like Luki, with shallower walls. It allows astronauts to be housed within the craft for up to fourteen days, although as a precaution it should only be taken out for ten days at a time [63]. This should allow full investigation of both of the land masses, should the mission be to land around Luki.

For the astronaut(s) left in space during the surface mission, it is a lot more difficult to assess what would be done. Ideally the craft would be in constant contact with the astronauts, and potentially there would be material test missions that could be done in space. An example could be a spacewalk to monitor the effects of radiation on various biological spores, testing to see if any of them are capable of surviving the sustained radiation of space. It would also be possible for them to create a video series similar to that which is done on the ISS, which would both give the astronauts in space something to do and aid public opinion of the mission. Other than the presented jobs, routine maintenance, upkeep, and daily logs should be able to fill the astronaut’s days.

Construction

The preliminary craft will be constructed in space, as the technology is assessed for failures. It sits, docked with the ISS as parts go together and form the main hull. Support trusses are added to protect the craft from the gravity gradients caused by its long body. Internal components start to trickle in, being secured within the craft. Upon final testing, work begins on the secondary craft for launch. Aerospace companies around the world churn out components for these spacecraft, employing thousands. Each module is launched by a dedicated launch vehicle, while the other components slowly get delivered through other launches. A live feed from the ISS hull mounted cameras shows the world the progress. It is the next moon landing in the making.

Preliminary Craft Launch and Arrival

As the secondary craft is being constructed, the preliminary craft launches on its way to Mars. Environmental monitoring sensors stream data back to Earth on the habitability of the modules as it picks up speed, cruising through deep space. Upon arrival, the solar sail acts as an air brake, slowing the craft as it enters the Martian atmosphere. Upon entry, the solar sail is released, parachutes are deployed, and the module comes to rest on the surface of the red planet, awaiting the next steps of the mission. Sensors that have reported their status throughout the journey to Mars will report one last time before going dormant to save power for the ground team. Here, the stowed Multi-Mission Space Exploration Vehicle lays deployed, prepared for the impending visit for the mission.

Secondary Craft Launch

Upon completion of testing, the secondary craft will undock from the ISS and enter a Geocentric Earth Orbit (GEO). From here, a kick stage mounted to the craft will fire and apply a rotation of 3 revolutions per minute. The kick stage will detach and the craft will maintain a GEO parking orbit with the solar sail closed and all supplies onboard. The craft awaits its crew.

Crew Boarding and Launch to Deep Space

The crew of the secondary craft is launched in Orion, arriving in the craft's GEO parking orbit, and docking with it. The crew boards the craft with any personal belongings and gets settled into their new home as Orion craft goes dormant for the long journey to Mars. With the crew onboard, the solar electric engines start their spiral path out of the Earth's Sphere of influence. Once clear of the debris belts around Earth, the solar sail will deploy and start the slow acceleration to Mars.

En Route to Mars

Travel to Mars will take roughly 220 days, almost ⅔ of a year. During this time, the crew will be exercising to maintain their physical condition, making repairs to any equipment that may require it, and tending to the plants aboard. Beyond these important tasks, the crew will keep busy with reading, viewing videos from home, watching television, or entertaining themselves with any activities they requested to be brought along. As the craft moves farther from Earth, the time for communications to reach Earth will increase, resulting in longer time between radio check-ins, longer wait time in downloads, and all other communication latency. The crew will need to get along well, and rely on each other for social interactions. During this stage, a healthy dynamic between crew members is most vital.

Arrival at Mars and Surface Deployment

As the craft approaches Mars, the solar sail will be undeployed and the solar electric propulsion will slow the craft into a stationary orbit above the preliminary craft's location. The Orion spacecraft will ferry the crew to the surface. Orion will use several parachutes to slow the descent. Here, use of the exoskeleton EVA suits will provide additional protection to the crew. Orion will detach from the main craft and be guided to the landing site by use of the on-board thruster and attitude control systems. The thruster shuts off as the module enters the atmosphere of Mars. The parachutes deploy and land the crew on the surface of Mars for the first time. The crew will shelter in the MMSEV until the preliminary module can be properly assessed as working.

Mars Mission

The mission is to examine signs of life on Mars. Here, contamination is a huge issue. The preliminary craft will be the base of operations, communicating with the secondary craft in orbit which then relays messages back to Earth. Here the latency is over 20 minutes each way. The crew is largely on their own. EVA missions will be conducted to take samples, and the onboard spectrometers will give results with no need for sample return. The crew will know the results of each EVA, allowing them to better refine their hunt. The MMSEV will provide a mobile base, allowing for 2 crew members to explore for up to 14 days without resupply [63]. This greatly expands their effective mission area.

Return Mission

As their mission draws to a close, the crew must return to the orbiting secondary craft. To do this, they will refuel the rocket booster of the Orion spacecraft and launch back into Martian orbit. Since Mars is about 40% of Earth's mass, it is much easier to get off the planet's surface. With all their findings in tow, the crew launches up to reunite with their ticket home. Once in orbit, attitude control systems from Orion will allow docking with the secondary craft, preparing for the trip home.

Arrival at Earth

After another 220 day return trip that was much the same as the trip to Mars, the crew is entering Earth's Sphere of Influence. The return trip used solely solar electric propulsion, allowing much more controlled reentry. The secondary craft enters a parking orbit, as a new Orion docks with the craft to shuttle the crew home. The crew leaves the craft, returning to Earth's surface with their findings in hand, destine for some well-deserved rest. The secondary craft re-docks with the ISS for repairs and evaluation.

Moving Forward

The Future of Space Exploration Using SAGON

The SAGON craft was designed with the intention to go to Mars, however, its modular design and large size allows it to be very versatile. The craft should be able to be adapted for deep space exploration, potentially to the asteroid belt or Europa. This was a key portion of the proposal, attempting to design a versatile craft, one which was a major focus of the design itself.

To go further into space, it isn't actually about adding more fuel to the craft. The main thing that needs to be done is to add food and water, as well as to ensure that the crew has enough to do. The solar sail allows the craft not only to go towards the planets without consuming any energy, but to also go back from the planets acting like a sailboat traveling upwind.

While the MELiSSA project research creates an ecosystem that is largely self-sustaining, it can be assumed that there would be some replacement needed, mainly in water on the craft. With a minimum necessary resupply like this, the craft is designed well for deep space exploration. However, modifications should be made if the craft is to be sent towards Venus or Mercury. These planets are closer to the sun, and the solar sail would have to tac and jibe on the way towards the planet, which is not advised, as you are moving away from aid while the ship is performing dynamic motions (which add a higher potential for failure).

New Technologies

In the proposal, all of the technologies and materials incorporated, there was a very high technology readiness level. A big way to expand this project would be to introduce less tested technologies. These would be technologies like polyurethane hull designs and radiation resistant bacteria. Both technologies presented are immensely viable, and they are not the only underdog technologies that could be implemented, they are just two good examples.

Polyurethane is a technology that has been developed and tested only moderately. It has been found to have three times the tensile strength of aluminum at under four tenths of the mass of aluminum [55]. This makes it an excellent choice to send to space after some more testing, as it could potentially save millions of dollars shipping the hull of future craft into space.

Radiation resistant bacteria are a substantially less tested in radiation absorption, and even less so at potential incorporation into the MELiSSA research, as a part of the ecosystem. These are things like radiotrophic fungi and deinococcus radiodurans, which are among the most radiation resistant organisms known to exist. Radioresistant bacteria and spores are good to study for three reasons. First, it is possible for these bacteria and spores to potentially be used as a radiation shielding for the craft. Second, these could potentially be used as a food source for the crew. And third, if not a food source, the materials could be used as a source of energy, helping to propel the ship [64].

Other technologies that could be incorporated into the design would be things like incorporation of quantum dot solar panels and superconductivity. Both of which are relatively untested technologies within a space based environment. Superconductivity has an immense amount of testing on Earth, and it is actually rather surprising that it is not overly tested in space. It potentially increases the overall efficiency of the electronics usage in the craft, if done right, and with that can save a large amount of money for the crew. However, on a manned craft it is not the best idea to test this for the first time. This is something that is better to test on a satellite first, and perfect any issues, then add onto a manned mission.

The quantum dot solar panels are slightly different than superconductivity for implementation. Quantum dot solar panels are a less supported solar technology, having a rather low efficiency now, but capable of having a theoretically high efficiency [65]. These are something that could be implemented onto a spaceship currently, however the mass and cost do not equate with the efficiency of the panels, so it is not worth incorporating.

The Path to Mars

The first manned mission to Mars will be reason to celebrate, but will mark the first step in a long process to establish habitable conditions on Mars. Be it through terraforming, planetary engineering, or specialized infrastructure; Mars will remain a hostile environment that will resist taming.

A big part of that process is legislation, not only by the United States, where this paper is being written, but by the United Nations. Currently there are many regulations about traveling outside of Earth, majorly designed to protect other planters and space objects from contamination, but also to protect the world from a monopolization of sorts by a single country [66]. And, while these regulations do not prevent manned space travel, they are very limiting as to how it should be conducted. More than likely, these regulations will be amended before manned travel to Mars is achieved. However, if they are not the regulations will be very limiting to the potential future of manned travel to Mars.

Already groups that plan on going to Mars have suggested creating a constantly manned Martian colony, like a long term ISS mission. This is a superb idea, as there is so much that can be learned in the short term from Mars. It was already touched on in the beginning of the paper how there are many questions about Mars that a manned mission could help answer. Among these would be the presence of liquid water as well as if life does or has ever existed on Mars.

A consistent manned mission onto the surface of Mars would be superb for answering these questions, as a short couple month mission is able to survey a substantially limited area. Having people living on the surface for years at a time would allow a larger search area, as well as more reliable results. This is something that has plagued the information found by the rover Curiosity, as is something that would likely happen from any samples and evidence brought back by a single manned crew to Mars [67]. However consistently receiving reports of water or bacteria on Mars over a multi-year mission would be considered more reliable.

A manned presence on a foreign planet also adds several benefits for space exploration beyond that planet. Having a station on Mars could act as a refueling/repair point for a craft on the way to Europa. Also, on the surface it would be possible to help with experiments past our solar system. As Mars is a very well-known distance from Earth, it could be used to verify and limit the error bounds on calculations to predict how close we are to the center of our universe.

Despite the drive to reach Mars, and the clear benefits it offers, it is far from easy to establish a foothold on Mars. It has taken over 60 years to provide technology that offers promise for this endeavor. Even then, much preparation is needed once the crew arrives on Mars. Several trips will be needed in order to establish a regular presence, from there self-sufficiency becomes a concern. The first steps have been taken, and the path to Mars will be long. However, this craft not only emphasizes short term exploration, but the satisfaction of adventure which mankind has longed for throughout history and will long for as long as the mysteries of the universe still exist. Not only is developing a colony on Mars an option in the coming centuries, but visiting moons like Europa, plotting the Marianas Trench, and even venturing towards the Sun and Mercury.

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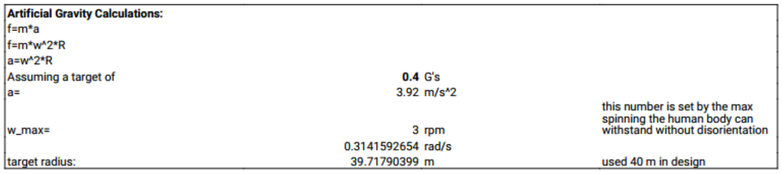
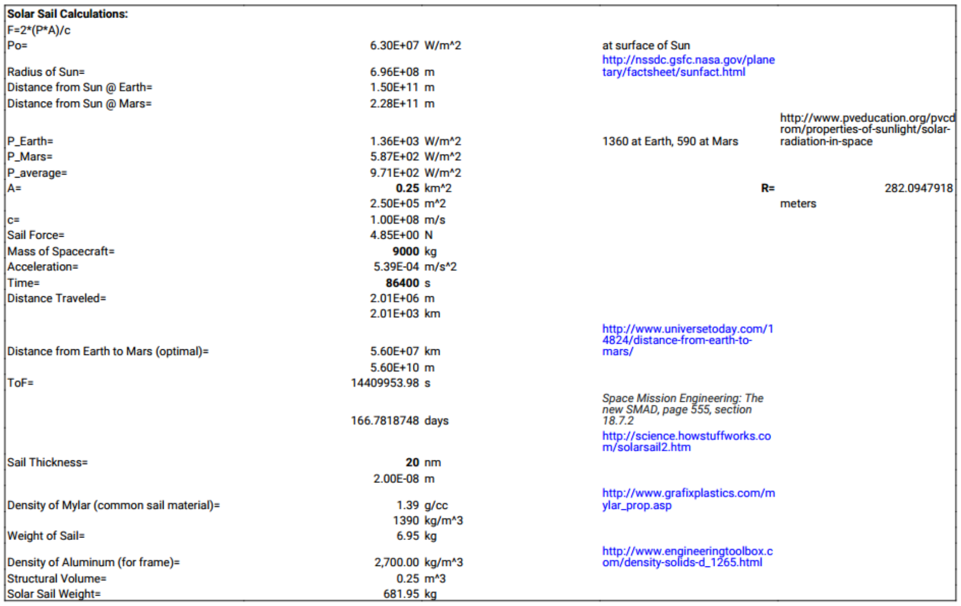
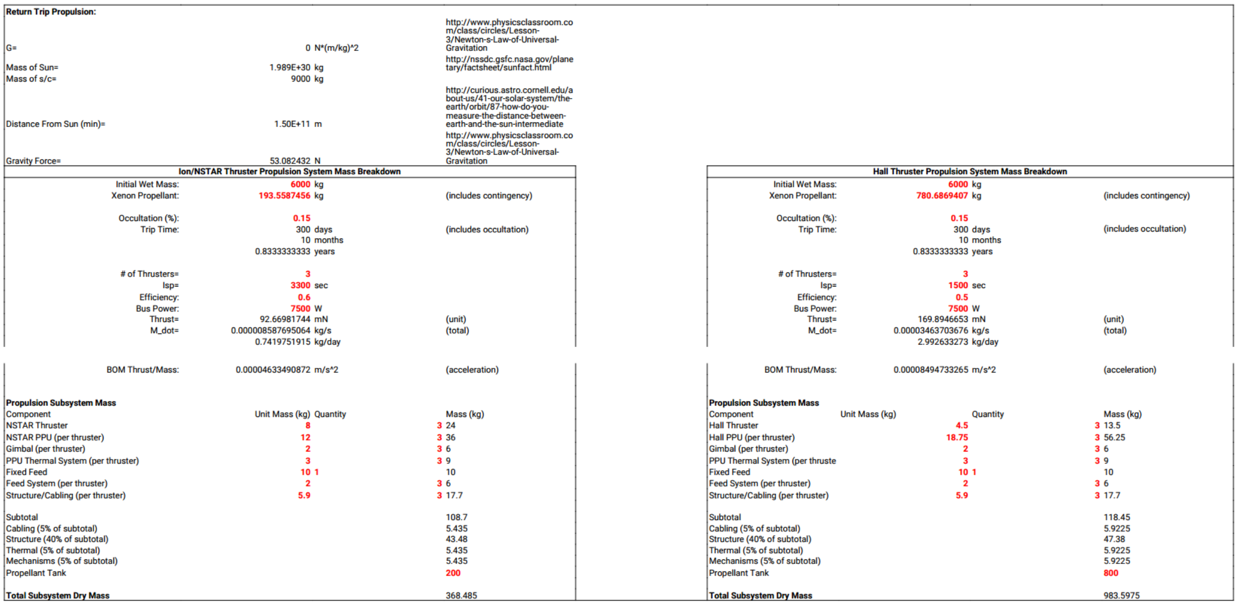
Appendix A: Design Calculations



Artificial Gravity Calculations:			
f=m*a			
f=m*w^2*R			
a=w^2*R			
Assuming a target of	**0.4**	G's	
a=	3.92	m/s^2	
w_max=	3	rpm	this number is set by the max spinning the human body can withstand without disorientation
	0.3141592654	rad/s	
target radius:	39.71790399	m	used 40 m in design



Solar Sail Calculations:				
F=2*(P*A)/c				
Po=	6.30E+07	W/m^2	at surface of Sun	
Radius of Sun=	6.96E+08	m	http://nssdc.gsfc.nasa.gov/planetary/factsheet/sunfact.html	
Distance from Sun @ Earth=	1.50E+11	m		
Distance from Sun @ Mars=	2.28E+11	m		
P_Earth=	1.36E+03	W/m^2	1360 at Earth, 590 at Mars	http://www.pveducation.org/pvcdrom/properties-of-sunlight/solar-radiation-in-space
P_Mars=	5.87E+02	W/m^2		
P_average=	9.71E+02	W/m^2		
A=	**0.25**	km^2	R=	282.0947918
	2.50E+05	m^2		meters
c=	1.00E+08	m/s		
Sail Force=	4.85E+00	N		
Mass of Spacecraft=	**9000**	kg		
Acceleration=	5.39E-04	m/s^2		
Time=	**86400**	s		
Distance Traveled=	2.01E+06	m		
	2.01E+03	km		
Distance from Earth to Mars (optimal)=	5.60E+07	km	http://www.universetoday.com/14824/distance-from-earth-to-mars/	
	5.60E+10	m		
ToF=	14409953.98	s		
	166.7818748	days	*Space Mission Engineering: The new SMAD, page 555, section 18.7.2*	
Sail Thickness=	**20**	nm	http://science.howstuffworks.com/solarsail2.htm	
	2.00E-08	m		
Density of Mylar (common sail material)=	1.39	g/cc	http://www.grafixplastics.com/mylar_prop.asp	
	1390	kg/m^3		
Weight of Sail=	6.95	kg		
Density of Aluminum (for frame)=	2,700.00	kg/m^3	http://www.engineeringtoolbox.com/density-solids-d_1265.html	
Structural Volume=	0.25	m^3		
Solar Sail Weight=	681.95	kg		



Return Trip Propulsion:			
G=	0	N*(m/kg)^2	http://www.physicsclassroom.com/class/circles/Lesson-3/Newton-s-Law-of-Universal-Gravitation
Mass of Sun=	1.989E+30	kg	http://nssdc.gsfc.nasa.gov/planetary/factsheet/sunfact.html
Mass of s/c=	9000	kg	
Distance From Sun (min)=	1.50E+11	m	http://curious.astro.cornell.edu/about-us/41-our-solar-system/the-earth/orbit/87-how-do-you-measure-the-distance-between-earth-and-the-sun-intermediate
Gravity Force=	53.082432	N	http://www.physicsclassroom.com/class/circles/Lesson-3/Newton-s-Law-of-Universal-Gravitation

Ion/NSTAR Thruster Propulsion System Mass Breakdown

Initial Wet Mass:	6000	kg	
Xenon Propellant:	193.5587456	kg	(includes contingency)
Occultation (%):	0.15		
Trip Time:	300	days	(includes occultation)
	10	months	
	0.8333333333	years	
# of Thrusters=	3		
Isp=	3300	sec	
Efficiency:	0.6		
Bus Power:	7500	W	
Thrust=	92.66981744	mN	(unit)
M_dot=	0.000008587695064	kg/s	(total)
	0.7419751915	kg/day	
BOM Thrust/Mass:	0.00004633490872	m/s^2	(acceleration)

Propulsion Subsystem Mass

Component	Unit Mass (kg)	Quantity	Mass (kg)
NSTAR Thruster	8	3	24
NSTAR PPU (per thruster)	12	3	36
Gimbal (per thruster)	2	3	6
PPU Thermal System (per thruster)	3	3	9
Fixed Feed	10	1	10
Feed System (per thruster)	2	3	6
Structure/Cabling (per thruster)	5.9	3	17.7
Subtotal			108.7
Cabling (5% of subtotal)			5.435
Structure (40% of subtotal)			43.48
Thermal (5% of subtotal)			5.435
Mechanisms (5% of subtotal)			5.435
Propellant Tank			200
Total Subsystem Dry Mass			368.485

Hall Thruster Propulsion System Mass Breakdown

Initial Wet Mass:	6000	kg	
Xenon Propellant:	780.6869407	kg	(includes contingency)
Occultation (%):	0.15		
Trip Time:	300	days	(includes occultation)
	10	months	
	0.8333333333	years	
# of Thrusters=	3		
Isp=	1500	sec	
Efficiency:	0.5		
Bus Power:	7500	W	
Thrust=	169.8946653	mN	(unit)
M_dot=	0.00003463703676	kg/s	(total)
	2.992633273	kg/day	
BOM Thrust/Mass:	0.00008494733265	m/s^2	(acceleration)

Propulsion Subsystem Mass

Component	Unit Mass (kg)	Quantity	Mass (kg)
Hall Thruster	4.5	3	13.5
Hall PPU (per thruster)	18.75	3	56.25
Gimbal (per thruster)	2	3	6
PPU Thermal System (per thruste	3	3	9
Fixed Feed	10	1	10
Feed System (per thruster)	2	3	6
Structure/Cabling (per thruster)	5.9	3	17.7
Subtotal			118.45
Cabling (5% of subtotal)			5.9225
Structure (40% of subtotal)			47.38
Thermal (5% of subtotal)			5.9225
Mechanisms (5% of subtotal)			5.9225
Propellant Tank			800
Total Subsystem Dry Mass			983.5975

Solar Wind Generator:			
Density of Particles=	5	particles/s/cm^2	http://genesismission.jpl.nasa.gov/educate/scimodule/data/briefing/STSolarWind.pdf
	0.0005	particles/s/m^2	
Charge of Particle=	0	C/particle	
Length of Wire=	2000000	m	
	2000	km	
Radius of Loop Circle=	318309.8862	m	
Area of Loop=	318309886184	m^2	
	318309.8862	km^2	
I=	0	Amps	
Particle Mass=	0	kg	https://www.chem.tamu.edu/academics/fyp/educator_resources/isotopes_introduction.php
Average Speed of Particle=	500	km/s	http://pluto.space.swri.edu/image/glossary/solar_wind.html
	500000	m/s	
Energy of Average Particle=	0	J/particle	http://www.wikihow.com/Calculate-Joules
Voltage=	207647464815	V	http://www.rapidtables.com/convert/electric/Joule_to_Volt.htm
Power Generated=	5.287699271	Watts	
	19035.71738	Watt-hours	
Weight of copper wire=	1	kg/km	http://www.nktcables.com/dk/products/railway/railway/technical-information/~/media/Files/NktCables/Products/UK/Railway/technical%20info/Copper-wire-table.ashx
Weight of System=	2000	Kg	

Comparative Solar Energy Generation Calculation:			
Dist to Sun:	1.5	AU	dist of s/c from Sun
G=	1368	W/m^2	flux at s/c
Tm=	5	yrs	mission life (siderial years)
Psa=	98108.80625	W	daylight pow req.
Cell Type:	TJ GaAs		
η=	0.3		cell (production) efficiency
α=	4.8	kg/m^2	array specific mass
Id=	0.77		inherent degradation
Θ=	23.5	deg	cosine loss angle (worse case)
	0.4101523742	radians	
Yd=	0.0375	/yr	annual environmental deg rate
Ld=	0.8125		lifetime degradation
P_o=	410.4	W/m^2	Ideal pow output (per unit area)
P_BOL=	289.79832	W/m^2	BOL pow prod capability (per unit area)
P_EOL=	235.461135	W/m^2	EOL pow prod capability (per unit area)
A_sa=	416.6666667	m^2	required array size
Psa_BOL=	120749.3	W	BOL pow output
M_sa=	2000	kg	Array Mass

Cell Type	η	Yd	
Si		0.148	0.0375
TFA Si		0.08	0.0375
GaAs		0.185	0.0275
InP		0.18	
TJ GaAs		0.3	0.0275

Key:

Planned, adequate	SubSet
Planned, average	Planned, poor

	ISS Baseline	30% due to distance from Sun	20% safety	Assumption
Assume:	110	0.3	0.2	165 kW

Total Power Requirement: 12,100 W **Power Generated:** 200000 **W** **Total Difference:** 187,900 W

	Power per Unit (W	Number of Units	Anticipated Power (W	Basis (W)	Requirements/Specifications	Sources
Exosuit			0.00		likely will use rechargeable cells that will plug into craft	
Exosuit-No Aid		4	0.00			
Internal Suit	0	4	0.00			
Basic Life Support		4	0.00			
Exercise Equipment			0.00			
Bike	0	1	0.00			
Mats	0	4	0.00			
Resistance Gear	0	1	0.00			
Life Support			0.00			
MELiSSA Incorporation	0	4	0.00			
On-board Water	0	1	0.00			
On-board Food	0	1	0.00			
Crew	0	4	0.00			
Environmental Detection			0.00			
Oxygen Sensors			0.00			
Module Structure			0.00			
Radiation Shielding	0	1	0.00			
Outer Module		4	0.00			
Inner Module		2	0.00			
Module Connector		4	0.00			
Docking Clamp/Airlock		4	0.00			
Propulsion			0.00			
Solar Electric (Ion/NSTAR) Thruste	3,000	4	12,000.00			
Xenon Propellant Tanks	0	4	0.00			
Solar Sail & Frame	100	1	100.00			
Impact Detector	0	1	0.00			
Power Systems			0.00			
Solar Panels & Arrays	0	8	0.00			
Distribution Systems			0.00			
Thermoelectric Generators			0.00			
Power Control Unit			0.00			
Regulator/Converter			0.00			
Hydrogen Battery			0.00			
Lighting			0.00			
Wiring			0.00			
Communication Systems			0.00			
Short Range Array			0.00			
Long Range Array			0.00			
Radio and Comms Computer			0.00			
Fire Fighting Systems			0.00			
Hydrogenated BNNT's			0.00			
Fire Sensing Camera			0.00			
Crew Fire Extinguishers			0.00			
Central Data-Processing Computer			0.00			
Thermal Management			0.00			
Radiator			0.00			
Louver			0.00			
Electric Resistance Heater			0.00			
Command & Control			0.00			
Navigation Computer			0.00			
Sensor Suite for Navigation			0.00			
Attitude Control Systems			0.00			
Repair			0.00			
Stock of Replacement Parts			0.00			
Tools			0.00			
3D Printer			0.00			
3D Printer print material			0.00			

Key:

🟩 Planned, adequate	🟦 SubSet
🟨 Planned, average	🟥 Planned, poor

Max allotted mass: 6,000 kg (for SLS co-manifest launch) **Total Mass:** 2,008,778 kg 2008.7783 **Metric Tonnes**

	Mass per Unit (kg	Number of Units	Anticipated Weight (kg)	Basis (kg)	Requirements/Specifications	Sources	
Exosuit	150			~225 kg		http://www.army-technology.com/projects/raytheon-xos-2-exoskeleton-us/	
Exosuit-No Aid	100	4	400	125-140 kg		http://history.nasa.gov/spacesuits.pdf	
Internal Suit	10	4	40				
Basic Life Support	200	4	800	178 kg suits used	Capable of two 4 hour EVAs	Appendix A	https://www.nasa.gov/externalflash/ISSRG/pdfs/emu.pdf
Exercise Equipment				~800 kg			
Bike	20	1	20	~10-20 kg			
Mats	1	5	3	~0-5 kg			
Resistance Gear	750	2	1,500	750 kg		http://www.nasa.gov/mission_pages/station/research/experiments/1001.html	
Life Support							
MELiSSA Incorporation	1,000	4	4,000		Enhancements and testing of deep space habitation systems such as Environmental Control and Life Support Systems (ECLSS), such as atmosphere revitalization and monitoring, water processing, lighting, and fire detection		
On-board Water	1,000	800	800,000		30-60 days of supplies	Appendix A	
On-board Food	500	800	400,000		30-60 days of supplies	Appendix A	
Crew	90	4	360	90 is normal for ta	4 crew members	Appendix A	http://www.esa.int/Our_Activities/Human_Spaceflight/Astronauts/Astronaut_training_requirements
Environmental Detection	1,000	6	6,000		Required to sample species found in craft		http://srag.jsc.nasa.gov/spaceradiation/how/how.cfm
Oxygen Sensors	500	6	3,000				
Module Structure							
Radiation Shielding			0				
Outer Module	89,436	4	357,744				
Inner Module	88,526	2	177,052				
Module Connector	26,138	2	52,277				
Docking Clamp/Airlock	600	4	2,400				
Propulsion							
Solar Electric (Ion/NSTAR) Thruste	200	4	800	calculator			
Xenon Propellant Tanks	20	4	80				
Solar Sail & Frame	1,000	1	1,000	~700-750 kg			
Impact Detector	5	1	5				
Power Systems			0				
Solar Panels & Arrays	35,000	1	35,000				
Distribution Systems	500	1	500				
Thermoelectric Generators	500	1	500				
Power Control Unit	4,000	2	8,000				
Regulator/Converter	5,000	2	10,000				
Hydrogen Battery	500	6	3,000				
Lighting	400	6	2,400				
Wiring	120,000	1	120,000				
Communication Systems							
Short Range Array	500	1	500				
Long Range Array	4,000	1	4,000				
Radio and Comms Computer	500	2	1,000				
Fire Fighting Systems				~20 kg per device		http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20130011664.pdf	
Hydrogenated BNNT's	1,000	1	1,000			https://www.nasa.gov/pdf/716082main_Thibeault_2011_PhI_Radiation_Protection.pdf	
Fire Sensing Camera	3	6	18				
Crew Fire Extinguishers	20	10	200	12.5-15 lbs			
Central Data-Processing Computer	100	2	200				
Thermal Management							
Radiator	2,000	4	8,000				
Louver	30	6	180				
Electric Resistance Heater	400	6	2,400				
Command & Control							
Navigation Computer	300	2	600				
Sensor Suite for Navigation	400	1	400				
Attitude Control Systems	3,000	1	3,000				
Repair							
Stock of Replacement Parts	200	1	200				
Tools	100	1	100				
3D Printer	50	1	50				
3D Printer print material	50	1	50				

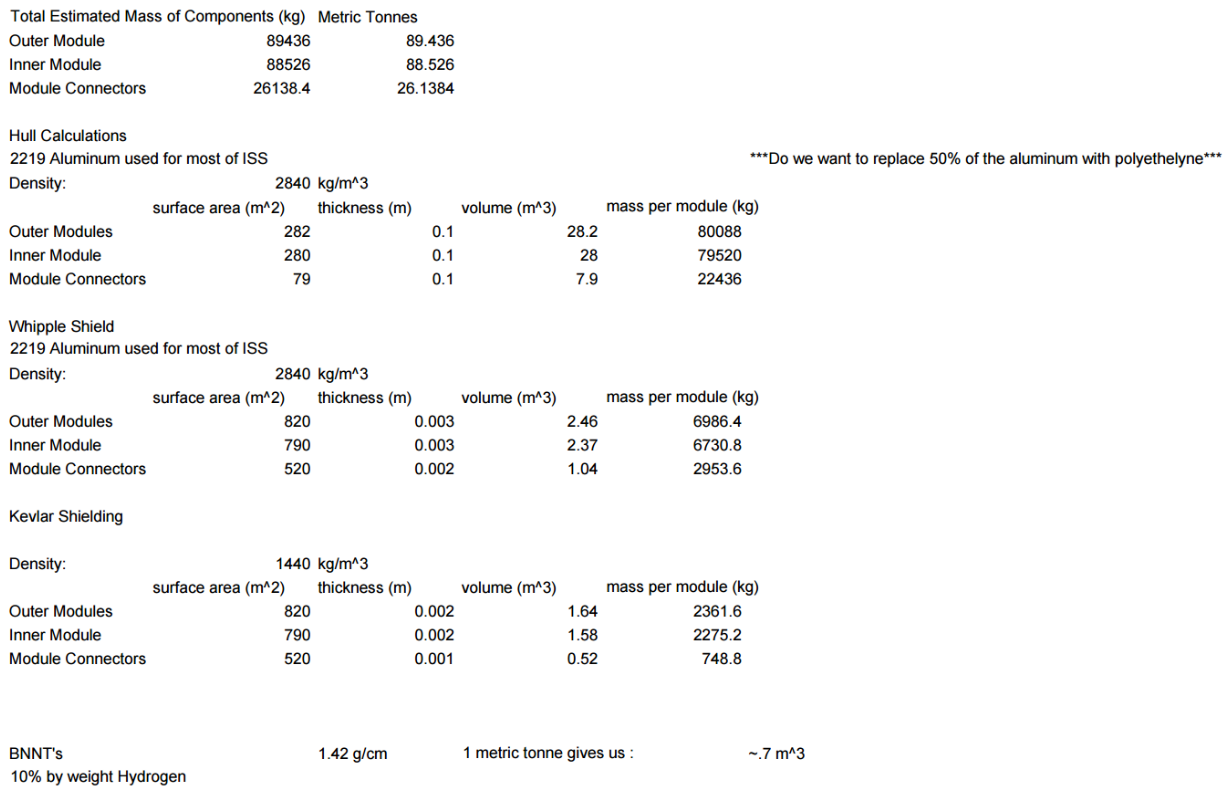
Key:

🟩 Planned, adequate	🟦 SubSet
🟨 Planned, average	🟥 Planned, poor

Launch Costs (dedicated $10.00 2,008,778 $20,087,783.00

Max allotted cost: $65,000,000.00 (not hard limit) Total Cost: $58,186,224.00 **Total Difference:** $6,813,776.00

	Cost per Unit	Number of Units	Anticipated Cost	Basis	Requirements/Specifications	Sources	
Exosuit				$15 million			
Exosuit-No Aid	$1,000,000.00	4	$4,000,000.00	$2 million		http://www.army-technology.com/projects/raytheon-xos-2-exoskeleton-us/	
Internal Suit	$1,000,000.00	4	$4,000,000.00				
Basic Life Support (old EVA Suit Design)	$2,000,000.00	4	$8,000,000.00			http://history.nasa.gov/spacesuits.pdf	
Exercise Equipment							
Bike	$150,000.00	1	$150,000.00	~$150			
Mats	$25,000.00	4	$100,000.00	~$25			
Resistance Gear	$50,000.00	4	$200,000.00	No clue		http://www.nasa.gov/mission_pages/station/research/experiments/1001.html	
Life Support							
MELiSSA Incorporation	$2,000,000.00	1	$2,000,000.00			http://www.esa.int/Education/Teachers_Corner/Food_From_Spirulina_experiment_underway	
On-board Water	$200.00	800	$160,000.00	It said ~$10,000 per lb		http://www.space.com/7597-astronaut-cookbook-thanksgiving-treat.html	
On-board Food	$200.00	800	$160,000.00				
Crew	$0.00	4	$0.00				
Environmental Detection	$10,000.00	6	$60,000.00	2,000		http://www.fwt.com/detector/support/DetDomesticPriceList_Jan2014.pdf	
Oxygen Sensors	$25,000.00	6	$150,000.00	10,000		http://www.coleparmer.com/Product/Scanning_Infrared_Spectrophtometer_115_230V/UX-83000-00?referred_id=778&gclid=CjwKEAjwpfC5BRCT1sKW2qzwqE0SJABkKFKR-AKUcP9NYAiLiWcRsCw2RbHDLlHz8I1Cp9Kb2ys7mhoCLwLw_wcB	
Module Structure							
Radiation Shielding	$10.00	206,610	$2,066,100.00	$2 per lb + labor		http://www.business-standard.com/article/markets/polymer-prices-rise-111030400026_1.htm	
Outer Module	$1,848,580.00	4	$7,394,320.00				
Inner Module	$1,828,190.00	2	$3,656,380.00				
Module Connector	$571,856.00	4	$2,287,424.00				
Docking Clamp/Airlock	$150,000.00	4	$600,000.00				
Propulsion							
Solar Electric (Ion/NSTAR) Thruster	$300,000.00	4	$1,200,000.00				
Xenon Propellant Tanks	$150,000.00	4	$600,000.00				
Solar Sail & Frame	$1,000,000.00	1	$1,000,000.00				
Impact detector	$30,000.00	1	$30,000.00				
Power Systems							
Solar Panels & Arrays	$15.00	200,000	$3,000,000.00				
Distribution Systems	$150,000.00	2	$300,000.00				
Thermoelectric Generators	$20,000.00	1	$20,000.00				
Power Control Unit	$50,000.00	2	$100,000.00				
Regulator/Converter	$50,000.00	2	$100,000.00				
Hydrogen Battery	$100,000.00	6	$600,000.00				
Lighting	$50,000.00	6	$300,000.00				
Wiring	$50,000.00	6	$300,000.00				
Communication Systems							
Short Range Array	$500,000.00	1	$500,000.00				
Long Range Array	$500,000.00	1	$500,000.00				
Radio and Comms Computer	$50,000.00	2	$100,000.00				
Fire Fighting Systems							
Hydrogenated BNNT's	$750.00	2,200	$1,650,000.00	$36-100/lb	***This is a Rad Shield***	Am in contact with 2 boron nitride manufactures NASA recommended, based on the product cost we can assume the final price	1.42 g/cm^2
Fire Sensing Camera	$30,000.00	6	$180,000.00			http://www.buildtheenterprise.org/spacex-breaking-the-1000-per-pound-launch-cost-barrier	
Crew Fire Extinguishers	$22,000.00	6	$132,000.00				
Central Data-Processing Computer	$100,000.00	2	$200,000.00				
Thermal Management							
Radiator	$1,000,000.00	4	$4,000,000.00				
Louver	$10,000.00	6	$60,000.00				
Electric Resistance Heater	$50,000.00	6	$300,000.00				
Command & Control			$0.00				
Navigation Computer	$500,000.00	2	$1,000,000.00				
Sensor Suite for Navigation	$2,000,000.00	1	$2,000,000.00				
Attitude Control Systems	$4,000,000.00	1	$4,000,000.00				
Repair							
Stock of Replacement Parts	$500,000.00	1	$500,000.00				
Tools	$500,000.00	1	$500,000.00				
3D Printer	$25,000.00	1	$25,000.00				
3D Printer print material	$5,000.00	1	$5,000.00				



Total Estimated Mass of Components (kg)		Metric Tonnes
Outer Module	89436	89.436
Inner Module	88526	88.526
Module Connectors	26138.4	26.1384

Hull Calculations
2219 Aluminum used for most of ISS ***Do we want to replace 50% of the aluminum with polyethelyne***
Density: 2840 kg/m^3

	surface area (m^2)	thickness (m)	volume (m^3)	mass per module (kg)
Outer Modules	282	0.1	28.2	80088
Inner Module	280	0.1	28	79520
Module Connectors	79	0.1	7.9	22436

Whipple Shield
2219 Aluminum used for most of ISS
Density: 2840 kg/m^3

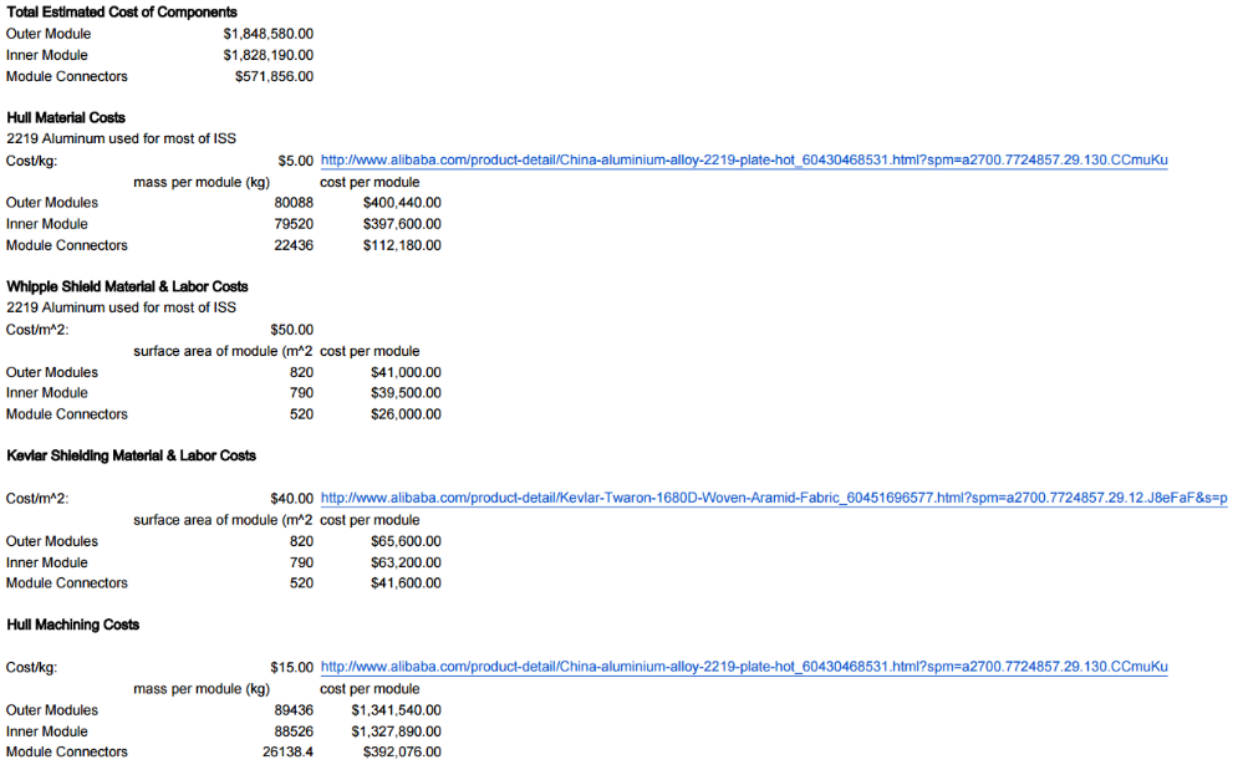
	surface area (m^2)	thickness (m)	volume (m^3)	mass per module (kg)
Outer Modules	820	0.003	2.46	6986.4
Inner Module	790	0.003	2.37	6730.8
Module Connectors	520	0.002	1.04	2953.6

Kevlar Shielding

Density: 1440 kg/m^3

	surface area (m^2)	thickness (m)	volume (m^3)	mass per module (kg)
Outer Modules	820	0.002	1.64	2361.6
Inner Module	790	0.002	1.58	2275.2
Module Connectors	520	0.001	0.52	748.8

BNNT's 1.42 g/cm 1 metric tonne gives us : ~.7 m^3
10% by weight Hydrogen



Total Estimated Cost of Components

Outer Module	$1,848,580.00
Inner Module	$1,828,190.00
Module Connectors	$571,856.00

Hull Material Costs
2219 Aluminum used for most of ISS
Cost/kg: $5.00 http://www.alibaba.com/product-detail/China-aluminium-alloy-2219-plate-hot_60430468531.html?spm=a2700.7724857.29.130.CCmuKu

	mass per module (kg)	cost per module
Outer Modules	80088	$400,440.00
Inner Module	79520	$397,600.00
Module Connectors	22436	$112,180.00

Whipple Shield Material & Labor Costs
2219 Aluminum used for most of ISS
Cost/m^2: $50.00

	surface area of module (m^2	cost per module
Outer Modules	820	$41,000.00
Inner Module	790	$39,500.00
Module Connectors	520	$26,000.00

Kevlar Shielding Material & Labor Costs

Cost/m^2: $40.00 http://www.alibaba.com/product-detail/Kevlar-Twaron-1680D-Woven-Aramid-Fabric_60451696577.html?spm=a2700.7724857.29.12.J8eFaF&s=p

	surface area of module (m^2	cost per module
Outer Modules	820	$65,600.00
Inner Module	790	$63,200.00
Module Connectors	520	$41,600.00

Hull Machining Costs

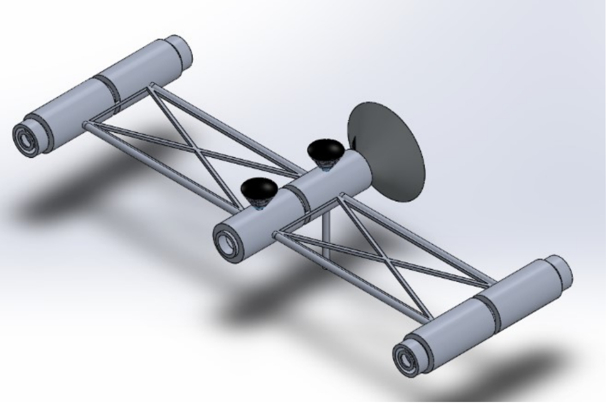
Cost/kg: $15.00 http://www.alibaba.com/product-detail/China-aluminium-alloy-2219-plate-hot_60430468531.html?spm=a2700.7724857.29.130.CCmuKu

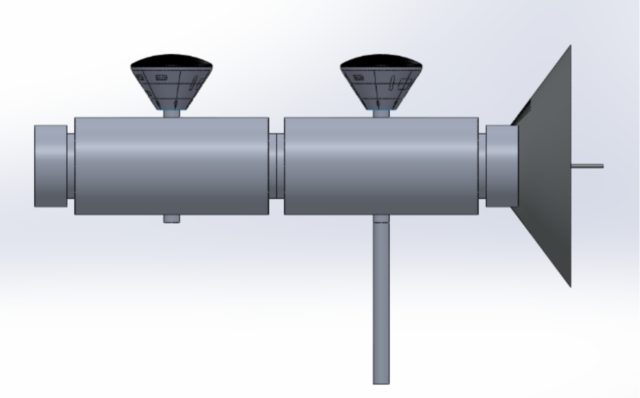
	mass per module (kg)	cost per module
Outer Modules	89436	$1,341,540.00
Inner Module	88526	$1,327,890.00
Module Connectors	26138.4	$392,076.00

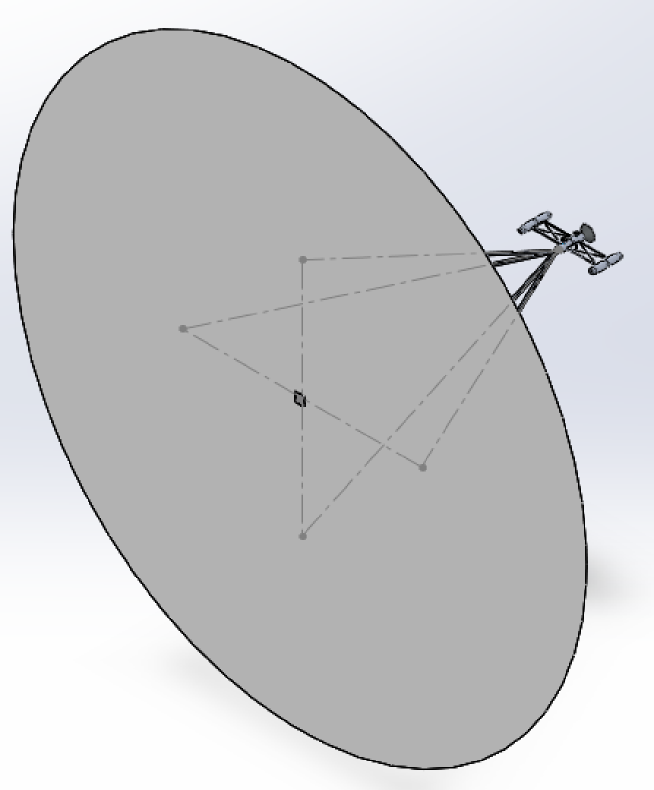
Radiation Shielding

Density:	970	kg/m^3	
Thickness:	0.1	m	
Area:	1	m^2	
Volume:	0.1	m^3	
Weight/area:	97	kg/area	
Surface Areas			
Outer Modules	820	m^2	
Inner Module	790	m^2	
Module Connectors	520	m^2	
Total Weight:	206610	kg	
Cost:	$2,000	/metric ton	
	$2	/kg	http://www.business-standard.com/article/markets/polymer-prices-rise-111030400026_1.html

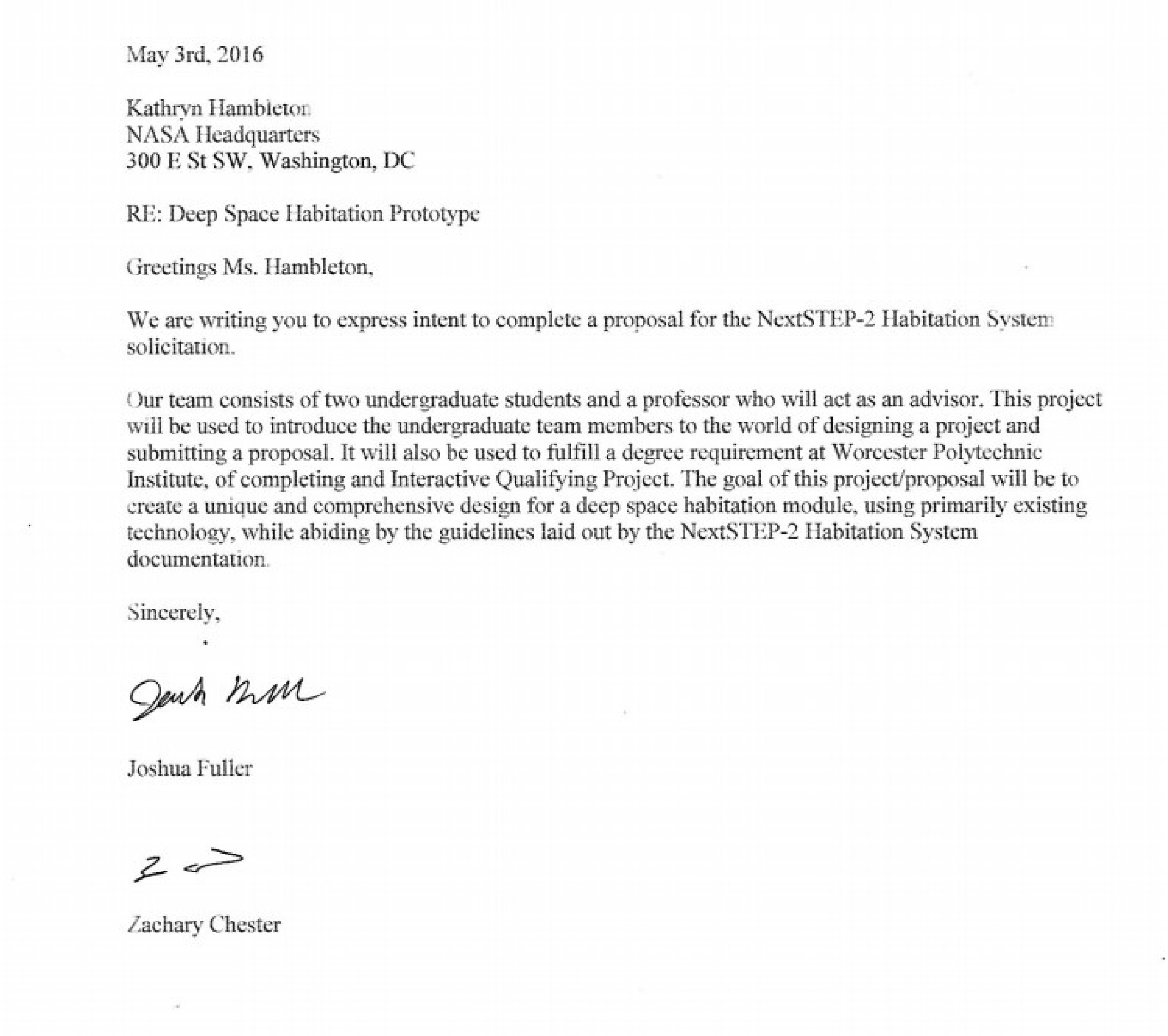
Appendix B: Design Simulations







Appendix C: Letter of Intent - NASA Proposal



May 3rd, 2016

Kathryn Hambleton
NASA Headquarters
300 E St SW, Washington, DC

RE: Deep Space Habitation Prototype

Greetings Ms. Hambleton,

We are writing you to express intent to complete a proposal for the NextSTEP-2 Habitation System solicitation.

Our team consists of two undergraduate students and a professor who will act as an advisor. This project will be used to introduce the undergraduate team members to the world of designing a project and submitting a proposal. It will also be used to fulfill a degree requirement at Worcester Polytechnic Institute, of completing and Interactive Qualifying Project. The goal of this project/proposal will be to create a unique and comprehensive design for a deep space habitation module, using primarily existing technology, while abiding by the guidelines laid out by the NextSTEP-2 Habitation System documentation.

Sincerely,

Joshua Fuller

Zachary Chester

Appendix D: NASA Proposal Submission

The Solar Adaptive Gathering/Observation Nautilus (SAGON)

Designed by: Joshua Fuller and Zachary Chester, Worcester Polytechnic Institute

Advised by: Professor Mayer Humi, Worcester Polytechnic Institute

NextSTEP Broad Agency Announcement -2

Solicitation Number:
NNHZCQ001K-HABITAT

Table of Contents

Section I: Executive Summary

The Solar Adaptive Gathering/Observation Nautilus, or SAGON, is a craft anticipated for a Mars mission, designed versatile enough to perform on missions throughout the solar system. It is a modular design, capable of performing multiple missions before needing to be retired. The ship is designed majorly off of existing technologies, therefore there are less costs associated with the ship and less room for error from technologies not yet matured.

This craft fulfills each of the goals presented in the NASA Next Space Technologies for Exploration Partnerships, NextSTEP, release. This release detailed six specific subcategories that that were key for the design to solve. These subcategories are life support, environmental monitoring, crew health, EVA, fire, and radiation protection. The SAGON ship design fulfills each of these requirements, in many departments it is expected to exceed them.

Life support is currently at a forty-two percent recovery of oxygen from carbon dioxide on the international space station, along with a water recovery of around ninety percent. The goals of the proposal are a larger than seventy-five percent oxygen recovery and a water recovery of more than ninety-eight percent. To meet this, existing water recycling systems are implemented along with a miniaturization of the Micro-Ecological Life Support System Alternative, MELiSSA, project research, which has created a self-sustaining ecosystem.

Environmental monitoring will be used to assess the habitability of the modules during extended missions in deep space. This will be done using spectrometers and other forms of sampling for air and water contaminants. It is important to not only identify if there a health risk, but where it originated for a quick resolution. Monitoring equipment is also vital to assessment of crew health and planetary environments. Fast, on site testing is to be incorporated to deliver as much information as possible to both NASA and the crew.

Crew health is a very unique issue, as there are many troubles currently faced in sustaining a manned mission. Even more so, there are many unique answers to the issues presented of current exercise equipment being cumbersome, issues with limited medical equipment, and food system based on consistent resupply. The question of food was already partially answered with the intention to incorporate the MELiSSA research, as the byproducts are all edible. However, that is not enough to sustain a multi man crew, so the incorporation of other plants like potatoes with limited amounts of processed food is anticipated.

For exercise equipment, the basis for equipment is exceedingly heavy and designed for zero gravity, both of which are potential issues in a long duration flight. The capsule designed for this proposal incorporates an artificial gravity of approximately .4g, which would both limit the weight of the equipment needed and allow for different equipment to be incorporated. For the design of this ship, in the main crew living area it is anticipated that there would be a bike and some mats. In the central part of the ship, there would be an adaptive resistance exercise device, which works in zero gravity. This is in case the gravity fails somehow, but also allows a manned crew on a portion of the ship while potentially only part of the crew is sent to the surface of Mars.

Medical supplies are another interesting issue, on a potentially multi-month mission to the surface Mars there are a lot of injuries that could happen. However, in space these injuries are less likely. So, if a preliminary pod were shipped to the surface, this could contain excess medical supplies and other materials. This would prove the autonomous viability of the craft and allow technologies that are not yet tested in space to be tested, at least partially.

EVA goals are to design a newer spacesuit capable of greater mobility, reliability, and enhanced life support. The design of the suit itself is anticipated to be contracted to an outside company, however it is anticipated that the design will incorporate an exosuit. This will allow for enhanced carrying capacity of astronauts, as well as ease of movement on missions, hopefully reducing the chances of injury.

Fire protection, is a more defined, less dynamic issue. The main goals are to create a unified approach, capable of working in almost any function. This would be done by incorporating heat sensors into potentially fire prone devices, and allowing water vapor extinguishers to autonomously target fires if an anomaly is detected by the sensors.

Radiation protection is a very important subject matter, as many people would not volunteer for a mission that does not offer adequate shielding, or where they are likely to encounter hazards later in life as a result of going into space. For this craft, there is an anticipated safe compartment, where astronauts can stay safely when there are severe radiation warnings. This shield will be comprised of the water supply, which is an excellent radiation shield. The rest of the ship will be shielded using polyethylene and hydrogenated boron nitride nanotubes (hydrogenated BNNT's).

Section II: Proof of Eligibility

Principal Investigators Joshua Fuller and Zachary Chester are members of the educational institution Worcester Polytechnic Institute. Project advisor Professor Mayer Humi is also a representative of the institution. Proof of incorporation can be found here: http://www.wpi.edu/offices/trustees/charterof.html

As an institution of higher education, cost sharing is not required, and as such, was not accounted for. The Principal Investigators seek no commercial gains in this proposal.

Section III: System Concept

Section III.1: Introduction

The proposed system is a habitation module spacecraft for deep space missions, capable of integrating leading edge technology as well as being mission flexible with a highly module design. In accordance with the six highlighted areas of development for this proposal, great emphasis was placed on these design criteria's. The focus was to attain each goal with existing, established technology, lowering R&D times, lead times, and development costs.

Section III.2: Life Support

Life support is a broad topic, it encompasses all systems that allow for the habitation of the spacecraft. The expectation was to retain or recover over 75% of the oxygen converted to carbon dioxide, and more than 98% of water used. Another goal was to assure a larger than two year mean time between failures of electronic parts. The initial design intent was to implement mechanical systems to cover life support needs, similar to current systems on the International Space Station (ISS). These systems would scrub the air and water, convert carbon dioxide to oxygen, and remove moisture from human waste; however, it seemed there was a better way.

On Earth, organisms specialize in performing these actions in a symbiotic relationship, allowing the great biodiversity that exists in every biome. These organisms are living and maintaining a stable ecosystem. Plants as a means of food is a clear solution to the mass and volume concerns from traditional supplies. The seeds take up less space than conventional food and plants give the astronauts something to do while in space.

There would ideally be three main types of food plants: radishes, beets, potatoes, and potentially a plant that each astronaut choses to grow. Radishes grow exceedingly fast, as quickly as three weeks, but provide little sustenance compared to the other plants. Potatoes are much slower to grow, taking beyond seventy days to be edible, however they provide a very large amount of sustenance. Beets are the middle ground of the two, averaging a growth between fifty and seventy days and providing a moderate to large amount of sustenance [1]. Protein would be lacking in this diet, but could easily be solved through use of protein supplements in water. Dietary variety is important to crew health, both physically and mentally. By using fresh, versatile crops, food will be less mundane than the current military rations, improving moral and other aspects of the crew's daily life.

Plants are a clear candidate for oxygen production, however, this introduces an additional water requirement, requiring more supplies be brought onboard. This ties in with the issues of water recovery, which is slightly more complicated. Currently on the ISS, there is an approximate 90% recovery, which seems adequate but with the thought of a potentially year long trip, with an assumed no chance of an in-space resupply, a 98% recovery sounds more reasonable. However, in research on water recovery methods, an article released by NASA suggests that only a 95% recovery would be necessary [2]. Also, including a hydrogen fuel cell on the craft and growing crops allows only a minimal need to convert carbon dioxide, if any, and the current technologies may be enough water recovery.

The Micro-Ecological Life Support System Alternative (MELiSSA) project is an attempt at an artificial ecosystem for regenerative life support on a long term manned mission, headed by the European Space Agency. While this project is very promising, it has yet to be fully tested in space [3].

In this design, there are four compartments, each with specific goals in mind. Compartment one uses bacteria to convert crew waste into carbon dioxide, along with volatile fatty acids and molecular hydrogen. The fatty acids and molecular hydrogen go to compartment two, where a different bacteria transforms them into biomass. The excess of this is ammonium and carbon dioxide, which are passed onto the next compartments. The third compartment uses two bacteria to convert the ammonium to nitrate. Compartment four, the final compartment, uses microalgae, and potentially a plant compartment, to generate oxygen and biomass from the carbon dioxide and nitrate from the other compartments.

There are two main areas of concerns with this technology are that the bacteria and algae have never been grown in space, so there is potential that something may be altered in their growth. However, other plants grown in space have not altered habits drastically, so it is unlikely that these cultures would change [4]. Another concern is the incorporation or plants into the design, with this system, there is no way to remove uneaten/processed parts. That means if something like carrots are grown, it is necessary to eat the tops or store it somewhere, which could cause a storage issue. Although, something like potatoes, which is a great vegetable to eat, does not have waste to worry about, so there are alternative solutions.

Section III.3: Environmental Monitoring

Environmental monitoring seeks to quantify on-board organics and particulates with an analysis capable of operating with no sample return. For this there are two parts, within the water recycling system, there should be onboard filters to detect contaminants. Detecting proper atmosphere is a much more difficult question, especially with plants onboard. Ideally, for the portion of the ship containing plants there would be a limited, or more relaxed filtration system allowing slightly more contaminants to be detected. For the portion of the capsule not containing plants, that is a much more difficult issue. Ideally there would be a detector capable of registering if a large percentage of carbon dioxide or harmful contaminant was detected. This could potentially be autonomously done with a spectrometer taking samples every hour, responding to changes by releasing more or less oxygen.

Another thing that would be included on the ship would be spectrometers in every subsection. These spectrometers would be used to take samples at a given interval of time from the ambient atmosphere. Each capable of being calibrated for different tolerances; the spectrometer in the plant room being much less sensitive than the spectrometer in the area with sensitive equipment. If a spectrometer detects a composition outside of its specific tolerances, it should adjust the oxygen/carbon dioxide output to that section.

Radiation detection is a very important part of the ship, especially one designed for deep space travel. As there is no ozone like here on Earth to defend the ship from bombardment, both radiation shielding and detectors are necessary to keep astronauts safe. For radiation detectors, it is planned to use advanced tissue proportional equivalent counter [5]. This is a tested device that is already good at its function, and with a slight upgrade should help to meet any requirements the existing detector does not meet.

Section III.4: Crew Health

For crew health, the overarching goals were to have small but effective exercise equipment, on board medical capabilities, and long duration food systems. The exercise equipment is a very big deal in a long duration mission, as astronauts would need to be able to adjust from having no gravity for months to gravity and needing to walk again. Currently there is extensive research being done on the subject, from analyzing astronauts when they return from space to paying volunteers to stay in a sedentary environment for months on end in attempt to analyze the effects on the body [6]. This is a very difficult answer to solve in a zero gravity environment, so our proposal would be that a simulated gravity is created.

For medical capabilities, there are several simple answers such as a first aid kit. However, for a more traumatic accident like a broken limb or a seizure, a ban-aid would not be enough. This creates many issues to address, namely, what is the furthest you are ready to prepare for? For the space flight itself, even a broken bone seems far-fetched, so there should be minimal risk for anything beyond what a first aid kit or something of that caliber can provide. However, reaching Mars is a very different story, where broken bones and more severe injuries are much more likely, not to mention a potential need to relearn to walk. To accommodate this, and safe room in the capsule for the astronauts, it would be ideal to send a preliminary test capsule containing excess equipment also capable of monitoring to make sure everything works.

Long duration food is a problem that has been touched on in a previous portion of the proposal, plants are a very simple answer but they are not enough. Radishes grow immensely fast, in as little as five weeks, and would be a great addition to a standard food supply. The main issue with food is that it takes up space and storing up to a year's worth of food would take up a large amount of space. Ideally with a preliminary test capsule being sent first, you could store extra food, and carry the amount of food you need for the flight, plus one month in case there are any issues on the trip.

Exercise for astronauts is also an important thing to look at, not only do they need to exercise while in space, the equipment needs to be rather small. Most muscle groups can be kept in shape with just a mat and some gravity. However cardiovascular health is slightly more difficult. For this, something like a treadmill or bike is ideal, allowing astronauts to work out their legs for a long duration, without too much mass being added to the ship. There is also resistance exercise gear, which is used on the ISS, but it not as practical for simulated gravity. The benefits to a bike are that it provides excellent cardiovascular exercises, while weighing a very limited amount. A treadmill also provides a good cardiovascular workout, but weighs slightly more [7]. The main benefit to it is that a treadmill may be designed for potential failure of artificial gravity, whereas a bike would not be able to provide the same functions. Ideally, though, a form of resistance devices in case of an issue with simulated gravity and a bike would be incorporated with mats.

Section III.5: Extravehicular Activity (EVA)

The EVA sub portion of the proposal had only one goal, to redesign the space suit to have greater mobility, reliability, life support, and operational flexibility. This is calling for a total redesign of the suit, one which would most likely be handled by an outside company. The main constraints to focus on are adaptable to different sizes/shapes of astronauts, capable of performing well on both surface and space missions, and ideally ease of access for equipping.

Another idea to increase crew safety was to create a new EVA suit with a built in exoskeleton. This would allow mechanical support for the crew in times of physical stress, such as landing and takeoff. This would also mitigate injuries on the planet's surface, such as broken limbs or stress failures due to bone and muscle deterioration. Furthermore, having better reinforced suits provide a sense of comfort and safety in an environment that is very alien and hostile.

Exoskeletons have been explored for many years, with primary focus being military use. Raytheon currently has the most developed exoskeleton for this application [8]. The skeleton can be scaled up or down, and provides an amazing amount of flexibility. By combining this suit with the MIT passive pressure suit prototype under the exoskeleton, and the NASA Z-2 prototype's protection outside the exoskeleton, the result is a suit that provides many layers of operational use.

Section III.6: Fire Detection and Suppression

Fire is a huge safety concern for both the crew and the craft's onboard systems. Detection and prevention are generally the best methods to minimize risk. For fire protection, there are many things to consider, with a goal of ultimately designing an approach that works both in space and on the surface of a planet along with across various size architectures. To start, each capsule and the subparts inside the capsules should have sensors capable of detecting excess heat areas, as well as being able to autonomously target and suppress these fires with carbon dioxide suppression. This is a system that could be proven in a test capsule, and with astronauts aboard, the main issue is sheltering them which may be accomplished in a multipart capsule, as the fire is prevented the astronauts must move to a separate, sealed, part of the ship.

One of the best options for autonomous fire detection is wide spectrum fire detection cameras. These camera look for IR, UV, and CO_2 outputs that are unique to fire signatures. A central computer compares input from the cameras to known fire signatures and triggers an alarm if there is a good enough match [9]. The alarm, in turn, could activate a suppression system localized to the section the camera detected the fire in. Since these cameras are continually gaining further resolution, it is becoming easier to detect the exact are the fire is likely to spread to. With these detection and suppression technologies coupled, fire risk should be nearly eliminated.

Suppression can be tackled by any of many proven methods. Carbon dioxide suppression is most common on spacecraft, has a high separation temperature and is non-hazardous to the crew and electronics onboard. Additionally, cleanup is not a concern as it would be with foams or liquids [10]. While fire on Earth has developed the majority of our technology in this field, fires in space require some special considerations. They burn at lower temperatures, and can continue to cause chemical reactions even when the flame is fully extinguished. For these reasons, a suppression method should encapsulate the possibly afflicted areas. Even with these systems, a manual firefighting system should be put in place for redundancy and safety of the crew. A new type of in-space fire extinguisher has been recently patented [11]. Further research on the application of this technology is needed.

Section III.7: Radiation Protection

Radiation protection is a unique issue, in deep space there is no protection from the Earth's magnetic sphere. Shielding from deep space particle bombardment and from solar particle bombardment is vital for the health of the crew and electronic components onboard. For this portion a solar particle event storm shelter, using onboard materials is desired. Also, minimal mass CQ's to help eliminate impact are ideal. Currently, radiation shielding is augmented with polyethylene to help protect astronauts. However, new materials are being developed, like hydrogenated boron nitride nanotubes (hydrogenated BNNT's), which are found to be more effective than polyethylene, and could take up less space [12]. The multi-compartment capsule design also helps with the radiation shelter. One of the compartments could be housed in the ship's water supply which could act as a secondary shelter to protect from radiation. In deep space, radiation poses the greatest health risk. Currently NASA and the University of New Hampshire are conducting separate studies on the effects of radiation in space on the human body. However, we can use the research done by the U.S. Navy, during the Cold War, to assess how much radiation exposure can be permitted and address this through various shielding methods. While new technology is the most promising avenue for light radiation protection, more developed technology, such as that seen on nuclear submarines and other spacecraft, might provide a greater basis for initial designs.

Section III.8: Propulsion

The solar sail was compared to a traditional solar electric propulsion system, namely the high power ion thruster. It was found to be marginally more efficient for only slightly more weight, and with a significantly lower cost and complexity. Weight is a driving factor in every space system design, however, with the spacecraft being constructed in space, this becomes less of a concern. This is due to the fact that components can be launched as secondary payloads, reducing cost of launch. The shorter time of flight (ToF) due to the solar sail also saves on the cost of supplies on board the spacecraft. Our calculated ToF with a .25 km^2 circular sail is about 170 days. The most attractive aspect of the solar sail, however, is its lack of complexity and thus, reliability. Gridded ion thrusters have a host of potential issues associated with their operation. A failure of a propulsion system could compromise the mission to Mars, or worse, lead to crew being stranded in a Martian/deep space orbit. Even in a worst case scenario, a return mission to Earth could be accomplished similar to how sailors sail upwind on a sailboat. The major limit in this technology is that it cannot be efficiently used to return to Earth. For this, solar electric propulsion will be most feasible.

Attitude control is possible the largest problem facing solar sail technology acceptance. A test of the Ikaros vessel from the Japanese Space Agency showed using liquid crystal panels as a sail material allows electric control over whether the material is reflective or not [13]. Since this would work on a gridded system, similar to LED strings, it is possible to rotate the sail while controlling the turning in a heliocentric inertial frame of reference.

For the return trip, a solar electric propulsion system will be used. The most likely candidate is the high yield gridded electrostatic ion thruster. This thruster is the preferred electric thruster for NASA missions, ensuring a high TRL and infrastructure for its most effective use. Each thruster uses 3000+ Watts while in use and consumes propellant (most commonly xenon). The complex thruster is known to have critical failures, although they are rare. We have decided to limit our use of this technology mainly due to the energy requirements, extra space and mass required for propellant, and unnecessary risk posed by a possible failure. However, this technology is needed in order to make the return trip to Earth reasonable. The calculated ToF for this thruster is about 215 days.

Impacts are of large concern to the spacecraft's hull. Research done into micrometeorites showed a focal point of these micrometeorites around a diameter of 200 micrometers. The occurrence of these entering Earth's upper atmosphere was found to be approximately 30,000 +-20,000 impacts every year. For micrometeorites, there would be approximately 1.08x10^-8 occurrences per day per square meter. For the intermediate size meteorites, there is not as much published research on the topic. However, it is known that the distribution of these micrometeorites follows a right, positive skewed distribution. So, treating the potential for impacts like a linear trend line, would provide an overestimate of the potential for impacts. This is acceptable, since limited data is available on the subject, so an overestimate would be better because it helps provide a buffer in case the limited information provides an underestimate.

From this data, it is predicted that on a 200 day trip, for a circular sail of 250 meter radius, there would be an approximate chance of 1.25 occurrences. For a 500 meter square sail, there would be an approximate chance 1.6 occurrences. The reason that the word occurrences is used here, as opposed to impacts, is because of the known habits of micrometeorite and meteorite impacts. It is known that when these impacts occur, they often occur as storms. When the impacts are calculated, they are calculated as single occurrences, but the probability of occurrence is treated as an event, as multiple are likely to impact the sail during the time.

Since impact rate research has been so neglected, and "storms" of micrometeoroids may occur, an impact detector will be mounted on the forward section of the solar sail. This will help to further our understanding of impact rates in deep space as well as give crucial information of when the sail is safe to deploy. Research suggests that LEO and GEO orbits have an incredibly high chance of impacts damaging the solar sail. Past GEO, these impact rates die down significantly. If the sail is assembled on Earth, attached in GEO, and deployed as the spacecraft left GEO, the sail should see no measurable damage. The Solar Electric Propulsion system can be used to guide the craft out of GEO before switching to the solar sail as the primary propulsion system.

Section III.9: Electric Power Systems

Power will be vital to the spacecraft's mission, and needs to be a large design consideration. Solar panels are commonly used for near Earth applications, however, their efficiency diminishes significantly as distance to the sun increases. Regardless of this, the spacecraft must use some level of solar cell technology. Additionally, thermal electric generators could be attached to the sun facing side of the craft in order to generate a small amount of power from pure radiated heat. In the case of an emergency, or high demand for power, hydrogen batteries will be used to store energy. This would work via electrolysis of water to store hydrogen, which could be combusted and reform water. This no-waste system allows for great chemical energy to be released in times of need, without sacrificing valuable space and weight.

When choosing solar cells for the array, there are more options every year. The newest of them, quantum flux solar cell technology, is very interesting and may be useful for this spacecraft, however the TRL (technology readiness level) is very low, barely breaking 5. This seems like a considerable investment and risk when there is already similarly efficient Triple Junction Gallium Arsenide cell technology with a TRL of 8 that can be employed. Possibly in future, the near limitless efficiency potential of quantum flux solar cells can be integrated.

Section III.10: Thermal Regulation

Thermal fluctuations in space are large, causing unique design challenges in order to combat them. The primary thermal regulation technology used in space is radiators. Radiators work on the principle of radiative heat loss, that is, any object hotter than its environment gives off heat, even through a vacuum. Using this principal, large panels are mounted to the hull of a spacecraft, facing into the dark of space, radiating their heat. When the craft is too cold, electric resistance heaters are used to warm up the crew and vital components. These work similar to a toaster, only requiring power to operate.

Section III.11: Communications

The communications systems are a vital part of any mission in space. For this mission, Delay Tolerant Networks (DTN) protocol is vital, as communications will take an average of 15 minutes to reach Earth. Any failed communications would take another 15 minutes to learn of the failure, leading to over 45 minutes of lost time per communication. DTN is slower than traditional communication protocols, however it is capable of sending fragmented data and having the receiver patch the information together. Similar to how one may read a letter out loud, and if you missed a word, there is no way to know what that word is, DTN gets all the words multiple times and then arranges them to form the letter. If a few words are lost in the transfer, the copies of them will take their place. This allows data upload and download, but stream becomes difficult due to the delay time for communication and slow rate of data transfer.

As for communication hardware, a small, 5 to 8 meter dish array will be used to communicate with the Marian ground station. This will use an S and X band radio, in order to ensure the signal is not distorted or lost due to interference. For communication from Earth to the orbiter, a larger, 15 meter dish will be mounted. This too will use S and X band radio communication, and will use the Deep Space Network (DSN) to communicate. The DSN is owned and operated by NASA and has current infrastructure to communicate in both S and X band radio, among others, as far as past Pluto. The fact that laser communication may need new types of receivers makes it expensive to pursuit.

In order to prevent blackout periods between the orbiter and Martian ground station, the orbiter will be in a stationary orbit. This would mean a roughly 80 minute black out period between the orbiter and Earth each Sol. This should not be an issue, as the crew will be well prepared and the craft will be mostly autonomous.

Due to rotation of the craft, a rear-mounted array will be used, with the possibility of a stationary tow satellite used to communicate with the ground station. With this design, all axes are covered for attitude control, and the craft has the ability to dock with a retractable arm, allowing resupply missions with the ISS.

Section III.12: Hull Design

The habitation module's hull sections were sized based precedent set by the ISS fabrication and while considering the fact that artificial gravity will require walking space, a consideration not employed by the ISS design. OSHA standards were then employed to define how much clearance and work space is required as a basis for comfortable work and habitation environments for the crew. These standards have been created from decades of research and should provide a great basis for refining the scale. The outer habitation modules will be primarily focused on crew and gear space while the inner module will contain the heavier radiation shield "panic room" as well as most of the bulkier redundancy equipment and electronics. The modules will all have the same external structure to reduce cost and time to manufacture.

Whipple shielding will be used on the hull of the craft to prevent ruptures caused by impacts. Whipple shields have been used since the 80's and have provided great protections in high impact environments such as LEO and GEO. External structures will be similarly hardened. The solar sail will be attached with a thick, carbon fiber mount, capable of taking direct impacts without much deformation. The communication dishes will use a mesh that is malleable, and the driving hardware will be housed in the same material as the craft's hull.

Currently, new materials are being examined to increase functionality, decrease cost, and trim off weight in order to stay competitive with our design. If new materials, such as the self-healing, self-alerting, and compounded material prototypes, do not show promise for being mission ready by 2020, the design will proceed with tried and true materials. Aluminum 2219 T-62 is the internationally accepted safe option for aerospace construction.

Using the OSHA standards, it was found that ladders need a 30 inch diameter "cage" in order to ensure comfort when moving with tools. This caused a reduction in the size of the module connectors. With the reduced material, a SolidWorks simulation showed a support truss was needed so that gravity gradients did not compromise the structure when in Earth or Mars orbits. Further reduce mass reductions are possible by thinning bulkheads through use of polyurethane shielding, Whipple Shields, and Kevlar coatings. With this combination, it is possible to reduce the bulkheads to as little as 10 centimeters. Advanced analysis with pressure loading will be necessary, however ⅓ atmospheres is all that is required to sustain life. This greatly reduces the pressure anticipated on the modules.

Section III.13: Docking and Resupply Systems

In order to ensure our design stays relevant, we are proposing the docking ports be made to the International Docking System Standard (IDSS) established just last year. This standard will soon be seen on all ships to ensure proper response for all spacecraft. This includes rescues, resupplies, repairs, and other vital changes in missions. This docking standard states our entry pathway be .8 meters wide, with a 1.2 meter wide mount. This is significantly smaller than the 2 meter wide pathway we had arbitrarily chosen before, yielding much more reasonable size for the craft.

Section III.14: Preparations and Construction

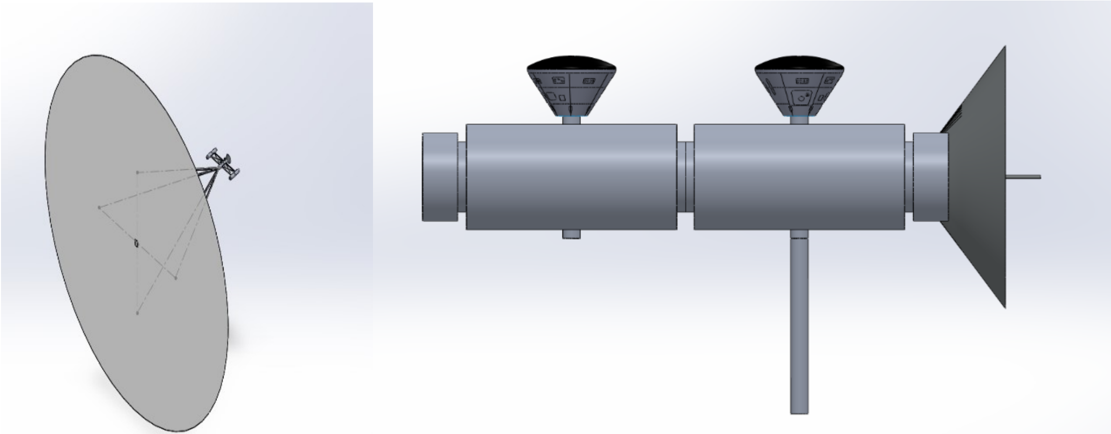
In order to reduce weight and costs, a LEO assembly is most attractive. This would entail components being launched as secondary payloads and assembled while in space, similar to how the ISS modules were added on. The appeal with this method resides in the reduction of launch requirements. A completed system would have to be built to withstand the harsh launch environment, adding unnecessary strength to components that would experience little stress in space. Additionally, dedicated launches are expensive, especially with complex payload geometries. With gradual assembly in space, the design can also be modified much more easily to fit mission modifications, as the craft will need to be modular. The obvious exception to this would be the main pressure vessels which would likely need to be assembled on Earth due to the advanced testing required. Each module would require a dedicated launch, however, all other parts could be secondary payloads.

As a means to reduce the size of the craft, either a preliminary module would be needed to send mission critical equipment to a planet’s surface, or a specialized deployment of an on planet habitation module would be necessary. To further reduce unnecessary costs, this craft would have no heat shielding and would rely on the Orion Multi-Purpose Crew Vehicle or a similar deep space capable capsule as a means to enter the atmosphere of any planetary body.

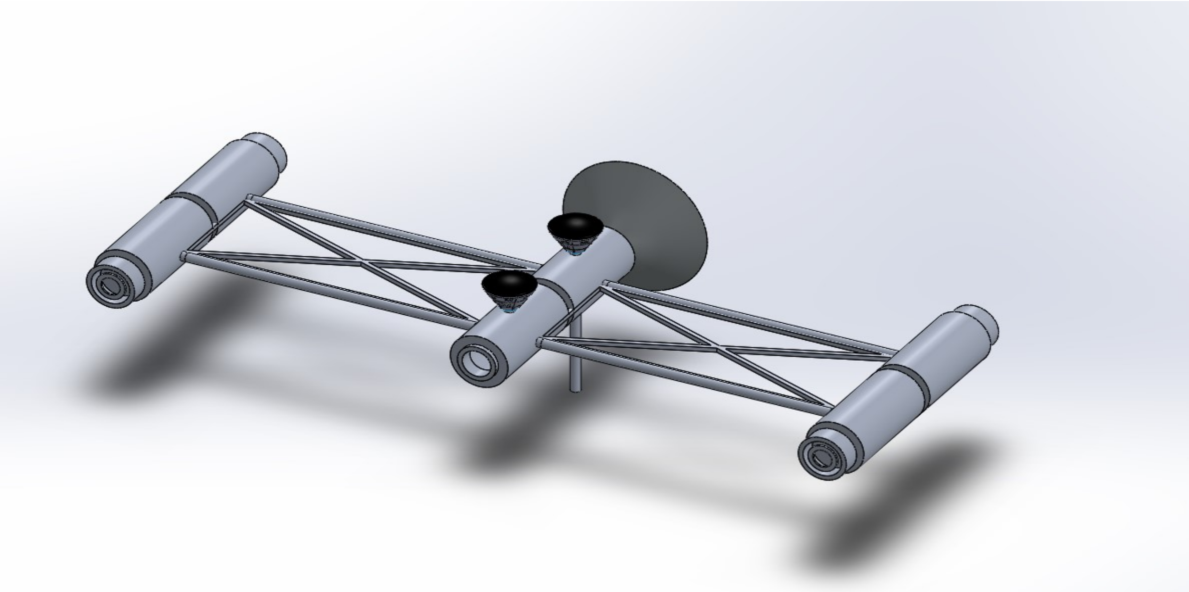
Section III.15: Repair and Risk Mitigation

Being able to repair components on a long period in deep space is vital. Currently, 3D printers are being tested for space, but even a simple soldering job is much more complicated in space. Lack of gravity may cause repair of electronics to be nearly impossible, however, with artificial gravity it is expected to be very similar to how it is done on Earth. Tools must be stored onboard to ensure the crew has all available means to fix any problems that may arise. The main issue is how do you fix a destroyed part? In many cases you cannot, which is why it is vital that it can either be printed, or a replacement is taken along. Several replaceable parts will be stored onboard in case of failures, as well as filament for a 3D printer and tools for repairs.

Section III.16: Overall System Design



Habitation Module with deployed solar sail, and side view with Orion MPCV docked



Isometric view of Habitation Module Hull w/ docking capabilities

Section IV: Technical Approach

Section IV.1: Testing Schedule

An idea for the capsule that was proposed very early on in the design process was to build the majority of the craft in space, this would save weight costs, as only part of the capsule needs to be assembled and sent into space at a time. This also would help streamline the design and development process, highlighting what parts need to go up and when. Ideally, the technologies and parts would all be tested and procured within the first six months of the contract, with any changes being determined by that time. During this time, awarding of subcontracts to other companies and beginning development of initial parts of the ship. Also during the first six months, initial loads would be taken to begin building the ship.

The following six months would consist of a large portion of the building of the design, along with continued testing of the parts. Along with a potential final six months past that for final building and testing.

Section IV.2: Technological Risks

There are many risks associated with manned space travel, and the more complex the design, the more issues that are created. While it is not possible to make a 'simple' design to get to Mars, it is possible to make a minimally complex design, which SAGON is intended to be. There are several key areas of largest potential failure, which will be addressed in this proposal. Other parts of the ship have the potential to fail, and a detailed contingency plan would be created should the SAGON design be selected. The main areas of potential failure are within the artificial gravity system, propulsion failure, issues with a technology not working properly in space, and issues with the failure of the hull of part of the ship.

A failure of the artificial gravity system, especially on the way to another planet or system would be catastrophic, and would be arguably the worst type of failure the capsule could incur. If this were to happen as the craft were traveling towards a foreign goal, that would cause the ship to immediately abort its' mission. There are redundancies to attempt to mitigate the effects of astronauts having to live for multiple months on end without any form of gravity, such as the incorporation of a resistance exercise device similar to the one on the International Space Station and making sure every technology works in space. Also, should there be a failure and the ship continues to go the planet, there are exo-suits anticipated to be incorporated into the spacesuits. This means that any atrophy of muscles that astronauts may have incurred should be countered by the suits. However, a gravity failure is an immediate abort mission because the system failure most likely means there are other issues with the ship.

Another area of potential failure within the ship is a failure of a propulsion system. While there are many propulsion systems designed for this ship, it is possible that one could fail at some point. That is the goal of incorporating multiple systems, is that should a single system fail there are other systems capable of replacing it. This could be the case of ion thrusters should the solar sail get damaged. While it is being repaired by an astronaut during the mission, the ion thruster could replace the lost momentum, ensuring the craft arrives on schedule. It also ensures that each portion of the craft is capable of acting on its own, in case a portion needs to be jettisoned after a catastrophic failure.

It was previously mentioned in the proposal that some of the technologies incorporated into the design had not yet been tested in space, which could be an issue. However, for many of the technologies there are similar counterparts that have been to space, so it should not be hard to convert them. Also, the majority of the plants and bacteria that are proposed to be sent to space have not been tested in space. Current research of other plants suggests that there would be little if no changes to how the plants perform.

Another big concern would be the partial failure of a portion of the hull of the craft. This could happen because of an error in the assembly of the craft or even a collision with an object in space. A failure of the portion of the hull is very dangerous, as it could kill anyone inside of that portion, or damage the rest of the ship. That is why a modular design is important, where any portion of the craft may be zoned off to protect the rest of the craft. A failure like this could signal an abort to the mission, assuming it is severe, however a failure of only a single compartment on a modular would allow the mission to continue with only minor alterations.

Section V: Business Addendum

As will be discussed in the capabilities portion of this overview, as students at an institution without any direct corporate backing, this is merely a design that may be over sought by the group or contracted out to an external party. However, in the proposed budget for the craft, it is assumed that there are some costs incurred in the design of the craft, which may be elaborated on in this portion.

Section V.1 Support of LEO Activities

It has been previously introduced how low earth orbit, or LEO, will be used for the creation of the majority of the craft, with only specific parts being built on Earth. This will help establish secondary payloads as an industry standard, opening up space to everyone from large corporations and governments to small start-ups and educational institutions. Secondary payloads offer a cost sharing system that, if fully adopted, could shave millions off of preliminary tests of new technology. Additionally, construction of a spacecraft of this size in space will require further development of debris management, construction capabilities, and in-orbit evaluation for LEO space. Such developments would greatly benefit both the ISS and all other spacecraft occupying this space.

Furthermore, technological developments outlined in this proposal will make LEO occupation significantly safer and cheaper. Use of biological systems to provide life support function will allow a more reliable means of keeping space stations habitable, relying on electronics only as a redundancy. Improved EVA suits will allow for longer, more complex space walks, allowing greater human impact in the LEO environment.

Section V.2: Business Partnership Model

All businesses brought onboard this project will be used as contractors to fabricate individual components, assembly will be taken care of by the overseeing body (likely a NASA center). All businesses will be given design requirements highlighted in the System Concept section, and will use their experience and expertise to develop a well performing prototype for first stage testing. Upon satisfactory results, the contract will continue in order to facilitate production of all necessary units. Businesses in this partnership model will retain all rights to their design and will be capable of further production of the component for integration with other space missions.

Section VI: Capabilities

The following systems will be contracted out to the identified businesses. The rationale of the choice will be identified. Unless otherwise stated, there is no prearranged deal with the cited business and was identified due to past performance.

Both authors of the proposal are students at Worcester Polytechnic Institute, WPI. Joshua Fuller being a senior mechanical engineering major with experience in robotics, spacecraft design, thermal fluid systems and prototyping. Zachary Chester being a junior physics major, both with experience in the fields of aerospace and the challenges of designing and implementing technologies in space, along with extensive knowledge of Mars as a planet. As a group we have the combined experience to design a craft that meets all expectations for deep space travel, capable of refining it with the aid of our advisor for the project, Professor Mayer Humi.

As we only are students at our institution, we do not have the capabilities to develop this craft or its systems on our own. It is planned that we would contract the design out to another company should the design be selected for building, or portioned out to other companies to build selective sections of the craft with ourselves overseeing the final build. Both are viable options, however, it will most likely be more cost effective to sell out the design to a company with a notable reputation. These companies would use reputable sub-contractors, and have the experience to keep a stable timeline.

Section VI.1: Life Support

Identified Life support systems would be integration of the European Space Agency's MELiSSA project and a redundancy of electronic systems currently in pace aboard the International Space Station. Contract for the MELiSSA project would be placed with Simplot Corporation. Simplot is a diverse biotechnology based company, offering a range of expertise allowing proper integration of the necessary biological components to ensure the principal aspects of the MELiSSA project are captured.

As a redundancy, an electronic system for life support similar to that of the International Space Station must be included. This system would be produced by the same contractors NASA has employed previously.

Section VI.2: Environmental Monitoring

Environmental monitoring systems will be contracted out to Raytheon, Lockheed Martin, and Orbital ATK based on past performance with such systems.

Section VI.3: Crew Health Systems

Use of an artificial gravity system allows for reduced equipment needed to stave off bone and muscle loss, however, exercise will be no less important. As such, exercise equipment must be integrated, and will be contracted out to either Caltech or MIT to reduce labor costs and provide furtherment of our next generation of great minds. Educational involvement in space missions is vital to the training and development of future aerospace professionals.

Section VI.4: EVA Suit

The EVA suit will require multiple systems to be integrated together. The innermost layer will be developed and overseen by MIT, as they developed the passive pressure suit, allowing for basic protection with extreme flexibility. The exoskeleton will be contracted to Raytheon, as their prototype combat exoskeletons were the inspiration for the integration. The primary protection will come from an external suit, contracted to the David Clark Company, due to their past experience with NASA spacesuit contracts. David Clark Company will oversee final integration as well.

Section VI.5: Fire Systems

Fire detection and suppression systems will be contracted to Tyco International. Their experience in fire protection equipment makes them a great candidate to develop the future of space fire safety systems.

Section VI.6: Radiation Protection

Radiation shielding for the hull will be contracted out to Techprint Inc., a Massachusetts based manufacturer of various forms of thermal and radiation shielding components.

Electronics radiation shielding will be integrated into the electronics or custom shielding will be contracted to Tethers Unlimited.

Section VI.7: Propulsion

Solar sail technology will be contracted out to The Planetary Society. Their past work with solar sail testing established them as one of the foremost experts in the underdeveloped technology. Solar electric propulsion will be contracted out to Busek or a NASA preferred contractor.

Section VI.8: Electric Power, Thermal, and Communication Systems

These systems would be contracted to a NASA preferred contractor or would be included in the Hull and Structures contract.

Section VI.9: Hull and Structures

The hull and structures would be contracted to either Raytheon or Lockheed Martin, as they have an established relationship with NASA as contractors and have the experience and resources to handle such a contract.

Section VII: Intellectual Property

All intellectual property, primarily copyrights and patents, shall belong to the entity who first completes a functional prototype. Functional prototype will be defined as any prototype that fulfills all expectations outlined in this proposal.

Section VIII: Price Proposal

The goal for this craft upon initial design was to build it in under $65 million. The end result of the SAGON craft was a proposed budget of around $60 million for construction and an estimated $20 million for dedicated launches (minimum of 6). Estimates were not made assuming use of secondary payload capabilities with a rideshare program. All figures are estimated through use of research estimations for the respective initial projects and estimation techniques detailed in Space Mission Analysis and Design, 3rd edition. A detailed expense report is as follows:

Section VIII.1: Life Support

Life support functions should cost around $8.3 million dollars. $2 million of the portion would go towards miniaturizing the MELiSSA project research. $320,000 would go towards food and water for the crew. Just under $225,000 would go towards environmental detection and oxygen sensors that help to monitor the crew.

Section VIII.2: Environmental Monitoring

Environmental monitoring costs were included with life support costs, along with fire systems. This is because the majority of these costs are intertwined, capable of assisting multiple subsystems. So, they were put into other sections costs.

Section VIII.3: Crew Health Systems

Crew health should cost $450,000 for resistance gear, mats, and bikes. This is the proposed budget for the crew health on the craft. It would vary from an autonomous capsule being sent, where more long-term solutions are necessary. However, in the end, the cost should even out between the two.

Section VIII.4: EVA Suit

EVA suits should cost approximately $4 million dollars. From this, the basic exo-suit/spacesuit design should cost approximately $3 million. This would include the internal suit allowing pressurization and minor protection, and the bulkier external suit to be worn for the most protection. From this, the exo-suit alone should cost approximately $1 million.

Section VIII.5: Fire Systems

Fire detection should cost just over half of a million dollars, around $.512 million. Of that, $132,000 into fire extinguishers, $180,000 are fire sensors, and $200,000 into computers for central data processing.

Section VIII.6: Radiation Protection

Radiation protection should cost approximately $3.9 million. This is the most variable of the prices, as it consists of two forms of radiation shielding, which may be interchanged with each other. If it is found that the hydrogenated BNNT's are too expensive it can easily be swapped for the cheaper polyethylene. A preliminary assumption of the price is that $2.2 million will go into polyethylene and $1.7 million would go into hydrogenated BNNT's.

Section VIII.7: Propulsion

Costs of the solar sail put it at around $1 million for a functional prototype. Solar Electric Propulsion is expected to be $3 million including propellant tanks, electronics and the thrusters.

Section VIII.8: Electric Power, Thermal, and Communication Systems

Electric Power systems will cost $5 Million including a mounting array. Thermal regulation systems in the form or radiators, louvers, and the required supporting systems will cost $3 million. Communication systems and structures will cost $10 million.

Section VIII.9: Hull and Structures

The hull and structures include the actual structure of this craft. This is expected to be $16 Million, with the largest amounts being the module at $1.5 million each and the connectors at $500,000 each.

Section IX: Data Management Plan

A Data Management Plan is not necessary for this proposal as it is only seeking to develop technology based on existing standards and implementation of current technology. No data will be collected as a result of this proposal.

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The Solar Adaptive Gathering/Observation Nautilus (SAGON)

Proposed Objectives

- Modular Design
- Self Sustaining Ecosystem
- Reusable Craft
- Use of Exo-suits
- Multiple Propulsion Systems

Team

Design Team:
  - Joshua Fuller
  - Zachary Chester

Advisor:
  - Mayer Humi

Major Milestones

Testing:
  - Ensuring all technologies work (~6 months)

Development:
  - Test module finished (~18 months)
  - Test module arrives on Mars (~26 months)
  - Manned module designed (~45 months)

Funding Requirements

Craft Design:
  - $60 Million

Launches:
  - $20 Million

Zachary Chester

Home Address
1129 Turkey Point Road
Edgewater, MD 21037

School Address
100 Institute Road
Worcester, MA 01609

June, 2016
443-454-6566 (cell)
zcchester@wpi.edu

Interest

I am an undergraduate student enrolled at Worcester Polytechnic Institute. I am interested in earning a bachelors degree in physics and then going on to earn a doctorate in astrophysics.

Education

2014-Present Worcester Polytechnic Institute
2010-2014 South River High School Graduate, 4.44 GPA, Class Rank 18 out of 548

- *STEM Program* (Science, Technology, Engineering, and Mathematics)
- *Research Projects*: An Analysis of Spectroscopic Surface Data from CRISM to Predict a History of Borates on Mars

Skills / Activities

- *Computer Programming*: **Experience With:** LaTeX, MatLab, Python, HTML, CSS, and JAVA
- *Physics Experiments*: Recreated several notable physics experiments including validating the gravitational constant, proving the duality of light, and testing the properties of superconductivity
- *3D Modeling*: Proficient with, but not certified in, Autodesk Inventor.
- *Cartography*: Proficient with ArcGIS.
- *Research Project*: Analyzed the surface of Mars, using a spectrometer called CRISM; the Compact Reconnaissance Imaging Spectrometer for Mars, to assess the prevalence of borates, a component in the formation of RNA. **Publication status**: Abstract Volume in Prep. (NASA)
- *Research Project, Contd.*: **Abstract Published:** Published in the WPI Undergraduate Research Journal
- *2014 USGS/NASA Planetary Geologic Mappers Meeting*: Attended and presented my research on Mars
- *Engineering Experience:* Experience building robots with FIRST Robotics and SeaPerch, also I have built several multicopters

Related Projects / Experience

- *BAE Systems Technical Internship.* (2012-2014) Paid position that provided experience building multicopters, preparing and presenting a proposal for funding, and compiling spreadsheets containing costs of materials.
- *HomeDepot.* (2015) Paid position working in the lumber department, provided valuable customer service experience.
- *FIRST Robotics*. (2013-2014) Worked on arranging the repair pit and creating a practice field to prepare for robotics competitions. Also worked on presentation about the teams outreach.
- *SeaPerch.* (2012-2014) Designed a submersible robot which performed multiple tasks and participated in the National SeaPerch Challenge.
- *Tutoring*. (2012- 2014) Tutored middle school children for several hours each week, attained over 100 service hours.

References:

Andrew Russette: Former, Senior Principle Hardware Engineer, BAE Systems (410-290-8400)
Dawn Turney: E/PO Specialist, Space Sector, Johns Hopkins University (240-228-8975)
Paula Perry: Teacher, South River High School (443-205-0419)
Laura Gibson: Manager, Home Depot Store #2557 (410-571-0820)

Joshua F. Fuller

JoshFFuller@gmail.com ◇ 1-508-556-4210 ◇ linkedin.com/in/joshffuller

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OBJECTIVE: Introductory full-time position in the mechanical or aerospace engineering industry.

EDUCATION: Worcester Polytechnic Institute (WPI), Worcester MA — Aug 2016
Bachelor of Science in Mechanical Engineering, GPA 3.2/4.0
Concentration: Thermal Fluids; Minor: Aerospace Engineering

COURSES: Prototyping & Machining, Intro to Electrical & Computer Engineering, Thermal-Fluid Design, Gas Turbines & Power Generation, Spacecraft Dynamics/Controls, Rocket Propulsion, Spacecraft & Mission Design, Kinematics of Mechanisms, WPI Advanced Leaders Program

SKILLS:
Programs: Solidworks, Creo, AutoCAD, MathCAD, MatLab, MS Office Suite, Trello, Slack, Labview
Coding: HTML, CSS, Python
Prototyping/Testing: Wind Tunnel Testing, Electrical, Woodwork, Metalwork, Carpentry
Design: Optimization, Dynamic Programming, Linear Programming, Cost Analysis
Collaboration: Multi-Discipline Teamwork & Communication, Critical Thinking & Problem Solving Abilities, Leadership & Delegation Abilities, Adaptable, Tolerant to High Stress Situations
Languages: English - Native, Spanish - Intermediate, German - Beginner

PROJECTS:

Interactive Qualifying Project: Deep Space Habitation Module, WPI — Apr 2016 - Present
- Designing and simulating deep space habitation systems for NASA proposal
- Using established technology, design is simulated and improved iteratively.

Satellite Development Club: NASA Cube Quest Challenge, WPI — Sep 2015 - Present
- Networking and fundraising to ensure project resources.
- Exploring team management, design considerations, and current nano-satellite technology.
- Design of CubeSat propulsion, thermal, and power subsystems in multidisciplinary team.

Major Qualifying Project: Bio-Inspired Automated Submersible, WPI — Apr 2015 - May 2016
- Developed a submersible robot propelled by bio-inspired soft robotic motion, as a team of 4.
- Designed and fabricated soft robotic actuator capable of lifelike underwater propulsion

Spacecraft & Mission Design: Design for Mars Mission, WPI — Jan 2016 - Mar 2016
- Sized systems for Marian mission simulation
- Designed spacecraft and selected launch vehicle for mission to Mars

Thermofluid Application and Design: Geothermal System, WPI — Nov 2014 - Dec 2014
- Designed geothermal cooling system for New England home
- Optimized system based on cost-effectiveness, given design parameters, and practicality.

Intro to CAD: Reaper Drone, WPI — Mar 2014 - Apr 2014
- Created a chassis and internal assembly of a reaper drone in Solidworks.

EXPERIENCE: **Engineering Intern**, Spirit Solar, Inc., Springfield MA — May 2015 - Aug 2015
- Troubleshot and serviced solar thermal and photo-voltaic systems.
- Performed electrical, plumbing, and general contracting for clients.
- Managed and implemented design projects for client contracts.

ACTIVITIES: **Satellite Development Club**, WPI, Treasurer, Public Relations, Propulsion Lead, Mar 2015 - Present
WPI AIAA, WPI, Sep 2014 - May 2016

Most recent copy of resume available at: www.linkedin.com/in/joshffuller Updated June 10th, 2016

Appendix E: TouchTomorrow Handouts

TouchTomorrow is a festival of science, technology, and robots. This event is hosted on the campus of Worcester Polytechnic Institute (WPI), and is a collaborative program between WPI and NASA. This project was showcased at TouchTomorrow.

Appendix F: TouchTomorrow Poster

Life Support:

Life support will be handled by the European Space Agency's MELiSSA (Micro-Ecological Life Support System Alternative) Project. MELiSSA was created to support off-Earth bases, or long duration missions with human crew. It uses symbiotic relationships between several organisms to recycle oxygen, water, and human waste at almost no loss. This systems uses bacteria that has not been tested in space to date, but is expected to perform just as well as on Earth.

Environmental Monitoring:

Environmental monitoring is accomplished by sampling species and organisms in the air and water, and detection of radiation. The goal is to be able to identify possible threats to the crew's health, monitor life support system status, and analysis of samples needed to be tested in real time. Strategic placement of spectrometers, dosimeters, and ion filters will allow real time analysis of the internal environment of the spacecraft.

Crew Health:

Lack of gravity creates the most unique health challenges to the crew. Without gravity, the crew may experience bone and muscle degradation, as well as damaged vision. In order to combat this, artificial gravity can be created from rotation of a spacecraft. The centrifugal force can apply a downward force, countering many of these issues.

In addition, the crew will be provided with many of the advanced exercise equipment used onboard the International Space Station. This equipment will help stave off bone and muscle degradation, as well as help the crew prepare their bodies for the stress of their mission.

Extravehicular Activity (EVA):

Current space suits are bulky and greatly restrict mobility, but offer great protection for the harsh environment of space. In the context of this mission, protection is of the highest concern. By integrating a robotic exoskeleton into the suit, the suit can be better fit to the crew member, and offer support when on the ground for Mars and beyond.

Fire:

Fire represents a huge hazard to everything aboard a spacecraft. While current fire prevention methods are reliable, detection and suppression technology is needed as an assurance of safety. Fire burns differently, and at much lower temperatures, in space. This requires higher sensitivity detection measures as well as quick response for suppression. Automated IR cameras, flame detectors, and CO2 sprayers will be used to ensure total protection of the spacecraft.

Radiation Protection:

Radiation poses a great risk to crew health as well as the health of electronics aboard. Radiation can be easily stopped with dense materials, however this is expensive for spacecraft. Polyethylene has been used as a low mass, cheap, and effect means to lower radiation exposure. Additionally, water makes a great shield to high energy particles. As the crew already requires water, intelligent placement of this reserve can serve as a shelter in the event of a high radiation event.

Habitation System Goals

System	Includes	Today	Mars Goal
Life Support	Air revitalization, water recovery, waste collection and processing	42% recovery of O2 from CO2; 90% recovery of H2O; <6 mo MTBF for some components	>75% recovery of O2 from CO2; >98% recovery of H2O; >2 yr MTBF
Environmental Monitoring	atmosphere, water, microbial, particulate, and acoustic monitors	Limited, crew-intensive on-board capability; rely on sample return to Earth	On-board analysis capability with no sample return; identify and quantify species and organisms in air & water
Crew Health	exercise equipment, medical treatment and diagnostic equipment, long-duration food storage	Large, cumbersome exercise equipment, limited on-orbit medical capability, food system based on frequent resupply	Small, effective exercise equipment, on-board medical capabilities, long-duration food system
EVA	Exploration suit	ISS EMU's based on Shuttle heritage technology; not extensible to surface ops	Next generation spacesuit with greater mobility, reliability, enhanced life support, operational flexibility
Fire	Non-toxic portable fire extinguisher, emergency mask, combustion products monitor, fire cleanup device	Large CO2 suppressant tanks, 2-cartridge mask, obsolete fire products. No fire cleanup other than depress/repress	Unified fire safety approach that works across small and large architecture elements
Radiation Protection	Low atomic number materials including polyethylene, water, or any hydrogen-containing materials	Node 2 CQ's augmented with polyethylene to reduce the impacts of trapped proton irradiation for ISS crew members	Solar particle event storm shelter based on optimized position of on-board materials and CQ's with minimized upmass to eliminate major impact of solar particle event on total mission dose