Iowa State University

COSMIC Capstone Challenge: Final Briefing

The Space Cyclones
Institute: Iowa State University

Students: Johnathon Beuter, Maheeka Devarakonda, Riley Heeren, Tanvi Mehetre, Daniel Sprout, and Benjamin Swegle
Advisor: Professor Rachel Shannon
Mentor(s): Benjamin Rupp and Botond Varga

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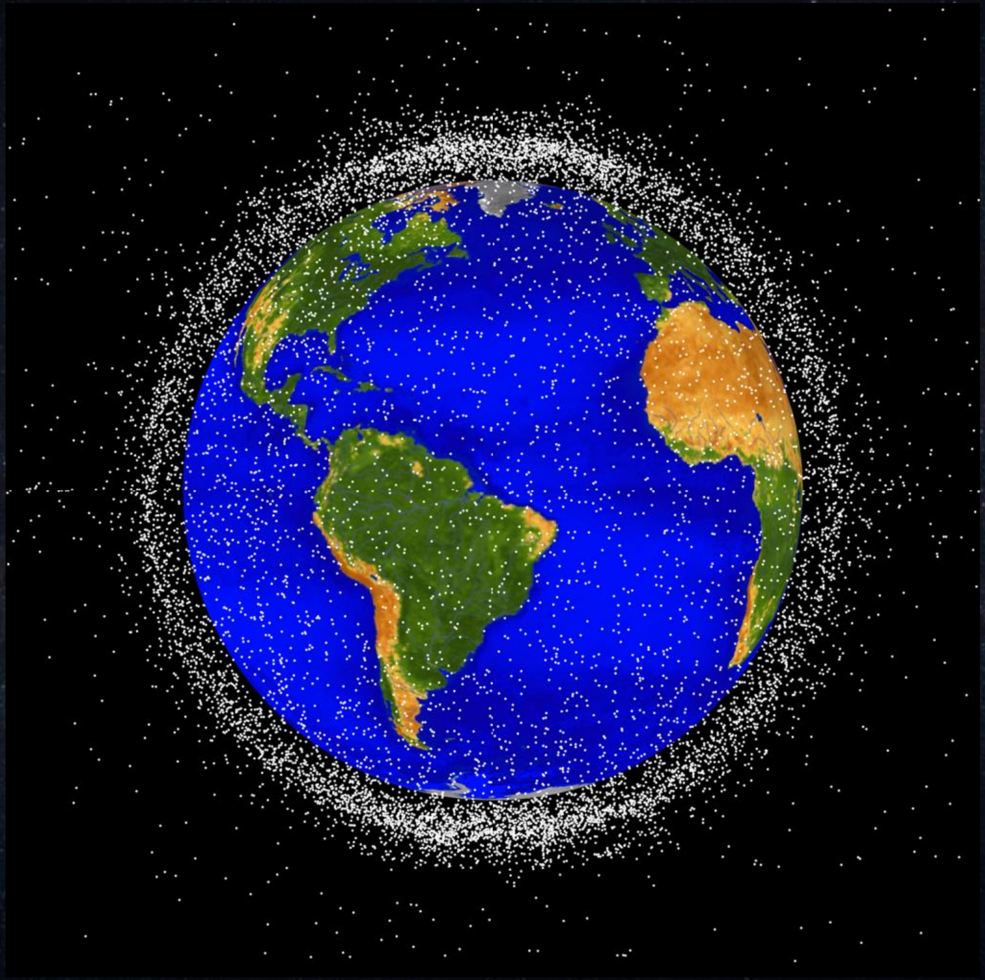
Executive Summary

- Large amounts of space debris in lower earth orbit
  - Potential to limit in space operations
  - Worsening debris chain reaction where piece of debris in space collide with other objects in space creating more debris, known as the Kessler Syndrome

- There is a need to sustainably and reliably deorbit in-space debris
  - Net launching satellites capable of capturing debris

- Our design is able to take out a piece of debris with each net launch

- Status: 3D printed prototype net launching module made



Team Overview

John Beuter
Major: Cyber Security Engineering

Riley Heeren
Major: Electrical Engineering

Daniel Sprout
Major: Software Engineering

Ben Swegle
Major: Electrical & Mechanical Engineering

Maheeka Devarakonda
Major: Electrical Engineering.

Tanvi Mehetre
Major: Computer Engineering

2.4 Systems Engineering Milestones

September 2024
Select program manager

October 2024
Chose operations/ capability

November 2024
Define System Requirements and Complete Trade Studies

January 2025
Finalized Conceptual Design

February 2025
Developed a Path to Preliminary Design Review

April 2025
Completed Code and Electronics for Final Prototype

1.1 Impact

LEO is the region with most man-made objects and debris from growing commercial and defense satellites

According to the European Space Agency (ESA) report, there are 34,000 space debris LEO orbits larger than 10cm. Slingshot Aerospace estimates 3,500 of these objects are defunct satellites.

Our solution targets reducing debris by de-orbiting objects from 10 cm to 1 meter in size, which:

- Reduces Kessler Syndrome and collisions
- Increases safety of future space operations
- Clears path for future space platforms
- Promotes space sustainability

Our design would be sustainable as the new net capsules can be loaded on our platform, which can be refueled to maintain orbit. And potentially lower cost as we keep the platform with possible future use for recycling operations in LEO..

1.2 Feasibility

Our design provides a sustainable solution to de-orbiting debris that maximizes the payload capabilities of the Venus bus.

- Our net capsule size and weight allows for 4 capsules in a housing unit
  - Optimally using space onboard the craft
- Our spring launch system reduces the force offset of launching a net capsule
  - Allows for more fuel available for net capsule mobility post launch
- Capturing space debris with a net has been proven feasible
  - RemoveDebris captured space debris with a net system in 2018

1.3 Innovation

- RemoveDebris program has already tested the functionality of a net in space
- Our goal was to improve the economics with a multi-target capability and re-useable platform
  - Multitarget capability - 4 net capsules
  - Satellite can be repeatedly reloaded with 4 new nets
    - Cost savings on launches and mass to orbit
- Our design will provide autonomous target of debris
  - Platform can pilot net capsule to debris
  - Ground control provides command, control, communication to ID target and guide platform

- At the cost of less fuel than single use platforms, we can deorbit multiple targets.
- We offer precise maneuvering of launched net travelling to target in order to reduce chances of errors.
- We provide eyes on the target from our platform
- We deliver deorbit of debris or netted target could be recycled in space

1.4 Required Elements

- Type of solution: Servicing in Space
- Autonomy: remote deorbiting of space debris with a focus on 10 cm to 1 meter size
- 3 operations:
  - launch of net capsule to target
  - capture of target
  - deorbit of target
- Why can our solution be implemented the end of this decade?
  - Sspace tested components reduce mass and cost and field life in next 5 years.
  - Net launch to capture debris was successfully tested in 2018.
  - Material and base research for improved components is completed.
  - Our proposed solution can be cost effective and team has or can get access to required tools & facilities.
- Venus Payload conditions:
  - fits the size dimensions: 17” x 16.4” x 27”
  - total power required: 220 W
  - payload mass: 75 Kg
- Limited ground operations: initiating space sequence.

1.4 Required Elements

- Consideration to operating in vacuum, operating in microgravity, how it will be operated, and designing to survive launch loads
  - design focuses on soft launch of the net capsule to avoid reaction forces
  - design eliminates the problem of tumbling objects
- Cost Estimate:

Material/Component	Low Estimate ($)	High Estimate ($)
Aluminium	80	1400
Microcontroller	7	17.9
PCB	5.99	29.99
Thrusters	1000	10000
LIDAR	129	3800
Servos	4.37	69.99
Spring	0.05	1
Net	6.95	345
Total Cost	1233.36	15663.88

1.5 Risks

There are several risk factors that our team took into consideration when generating a concept for our in space servicing solution. The individual risks for the long-term viability of our platform all fall under the umbrella of avoiding and not creating more space debris.

- Competing orbits
  - With our main objective to deorbit cube satellites and debris from LEO we must avoid the orbits of other platforms and debris that could damage our platform.
- Proper Deorbiting of Targeted Cube Satellites or similar sized debris
  - A failed attempt to deorbit could result in increasing the propagation of space debris instead of decreasing it. We need to test on Earth and in orbit to 6 nines to ensure error probability is close to zero
- Fueling/Craft Longevity
  - Refueling has costs and may not be available at end of life, we need to plan to de-orbit or recycle with on board fuel.

1.6 Path to PDR

We recognize that aspects of our project, namely the testing our our design for launch and in zero gravity. For a completed design we would need to model and simulate these environments as well as to prove our test our net capsule launch and capture target mechanics are feasible.

- Launch testing of design
- Zero gravity testing of design
- Refueling procedures/craft design

We assessed that the Venus bus would be large enough to support our payload. Our capsule would integrate with the onboard electrical system of the craft to provide power to our payload. Given the limited size of our payload, we had to make restrictions to the size of our payload in terms of potential net capsules. To address these constraints we have created SOPs for refueling our payload (rearming onboard gas and providing additional net capsules).

1.7 Trade Studies

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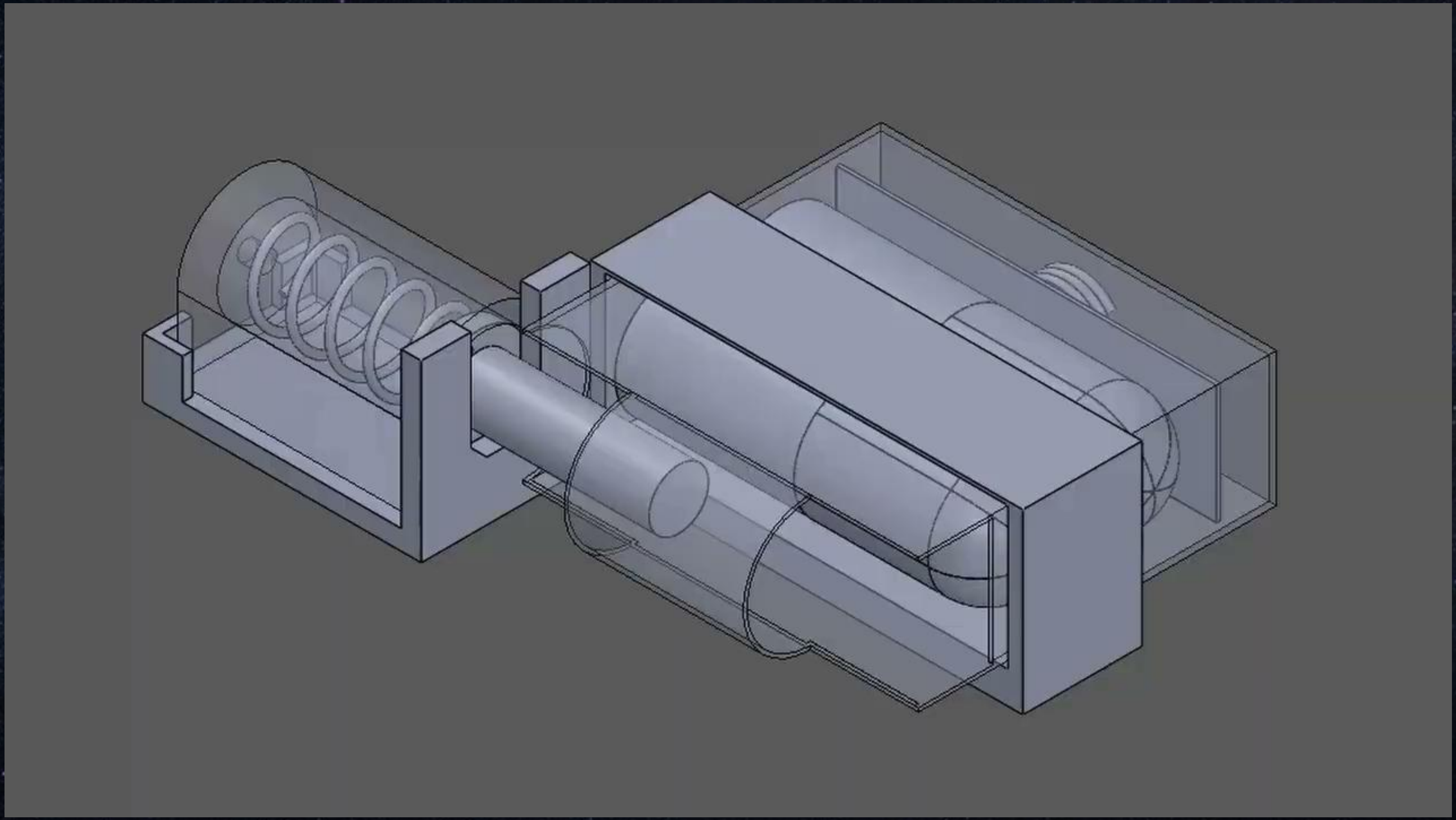
Design Option	Pro’s	Con’s
Robot Arm	Fine Control	Mass/Inertia Difference
Net	Robust	Poor Control
Ionic Propulsion	Energy Efficient	Slow
Gas Propulsion	Common Use	Limited Fuel

2.1 Animation of Key Operating Sequence

Space Cyclones

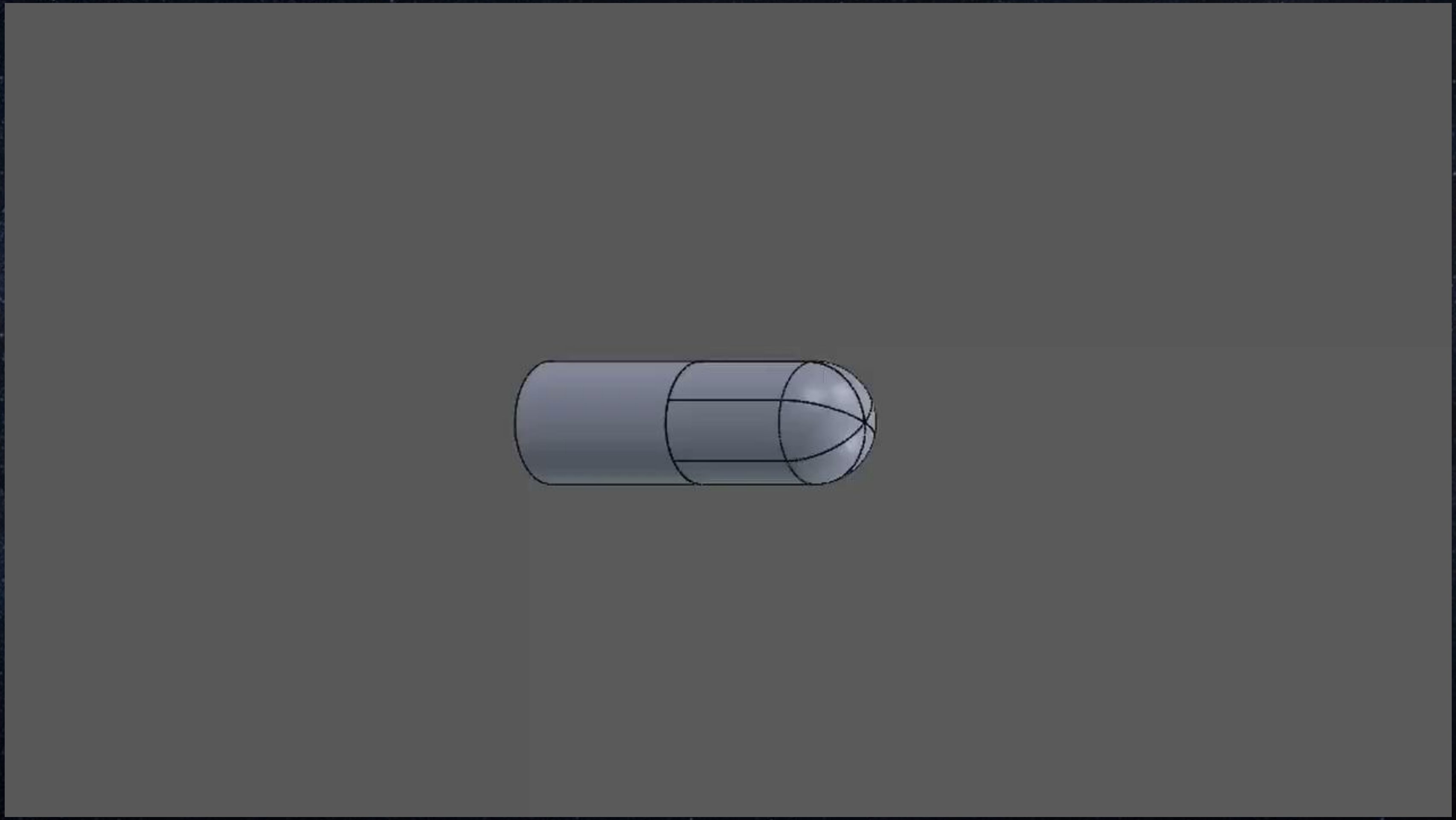
- Launcher Animation
  - Spring powered piston
  - Spring compressed by a servo motor with a winch and cable attached to the piston (not shown)
  - Spring powered reloading magazine



2.1 Animation of Key Operating Sequence

Space Cyclones

- Capsule Expansion
  - Cold gas thrusters in the capsule will generate rotational motion (not shown)
  - Rotation generates centrifugal force to expand the capsule net compartment which expands the net (not shown)



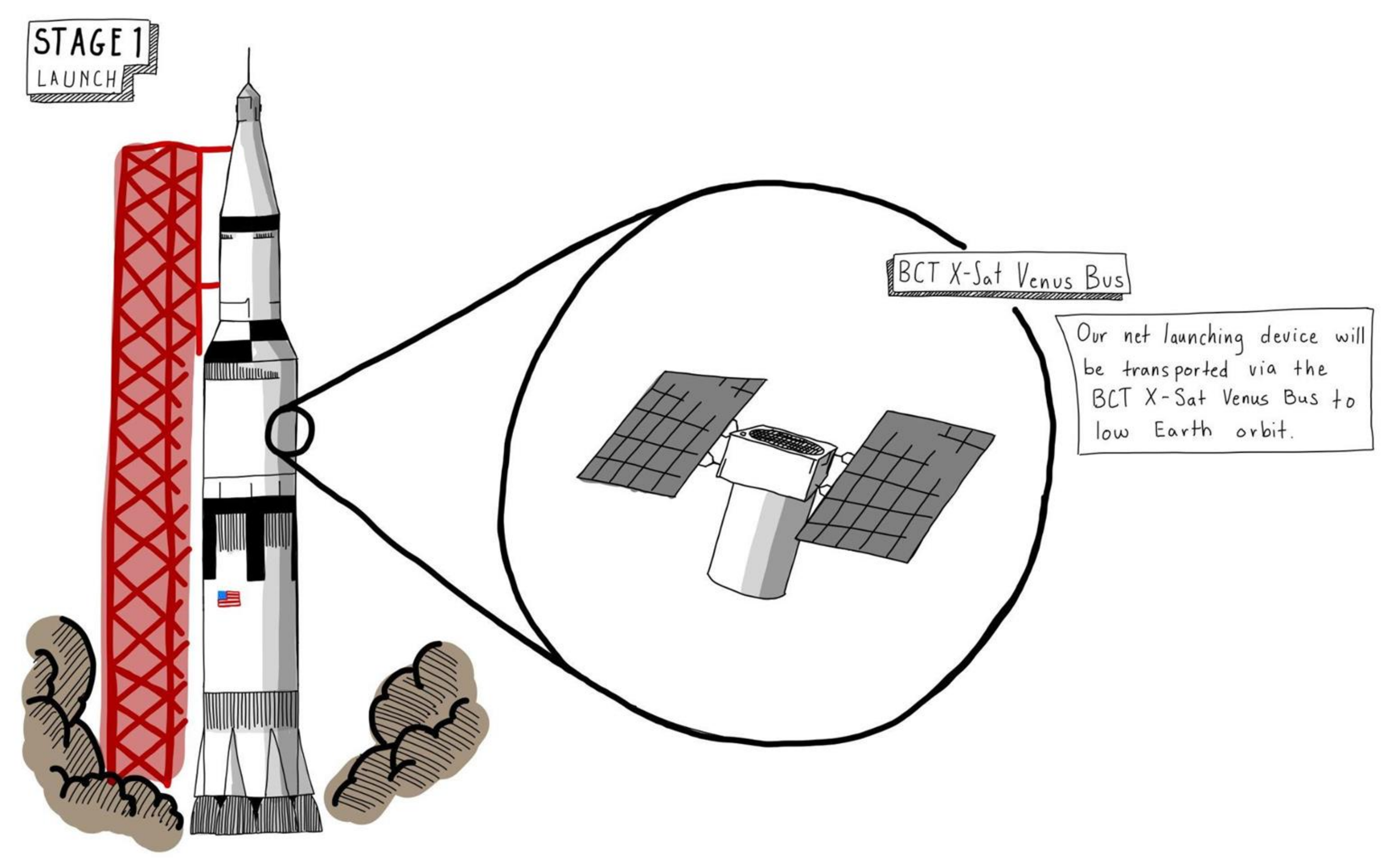
2.2 Storyboard of Complete Operation

- **Orbit:** Our craft will launch into orbit via the launch platform suitable for the Venus bus

- **In Flight:** Our craft will navigate in target LEO orbit using instructions from ground to maneuver to identified pieces of debris. Once a piece of debris is found in space, our craft will fire and steer a net capsule to the target to capture the debris and propel it into the earth's atmosphere.

- **Sustained Operation:** Our payload is be configured to support resupply of net capsules and gas propulsion. Continues resupply will allow our craft to operate as long as there are no technical failures on board the craft. Alternatively, our craft is equipped with enough fuel to steer itself into the atmosphere once the satellite has run out of fuel.

2.2 Storyboard of Complete Operation



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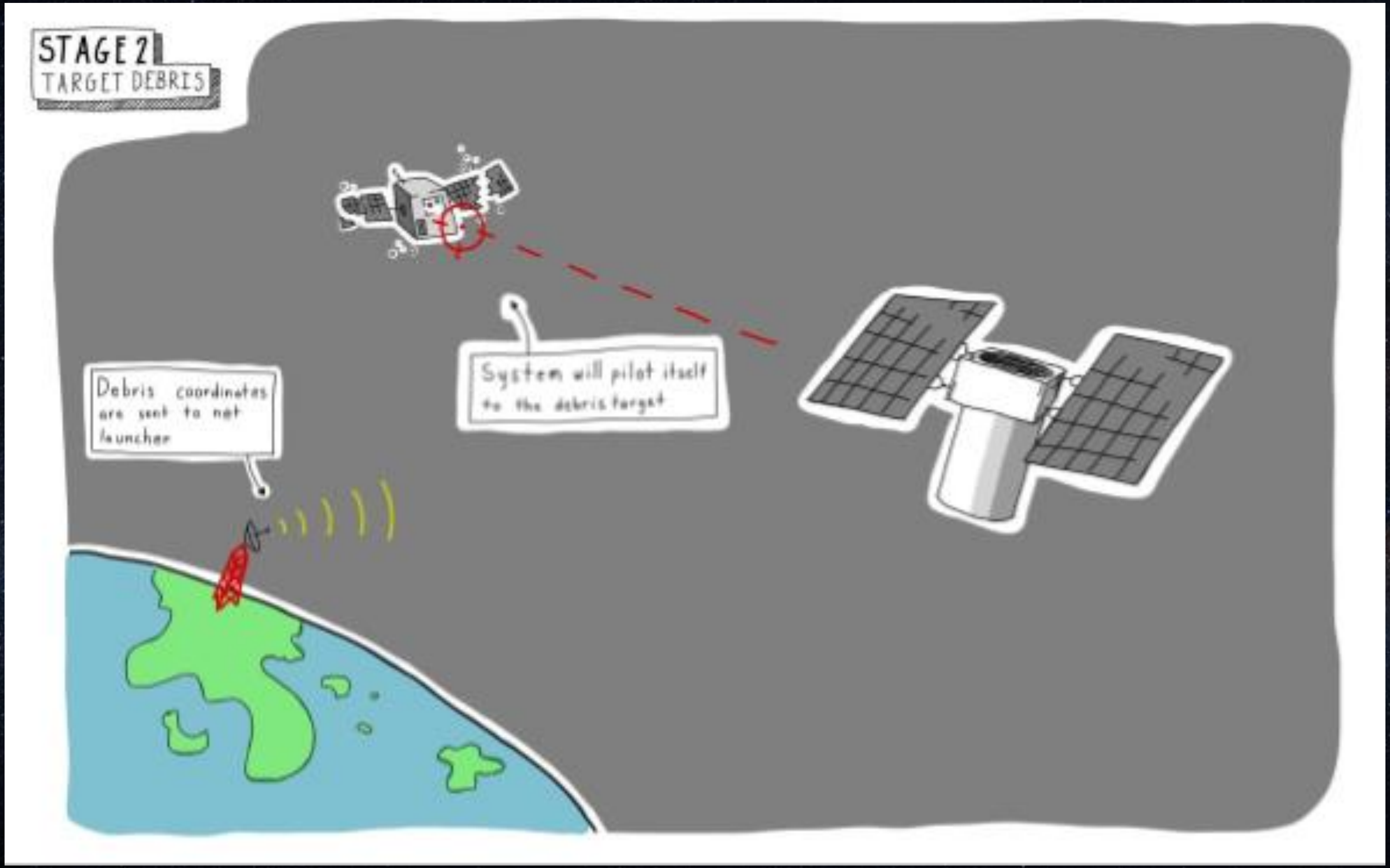

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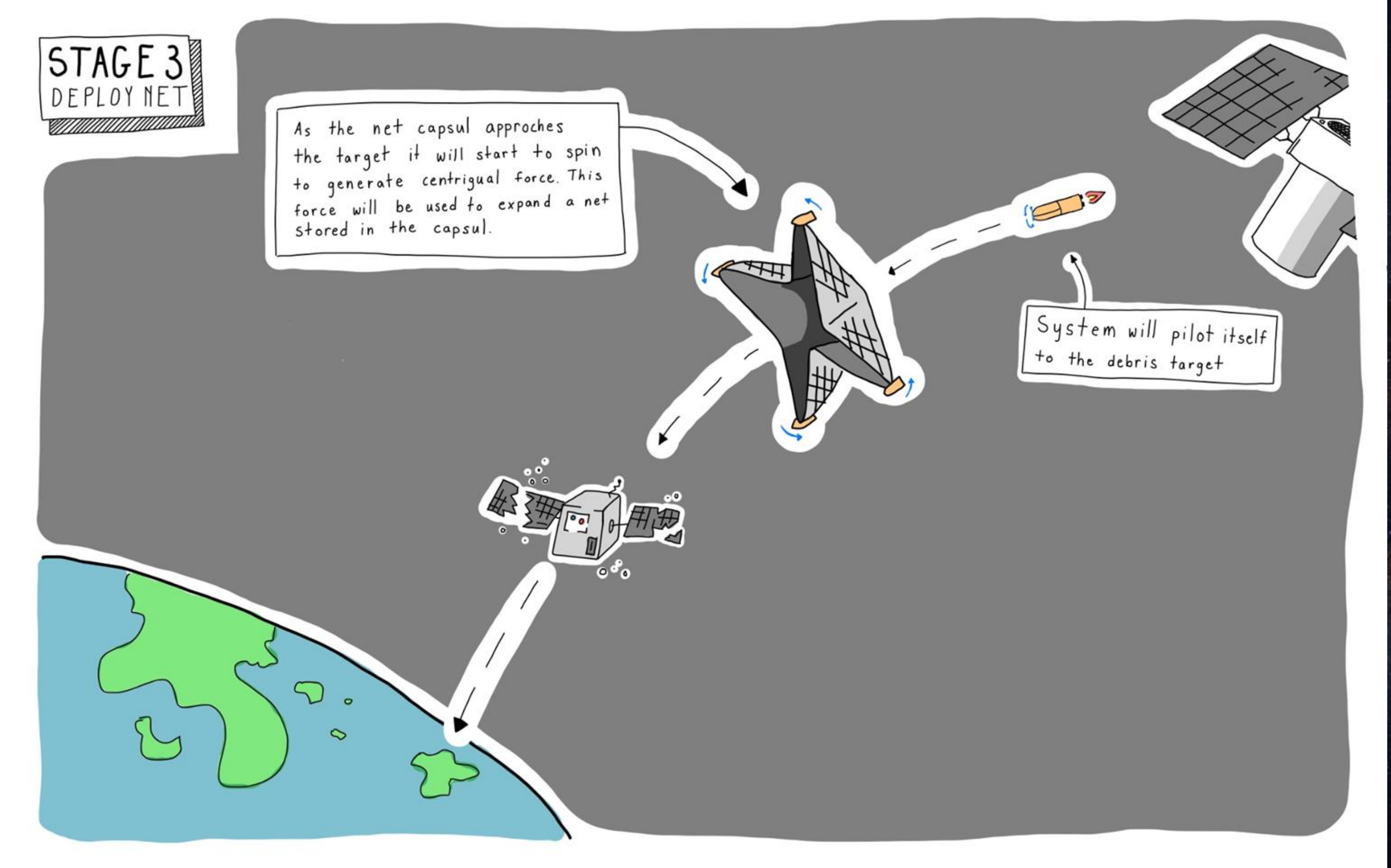

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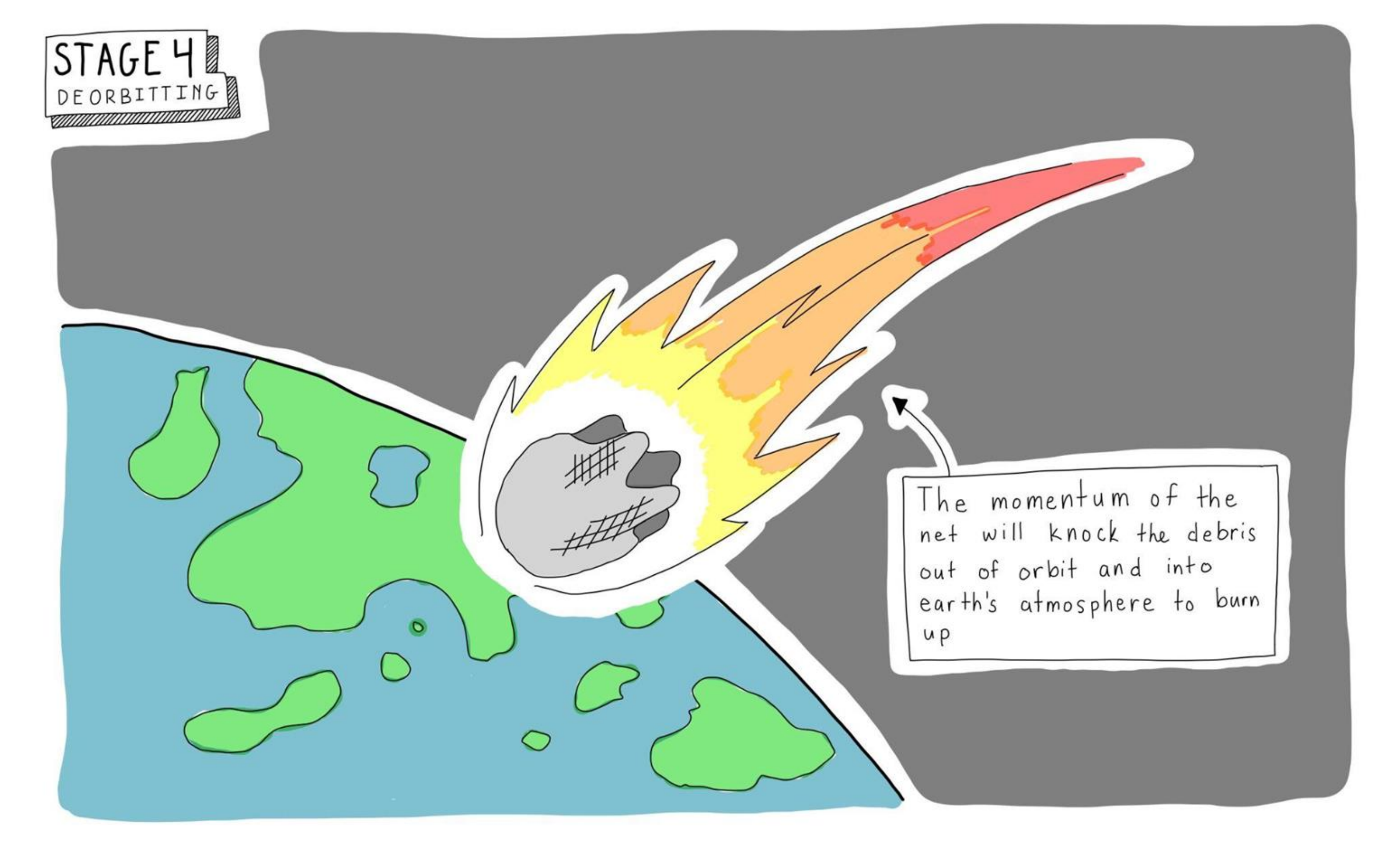
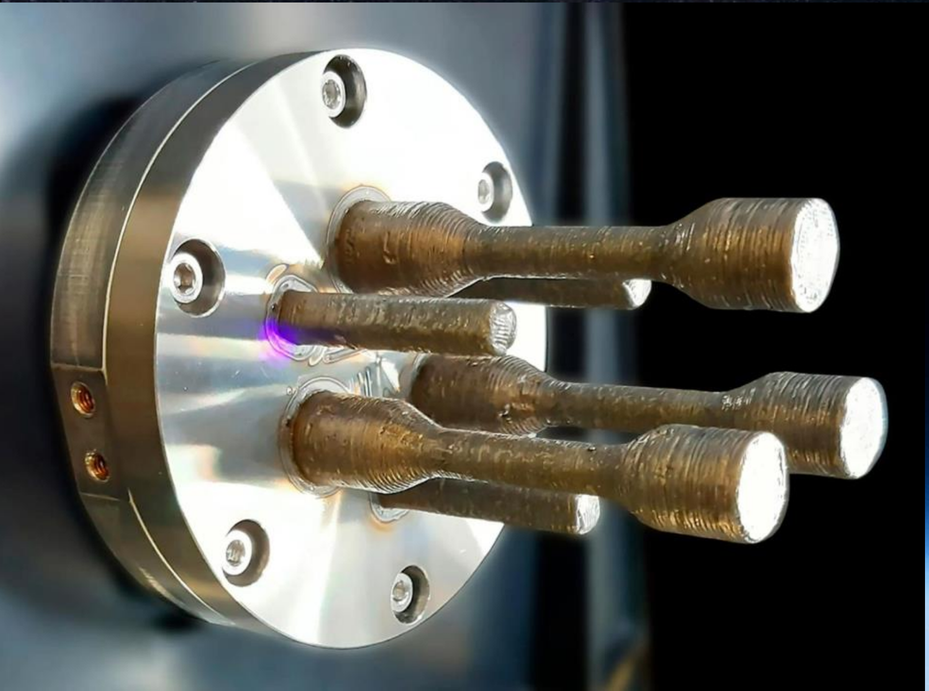
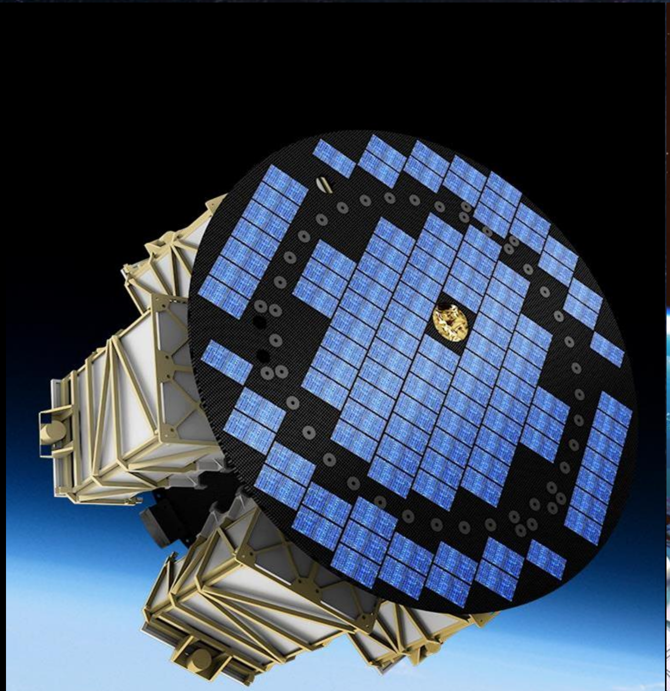


2.3 Data Handling and Comms

- Ground Communications required for target assignment/updating
  - RF communications
  - Assignment contains size, mass, location, velocity. Autonomous determination of feasibility
    - Based on size/mass and conflicting execution times with other missions
    - Returns rejection or confirmation message upon target designation.
  - During mission execution status updates are provided to ground.
- Fully Autonomous mission operation with built in observer
  - Track and Predict target’s motion
  - Launch and Guide Cyclone to capture target.
  - Direct captured target to accelerated deorbit
    - If mission fails, direct Cyclone to deorbit itself and notify ground of failure

3.1 Most Innovative Concepts Considered

- Manufacturing metals [3D printing in space]
- Satellite Tug [A fuel station in space]
- Anti-satellite weapon shielding of spacecraft


3.2 Most Important Technology Gaps

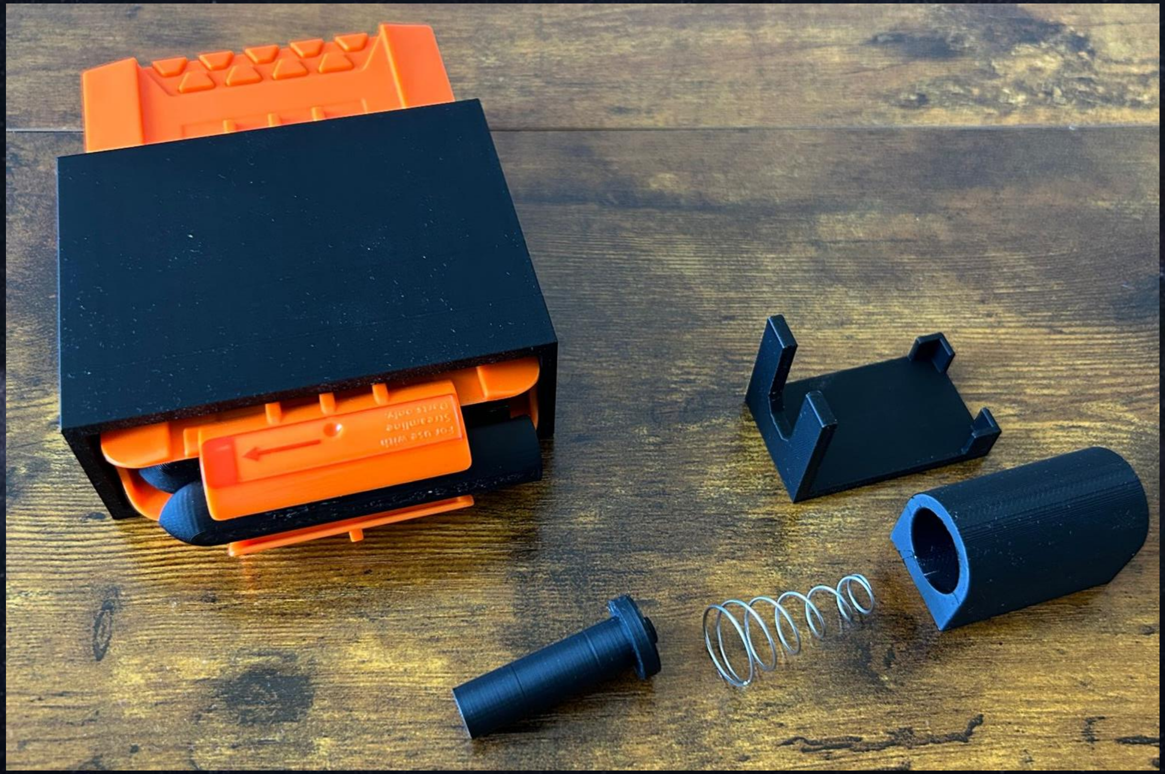
- **Low-Cost & Lightweight LiDAR/Camera Array**
  - Current high precision LiDAR systems are costly, bulky, and high power consumption limit mission feasibility.
  - Compact alternatives fail to meet the required accuracy, range, or durability.
  - Lack of precision in current systems for small scale missions where space is limited.
- **Adaptive Thruster Control**
  - Traditional thruster systems lack control and adaptability.
  - They lack the mechanism for correcting misfires automatically.
  - This reduces reliability in case of our mission where there is a possibility of misfire.
- **Autonomous On-Orbit Inspection & Repair**
  - Current methods for inspections of systems rely on manual or remote methods.
  - Lack of autonomous systems for instant repairs.
  - This increases mission cost and reduces long-term operational efficiency.

3.3 Biggest Challenges Encountered

- **Limited Aerospace Background**
  - Team lacked prior experience in aerospace engineering, requiring rapid knowledge acquisition.
  - Conducted extensive research in propulsion, thermal dynamics, and space-grade materials to develop a feasible design and CONOPS.
- **Weight & Power Constraints**
  - Limited weight and power budgets influenced the selection of components.
  - Required careful trade-offs to maintain performance while staying within mission limits.
- **Design Complexity**
  - Significant amount of time was spent attaching and integrating various components, ensuring they fit together seamlessly.
  - Balancing modularity, reusability, and mission feasibility required overcoming challenges in making all modules work efficiently together.
- **Thermal Management**
  - Selecting materials capable of withstanding extreme temperature fluctuations in space, without relying on excessive insulation or active cooling, was challenging
  - Limited experience in material science and thermal management posed challenges.

Optional: Prototype

- Competition in conjunction with course: Part of senior design course requirements
- Limited Functions to a 2D space for development
- Functions:
  - Detection and Tracking of a designated object
  - Predict Motion of the designated object
  - Autonomously Determine launching time and direction



Summary/ Conclusion/ Highlights

Summary:

- The objective of our design is to capture and deorbit defunct satellites.

Lessons:

- The challenges encountered were problem regarding tumbling in space which was effectively eliminated through a net launch
- Learned about the effects of recoil (thereby deciding on soft launch).
- Learned about space constraints and challenges etc

Next steps:

- Given our funding, next steps would be to test our prototype it in zero gravity space environment.
- Orbital mechanics calculations will be integrated on our microcontroller.
- LiDAR array and LoRA piloted capsule will be integrated.
- Another iteration of this solution is turning the net solid and magnetic to attract nearby microdebris since microdebris is a major concern.

Questions?

References

Space Cyclones

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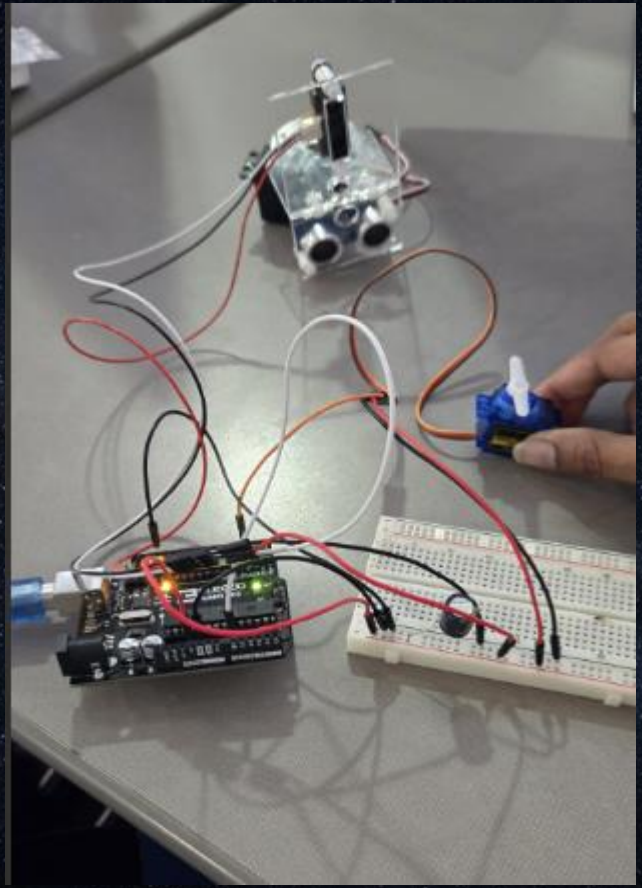
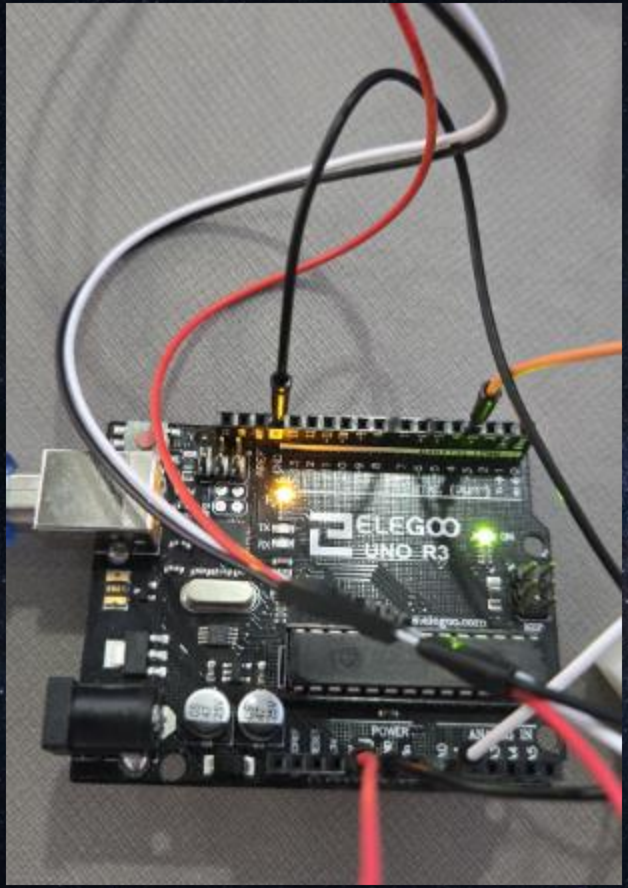
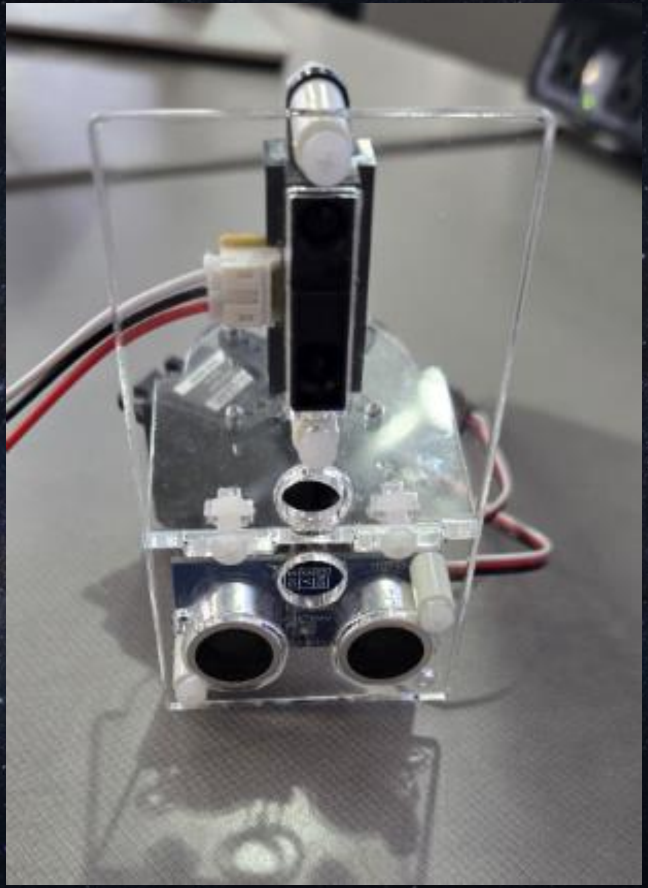
Backup Slides

Pictures of prototype







Assembled Prototype

Overview of all components put together for prototype