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Electromagnetic-Net for Catching Space Debris: An Objective towards Recycling the Lower Earth Orbital Elements.

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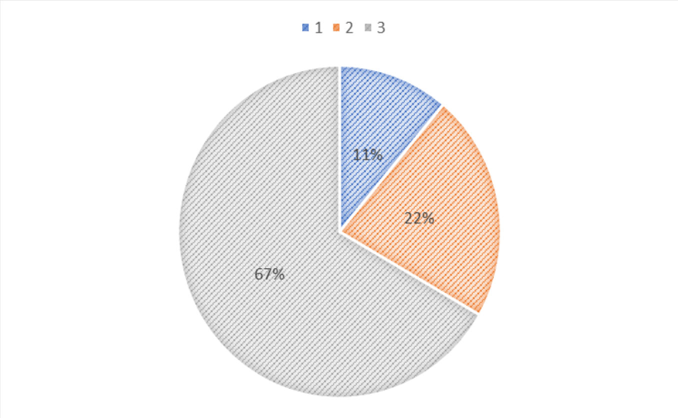
Introduction

According to Mark Garcia's published report for NASA in 2021, more than 100 million of small debris are surrounding the earth's orbit as of date. To add to this number, about half a million of debris the size of a marble and roughly 23,000 pieces larger than a softball are orbiting the earth at the rate of 17,500 miles/hour. Space debris, or as often called "space junk" accounts for non-useful, artificial materials and pieces floating in space. With a chemical composition of polymers, non-metal debris, metals and alloys, oxides, sulfides, carbides and halides, this 'debris' comes from many sources - the most common of them being spacecraft and satellites. Data results from 1957 to 2022 show that all together, the world's annual average of objects launched in space (including probes and landers) surpasses 2000, with the United States being the biggest contributor at 1800 objects launched annually. These objects, when going through collision, breakage, or failure of tenure tend to break apart into small pieces, forming a cycle of revolution around the earth's orbit. With a high velocity and a bulk of space occupied around the lower earth orbit (12,000 miles from surface), this debris acts as a barrier to any launched object and prevents it from safely surpassing the orbit.

With a variety of construction components such as solar panels, circuit boards and connectors, optical components, thermal insulators, and rocket propellers, these leftover parts of satellites, spacecrafts, and other launch objects are specific to their purpose and extremely expensive. In essence, when these objects become a non-functional unit of space, they tend to not only possess a threat to the environment but also become a huge waste of human science and resources. Since there is no guarantee of full success of a launch, this would then imply that once an object has been into space, it carries high risk of value and a definite loss of material used in construction. What if the International Space Station (ISS) could evaluate the effectiveness of their space launches and reuse material? While the debris cannot go back to its original form, attempts of recycling can aid the aerospace industry in using defunct material for communication and electricity generation.



The pie chart on the left shows the debris allocation in LEO, with 1 representing debris of size 1 cm and less, 2 representing debris between 10 and 50 cm, and 3 representing all larger sizes. The percentages show their relative population.

Consequences of Debris:

The small, broken parts of space launches making up the orbital content of the earth possess several characteristics such as varying size and shapes, high velocity, high density leading to frequent collisions, lightweight and durable material composition. When taken into consideration as a single unit, these characteristics build up to form a huge threat to the environment - both ecologically and economically. When debris collects in the lower earth orbit or in some cases, the geospatial earth orbit, it tends to act as a shield around the earth. This shield of small pieces moving at a velocity of over 4.5 miles/second forms a consistent barrier with little to no space for any intervention. Therefore, when any new object is launched from the earth - rockets, satellites, flight elements, etc, they are met by this shield of old, non-functional material. After launch, rockets are recorded to be traveling at a speed of roughly 4.42 miles/second in the lower earth orbit (LEO), whereas satellites travel at 4.85 miles/second - speeds roughly equal to that of debris in a circular motion. When these high-speed moving objects collide with debris materials, they tend to go through small fractures and lose a couple constituents. This also means that the launched entity is likely to suffer through dents, scratches, and bugs in communication of satellites. Yunhai 3 is an example of the approaching threat of space debris. On November 11, 2022, China's Long March 6A rocket launched its satellite Yunhai 3 in the sun-sync orbit from Taiyuan. The next day, however, The U.S. Space Force reported that the rocket's upper stage suffered through a breakup, creating over 350 pieces of space junk in the LEO. In addition, The European Space Agency's Space Debris Office at Darmstadt, Germany noted 630 breakups and explosions in space to date. Mathematically, this would suggest that if an average collision leads to 350 debris pieces, then 630 collisions would be responsible for creating 220,500 debris pieces. Given that factors such as the size and nature of the launched entity matters, an estimate of debris pieces between 220,000 - 230,000 would be relatively more accurate. Table 1.0 below records the approximate amount of debris by size as of 1995. Assuming the year 1995 as the anchoring bias, the present year 2023 would then fall under the ratio 1:28. Table 1.1 demonstrates the amount of debris in 2023. Table 1.2 shows the increase in debris and the rate of growth.

Research Through Innovation

Orbital Debris	**Amount**	**% by mass**
Large (> 10 cm)	> 10,000	> 99.95
Medium (1 mm - 10 cm)	> 10,000,000	< 0.05
Small (< 1mm)	> 1 trillion	< 0.01

Table 1.0
Orbital Debris in LEO as estimated in 1995

Orbital Debris	Amount
Large (> 10 cm)	> 37,000
Medium (1 mm - 10 cm)	> 128,000,000
Small (< 1mm)	> 1 trillion

Table 1.1
Orbital Debris in LEO as estimated in 2023

Size	Debris 1995	Debris 2023	Increase in Debris	Rate
Large (> 10 cm)	10,000	37,000	27,000	964.29
Medium (1 mm - 10 cm)	10,000,000	128,000,000	118,000,000	4214285.71
Small < 1mm)	1 trillion	1 trillion	Infinite addition (can't be calculated)	N/A

Table 1.2
Change in Debris since 1995 and rate of change

The rate of change here is calculated by dividing the increase in debris value by 28 - the number of years since 1995. This shows that there is an increase of 964.29 pieces of large debris annually, 4214285.71 pieces of medium-sized debris and an infinitely estimated amount of small pieces. This suggests that for every explosion in space, there will be a high chance of collected debris in LEO. Furthermore, these existing parts of debris possess a threat to new launch objects. A popular example would be the collision of the 1996 French Cerise military reconnaissance satellite with an Ariane[1] rocket debris particles. The collision took place in LEO, the estimated site of the majority of debris. This event highlighted the significance of operated monitoring of satellites, but most importantly provided an insight into the danger posed by 'junk' in space.

While this was a posed barrier towards space launches and the exterior of the earth, another ecological threat is the falling of space debris *on* earth. Contents below 370 miles of the earth's orbit are likely to fall back to Earth within a period of decades. This is primarily due to Earth's gravity pulling the contents downward toward the surface. Since these orbital contents are in LEO, 1200 miles from earth's surface, over a period of extended time they experience orbital decay and lose altitude, eventually shifting to closer orbits and later spiraling towards the earth's surface. According to Dr. Peter Brown of University of Western Ontario, estimated 40,000 metric tons of space matter strike the atmosphere annually. Since meteorological strikes are rarely witnessed in a year, the major constituency of this matter is space debris. An example of this is the falling of a whopping 23-ton piece of debris from China's Long March 5-B rocket into the south-central Pacific Ocean in November 2022. The rocket's purpose was to launch China's Tiangong space station's core module into orbit. With no plan for a controlled entry into the atmosphere, the piece of debris with an uncontrolled trajectory hit the earth's surface without burning up in the process. Although the hit was safe to land, the Pacific Ocean got another contribution from a waste entity. These examples demonstrate the threats imposed by the growing collection of space debris around the earth.

[1] A family of European civilian space launch vehicles. The rocket debris is from Ariane 40 third stage.

Previous ideas

In regard to dealing with space debris, space companies and manufacturers have come up with a few solutions - the most common being the RemoveDEBRIS satellite. According to the mission of the RemoveDEBRIS satellite built by The Surrey Space Centre at the University of Surrey, the satellite is equipped with a spear in the form of a giant net. This giant net carrying satellite detects the presence of a single space content and directionally moves towards it. Once the satellite is in a suitable distance range with the selected piece of debris, it releases a balloon-like inflated giant net to capture the debris. Keep in mind that the net is yet not independent of the satellite, thus it is connected with a deployer that is used to extend the sail away from the site. The next step of the process is to simply use the deployer to shoot away the net from the satellite to de-orbit the net-captured content and let it move towards the earth's atmosphere. Considering that there will be high friction as the object approaches the earth's surface with a high velocity, this would lead to intense heat development which would burn up and/or melt the space debris. However, this would also imply that debris containing composite metals and polymers that consume ozone will go through chemical reactions once they enter the atmosphere and take the heat; these reactions will produce nitric oxide which contributes to depleting ozone. Furthermore, even if we assume that the matter captured is free of any polymers, the process of removing debris itself is extremely slow and exhaustive. Since one piece of net is aimed at each object, the aim to remove major debris, if not all, would require a large number of nets and more than just a single associated satellite, thus having an inflated cost of production for a relatively slow and unreliable process, making the overall solution impractical and inefficient.

Another solution towards cleaning up space debris is the use of magnets to induce electromagnetic characteristics within debris. The University of Utah's engineering team designed an 'omnimagnet' solution to manipulate debris gently. Given that the speed of orbital contents is significantly high for a slow-moving independent object like a satellite, the solution aims to induce a changing magnetic field that would turn the targeted debris into an electromagnetic object with torque and force. This would allow moving the debris without physically capturing or grabbing it. One other study by the University of Toulouse in France proposes the idea of a magnetic space tug that would incorporate a similar debris removal solution through the idea of capturing debris by the continuous process of inducing attraction and repulsion forces to capture debris from a safe distance. The new convention here is the use of 'tugs' in targeting satellites using their magnetorquers.[2] This contactless capture is expected to work from a distance of 10-15 m from the targeted debris. The primary idea connecting both pieces of the research is that they're both aiming towards an automated proposal to remove debris from the orbital site. However, although suitably accurate for magnetic materials, it is also important to note that the majority of space debris is composed of non-metallic structures or lightweight metal alloys that allow the content to easily stay in the orbit without getting deflected by an external magnetic source. Since the idea of using magnetic fields to deorbit debris involves the integral process of attraction and repulsion, it can be inferred that this idea will most likely not be suitable for the majority of debris particles that cannot be used as targeted magnetic poles. Particles such as polymers and non-metallic human-made compounds tend to exhibit properties of individuality in nature and are unlikely to be influenced by a strong magnet. Furthermore, for the few particles carrying magnetic characteristics, the idea of an electromagnetic space tug itself would require the fast-moving debris particles to be 'slowed-down'. This shows that the solution can't do the following:

1. Keep up with the high velocity of the debris, thus making it hard to target a single particle.
2. Allow having more than one target object.
3. Be time and cost efficient.

[2] A device used to control the altitude and/or orientation of satellites using magnetic fields.

These are examples of how and why solutions aimed at destroying space debris can, in turn lead to extended waste of cost and resources employed. There's no single-handed solution for removing space debris, however certain experiments also demonstrate that debris is volatile - it keeps on moving within the orbit. Proposals that aim towards a single subject matter are highly likely to fail because debris cannot be controlled or held in a place. With its consistent revolving nature, space debris exhibits circular motion around the earth with a velocity that beats any intruding object. It is also important to note that debris moves in large clusters, thus the density along with the high velocity possesses great threat to any trespassing material. This concludes that satellites and debris removal objects also stand a high chance of getting wrecked as a consequence of not being able to match the motion of the revolving space contents.

Reusing Debris

Cases above highlighted the danger posed by interspace substances that tend to get back to the surface of the earth after the expiry of their tenure in the lower orbit. This shows how millions of dollars worth of space objects lose their value after simply striking past another non-resourceful object of their kind in space. Not only that, this cluster of waste contents also acts as a barrier for human space exploration - becoming what is referred to as the Kessler Syndrome. The Kessler Syndrome, a concept proposed by NASA's Donald J. Kessler in the year 1978 refers to a phenomenon that entails the impact of increasing debris around the earth, causing human space exploration to be either confined or less independent of the spacecraft. This implies that if not taken care of, then astronauts would stand high chances of getting struck by pieces of floating waste space content every time they try to approach the earth. Could this also imply that since we won't get a closer look of the earth, the next few years would have pictures of the earth surrounded by a cloud of materials?

Debris recycling can be hard, but if measures to capture and throw materials have been possible, then so can bringing back earth's waste. Instead of making an effort to collect and throw debris, the proposal could be changed to collect and reuse debris. Considering that space is a free territory, it is no doubt that the entire world's waste is united in the orbits. For an estimate, an average weather satellite carries a hefty price of over $250 million. When altered to fulfill specific purposes, this price can expand to $400 million. With about 3000 futile satellites in space, this waste accounts for a huge sum of money invested in scientific innovation and resource development. A rough estimate of these total costs determined by Morgan Stanley in 2022 reveals that there is a projected amount of more than $350 billion worth of space content. This further accounts for an evaluation of over a trillion dollars worth of space content by 2040. Measures to take down and remove space debris have involved the procedure of strategically either removing debris from the orbit, pushing it away from the earth, or bringing it closer to earth, allowing it to experience friction due to high velocity and pressure, thus enabling it to burn up as soon as it reaches the earth's atmosphere. Although these solutions have been quite effective in their thesis, they haven't yet focused on repurposing the idea of junk into resources. Majority to nearly all of space debris prevention conventions are focused on simply getting rid of debris, which also accounts for having to find solutions that 'clean' the waste in the orbit. Considering that the orbital waste doesn't comprise a single variety of debris - metal or polymers, and instead, is a huge combination of various materials and compounds, solutions are also catered to remove specific types of waste. This involves the examples of the magnetic debris that is only effective in attracting materials that exhibit magnetic properties. Furthermore, large, non-metallic materials that tend to occupy a big matter of the orbit tend to stay intact because of their lack of exhibiting magnetic characteristics. In regard to using nets for capturing debris, a net can either pull debris out and throw it away from the earth or towards it - leaving it to burn in the atmosphere. In both circumstances, materials are wasted and investments are essentially losses. From an economical aspect, an increasing number of space debris implies that the International Space Station carries huge risk on every launch. As the shield of junk for surpassing LEO becomes stronger and more resilient, launched objects will increasingly face uncertainty of securely making it out of the orbit.

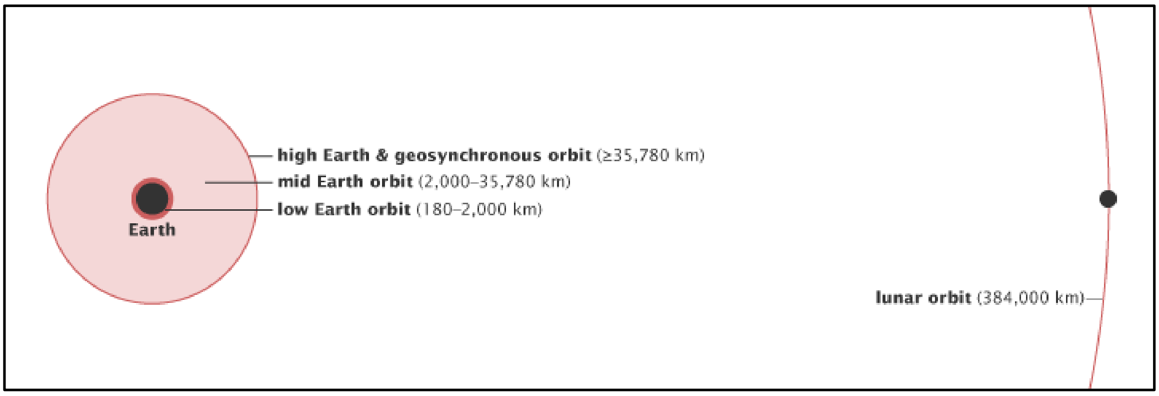
Reusing debris can have many aspects, the most significant being sustainability. From polymers to splashes of paint floating in no gravity, orbital matter can't simply be classified within a few categories. While removing debris is the primary objective, reusing it will help the economy equally. A $250 million satellite crashed into pieces can be brought back and experimented on, and most certainly can be reorganized to fulfill the purpose better or a new, better purpose. Experiments involving stability of matter and faults in launched vehicles will also experience a growing standard of certainty and value once 'resourceless' material is returned and examined. In essence, a major aspect of debris is its efficiency. This would also allow the 'junk' to be named a 'resource' and risk can be termed an 'experiment'. Resource conservation of materials used in building space objects is another reason why reuse and recycling should be a boon for scientific research and innovation. When these objects are provided with a nature of reconstruction and organization, it makes it beneficial for both environmental sustainability and economic efficiency. Satellites and mission landers' debris can be used for research and dissection - further allowing researchers to expand knowledge in systems they had been previously unmotivated about. Where a mass communication satellite can provide curiosity to astronomy enthusiasts, debris as large as a spacesuit can be used for investigation and educational presentations. Among the various uses that this junk is prospective of, another important factor that comes with bringing debris back is the large size of its carrier. In 2018, John Mason International Movers sent a shipping container in space - providing reference for the size of an object that can be practically launched into space as a container for collecting debris. This accounts for a possibility of a prospective solution in progress. Perhaps debris could be stored rather than thrown away? Would satellites bring some useful information back to earth and reveal what it's like in space when nobody's watching?

Earth's Orbital Layer

The earth has three classified orbits, namely - low earth orbit (LEO), medium earth orbit and high earth orbit. The low earth orbit is closest to the atmosphere, known to be just above the exosphere. LEO extends from an altitude of 160 kilometers to 2000 kilometers, thus offering several perks to a spacecraft or satellite. LEO's belt[3] prevents the ultraviolet radiation of the sun from entering the earth and acts as a shield for launched objects. Because of this, the majority of launched objects including spacecraft are designed to stay in LEO to protect the system from damage by radiation. Satellites, on the contrary, tend to reside in the high earth orbit for more accurate weather and communication forecasts. For regional monitoring and signal detection, certain satellites are also kept in the medium earth orbit. This arrangement of launched objects within their respective orbits allows proficient and successful operation of each space entity's task. As discussed before, since the majority of debris is present in LEO, it can be derived that LEO's geographical location is best-suited for many aerospace initiatives and launches. While satellites hovering right above the equator tend to be in GEO[4], because of their nature of being closer to LEO, they carry a high possibility of spiraling into LEO upon the completion of their tenure or factorial damage. The illustration below by Robert Simmon for NASA shows the extent of the three major orbits in comparison to the lunar orbit.

[3] Earth's Van Allen Belts are present in LEO, formed of high energy particles that provide a deep radiation protection zone.

[4] Abbreviation for the Geosynchronous Earth Orbit. This is a suitable orbit for communication satellites as the satellites' orbital period coordinates with the period of the Earth's rotation.



Representation of LEO, MEO, and HEO by altitude. Source

As seen in the illustration, since most of the space entities lie within the red hue-highlighted portion, this area hosts a significant amount of debris. Furthermore, the dark red narrow portion surrounding the earth - representing LEO is the site for all the spacecraft debris and expired satellite debris. This concentrated region of junk is an immediate barrier for human space exploration and environmental harm, thus making LEO not only unsuitable but also threatening for further hosting.

Electromagnetic-Net Carrier (Summary)

Observing the practical aspect of dealing with debris, it's important to customize a solution that offers a targeted yet holistic solution to the problem. This can be justified as targeted to capture pieces of debris without failure and holistic as in having the capability to take in a variety of debris materials regardless of their chemical composition and nature of magnetism. When dealing with such a solution, it's also efficient to take into account the possibility of incorporating the solution, the tenure of its survival as well as cost efficiency in relation to the time period used. After numerous takeaways from previous ideas, setbacks and development of a cleaner, ultimately more stable, and practical idea, it is significant that a system of combination is used as the space debris removal solution. To introduce this into the aerospace and mechanical industry, a proposal of an Electromagnetic-Net Carrier is put forward.

The Electromagnetic-Net Carrier is a machine that operates on the collaboration of electromagnetic and hardware engineering domains. It combines properties of net control, capture and release as well as magnetic attraction. The idea of the solution itself is that its compound nature of catching debris of all chemical and physical types enables it to stand out as a more holistic and efficient solution. The carrier is formed by the use of engineering a stainless steel container. The use of stainless steel is due to its non-corrosive properties. Being an alloy of iron (Fe), carbon (C), chromium (Cr), and nickel (Ni), stainless steel is resistant to rusting as compared to steel with ordinary iron-carbon combination of compounds that is likely to get damaged due to corrosion in LEO. With SpaceX's extensive use of stainless steel in Starship, it can be implied that using the material has a strategy - its non-magnetic property. While some stainless steel can exhibit magnetic properties, the essential idea comes down to the microscopic structure of the alloy such that ones with nickel and chromium exhibit low to negligible magnetic properties. Since the aim in reusing debris is primarily to take in the debris instead of attracting it to the surface of the container, austenitic 304[5] stainless steel[6] is arguably the most suitable

[5] Steel 316 is not taken into consideration in part because of its relative nature of being more suitable in dealing with environments in exposure to chloride ions.

[6] While non-magnetic when freshly used, upon cold-working the material may start to show magnetic properties. Thus, it is important to take into account the duration of manufacture.

material for carrying out the mission. In addition to its material characteristics, the container will have ridges that prevent the steel container from suffering through any particle damage that impacts the entire surface. Furthermore, the ridges will provide extensive strength for the debris stored inside to prevent the contents inside from being crowded or stuffed - thus, causing any scratches or breakthroughs. This steel container will then be equipped by two centered entrance sliding doors. On the inside opposite side of the container will be two panels of soft iron core plates that exhibit electromagnetic properties. The two panels will be attached to the inside of the container, opposite to the entrance. Along with and underneath the panels, there will be sheets of net made of polyethylene Dyneema with narrow formulated borders of ferritic[7] stainless steel. Unlike austenitic, ferritic steel's thin border will enable the net to attach itself to the panels of soft iron electromagnet, thus sticking to the plates and covering up the gap in between. This arrangement will allow the assembling of the electromagnetic characteristics with the placement of the net such that a variety of collected debris would be captured.

Detailed Construction and Assembling

The Electromagnetic-Net Carrier is a space machine set to fulfill the goal of recycling and reusing waste in space. The launch vehicle functions as a spacecraft with a specific purpose that involves components of engineering and physics. The spacecraft-machine is manufactured in steps that fulfill each purpose and are organized in a relatively simpler manner. To begin with, the construction takes place with the use of an aluminum alloy used for manufacturing the spacecraft's body. This aluminum alloy is a fine composition of Aluminium, Silicon, Magnesium and Copper, called the AA6061. This alloy is used to compose the sphero-cuboid[8] shaped body of the spacecraft. The sphero-cuboid-shaped is essential to ensure that the spacecraft can collect debris efficiently while being durable and having a fair performance maintaining pressure across the edges. The spacecraft body's broader face will have an opening that slides outwards as the magnetic material is projected forwards from the inside. Opposite to the opening, on the inside of the spacecraft, will be a metal platform, topped with parallel plates of magnet that get electrically conductive. The plates will be composed of a soft iron core and will be charged to form poles on the top and bottom, rather than on sides to avoid them from attracting one another. Between the plates, will be a net of polyethylene Dyneema, with a tensile strength of roughly 43cN/dtex and borders of ferritic stainless steel. The net will be attached to the iron core plates by spring hooks attached to the metal aluminum platform and the magnet plates through the ferritic steel borders. This allows for the springs to extend and contract as the plates are charged and move forth. The other two, opposite surfaces of the spacecraft will be closed. There will be a satellite extension on the top of the spacecraft to enable tracking of the spacecraft's movement. The satellite will help in navigating the spacecraft through the LEO. The sliding doors will operate sideways to allow the spring to extend and the magnetic plates to project outwards. As the plates project outwards, the net attached in between them expands, creating a broad surface area for the revolving debris. The plates, having dissected poles, then adjust their poles to the adjacent sides, creating opposite poles on each facing end due to induction. This allows the panels to close with the net captured debris in between, creating enough pressure for the spring to compress and the net as well as the panels to project inwards, leaving the attached net in. The platform on the opposite end will have a bulk of Dyneema nets that can be discarded upon single use. This ensures that each net is able to take a suitable content of debris with it, and other nets can be used for repeating the process. The net, in essence, will be attached to the spring hook between the two panels and once there is a certain amount of pressure on the net, the hook loosens up and allows the net to fall down, taking away the debris content with it. This is elaborated upon in the assembling process of the net with the plates.

[7] Ferritic steel is composed of an alloy with higher iron content, thus exhibiting magnetic properties.

[8] A cuboid shaped body with curved corners. The curved corners allow for efficient maintenance of pressure difference across the spacecraft body.

Size and data (in inches):

The Dyneema net, each unit: 60 x 38 (15 minimum)
Magnetic plates: 35 x 18 (2)
Spring extension length: 75 (minimum)

Considering that the material used for spring is stainless steel with double coils and closed grounded ends, the spring constant is thus, roughly 11840 N/m[9]. Using this value, we can calculate the spring force by Hooke's Law:

$F_s = -kx$
$= -11840 \times 1.905$
$= -22555.2$ N, or -23 kN.

This shows the total force needed by the spring to extend to its full length. An important point to note is that the spring is controlled. That being said, it is important to note that it has two rounded close-ended coils of stainless steel with a 0.48 cm diameter each to control the extension. The superior material with a larger diameter helps the springs stay in control and not lose their spring force easily.

Opening surface area: 38 x 43
Opening slides: 38.2 x 26.2

The opening slides cover the surface area and open sideways to allow way for the magnetic plates. The opening surface area acts as a covering for the magnetic plates inside.

For spacecraft's body: external configuration

Sphero-cuboidal length x breadth: 77 x 98
Navigation satellite attached: TBD*
Thrusters on each opposite end: length x diameter - 16 x 21 (3)

Energy supply

To account for inducing and storing current for the induction of magnetism in the iron plates, the spacecraft will have solar arrays on opposite ends. These solar arrays will be the primary source of power generation as they convert solar energy into electrical energy for the operation of the spacecraft. This electrical energy will be used to induce current through the equations:

$I = VR$

This equation is applicable to the battery source that powers electromagnetism and is charged through solar power. The following equation delivers the strength of the magnetic field in the plates.

$F = q_e (v \times B)$
$F_{magnetic} = qvB\sin$□

[9] The spring constant value is obtained by using the material property of the spring, the extended length, diameter and number of coils.
* variable

Where q_e = electric field charge
v = particle velocity
B = magnetic field strength (T)

The operation of inducing an electromagnetic field in the plates will require the use of a coil and wires to induce current. In this scenario, the coil of insulated wire used is Helmholtz copper coil with a radius of 0.5m, and about 200 turns. The estimated current is about 400A and the coil is approximated to be 170m.

Considering the magnetic flux density of the plates, the following equation can be used to determine the strength of the plates:

$H = NI/L$

$H = 200 \times 400/170$
$H = 4.7$

Given that the core material is soft iron, the relative permeability is measured to be 2E5.

$B = \mu \times H$
$B = 2E5 \times 4.7$
$B = 940{,}000$ T

This gives the magnetic field strength of the electromagnet, which is then attached to the platform beneath the iron plates to induce magnetism in them. Considering that this is a hypothetical value, as the relative permeability of the core material can greatly impact the value of B, it can be hypothesized that the obtained value of B is on the extreme maximum end.

Dyneema net discarding and functioning with the plates:

The Dyneema net will be used to catch debris. The primary operation of storing debris will be carried out as such:

1. The plates are released from the platform, expanding the spring attached to the platform and the panels[10].
2. The expansion of the spring allows the net to expand fully between the plates, covering the surface area and dwelling backwards, creating volume for potential debris.
3. The plates exit the slider and electromagnetic current is induced, with the net expansion in between.
4. The high velocity of debris revolving around the machine is attracted by the electromagnet.
5. While some (not all) debris exhibit magnetic properties, the accompanying non-magnetic debris will be transferred into the net as a result of getting carried away with the bulk of heavy particles attracted towards the magnetic plates.
6. As the maximum weight is detected, the plates move close together until they start getting attracted by each other's opposite poles.
7. Once the plates close, they move inwards the spacecraft.

[10] Panels and plates are used interchangeably.

8. The attached hook springs on both plates detangle upon coming in contact with each other, hence, dropping the net with stored debris.
9. The plates continue to move back to the platform, where they detach and the spring hooks get tangled into a new net, hence repeating the process.

The arrangement of the spring hook is such that the two ends of the spring attached to the plates form a concentric shape, which when comes into contact with the other concentric tangles and detangles within the surface space between the two spring wires. This feature does two things:

1. Allows the spring hooks to tangle with the net before releasing the panels out.
2. Tangles the spring hooks among themselves after debris storage to allow the net to drop.

The other nets attached at the back of the plate platform are now tangled into the spring hooks and used and discarded in the same way. For weight sensing of the debris, a smart waste management system will be imitated. Since the net is attached to the two plates, both plates' edges attached to the net will be equipped with recycling compactors and sensors that detect the maximum load of the debris in the net. Once this happens, the plates will automatically close. The sensors on the edges consistently monitor the weight of debris occupied, with the suitable range being 130-160 kg. A control system enabled within the spacecraft will have microcontrollers that are programmed to operate in closeness with the magnetic plates. As the microcontrollers detect the weight within the range, they send a signal to the magnetic plate detectors to close, hence, activating the closing mechanism. For sensors attached to the plate-net edges, load cells or strain gauges can be used to fulfill the purpose. Next, a microcontroller like Arduino can be used to function as a sensor for controlling the closing mechanism of the plates. The solenoid system used for the electromagnetic property of the plates will also accommodate the actuation mechanism that responds to signals from the microcontroller. This system allows for an effective detection of the suitable weight of debris that can be collected once using the carrier system, allowing the plates to close and drop the net with the captured debris and repeat the process with new net sheets. One other advantage of the system is that it uses both magnetism and net capture to regulate collecting space debris. This is particularly important because not one system individually can be as effective in catching a vast variety of materials embedded as waste.

The following graphs show the relationship between mass of debris captured with each net use:

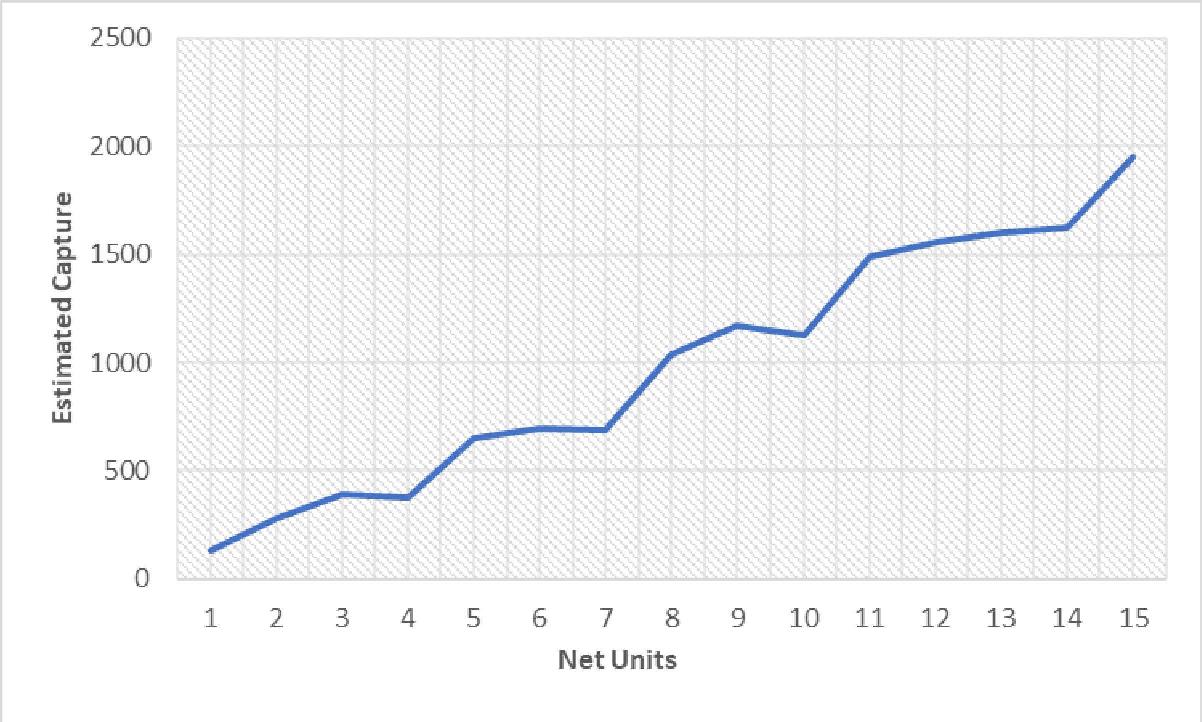


Figure 1. Debris Capture with Dyneema Net Use

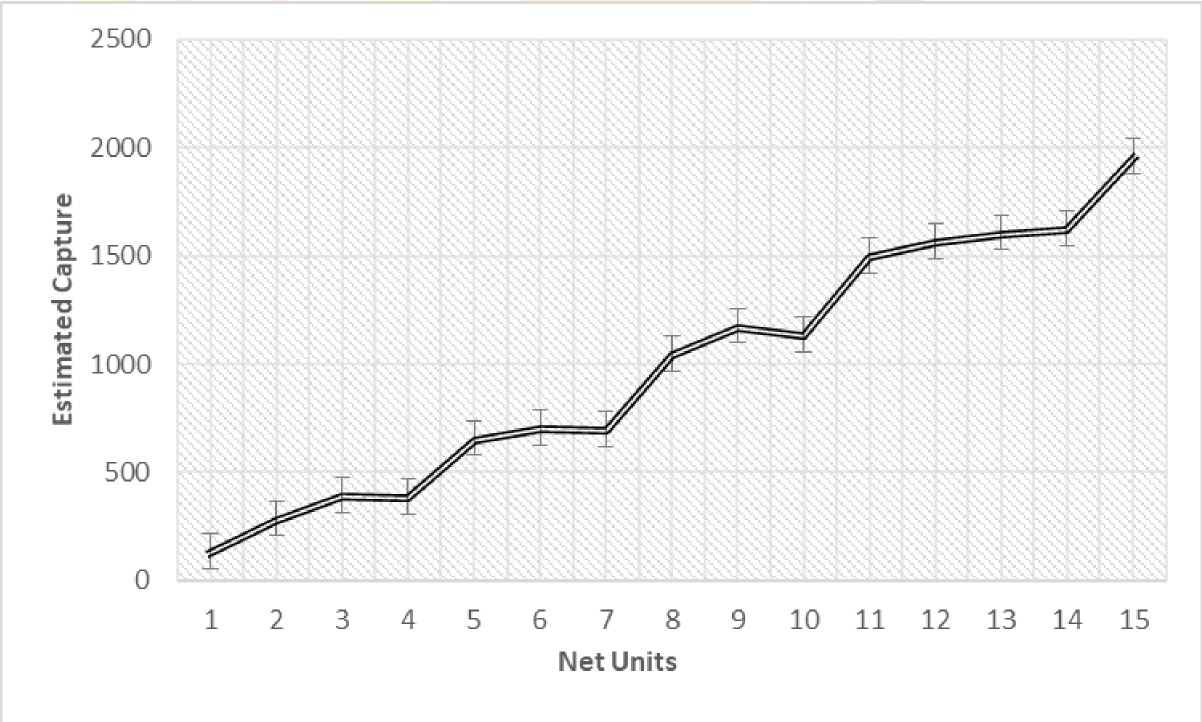


Figure 2. Allocation of Uncertainties.

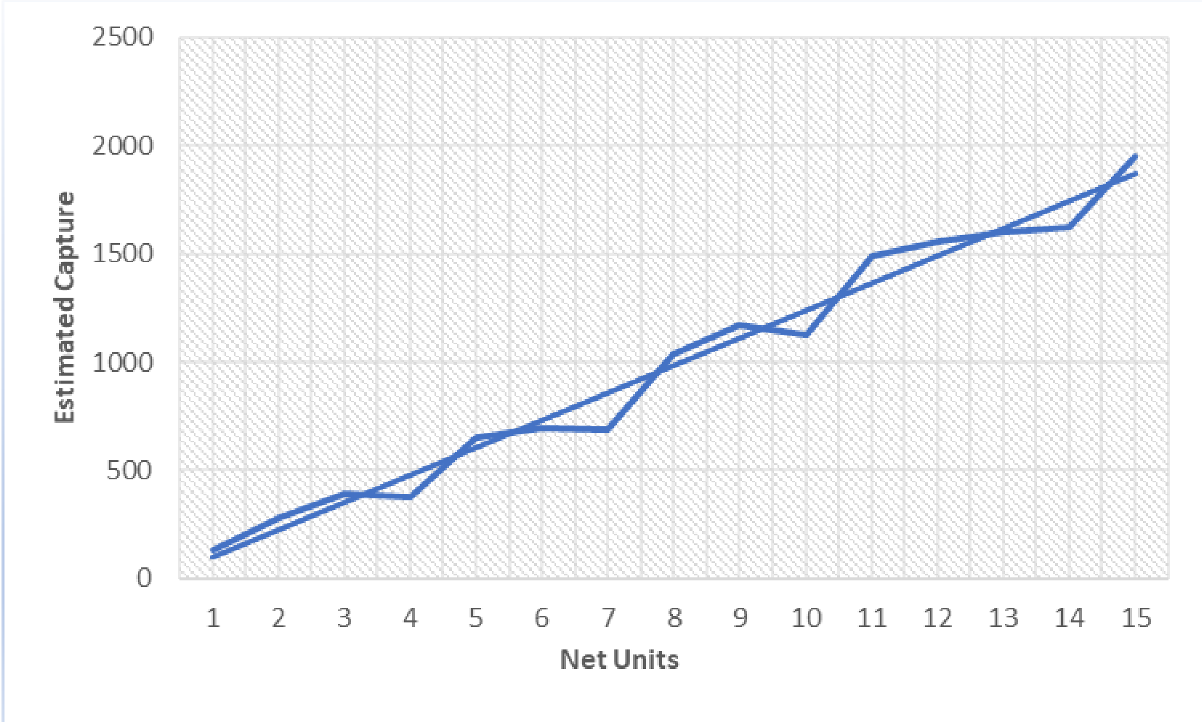


Figure 3. Trendline

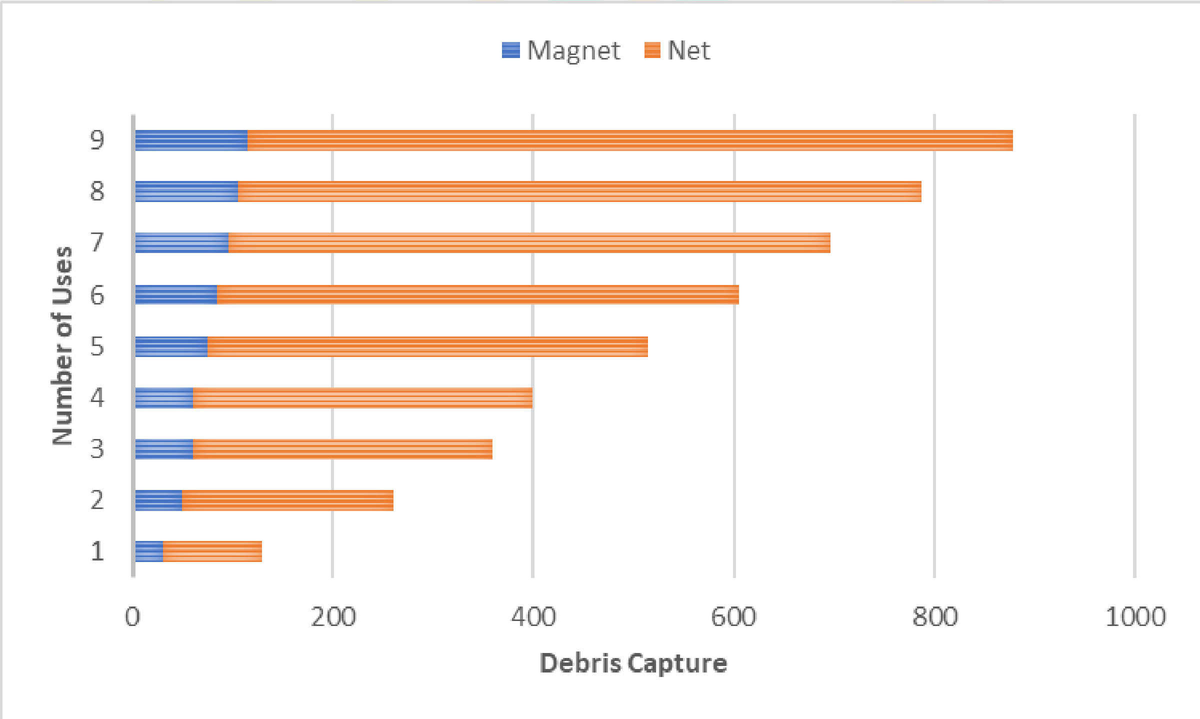


Figure 4. Debris Capture by Magnet vs Net/Use

Research Through Innovation

Back to Earth:

The carrier machine is brought back to Earth after a completion of 90 days in space. This is to regulate the waste management system and ensure that the carrier does not suffer from overload and its operability isn't compromised. To bring the carrier back to Earth, an ordinary spacecraft's trajectory will be used and calculated, per the weight system of the carrier. Once the carrier has reached the estimated site, its contents can be released from the net and. However, one key thing to note is that as the magnetic property of the plates influence the functioning of the carrier, when the plates have captured enough magnetic material and return back to the carrier towards their platform, the electromagnetic property will be turned off for the material to drop down alongside the net capture. This allows for the reuse of the plates in the next rounds of waste capture. The primary idea behind this prototype is to enable the recycling of debris rather than leaving it to burn in the Earth's atmosphere or displacing somewhere else in space. This is particularly significant because artificial waste must be returned to Earth, and either recycled or presented as artifacts for higher learning, experimented on and used for experiential knowledge development. Since the carrier solution works as an automated spacecraft, it requires fuel and general requirements of a spacecraft. For this purpose, the optimal fuel would be liquified hydrogen. LH2 can be combined with LO2 to further maximize specific impulse and provide efficiency. The propellant combination can be further estimated to remain relatively the same as for any other spacecraft, the carrier will be attached as a central body to allow balance of pressure on all corners.

APPENDIX

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