Product Proposal:

Troy Lee, Drew Shoenbach, Juan Mendoza, Ryan Siu

S-Ring™

March 24, 2018

Dr. Amanda Stansell
UC Santa Barbara
Santa Barbara, CA 93106

Dear Dr. Stansell,

We are writing to you about our proposal for the S-Ring. The S-Ring aims to solve the issue of space debris. The S-Ring works by attaching on to defunct satellites and moving them either from the low Earth orbit or the geostationary orbit into an outer orbit called a "graveyard orbit."

This proposal aims to show that space debris is a problem that needs to be solved and the best solution is the S-Ring. The proposal covers the increasing growth of space debris and the issue it poses on the advancement of space technology and exploration. Current attempts at solving the space debris issue are covered and we explain why they don't adequately fix the issue like the S-Ring. A product design is included that details the S-Ring's features: the power system, debris tracking, thrusters, hydraulics, and the launching system. A design option section is included which looks at theoretical technology that can be incorporated into the S-Ring. This proposal also covers the environmental impact that the S-Ring will have, in particular, the mining and manufacturing of heavy metals needed for the S-Ring and the environmental effects of launching the S-Ring into space.

We would like to mention that the S-Ring is an in-development product and future modifications are necessary. At the moment, we would have to send thousands of S-Rings into space to remove all the defunct satellites. Additionally, some parts required to construct the S-Ring are still in development. However, as of right now there doesn't seem to be any realistic solutions to the space debris issue and it's more important that the S-Ring is implemented to represent a starting point for raising awareness and finding a solution.

We hope that this proposal will encourage you to invest in the S-Ring and in fixing the issue of space debris. We look forward to hearing back from you.

Sincerely,

Caelum

EXECUTIVE SUMMARY

Space debris is an extraterrestrial problem that has taken a backseat to other major environmental problems and has, as a result, grown without adequate control. The problem lies in the probability of space debris collision with spacecraft inhabiting the earth's orbit. Even fragments of only a few centimeters are able to attain velocities that can prove to be disastrous. Unfortunately, present technology lacks the capability to even locate debris this small; therefore, the S-Ring targets larger inactive satellites.

In order to capture these satellites, the S-Ring must first be relayed information regarding the satellite's location. The Falcon 9 Rocket's trajectory will then adjusted to launch the S-Ring into close proximity with the satellite. In space, the rotational and orbital thrusters will orient the S-Ring until it surrounds the satellite. The hydraulic system contracts until the satellite is held firmly by the pistons and the thrusters then ignite again to take the debris and itself into the graveyard orbit.

The circular shape of the S-Ring allows flexibility in terms of component placement - the main components being the power source, thrusters, and hydraulic system. The power source is a Proton Exchange Membrane Fuel Cell (PEMFC) which converts hydrogen (fuel) and oxygen (gas) into electrical power, unused air, water, and heat. Powered by the PEMFC will be two groups of thrusters - one for rotation and one for orbital change. The rotational thrusters are 20N monopropellant hydrazine thrusters - created by the Ariane Group - that are responsible for ensuring the angular orientation of the S-Ring lines up with the targeted satellite. These hydrazine-propellant-driven (N_2H_4) thrusters will be located on the outer rim. On the bottom of the S-Ring will be the PPS®1350-G plasma thrusters created by the Safran company; these will be the "thrusters for orbital change" responsible for facilitating vertical and horizontal movement. PPS®1350-G plasma thrusters utilize xenon gas and offer a great pulse-to-electrical power ratio (90 mN and 1,500 W). Once the S-Ring is correctly oriented, the hydraulic system - located around the inner rim - will come into play. Essentially, the pistons will push piston rods that are attached to surfaces made of shape-forming soft metamaterial which will all extend out until the satellite is firmly in the S-Ring's hold.

Along with the main structure of the S-Ring, we also need a ground-based debris tracking system, launching system, and sensors around the S-Ring. The S-Ring uses the Department of Defense's tracking system, which charts real-time positions of space objects and anticipates their orbital paths. In cooperation with SpaceX, the Falcon 9 Rocket will be used for its reusability and power. Utilizing a variety of sensors, the S-Ring will also be able to find the exact moment to stop the propulsion system, scan itself for irregularities, and pinpoint the location of the satellite while floating in space.

Due to space debris' status as a novelty issue, there is a lack of available technology in the field of space debris removal. Our design options are additional components that are still in the process of being perfected and further developed. For instance, Tiled Ionic Liquid Electrospray (TILE) is an extremely small thrusting system in development with an optimized power-to-thrust ratio. If perfected, the S-Ring could lose unnecessary weight and operate at a higher efficiency. The 10 kW PEMFC stack could potentially upgrade the Proton Exchange Membrane Fuel Cell (PEMFC) system we're using as a power source. It aims to combine PEMFCs into a stack, in an effort to improve cell voltage while maintaining stability.

It would be counter-intuitive to create a space-debris-removal product that could add to that problem of "space junk." Minimizing environmental impact affected many of our decisions on choosing certain systems to use in the S-Ring, although we couldn't negate them entirely. The SpaceX Falcon 9 rocket produces less carbon emissions and waste overall in comparison to traditional space rockets, yet still consumes around 130 tonnes of RP-1 kerosene (34% carbon content). Conventional spacecraft building materials used for the S-Ring are aluminum-based, which produce greenhouse gas emissions upon refining and smelting. However, a viable solution to the problems aluminum-manufacturing poses, could be found in the usage of renewable hydroelectric energy.

The S-Ring serves as a starting point for space debris removal systems. Current technology is limited and space debris research is still being conducted. While the S-Ring limits its scope to only removing large inactive satellites, it will eventually evolve into a product that is all-encompassing. Integration of the design options, once they are fully developed, will push the S-Ring into becoming a major vessel for space debris removal.

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1. Introduction

1.1 Problem

In 1998, the UN and NASA formally recognized space debris as a serious issue that could limit space exploration and create issues for both in-orbit and incoming satellites [2]. Unless nations reduce the amount of orbital debris they produce each year, future space activities could suffer loss of capability, loss of income, and even loss of life as a result of collisions between spacecraft and debris [7]. The space debris issue is already at large; ignoring its current impact on space operation will only contribute to the growth of obstacles for upcoming space operations. Left unattended, lingering space debris will continue to occupy earth's orbit as hindrances, limiting space exploration and satellite implementation.

The concern for space debris interference stems not only from the fear of future occurrences, but also from various past encounters. In 1996, a French rocket, that had been used about decade prior, collided with a French Satellite, causing serious damage to the satellite. In 2007, China attempted to "clean up" an inactive weather satellite by testing their missile-driven anti-satellite system. Unfortunately it accomplished the exact opposite and, upon impact, the weather satellite fragmented, leaving 3,000 more pieces of space debris in its stead [1]. Lastly, in 2009 a defunct Russian satellite collided with and destroyed a U.S. Iridium commercial satellite. It is estimated that more than 2,000 pieces of space debris were added to Earth's orbit [1].

While all sizes of space debris pose a problem, the smaller sized space fragments pose a problem that is nearly impossible to solve. The problem with trying to remove smaller orbital debris is:

1. Most satellite tracking systems use radar and radio frequencies, but it is nearly impossible to locate smaller debris particles with those frequencies.
2. Latching onto small debris via machinery at such small scales and high speeds requires machinery with durability and finesse that far exceeds what is currently possible or what will be possible in the near future.

Therefore, the problem the S-Ring will attempt to fix is the issue of larger scale orbital debris, particularly defunct satellites. It has been shown that defunct satellites pose the issue of collisions with anything that is sent into space and run the risk of fragmenting into smaller space debris [3].

1.1.1 Growth of Space Debris

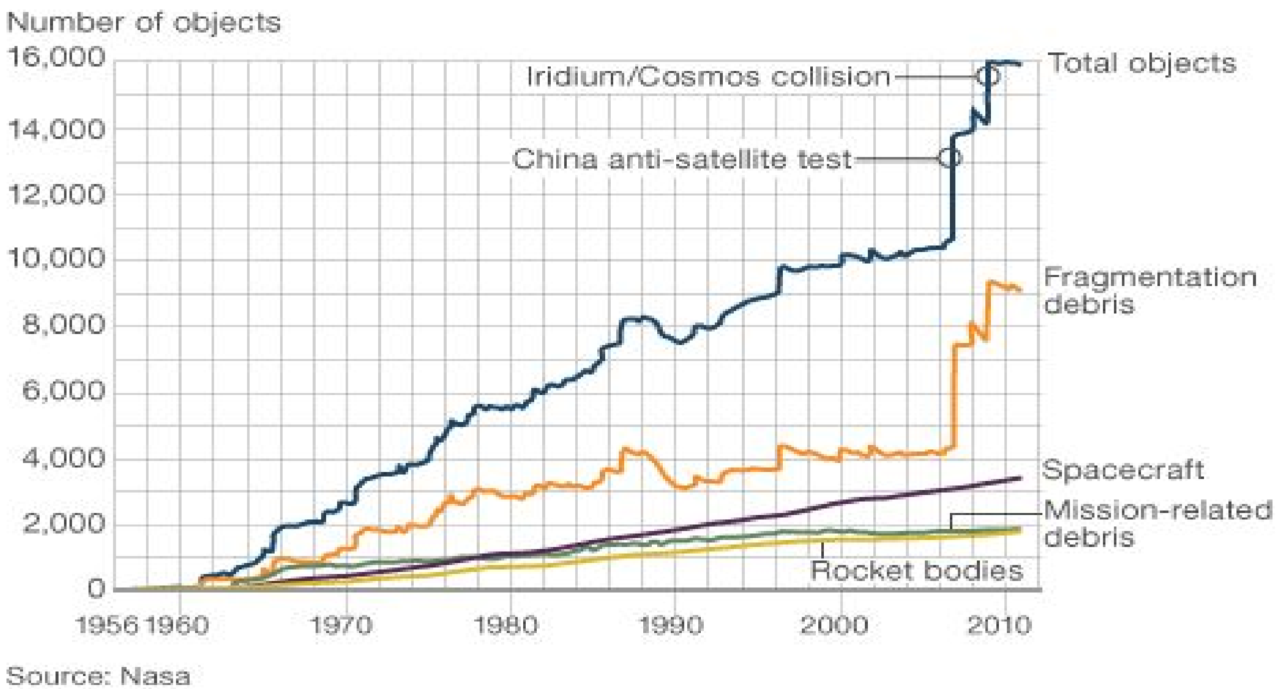


Figure 1.
[https://www.zmescience.com/space/iss-crew-escape-capsules-space-junk-alert-26032012/]

Figure 1 is a graph from NASA that demonstrates the inflation of space debris observed in the steep increase from the mid-2000's to 2010. This observation is consistent with the Chinese anti-satellite test that ended up created thousands of more debris in space when attempting to get rid of an old satellite. Fragmentation debris makes up more than half of the total objects in space as of 2010. The defragmentation of rocket bodies is associated with lowermost line on the graph, leaving the defragmentation of satellites that most contributes to the "Fragmentation debris" line.

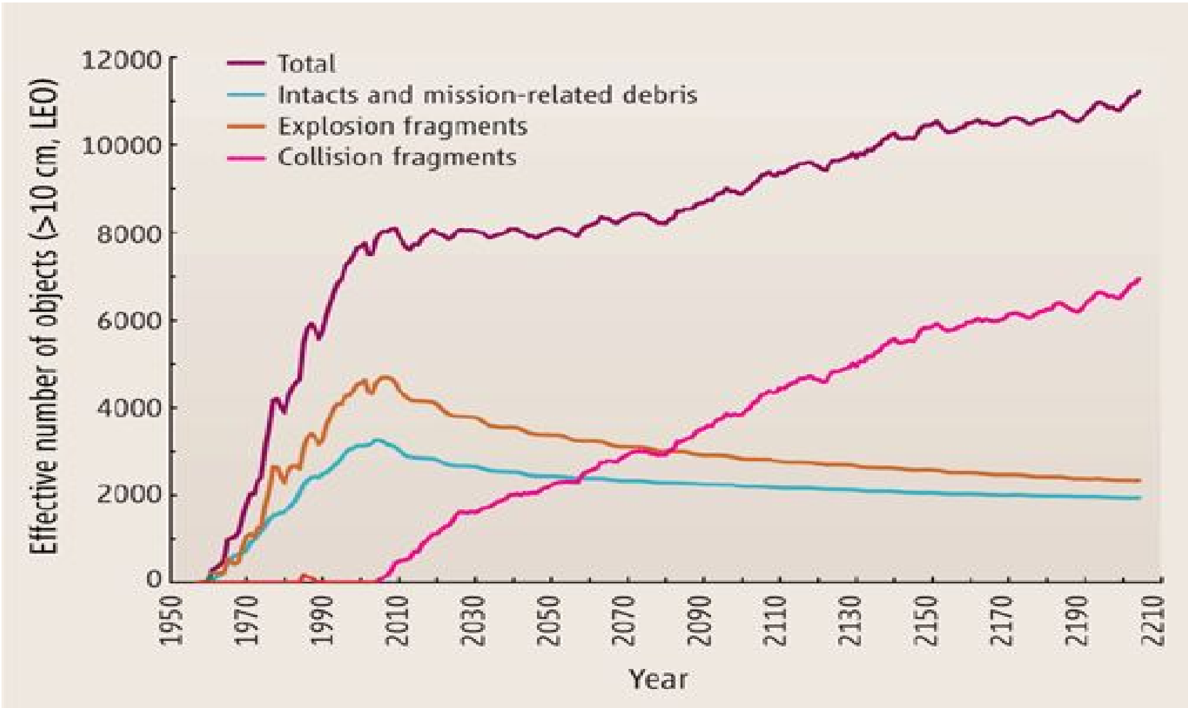


Figure 2. (http://science.sciencemag.org/content/311/5759/340.full)

The graph above (Figure 2) presents the increase in space debris from the very first mission to the projected estimate in 200 years, with respect to the 2010 date the graph was released on. Consistent with the graph in Figure 1, explosion or defragmented debris are at peak within the 2000's and 2010, however it is important to comprehend the lowermost line trend in this graph that predicts a significant upward-sloping increase in collision fragments starting around 2010.

1.2 Current Solution Attempts

1.2.1 JAXA System

The Japan Aerospace Exploration Agency (JAXA) has made notable strides in creating an efficient space debris removal system. Their system relies on electrodynamic tether (EDT) technology that "provides a possible means for lowering the orbits of objects without the need for propellant" [5]. The lowering allows usage of Earth's geomagnetic field to redirect satellite remnants into earth's atmosphere where they will burn up. This methodology, however, doesn't account for the larger satellites which will not disintegrate. Our S-Ring targets these specific satellites and proposes a solution to removing them by way of pushing them out into disposable orbits.

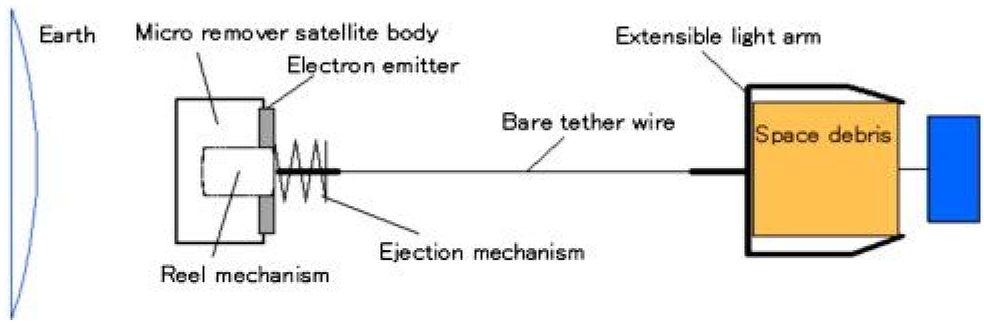


Figure 3. (https://www.sciencedirect.com/science/article/pii/S0094576509000320#bbib6)

JAXA's conceptual design (Figure 3) consists of a robotic arm, a tether, and an EDT package.

The conductive tether wire consists of an aluminum build with high-strength braided fibers [5]. While they have addressed the problems of strength and durability by introducing the concept of "high-strength braided fibers," the material is still in question and it is possible that incoming space debris could dislodge or break the tether. The S-Ring's circular design consists of only an individual base and lacks thin string-like attachments, giving it a stronger construction that will be able to withstand possible incoming debris.

A major problem discussed in the JAXA's design development was the ability to capture satellites traveling with angular momentum. "Since failed satellites do not have functioning attitude control, in many cases they will be rotating due to the transfer of residual angular momentum from their control systems" [5]. These non-cooperative targets create a difficult task of slowing down the rotation of the target, in order for their robot arm intervention. The S-Ring completely dismisses the problem as it will surround the object and match its rotational speed, allowing for easier capture.

1.2.2 Built-in Satellite Removal

There are two ways that engineers have designed satellites so that the satellite is able to remove itself from possible collision: the satellite launches itself into what's called a "graveyard orbit" or the satellite launches itself into Earth's atmosphere.

The graveyard orbit is about 200 kilometers further than the furthest active satellite. Despite the name "graveyard," it is not a single location and is actually a region above the earth's geostationary orbit. Targets that are pushed out into graveyard orbits are ones that occupy the geostationary orbit, where they are too far to be redirected into the earth's atmosphere for disintegration [6].

Satellites redirected for re-entry into the Earth's atmosphere are usually of smaller size. Depending on the weight, size, and speed of the object, it is possible for space debris to survive re-entry [9]. This is also useful for space-recycling, as it allows reuse of materials from inactive spacecraft. It, however, also comes with the risk of landing in an unintended area.

The problem with both of these removal systems is that it requires the engineers to design extra fuel into the satellites design. This means that there is an extra step and cost when designing a satellite, which can often limit what can be done during a space operation. The S-Ring centralizes the process of space debris removal, allowing engineers to ignore additional designing and parts.

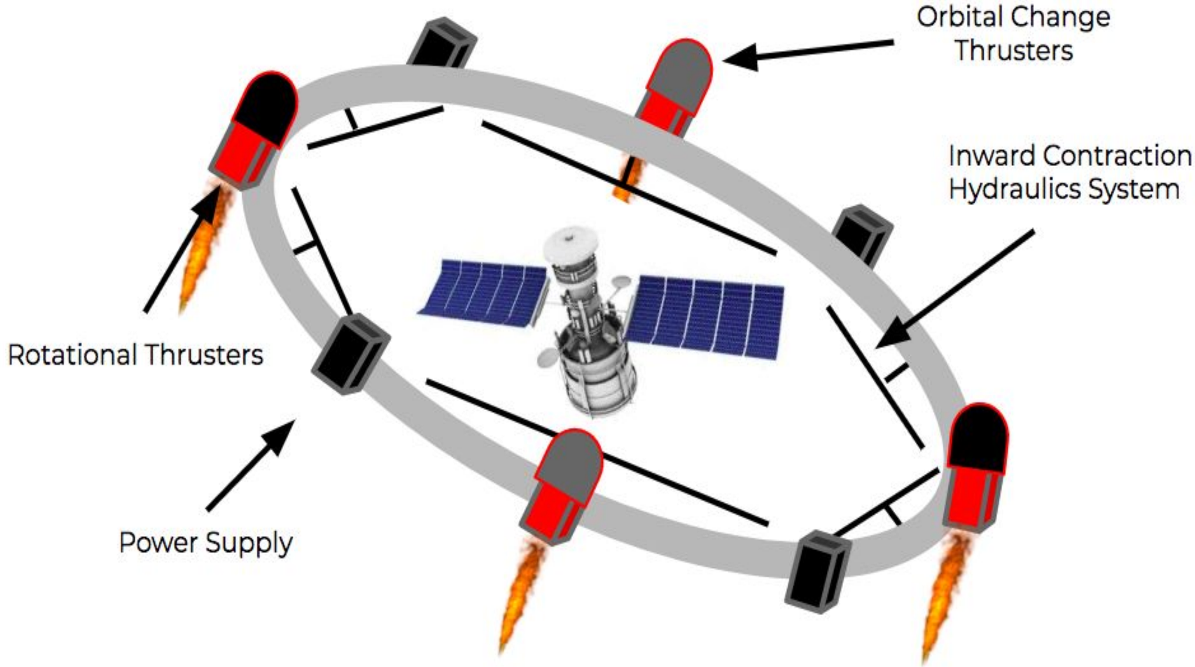
Another issue is that both processes are at risk to increasing the amount of space debris. As stated before, burning up in Earth's atmosphere doesn't always work and instead can fragment the satellite and leaves hundreds, or even thousands, of smaller space debris orbiting Earth. The graveyard orbit also has its related risks with it being a possible nuisance for future space endeavors.

With this in mind, the S-Ring will still look to push out space debris into graveyard orbits. The main problem that needs to be solved is the presence of space debris within earth's low orbit and earth's geostationary orbit. The S-Ring embraces that goal and looks to take space debris out of harm's way for active spacecraft and satellites.

2. Product Design

2.1 S-Ring Overview

The S-Ring is a autonomous-circular spacecraft that is launched into space with the intent of attaching on to a defunct satellite and moving the satellite into what's called a "graveyard orbit". The S-Ring will use the Department of Defense's radars and tracking system, along with public databases, to track and identify satellites for removal. Once the satellite is determined, the S-Ring will be launched into space and on a trajectory towards the satellite via the Falcon 9 rocket (developed by SpaceX). The S-Ring will use sensors onboard to make sure that as it approaches the satellite that is has the correct velocity and rotational speed. Once the S-Ring has surrounded the satellite, the hydraulic system will contract around the satellite to make sure that the S-Ring is attached. After attachment, the S-Ring will fire it's orbital change thrusters to launch itself and the satellite into the graveyard orbit.



2.2 Power Source

2.2.1 Evaluating Power Sources

The major power sources we evaluated were solar power, atomic power, and PEMFC (Proton Exchange Membrane Fuel Cells). With a task of pushing inactive satellites to graveyard orbits, the power source doesn't need to last too long nor will it have to compensate for far journeys.

However, an efficient power source is still needed to maintain the working status of the S-Ring's thrusters.

"As a spacecraft enters a planet's orbit, the solar arrays become less effective; they become unable to generate as much energy..." [16]. Solar energy would be implausible due to the path of the S-Ring being solely inside of earth's orbit. It's potential of long-distance travel is unnecessary, and it's lack of power will inhibit the S-Ring's ability to remove space debris in a timely manner.

Examples of atomic power include RTGs (Radioisotope thermoelectric generators), nickel-hydrogen batteries, etc. With life-spans of 15 to 30 years, these power sources are extreme overkill for the one-way relatively short trip taken by the S-Ring.

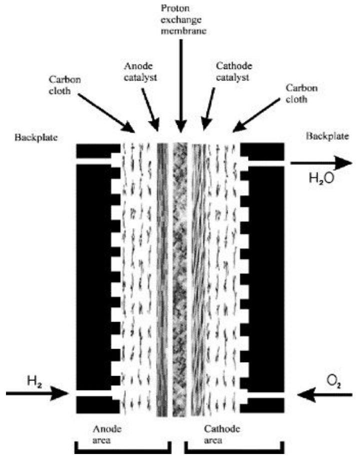
The PEMFC system is the most optimal for our situation. With a lifespan of a few days (or possibly weeks), it falls closely in line with the S-Ring's approximate time of travel, but also leaves enough extra time if needed.

This rules out options of solar power and atomic power for the time being, which are more used for long distance and time consuming space exploration. If in the future the S-Ring switched from a final destination of graveyard orbits to the sun, these options could once again be viable. Even with that being said, the PEMFC has potential to increase its longevity as well and could be developed to reach distances rivaling solar or atomic power.

2.2.2 PEMFC System

With thrusters both on the outer rim of the S-Ring and the bottom side, it is essential that we choose a compact and efficient power source with the ability to power all thrusters. "The PEM system allows compact design and achieves a high energy-to-weight ratio…" [17]. Incorporating this system into the frame of the S-Ring will be easily accomplished; and despite its small size, it will generate the power necessary for space travel.

The Proton Exchange Membrane Fuel Cell (PEMFC) uses a polymer electrolyte and is used in both daily operations as well as space endeavors. It is an electrochemical power generator that converts hydrogen (fuel) and oxygen (gas) into electrical power, unused air, water, and heat.



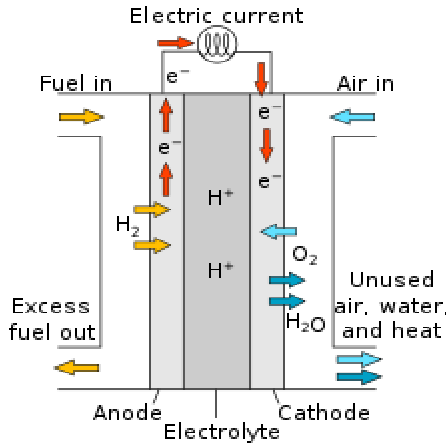


Figure 4 & 5.

At the anode the hydrogen molecule is split into two protons and two electrons

$H_2 \rightarrow 2H^+ + 2e^-$.

At the cathode oxygen reacts with protons and consumes electrons to form water

$O_2 + 4H^+ + 4e^+ \rightarrow 2H_2O$. [18]

The Proton Exchange Membrane (PEM) - or the Polymer Electrolyte Membrane - only allows positively charged ions to pass through to the cathode. As a result, the two electrons produced from the splitting of the hydrogen molecule, are forced to funnel into an external circuit around the PEM. The movement of electrons along this external circuit creates the electrical current that is used for power.

3.1 Power Generation 3.1.2 Chemical		**3.1.2.1 Polymer Electrolyte Membrane Fuel Cells (PEMFC)**	
TECHNOLOGY			
Technology Description: Fuel cell system that employs a hydrogen ion conducting polymer electrolyte membrane and is capable of operating on hydrogen and oxygen at a temperature of < 100° C.			
Technology Challenge: Challenges include performance on propellant-quality fuels, water management in zero-g; seals fabrication and materials selection, maintaining stack integrity, load swing cycle tolerance, long life, and high reliability.			
Technology State of the Art: Advanced polymer electrolyte membrane fuel cell (PEMFC) for future human space missions with emphasis is on non-flow through PEMFC designs.		**Technology Performance Goal:** High specific power, high specific energy, high conversion efficiency, long life, high reliability, and operational tolerance with propellant grade hydrogen and oxygen at an operating temperature of < 100° C.	
Parameter, Value:	**TRL**	**Parameter, Value:**	**TRL**
Power: 1 kW; Efficiency: 70%; Lifetime: > 100 hours; Operating temperature: < 100° C	4	Power: 5 kW; Specific power: 130 W/kg; Efficiency: > 75%; Lifetime: > 10,000 hours	6
Technology Development Dependent Upon Basic Research or Other Technology Candidate: None			

Figure 6. [19]

Along with the “high energy-to-weight ratio” mentioned before, the PEMFC is a low temperature fuel cell system, ensuring a fast start-up time. Due to the symmetrical and circular shape of the S-Ring and the evenly-spaced placement of the thrusters, the power system can be integrated with virtually any part of the S-Ring.

“The primary objective for PEM fuel cells is to demonstrate reliable operation for > 10,000 hours with high efficiency (> 75 percent) when operating with propellant-grade hydrogen and oxygen” [19]. State-of-the-Art Technology concerning PEMFC is limited to the parameters as shown in the table above. At the moment, the PEMFC is perfect for the S-Ring’s journey to graveyard orbits. The lifetime of 100+ hours is enough to sustain the relatively short trip of the S-Ring, and it’s high efficiency and power is adequate for operation of the rotational and orbital thrusters.

In the future, the S-Ring’s final destination may shift from the graveyard orbit to the sun. This will require a power source that has a much greater lifetime than the current PEMFC. However, the PEMFC is developing and ideas such as the 10 kW PEMFC stack (design option) have the potential to fulfill the idea of travel to the sun. The PEMFC is a great fit for the S-Ring for not only now, but also in the future. Both products will develop over time, along a guideline of the same functionalities: travel time, power, and efficiency.

2.3 Debris Tracking

The tracking system the S-Ring will use is going to detect, track, catalogue, and identify man-made objects orbiting Earth. Among these objects are active/inactive satellites, burnt out rocket bodies, and fragmentation debris. The Department of Defense’s tracking system and public database will be utilized in order to chart the present position of space objects and plot their anticipated orbital paths [8].

To manage a system that creates an anticipated unique path for the launch, the S-Ring will make use of the existing Department of Defense Space Surveillance Network shown in Figure 3. This surveillance network consists of phased-array and conventional radars as well as a Ground-Based Electro-Optical Deep Space Surveillance System that are strategically dispersed geographically.

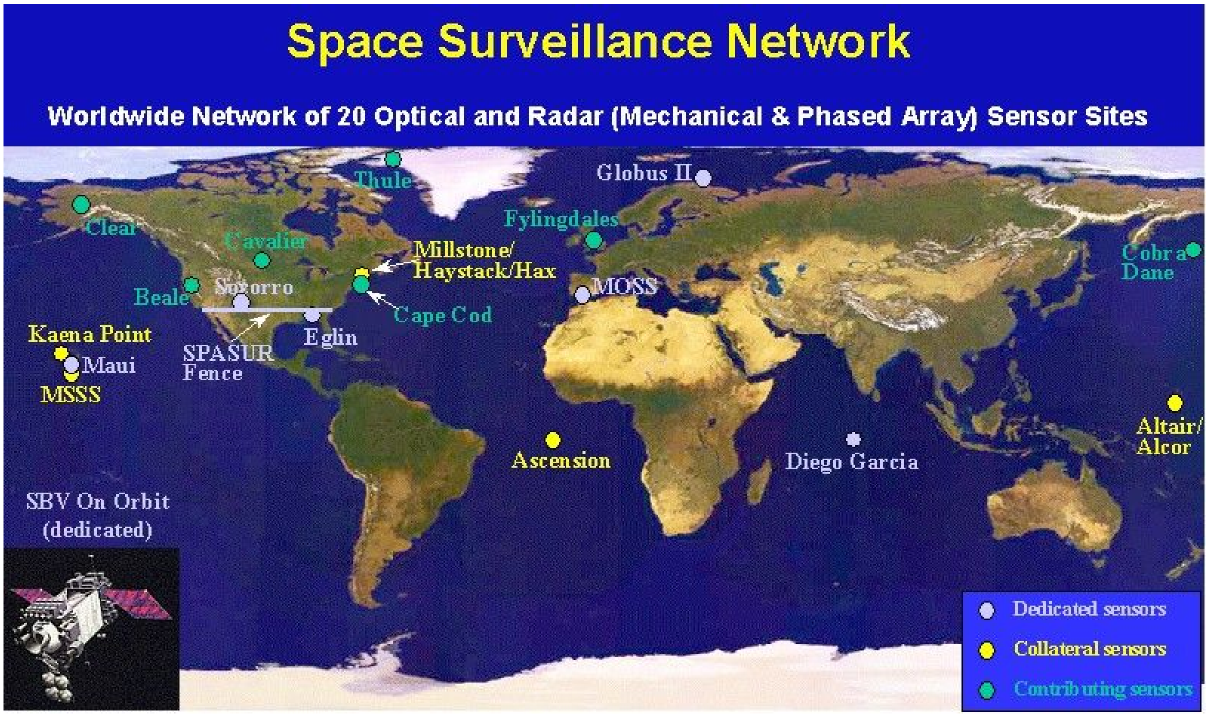
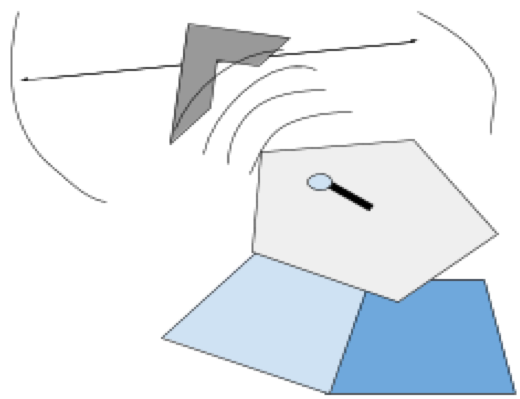


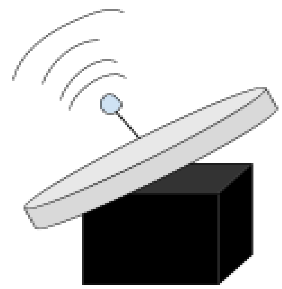
Figure 7. [http://www.au.af.mil/au/awc/awcgate/usspc-fs/space.htm]

2.3.1 "Space Fence" Phased-Array Radars



A phased-array radar has an antenna that shifts the oscillating cycles of the signal emitted to steer the beams in the desired direction [40]. Due to the varying electronically steered signal cycles, the phased-array radar is able to scan greater areas in space in a fraction of a second [8]. The Department of Defense is currently working with Lockheed Martin on developing and implementing a phased-array radar called "Space Fence." Lockheed Martin's "Space Fence" phased-array radar utilizes an "S" frequency band and fixed array faces that enable the radar to significantly improve the time with which operators can detect hazardous space events that could pose threats to GPS satellites or the International Space Station [40]. The current radar system provides up to a 12,000 km range and sweeps a wider range of 7,000 square feet while simultaneously tracking and detecting objects anywhere in its wide field of view [10]. With these features, the radar is capable of tracking the debris more efficiently because it takes less time than any other radar and provides an exact location and approximate size of the debris prior to launching the S-Ring.

2.3.2 Conventional Radars



Conventional radars used by the Department of Defense use energy in the form of a large fan that is emitted to space. This radar emits a narrow beam onto the target object that triggers the tracking antenna [8]. Through the tracking antenna, orbital data of the monitored object is recorded and transferred to the rest of space sensor system, delivering a precise orbiting speed of the debris. In comparison to the phased-array radar, the conventional radar cannot sweep space in seconds neither can it sweep large regions of space. Although it does not function like a phased-array radar, the conventional radar provides beneficial orbital data that allows for precise calculations of the targeted object's speed.

2.3.3 Ground-Based Electro-Optical Deep Space Surveillance System

The GEODSS is an Air Force Space Command telescope system that consists of three geographically dispersed sites. These sites are located in New Mexico, British Indian Ocean Territory, and Maui, Hawaii [41]. This system tracks more than 2,500 objects at a distance of 10,000 to 45,000 kilometers from Earth [42]. The GEODSS utilizes telescopes that include highly sensitive camera technology that can observe objects that are 10,000 dimmer than what the human eye can see [42]. The telescopes take quick electronic snapshots of satellites at night which show up as tiny streaks. Computers then measure these streaks and use the data to compute the position of satellites in their orbits [42]. Using these computations, the data from the phased array radar and the conventional radar can also be taken and calculated together in order to provide overall precise locations and sizes of objects. Given the size of the objects, it will then be determined whether they are worth being collected by the S-Ring.

2.4 Thrusters

2.4.1 Thrusters for Rotation

In order to match the rotation of the satellite a thruster will need to be in place to match the rotation. The Rotational thrusters that will be used on the S-Ring will be a 20 newton monopropellant hydrazine thruster created by the Ariane Group [13]. Monopropellant thrusters are usually used to control altitude, trajectory, and make small maneuvers in space aboard spacecraft. This small amount of thrust is perfect for matching rotational speed as there isn't any frictional forces in space and very little thrust is needed to get up to the speed of a rotating satellite.

Figure 8. [http://www.space-propulsion.com/spacecraft-propulsion/hydrazine-thrusters/20n-hydrazine-thruster.html]

Parts [14]:

1. Flow control valve
2. Internal redundant catalyst bed heater
3. Thrust chamber
4. Decomposition Chamber
5. Fuel supply pipe
6. Heat barrier
7. Injection plate
8. Nozzle

The flow control valve, which delivers the propellant to the thruster, consists of two monostable valves. When the valve is activated, propellant flows via a fuel supply pipe to the injection plate. The injection plate has the proper amount of holes as to make there is an equal distribution of propellant, hydrazine (N_2H_4), to the catalyst bed. As the propellant is delivered to the catalyst bed, via the injection plate, the hydrazine undergoes a decomposition reaction due to the catalysts and the fact that the catalyst is kept at higher temperatures. The decomposition of hydrazine produces ammonia gas which flows from the catalyst bed to the nozzle. Once the gas is in the nozzle it expands which provides thrust.

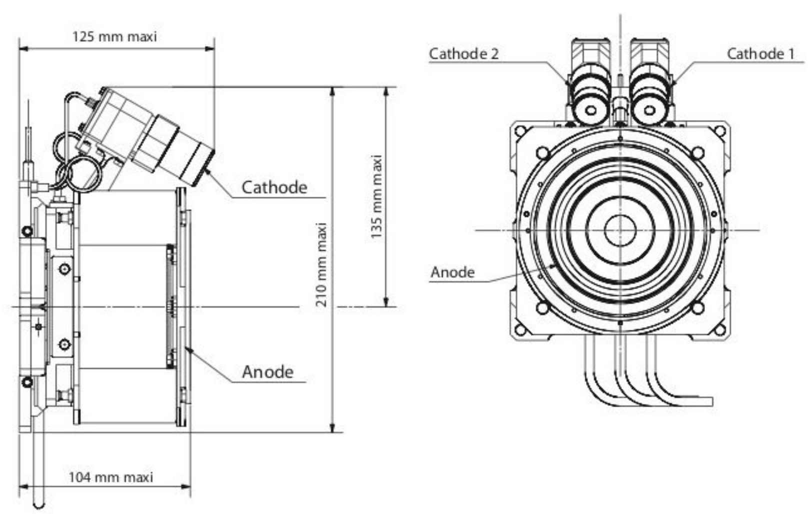
2.4.2 Thrusters for Orbital Change

The thrusters to be used for changing the orbit of the satellite and S-Ring will be the PPS®1350-G plasma thruster [21] created by the Safran company. The 1350-G plasma thruster is meant to maintain an orbit of a satellite or a spacecraft or to transfer the craft to another orbit, in this case the thrusters will be used to change orbits.

The plasma thruster offers many advantages over traditional chemical propellant systems. One, the plasma thruster has a high specific impulse (1660 seconds [22]) which allows it to weigh less than chemical systems. The 1350-G also has a great pulse-to-electrical power ratio (90 mN and 1,500 W [22]) which means that there are less thrusters needed.

The 1350-G plasma thruster works by using xenon gas. First, an arc of electricity is ran through the fuel (the xenon gas) which is heated up and turned into plasma which is charged. The xenon ions are than injected between two charged plates (an anode and a cathode). Since the ions are charged they create a circuit between the plates which allow electrons to flow through the plasma. A property of flowing electrons is that they create a an electromagnetic field (Ampere's Law). The magnetic portion of the electromagnetic field created by the electrons acts on the plasma which is a moving electrical charge. The acting force is called Lorentz force and causes the plasma to be ejected from the thruster which provides thrust. The thruster pulses as the circuit has to be recreated after the plasma is ejected.

Figure 9.



2.5 Inward Contraction Hydraulics System

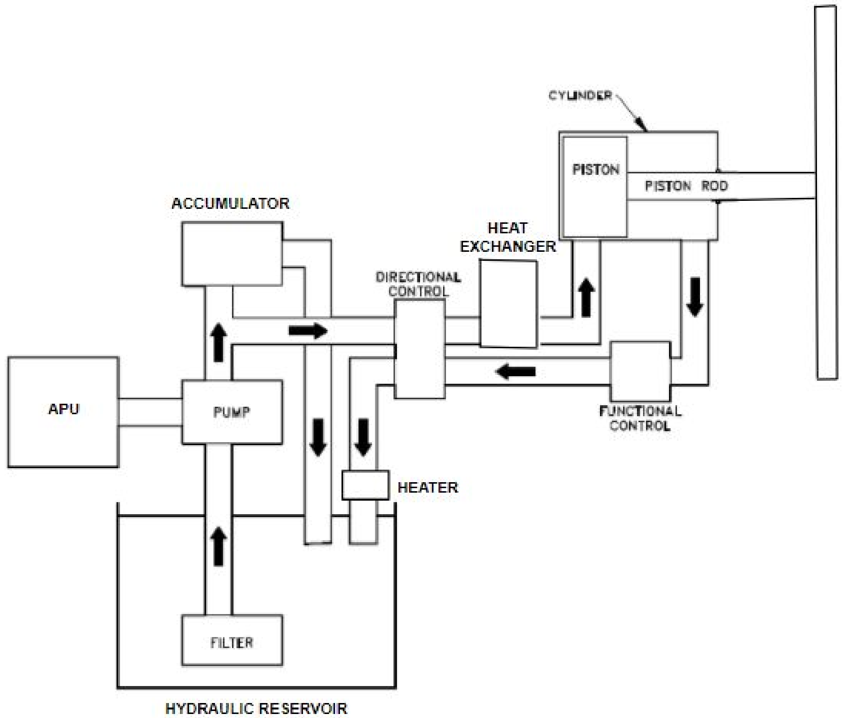


Figure 10. [http://www.enggcyclopedia.com/2012/02/hydraulic-systems/ (edited)]

The S-Ring must be able to have the functionality to contract to change the interior circumference of its body in order to be efficient in the removal of varying sizes of satellites from Earth's orbit. The S-Ring must also contract precisely as to not crush the satellite and create more space debris in the process.

2.5.1 Components of Hydraulic System

The hydraulic system will play a key role in the acquisition of satellites by extending pistons out within the inner rim which are attached to slabs of shape-matching soft meta-material that will come into contact with the target satellite. The pistons will extend to an appropriate length, which will be gauged by sensors, in order to prevent causing further damage to the satellite and creating more debris. The S-Ring will consist of a various amount of hydraulic systems that will consist of a main hydraulic pump, hydraulic reservoir, hydraulic accumulator, hydraulic filters, a heat exchanger, electrical circulation pump, and electrical heaters. [15]

2.5.2 Main Hydraulic Pump

The main hydraulic pump will operate at approximately 3900 rpm and be operated by an APU. The hydraulic pump also consists of a depressurization valve that helps to discharge pressure from 2900 to 3100 psi down to 500 to 1000 psi to help reduce the amount of torque on the APU at the start. [15]

2.5.3 Hydraulic filters

Hydraulic fluid will pass through a 5-micron filter before entering the hydraulic system to leave out and impurities and subsequently pass through a 15-micron filter before entering the reservoir. [15]

2.5.4 Hydraulic Reservoir

The reservoir tank will be 6 gallons and will house hydraulic fluid. The hydraulic fluid used will be MIL-H-83282, which is a synthetic hydrocarbon that will help to reduce fire hazards. A pressure relief valve will be incorporated into each reservoir to protect from overpressurization. [15]

2.5.5 Hydraulic accumulator

The accumulator is a piston type mechanism that insures that the pressure within the hydraulic pump is adequate. Nitrogen will be precharged within the accumulator at 1650 to 1750 psi. While the hydraulic pump is in operation, the accumulator will be pressurized to around 3000 psi. When the pump is no longer in operation, the accumulator will be pressurized back to 2500 psi. [15]

2.5.6 Heat Management

In order to keep the hydraulic fluid at optimal temperatures within space, a heat management system must be implemented within the hydraulic system. The hydraulic system fluid will be driven by the electrical circulation pump through the Freon-21 heat exchanger and distributed to areas of the hydraulic system that are being actively used. There will be electrical heaters positioned around areas in which fluid circulation won’t be able to heat. [15]

2.6 Sensors

List of sensors on the S-Ring:

- GPS sensor (Radio antennas)
- Gyroscopes
- Battery level sensor
- Temperature sensor
- Current sensor
- Voltage sensor
- Force Sensors
- Active Sensor (Radar)

In order to keep location of the S-Ring and to make sure that it maintains correct orientation two sensors are needed. One is a GPS sensor, in particular, this sensor is using radio antennas and measuring the phase difference of the wavelength would give the orbital location [34]. A gyroscope will also be aboard the S-Ring to measure it's rotation about its axis and to make sure that it can match the rotation of the satellite.

The S-Ring will also have to be monitored for in irregularity in case of problems. For this, the S-Ring will have battery level sensors, temperature sensors, current sensors, and voltage sensors. These sensors will monitor for irregularities in the functioning of the S-Ring. The voltage, current, and battery sensors will allow for monitoring of the circuits of the S-Ring which will show any issues that might arise with short circuiting, or malfunctioning devices. The battery sensor will also allow for updates on whether or not the S-Ring has enough power to enter into the graveyard orbit or if a new path needs to be calculated. The temperature sensors will check to make sure that none of the systems overheat or cold down too much, the hydraulics has fluids that needs to be constantly heated and the thrusters involve fuel sources that can only be used at specific temperatures.

The S-Ring will also have to measure how far away a satellite is and how fast the satellite is rotating. To measure the distance and speed of the satellite that is to be removed, the S-Ring will have active sensors. In particular, the S-Ring will use radar, which is a sensor that emits microwaves that are reflected off the object (the satellite) and return back to the sensor which is timed [34].

The S-Ring will also have to detect how tight to contract around the satellite. For this, the S-Ring will have a force sensitive resistor. A force sensitive resistors measures the amount of force applied because the polymer contained in the resistor changes resistance as the force applied changes [36].

2.7 Launch System

In December of 2017, Elon Musk became the first to successfully launch a reused rocket, the SpaceX Falcon 9. The S-Ring takes advantage of this new development and chooses it as its launch system.

Type	Falcon 9 v1.1
Reusable Version	F9R
Height	68.4m
Diameter	3.66m
Launch Mass	>505,846kg (F9R)
Stages	2
Boosters	None
Mass to LEO	13,150kg
Mass to GTO	4,850kg
Launch Cost	$61.2M

The Falcon 9 is a two-stage rocket and also contains an interstage that connects the two.

2.7.1 First Stage

The first stage has nine Merlin engines and aluminum lithium tanks containing oxygen and rocket-grade kerosene (RP-1) propellent. The Merlin engines launch with thrust greater than fiver 747s at full power. It generates more than 1.7 million pounds of thrust at sea level but gets up to over 1.8 million pounds of thrust in space. [38].

2.7.2 Interstage

The interstage connects the first and second stages and holds the release and separation system. The picture to the left illustrates the inside of the interstage. Connected to the second stage is a single Merlin vacuum engine, modified to operated in the vacuum of space. “SpaceX's Merlin vacuum engine has the highest vacuum specific impulse (isp) - a measure of engine efficiency - of any American liquid oxygen/kerosene engine with a vacuum isp of 348 seconds. The engine is housed inside the rocket’s interstage” [38].

2.7.3 Second Stage

The second stage, as stated previously, is powered by a single Merlin vacuum engine. This is the stage that delivers the Falcon 9’s load to its desired orbit. Upon stage separation, the second stage engine can be ignited several times for rerouting and changing orbits [38]. The S-Ring, which will be traveling across orbits, is therefore allowed multiple tries for satellite locating.

3. Design Options

The different design options for the S-Ring are based around emerging technologies and future technologies within the space sector. The different design options aim to show that the S-Ring is not a static technology, but a dynamic one that is capable of changing and advancing with the technology that is available.

3.1 Tiled Ionic Liquid Electrospray

A new emerging thruster technology is the TILE (Tiled Ionic Liquid Electrospray) created by Accion Systems company. The TILE is a dime sized chip that provides thrust. The TILE can be scaled as multiple TILE chips can be placed together to provide thrust [31].

The TILE works in a similar fashion to traditional electric static thrusters. At room temperature the ionic liquid is molten salt which is composed of positive and negative ions [33]. The ions are forced into an array of sharp emitter structures by capillary forces [33]. A voltage is than applied to the ions and a counter-electrode. The applied voltage creates an electrostatic pull which is counteracted by the surface tension of the liquid salt. Once a certain voltage threshold is reached, ions are extracted and accelerated by the voltage to high velocities, therein by creating the thrust. Since the liquid salt is composed of both negative and positive charges, the voltage can change polarity and be more efficient (i.e apply an alternating current) [33].

There are clear benefits of the TILE in comparison to other thrusters. For one, the TILE is small and much simpler, this allows for an optimized power-to-thrust ratio [32]. The TILE also has an incredibly high conversion efficiency, 60% percent higher than plasma thrusters [32]. Since the TILE can be manufactured using the batch method [32] this allows the TILE to be produced more reliably and at a lower cost.

3.2 10 kW PEMFC Stack

“PEM fuel cell stacks are currently available in a prototype stage and often not readily available on the market” [23]. Due to the young age of PEMFC (Proton Exchange Membrane Fuel Cell) prototypes, there is much room for improvement. The S-Ring’s design relies on PEMFC as a power source, but is limited to the prototypes currently available In an effort to reach to perfect the PEMFC, a concept using graphite composite bipolar plates was developed.

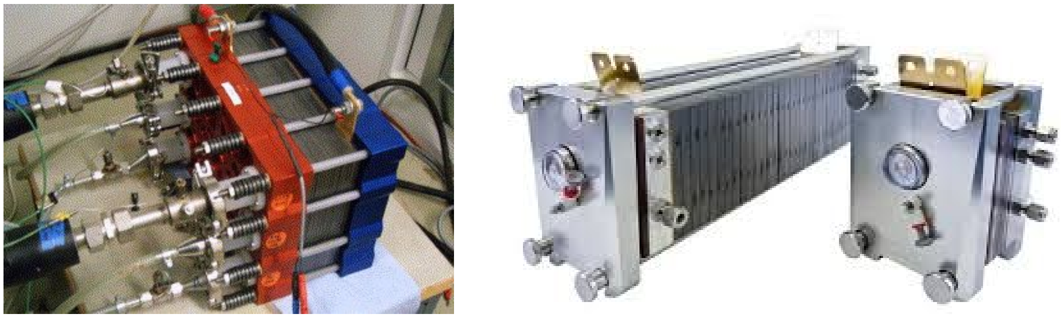


Figure 11 & 12.

Achieving this idea would allow for the S-Ring to expand its capabilities, possibly redirecting its current route of a graveyard orbit to the sun itself. Although graveyard orbits are suitable places for disposable right now, in the far future crowding those areas may cause interference.

The concept of a 10 kW PEMFC stack relies on the foundation of "allowing operation at a power of 10 kW at non-pressurized conditions." The basic design consisted of GORE PRIMEA 5510 MEAs (Membrane Electrode Assemblies) that have a platinum loading of 0.3 mg/cm^2 at the anode and 0.4 mg/cm^2 at the cathode side. In order to achieve a 10 kW-stack, it was approximated that 70 cells would be required (this would be stack III).

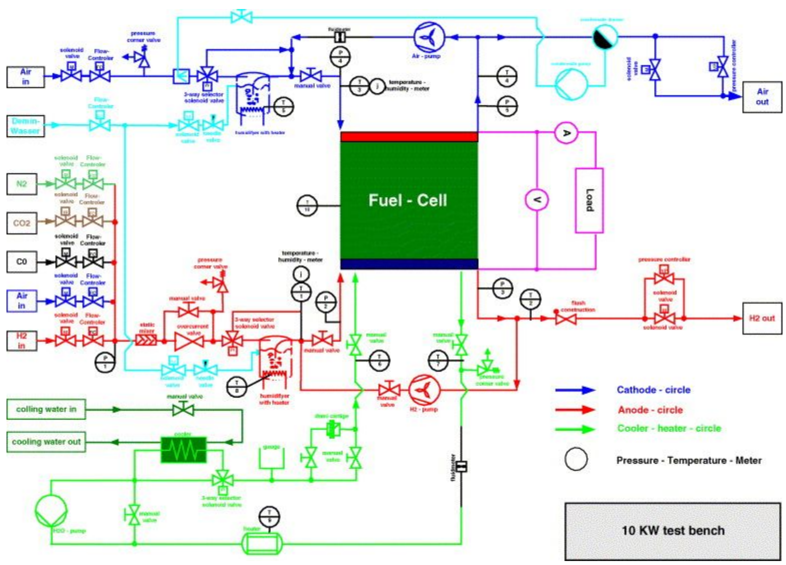
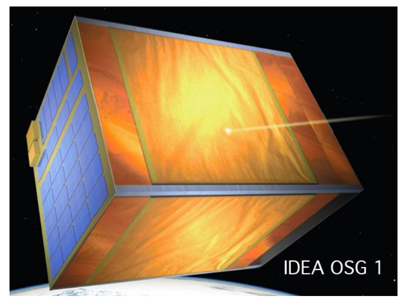


Figure 13.

As shown above, "the stack performance was determined in a test bench developed at ZSW in cooperation with hydrogen systems" [23]. After undergoing several tests, it was found that the full size stack III, which utilized optimized gas diffusion layers, achieved improved cell voltage at a given power density. However, long-term experiments showed that the stack III had stability problems, particularly when operated at 70^{+} °C. The developments were promising and optimization may become realized. This possible design option will improve the S-Ring greatly.

3.3 IDEA OSG 1

The purpose of this microsatellite is to track smaller pieces of debris on a real-time basis. This is a satellite that has been developed by the Japanese Aerospace Exploration Agency that has taken an initiative to also get rid of space debris. The satellite creates an environmental model demonstrating the distribution and quantities of space debris to formulate measure to counter debris [43]. Since the IDEA OSG 1 is a “microsatellite” it weighs 20 kilograms and is equipped with sensors that can detect debris within a 1,000 cm^2 area [43]. This microsatellite can be attached to the S-Ring as a substitute for the public database offered by the Department of Defense. Since this satellite was developed by a private agency, the database is private which results in lesser amounts of possible data acquisition and cataloging of space debris in comparison to the one that publicly exists. After design implementation, this microsatellite would work while the S-Ring is in space, therefore, it will not provide any predetermined data of space objects prior to the S-Ring’s launch like the DoD’s tracking system.



4. Environmental Impact

The S-Ring's environmental impact is expected to come from the mining and refining of Earth metals used construct the device and the burning of rocket fuel that is required to launch the S-Ring into space. However, there are many aspects of the S-Ring that take a more environmentally friendly approach to space operations, like the use of a reusable rocket.

4.1 Production and Manufacturing of Materials

The S-Ring will be constructed from materials that are found in active space satellites like: titanium-aluminum alloys, scandium-aluminum alloys, and kevlar.[24] In order to obtain these materials, there is a complex process that involves mining and refining of the metal material to get it from it's raw ore form into its shiny ductile and malleable form.

Since aluminum makes up a majority of the material, refining and smelting it causes greenhouse gas emissions, producing gases like: perfluorocarbons (PFC), polycyclic aromatic hydrocarbon (PAH), fluoride, sulfur dioxide (SO_2), and carbon dioxide (CO_2).[25] The production of atmospheric pollutants like sulfur dioxide can lead to mixing water molecules in the air and cause acid rain.[29] The environmental toxicity of aluminum poses no danger as long as the pH level of the soil remains above 5.0, yet acid rain poses the risk of lowering the pH levels.[25] At low pH levels, aluminum toxicity can impair the growth of roots causing a reduced crop yield.[26] Carbon dioxide accounts for about 15 percent of total U.S. CO_2 emissions and 12 percent of total U.S. greenhouse gas emissions in 2015.[28] The impact of CO_2 on the environment has been tied to climate change as it forms part of the Greenhouse Gases that trap heat within Earth's atmosphere.[28] In order to reduce the amount of gas emissions from smelting metals, it is recommended that there is more usage of hydroelectric or nuclear power plants. [39]

Smelting metals such as aluminum also consumes large amounts of electricity. For this reason, the best solution for providing electricity is through hydroelectric power that is readily available in countries like Canada, Norway, Venezuela, and Brazil. [37] Apart from being inexpensive, hydroelectric power is a clean source of energy that reuses resources like water instead of burning carbon-emitting resources and contributing to the accumulation of Greenhouse Gases. [37]

4.2 Launch System

The use of the reusable SpaceX Falcon 9 rocket as the preferred choice for the launch system is appealing and is advantageous compared to almost all other rocket competitors. Traditional rockets are not reusable and usually burn up in the atmosphere or sink into the bottom of the ocean after a successful launch. Furthermore, traditional rockets also discharge microscopic particles of aluminum oxide and soot that contribute to the depletion of the ozone. As a result, rocket launches usually create a greater buildup of hazardous materials due to break up within the atmosphere and the ocean. [20] Thus, the Falcon 9 is able to combat these negative impacts by being reusable.

However, in terms of environmental impact, the launch system will still have an overall negative impact, despite being more environmentally friendly overall than traditional rockets. Each launch will consume around 130 tonnes of RP-1 kerosene, which has a 34% carbon content. [27] Despite a seemingly small amount of carbon emission compared to industrial emissions, the Falcon 9 will be deployed more frequently than traditional rockets due to its reusable nature, which will cause the amount of carbon being released to add up rapidly. This increase in carbon within the atmosphere will contribute further to the overall greenhouse effect and drop the pH within the ocean due to the creation of carbonic acid. [30]

5. Conclusion

With the emergence of the private space sector, with companies such as SpaceX and Blue Origin, it seems that human operations in space is increasing. In order for humans to continue to explore the cosmos and to push the limit of satellite technologies there is a need to limit space debris. Space debris poses an issue that will stymie human space operations and will limit the growth of scientific knowledge and lose potential economic growth. Space debris runs the risk of damaging future satellites and future telescopes that will help advance the human understanding of the universe. Furthermore, there is an increasing interest in asteroid mining. However, if mining missions run the risk of colliding with space junk than there will be a loss of economic wealth as space operations will be either destroyed or deterred.

Therefore, there is a clear need to reduce the growth of space debris and currently the best option is the S-Ring. The S-Ring will provide a method of removing the threat of large space debris which will result in the overall reduction in the growth of space debris in the LEO (Low Earth Orbit) where space debris runs the greatest risk of collision. In order to ensure the growth of human space technology, scientific understanding of the universe, and future economic growth the S-Ring needs to be put in place.

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7. Appendix - Resumes

Enclosed are the resumes of the founders of *Caelum Inc.,* creators of the *S-Ring*.

Troy Lee - Electrical Engineering

Juan Mendoza-Martinez - Computer Engineering

Drew Shoenbach - Electrical Engineering

Ryan Siu - Electrical Engineering

Troy Lee
2546 Pearblossom Street, Fullerton, CA 92835
Troylee1955@gmail.com / (714) 932-1011

EDUCATION

University of California, Santa Barbara, CA **September 2017 – Expected June 2021**
Electrical Engineering Major
GPA: 3.6

INTERNSHIP & JOB SHADOW EXPERIENCE

City of Fullerton **June 2016 – July 2016**
Student Intern
- Interacted with the engineering and public works departments to job-shadow and assist.
- Served as a general office intern & supervision of children's activities parks & recreation program.

EXTRACURRICULAR ACTIVITIES & COMMUNITY SERVICE

Alzheimer's Awareness **September 2015 – May 2017**
Founding Member
- Started a new club dedicated to raising awareness and funds for people with Alzheimer's disease.

Troy High School Basketball Team **Summer 2013 – May 2017**
Varsity Player (12th), JV Co-Captain (11th), Frosh Soph Co-Captain (10th), Frosh Soph Player (9th)
- Led/assisted with basketball-related training, activities and events including shot clock keeper, snack bar volunteer, Polio Walkathon fundraiser, Hoop-it-Up Summer Youth Basketball Camp coach.

Young Leaders of Orange County (YLOC) **2013 — May 2017**
Board Member: Secretary & Team Leader (12th, 11th); Member / Tutor (10th, 9th)
- Created motivation award sheets and chose weekly curriculums as a board member
- Volunteered for recycling fundraisers and "I Love Fullerton" city clean up.

HONORS AND AWARDS

Academic Honors

AP Scholar with Distinction **2016, 2017**
Scholar Athlete **Winter 2014, 2015, 2016, 2017**
Principal's Honor Roll **Fall 2013 – Spring 2017**

Community Service Awards

Orange County Board of Supervisors Award **June 2016**
Recognized by the County of Orange for outstanding dedication and contribution to the lives of others and the community at large through community service and leadership.

COMPUTER SKILLS

JAVA Programming, Computer-Aided Design (CAD), Alice, Microsoft Office Suite

Juan M. Mendoza-Martínez

2143 Santa Cruz Hall
Santa Barbara, CA 93106
(559) 598-3467 | juanmendozamartinez@umail.ucsb.edu

EDUCATION:

University of California – Santa Barbara
Santa Barbara, CA | September 2017 – June 2021
Computer Engineering Major

VOLUNTEER EXPERIENCE:

Chowchilla Skilled Nursing Facility
Chowchilla, CA | July 2016
Volunteer assistant/ concession stand

- Acquired costumer service experience
- Split tasks with partner making and selling cotton candy

Chowchilla Public Library
Chowchilla, CA | March 2015 – April 2015
Volunteer Library Assistant

- Assisted visitors finding books
- Checked books in and organized them in shelves
- Dusted shelves
- Provided IT support for printer, scanner, and computers

Wilson Middle School
Chowchilla, CA | November 2013 – January 2014
Volunteer at Main Office Front Desk

- Filed and organized documents
- Attended incoming phone calls
- Provided IT support for setting up projectors and faulty computers

ACTIVITIES AND LEADERSHIP

HOBY Leadership Seminar,
Sacramento, CA | June 2015

- Led a group of "constituents" to develop efficient, ethical decision-making skills
- Led a community clean-up project at a park in Sacramento to emphasize value of the environment

COMPUTER SKILLS

- **Operating systems**: Microsoft Windows XP and Macintosh OS X
- **Programs**: Proficient in Microsoft Office suite (e.g., Word, PowerPoint, Excel) and Macintosh programs (e.g., iMovie, Logic X Pro, GarageBand), Certified in Adobe suite (Dreamweaver, Photoshop, Premiere)
- **Programming Languages**: Proficient in HTML5, CSS, and Python

Drew C. Shoenbach

(805) 903-2223

drewshoenbach11@gmail.com

Education

University of California, Santa Barbara *Expected Graduation: 2021*

GPA: 3.90

- B.Sc Electrical Engineering
- Relevant Courses: CHEM 1A, ENGR 3, Physics 1, ECE 5

Dos Pueblos High School, Goleta, CA *Graduated 2017*

GPA: 4.77 (4.0 unweighted)

- College Courses: Calculus (MATH 3A,3B), Multivariable Calculus (MATH 6A,6B), Linear Algebra (MATH 4A), Differential Equations (MATH 4B)
- Clubs: Math Club, FSEA (Future Scientists and Engineers of America)
- Honors Received: National Honor Society, California Scholarship Federation, AP Scholar Award

Work Experience

Tutor, Dos Pueblos High School, Goleta, CA *Fall 2014 - Spring 2017*

- Successfully lead AP calculus students towards a greater understanding of mathematical principles
- Worked in the math center helping teach a wide variety of mathematical principles

Volunteer Experience

Administrative Assistant, Dos Pueblos High School, Goleta, CA *Fall 2014 - Spring 2015*

- Answered phones and relayed necessary information
- Guided visitors and provided directions and information to them

Leadership Experience

President of FSEA, Dos Pueblos High School, Goleta, CA *Fall 2016 - Spring 2017*

- Managed funds by making sure projects wouldn't exceed club funds
- Lead group meetings and oversaw projects from start to finish
- Constructed science and engineering projects

Skills

- Experience with micro-controllers and basic electronic components
- Programming Languages: JAVA, C++, MATLAB

Ryan Siu

Ryansiu10@gmail.com
(626)581-2434

San Miguel Hall, Room 3412
Santa Barbara, CA 93107

EDUCATION

University of California, School of Engineering *September 2017 – June 2021*

Major: Electrical Engineering

GPA: 3.70

WORK EXPERIENCE

Summer Internship *Royal Business Bank*, Los Angeles, CA *July 2017 – August 2017*

- Managed, updated, and re-categorized business, commercial, and industrial loan files

Server *Poki Ave*, Los Angeles, CA *May 2017 – July 2017*

- Aided in setting up electronic cashier system
- Created customer's poke orders

Summer Internship *Creative Design Associates,* Los Angeles, CA *June 2016 – July 2016*

- Created CAD models for fire safety regulations
- Updated information with the ADA database
- Used Adobe Illustrator to create plans for upcoming projects

ACTIVITIES

Cadet Senior Airmen *Civil Air Patrol – United States Air Force Auxiliary* *Summer 2013 – May 2017*

- Learned the fundamentals of how to lead and follow, while also upholding values of respect, volunteer service, excellence, and integrity through various drills and activities

Tutor *Good Hands for One* *February 2017 – May 2017*

- Tutored students in their current math subject and checked over problems they had

Tournament Team Member *Global Badminton Academy* *Summer 2012 – May 2016*

- Trained regularly and participated in Junior Regional/National Tournaments

President/Founding Member *Imagiscience Club* *August 2015 – May 2016*

- Founded a new club that was aimed toward inspiring the youth with a passion for science

Selected Applicant *Michigan Tech Engineering Scholars Program* *July 2015*

- Attended scholarship program that provided the opportunity for students to investigate careers in engineering and science

AWARDS/CERTIFICATES

Howard P. Allen Edison Scholarship Highest Honor *2017*

California Scholarship Federation: President Honor Roll *2013-2017*

Nation Merit Finalist *2016*

AP Scholar with Distinction Award *2016*

Community Emergency Response Team Certificate *2015*

Civil Air Patrol: STEM Academy; Basic Cadet Program *2014*