C3: Cosmic Capstone Challenge

Design Document

SENIOR DESIGN MAY 25 TEAM 9

Client: Cosmic Space Consortium

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Executive Summary

Currently, there is a lack of In-Space Servicing, Assembly, and Manufacturing (ISAM) capable satellites, which reflects the relatively new landscape of commercial space engineering. With additional ISAM-capable satellites, engineers provide innovative solutions to complex space and Earth problems.

For our project, we were tasked with designing a payload that can be housed on the Venus bus(the designated launch vehicle provided for the competition) and perform three continual ISAM motions autonomously. Our solution should be capable of withstanding the stress of launch and the course of its operation. Our solution uses a spring based system to launch multiple nets stored in the net housing compartment. The net capsules have their own thrusters to navigate through, capture the target and deorbit.

Our approach was heavily influenced by previous net launch satellites and took inspiration from conventional net launchers used on Earth. At our current stage, our team has been able to develop computer aided design (CAD) models to reflect our prototypes. Our current design will provide at least three ISAM actions. The implementation we have created will operate in three portions that can each represent an ISAM action. The first action will propel the net launching capsule out of the craft using a spring-powered launching mechanism. Our second action will comprise the autonomous piloting of the net capsule to the target. The final stage of our design will be deploying the net on target. With our task decomposition provided in the previously mentioned way, our team is successfully breaking down our project to meet the project requirement of three continual ISAM motions.

As we move forward into our second semester with the C3 capstone challenge, our group will challenge ourselves to progress into physical testing of our device using resources available on campus. With specific resources through the Aerospace department, our team can accurately test and replicate our prototype implementation environment of lower earth orbit.. Beyond the implementation of our device, we will conduct stress testing to assess the viability of our design as it undergoes the stress of launch.

Learning Summary

Development Standards & Practices Used

List all standard circuit, hardware, software practices used in this project. List all the Engineering standards that apply to this project that were considered.

- Standard Practices:
    - Hardware Practices:
        - Robust power design
        - Fuel efficiency
        - Minimizing heat dissipation
        - Effective material selection for space constraints
        - Modular components
    - Software Practices:
        - Testing CAD model for mission validation
        - Ensuring code is readable and robust
- Engineering Standards:
    - ISO 24113: Space Systems – Space Debris Mitigation Requirements
    - NASA-STD-5001: Structural Design and Test Factors of Safety for Spaceflight Hardware
    - ECSS-E-ST-31-01C: Thermal Control Engineering
    - ASTM F3309-19: Standard for Testing Capture Mechanisms in Microgravity

Summary of Requirements

List all requirements as bullet points in brief.

- Analysis is required to sufficiently determine if a design is feasible, can survive launch, can operate successfully in a lower Earth orbit (LEO) environment, and can meet the BCT X-Sat Venus Class bus specifications
- The design needs to demonstrate three or more operations to demonstrate an orbital ISAM capable
- The payload should be designed to function autonomously with limited remote commands

Applicable Courses from Iowa State University Curriculum

List all Iowa State University courses whose contents applied to your Project.

- English 3140: Technical Communication
- Physics 2310: Introduction to Classical Physics I
- ME 1700: Engineering Graphics and Introductory Design
- ME 2700: Introduction to Mechanical Engineering Design
- EE 3030: Energy Systems and Power Electronics
- EE 3110: Electromagnetic Fields and Waves
- EE 3210: Communication Systems 1

New Skills/Knowledge acquired that was not taught in courses

- CAD modeling
- Materials engineering and analysis
- Systems Engineering
- SWAP-C analysis

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4.3.2 DETAILED DESIGN AND VISUALS

1. INTRODUCTION

1.1. PROBLEM STATEMENT

The demand for In-Space Servicing, Assembly, and Manufacturing (ISAM) technologies is rapidly increasing, driven by both NASA and private sector interests. Historically, space endeavors have relied on single-use, non-recyclable systems, which hinder commercial viability. As part of the C3 competition, our project aims to address one of the pressing needs in this emerging field by designing a satellite payload to demonstrate and test innovative ISAM capabilities.

We aim to design a satellite payload to perform one or multiple ISAM tasks. This proof of concept will allow for gathering data critical to the future development of the ISAM field. As the space sector becomes more economically viable, this project will pave the way for technological advancements. Our project aims to establish a foundation for further ISAM development to enhance the sustainability and efficiency of space operations.

1.2. INTENDED USERS

NASA Employee

- **Wants:** Wants to reduce the cost of space travel so more funding is available for other projects and further funding is easier to obtain. This will help create new missions to send people back to space.
- **Sees/Hears:** Budgets shrinking, engineers complaining about satellite failures, deadlines.
- **Thinks:** There needs to be in-space servicing options to fix various issues.
- **Does:** Brainstorm solutions to current mission problems.

Industry Mentors

- **Wants:** Help the team succeed and foster new and innovative ideas.
- **Sees/Hears:** Ideas students come up with and weekly progress reports.
- **Thinks:** How to provide guidance to the student team to hone ideas and achieve required deliverables.
- **Does:** Provides industry experience and knowledge.

Private Industry

- **Wants:** Ideas that can be used to generate profits.
- **Sees/Hears:** Ideas for ISAM technologies and the potential economic market implications.
- **Thinks:** How to turn ISAM ideas into profitable business models.
- **Does:** Invests capital and other resources into ideas determined worthy of investment.

2. REQUIREMENTS, CONSTRAINTS, AND STANDARDS

2.1. REQUIREMENTS AND CONSTRAINTS

- **Requirements: Things we want/need**

I. Design
  A. Accomplishes one of ISAM's main three goals: servicing, assembly, or manufacturing.
    1. Servicing
      a) Provide a specific service to satellites in orbit around Earth i.e. fueling, repair, etc.
    2. Assembly
      a) Support satellite/spacecraft assembly in some capacity.
      b) This could also fall under the repair category somehow.
    3. Manufacturing
      a) Support or design some manufacturing capability.
  B. The design should be autonomous with minimal remote control commands.

II. Environmental
  A. Does not create additional debris
  B. Must be resistant to Radiation Single Event Effects/

III. Resources
  A. Weight: The solution should be as light as possible without sacrificing the functional integrity of the unit.
  B. The unit should be reusable within its use case, not be single-use before retirement.

IV. Economic
  A. Target Market: The solution should position itself as an economic solution to a problem facing NASA and other aeronautical companies investing in ISAM space technologies.

- **Constraints: Actual Limitations**

I. Design Constraints
  A. The payload should be designed for the BCT X-Sat Venus Class bus.
    1. Available volume: 20.5" x 16.4" x 27.0" (single solar array) or 17.0" x 16.4" x 27" (dual solar array)
    2. Payload maximum mass capability: 70kg
    3. Available Solar array power: 222W (single array) or 444W (dual array)
    4. Energy storage: 10.2 Ah

   B. The design should be autonomous with minimal remote control commands.
   C. The design should fulfill ISAM (In space, servicing, assembly, and manufacturing)

II. Environmental Factors
   A. Near-Zero Gravity
   B. Minimal Atmosphere
   C. Radiation
   D. LEO Temps –65 ºC to +125 ºC (cycling depended on orbit)

III. Autonomy
   A. The design should be autonomous with minimal intervention through commands.

IV. ISAM
   A. The design must demonstrate three operations together, demonstrating an ISAM capability.

2.2. ENGINEERING STANDARDS

Engineering standards provide a set of common rules that help create a foundation for engineering practices. They primarily help support safety, quality, and ethical compliance. Engineering standards help to ensure that products are designed and manufactured with high standards of safety. This can help manage and mitigate risks in both the workplace and day-to-day lives. They also help to ensure that products are reliable and that they meet the necessary regulatory requirements. Another important aspect of engineering standards is interoperability. It is important to ensure that different components and systems work together effectively.

Examples of some standards are listed below:

- ***AIAA S-159 (202X)*** *– Best Practices, Functional Requirements, and Norms for In-space Servicing, Assembly, and Manufacturing (ISAM) Power and Data Interfaces (submitted to AIAA July 11, 2024):*

The standard outlines best practices for designing and implementing power and data interfaces for ISAM missions. This standard helps with the overall integration of ISAM capabilities across various platforms. It also describes multiple applications of ISAM capabilities that need to be satisfied with these power conditions, such as robotics, assembly, etc. This standard is important to drive advancement in space innovation.

- ***AIAA S-158 (202X)*** *– CONFERS Recommendations for Best Practices, Functional Requirements, and Norms for Prepared Free-Flyer Capture and Release (Approved by AIAA Standards Steering Committee, May 2023)*

The standard specifies the functions that systems involved in capture and release must support. It provides detailed descriptions of criteria such as performance, reliability, and safety. This standard is applicable to satellites and other spacecraft in terms of service and assembly thereby supporting autonomy in space.

- ***IEEE/ISO/IEC 29119-2-2021 -*** *ISO/IEC/IEEE International Standard - Software and systems engineering - Software testing -- Part 2: Test processes (Last modified: 2 August 2024)*

This document specifies test processes that can be used to govern, manage, and implement software testing for any organization, project, or testing activity. It comprises generic test process descriptions that define the software testing processes. Supporting informative diagrams describing the functions are also provided. This document applies to testing in all software development lifecycle models. This document is intended for, but not limited to, testers, test managers, developers, and project managers, particularly those responsible for governing, managing, and implementing software testing.

Using the above standards provided by space organizations like CONFERS, our team can utilize standard industry practices to build more effective designs. Implementing these designs will guarantee that we create a product compliant with standards and interoperable with other organizations. As an entry in a design competition, our project must adhere to industry standards for all performance metrics, and the best way to do this is to follow the best practices that the space industry also follows, allowing other organizations more ingrained in the field to understand our interpretation of the field easily.

While the enlisted standards apply to our project, our team members also picked IEEE/AIEE 750.1-1960, which outlines aircraft and missile guidance systems standards. The standard addresses the challenges of power systems in space using factors such as harsh environments, reliability requirements, and the need for lightweight components. This could apply to our project depending on whether the project will use a guidance system.

We plan to review the standards' best practices and recommendations and implement them into the project design as needed. The Standard for Software and Systems Engineering (IEEE 29119) will help design testing to ensure functionality. The Best Practices, Functional Requirements, and Norms for ISAM (AIAA S-159) will shape overall design decisions for materials and backups. Finally, the CONFERS Recommendations For Free-Flyer Capture and Release will be used to help shape the design of the net itself and the metrics used to measure its performance.

3. PROJECT PLAN

3.1 PROJECT MANAGEMENT/TRACKING PROCEDURES

The project management style that our team is following is the Agile style. Our project deliverables are due at various times; the mid-check-in is due on December 9, and the final deliverables are due in April. As we have a flexible schedule and a lot of research work to do on how our design should function, we decided to follow the Agile management style.
Our team has two weekly joint meetings to discuss individual progress and how the team is progressing towards weekly goals. At these meetings, we break down tasks for the upcoming week and collaborate on the weekly lightning talk presentation. The progress is communicated through Discord if the team members cannot attend the meeting.

3.2 TASK DECOMPOSITION

The design's mission cycle can be broken into several steps as follows. Launching payload host into space from Earth, target acquisition, net deployment, target retrieval, deorbiting target, and reloading the net launcher. Due to the timeline constraints of this capstone project, several of these mission cycle steps will be assumed to be completed or done by another outside party. Instead, this project's design will focus on three key mission steps. The steps selected are net deployment, target retrieval/deorbiting, and reloading of the net launcher. These phases can be further broken down into key milestones and tasks based on the deliverables and timeline of the capstone challenge.

3.3 PROJECT PROPOSED MILESTONES, METRICS, AND EVALUATION CRITERIA

From a project timeline point of view, key milestones for this capstone challenge are listed below in section 3.3.1. In addition to the milestones, there are important metrics that the design will be evaluated on, such as demonstrating at least three consecutive ISAM steps, as discussed in section 3.3.2.

3.3.1 MILESTONES

- (10/27/2024) - Idea Selected
- (12/09/2024) - CAD model
- (03/14/2025) - Animation
- (04/14/2025) - Final Presentation and Report
- (05/04/2025) - Prototype Complete

3.3.2 METRICS/EVALUATION CRITERIA

- Design executes 3 Operations, as defined by the C3 guidelines.
- CAD model animation demonstrates an ISAM application through 3 or more consecutive steps.
- The prototype can execute actions described in the CAD model animation within a neutrally buoyant environment.
- Energy Storage needs cannot exceed 10.2 Ah
- The design does not exceed a power draw of 444W
- Design is not larger than 20.5” x 16.4” x 27.0”
- Design does not exceed a power draw of 222W while larger than 17.0” x 16.4” x 27”
- The design does not exceed 70kg

3.4 PROJECT TIMELINE/SCHEDULE

The project tasks and milestones can be written into a timeline in the following Gantt Chart in Figure 1. To summarize the chart, it marks the dates each milestone should be started and finished in coincidence with the given deliverable due dates for our capstone course and the design competition. The initial brainstorming phase took about a month to discuss and choose an idea, of which nets were chosen as the idea. The next stage is the CAD model development for the net launcher, which was allotted about a month and a half. Not shown in this segment of the Gantt chart are the animation, final report and presentation, and prototype milestones. The CAD model animation will be completed by March 31st, 2025, starting after the CAD model is completed. After the CAD animation, the final presentation and report will be completed by April 14th, 2025. Finally, after the animation, the design prototype will be completed by May 4th, 2025.

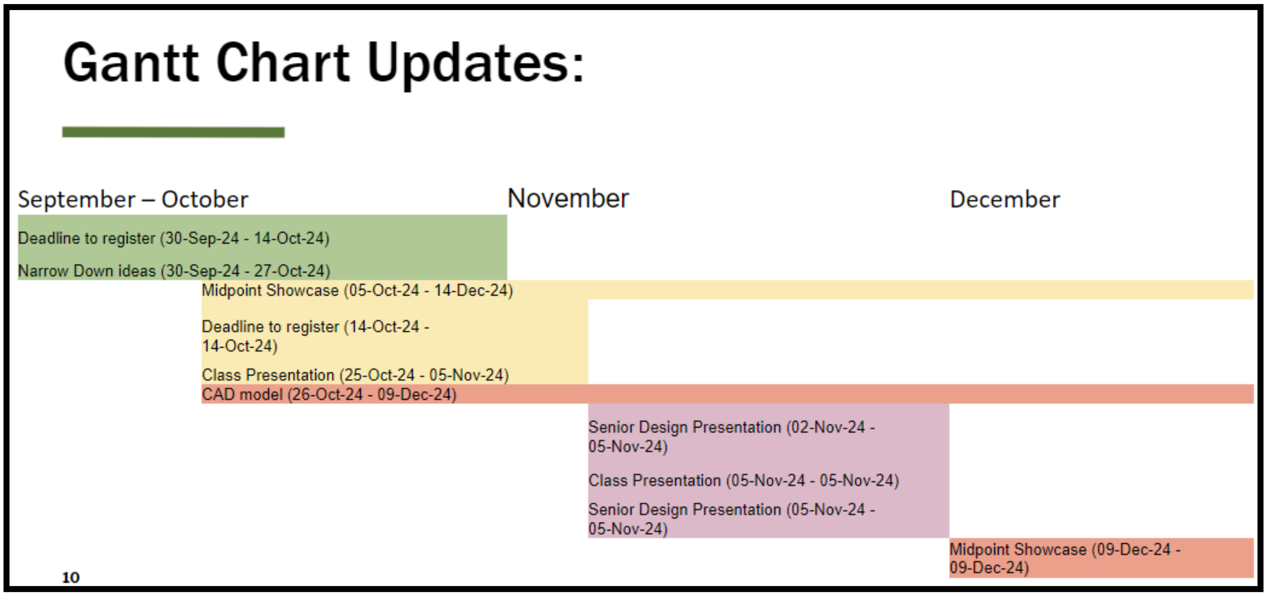


Figure 1: Milestone breakdown

3.5 RISKS AND RISK MANAGEMENT/MITIGATION

Net Deployment Risks

1. Deployment failure of the net.
    a. Conduct multiple tests to improve accuracy and eliminate any risks during deployment.
2. Misfire or misalignment of net
3. The net material is not able to withstand the environment.
    a. Use durable materials and carry a replacement net on the payload.

Target Retrieval and Deorbiting

1. Target escaping the net
2. Failure to secure the object correctly
3. Deorbit mechanism failure
4. Net Module Collision with non-target objects

Reloading the net launcher

1. Failure to retrieve the net
2. Failure to align and fold the net correctly for deployment again
3. Environmental wear and tear of the net
    a. Carry a backup net or establish protocols for mid-mission net replacement.
4. Jamming or incorrect arrangement of launching apparatus
    a. Design a process to release or reverse actions until an unjammed state is reached

Other Risks

1. Radiation-based electronic malfunctions (Mitigation: Radiation Hardening)
2. Unintended Outgassing of propellant
3. Designation of an invalid or non-existent target
4. Hacking of the targeting system

3.6 PERSONNEL EFFORT REQUIREMENTS

Table 1 below lists the personnel effort requirements with an estimated number of hours for completion. These essential tasks within the project will comprise the majority of the time spent on this project.

Table 1: Personnel Effort Requirements

Task	Estimated Number of Hours
ISAM Research	50
Net Launcher Concept	30
Comparative Market Research	30
CAD Model	20
CAD Model Animation	20
Prototype Design/Construction	50
Final Presentation and Report	20

3.7 OTHER RESOURCE REQUIREMENTS

- Details on BCT X-Sat Venus Class bus

Our project is a payload that will be carried by the Venus Class Bus. As a result, we are limited in resources such as size, energy consumption, and weight.

- List of Viable Materials for use in space

Our project's operating environment is in the vacuum of space where factors such as high radiation and low temperatures will be experienced. Our material selection must comply with the unique aspects of the in-space environment. Beyond the use of our design in space, we must also consider materials that can handle the intense process of launching into orbit.

4. DESIGN

Within Low Earth Orbit (LEO) there are numerous objects that have been launched since the first satellites in the 1950s. Since then, satellites for use in space have been designed to be launched into space, run for their designed lifetime, and then once out of power, they just become "dead satellites." Once dead, the satellites drift uncontrollably around the planet in their orbit or into new orbits. The concern of having many dead satellites in space is the increased chance for collisions between dead satellites or dead satellites into operational ones. The result of a collision causes many pieces/fragments of the collided satellites to break apart and move outward in all directions. If fragments from that collision cross the orbits of other satellites at the wrong time, they can cause further collisions, and then the cycle repeats. With enough fragments and dead satellites in space, there comes a point where these repeated collisions become a runaway process which is known as Kessler's Syndrome. So, the need for the removal of dead satellites is an important one for maintaining clean space for satellites to operate.

The process of removing dead satellites is an example of the service portion of ISAM. More specifically, the service provided by the design proposed in this section is the capture and removal of a class of satellites called Cube Satellites (CubeSats).

4.1 DESIGN CONTEXT

4.1.1 BROADER CONTEXT

The context in which this design problem is situated is the removal of dead CubeSats to create clean space for future satellites to be launched and operated in LEO. Today, CubeSats are used for a variety of purposes, such as internet services, communications services, scientific research, and government security applications. Communities that utilize CubeSats for such purposes are what this solution is designed for as a means to maintain the current CubeSat services. This will be achieved by removing old CubeSats at the end of their planned mission/service lifetime. On a greater scale, the general societal need is the preservation of clean space in LEO for the continued use of communication, internet, and other CubeSat-provided services. Societal areas affected by CubeSat services and the design solution's impact on removing exhausted CubeSats are categorized and explained in Table 2.

Table 2: Design Solutions Impacts

Area	Description
Public Health and Safety	The result of the design is the preservation of clean space for CubeSats in LEO to operate. An additional benefit is if manned missions are conducted in the future in LEO, there will be a reduced risk of a dead CubeSat collision, which otherwise could pose a life-threatening situation.
Global, Cultural, and Social	Removal of dead CubeSats provides clean operating space for all nations and cultural groups with active LEO space programs to continue their operations.
Environmental	Should it be decided that dead CubeSats are to be retrieved rather then pushed into Earth's atmosphere to burn up, the materials on the dead CubeSats could be recycled to create new ones.
Economic	Should dead Cubesats be retrievable and able to be brought back to Earth for recycling, the cost of space missions would significantly decrease allowing further advancements in space programs.

4.1.2 PRIOR WORK/SOLUTIONS

The design proposed is not the first net launcher to be designed for use in space. One example of a previous project was the Remove Debris mission by the Research Executive Agency (REA) from the European Union. The project began in 2013 with the goal of demonstrating several experiments to catch self-launched targets representing space debris such as a dead CubeSat [11]. One of the experiments was a net launcher designed to capture a small satellite approximately 1 meter across. This small satellite was released from the Remove Debris satellite and once far enough away, the Remove Debris satellite launched it's net toward the small satellite. The net capture system design of the Remove Debris satellite is shown in Figure 2 below. The design used 5 masses attached to corners of a net that were spring-loaded and launched outward to expand the net. When the small satellite was ensnared in the expanded net, motors within each mass reeled in the remaining slack of the net to ensure the small satellite remained entangled in the net. The small satellite then began deorbiting due to the excess drag induced by the net. This experiment was successfully conducted in space in 2018.

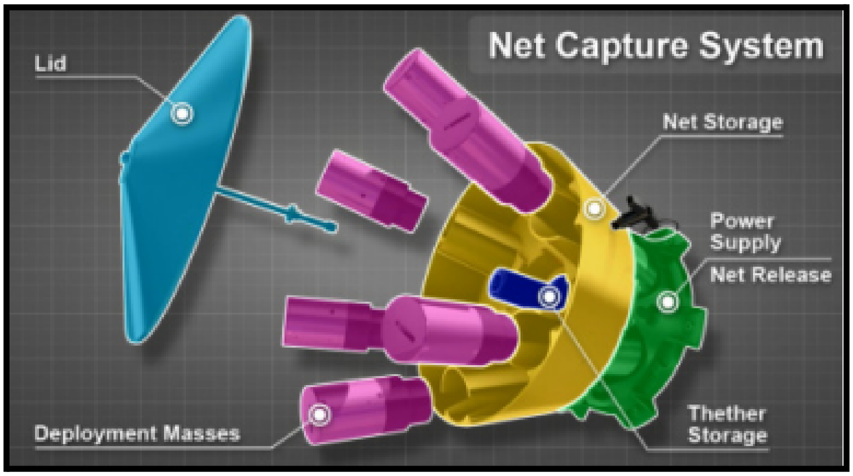


Figure 2: *Remove Debris Net Launcher Design*

Another project was conducted at McGill University in Montreal, Canada, to create a simulation package for modeling a tethered net capture mechanism. This tethered net mechanism was designed to capture space debris such as rocket upper stages [12]. Publishing findings in 2018, the project results concluded the tethered net mechanism was successful and could also be used to capture small asteroids. Looking further into the project's details, the simulation model used a C++ program to model the vortex dynamics, or more specifically, how a real net would experience bending stresses as it moves through space and wraps around the target object. For inputs, the user-specified parameters such as the target object shape and orbit behavior in a vortex editing software. From there the equations of motion were solved by another C++ implementation called an Application Programming Interface (API) and used to visually show the simulation results. Additionally, data such as position and velocity of points on the net were saved for processing in MATLAB. Below in Figure 3 is a schematic representation of the simulation process just described.

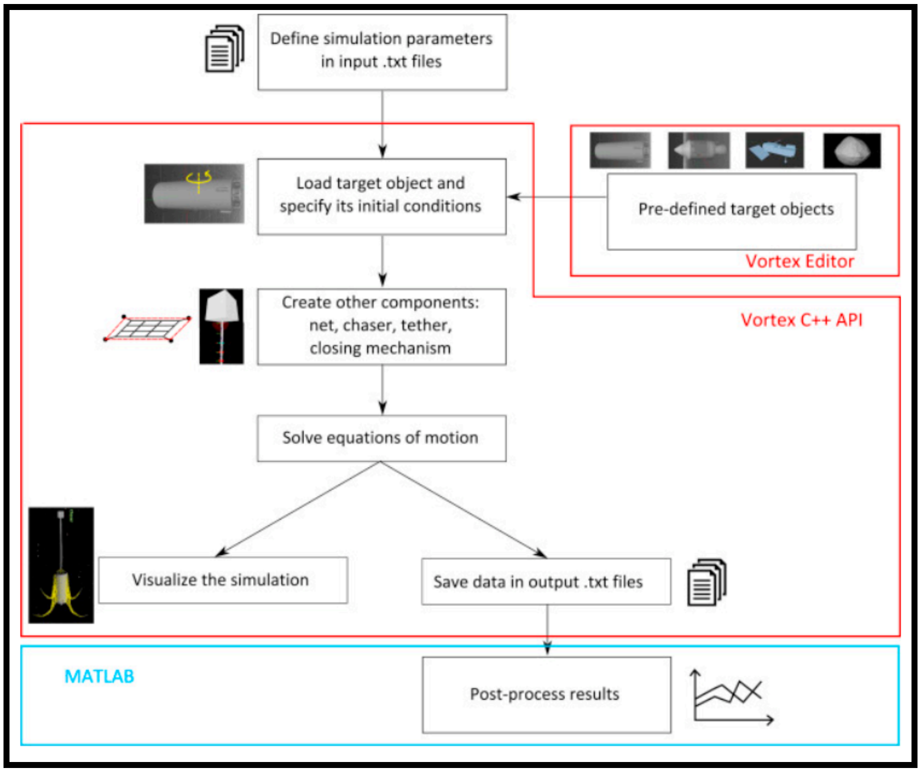


Figure 3: *Schematic representation of the tethered net simulation processes*

Finally, a third project that utilized a net capture mechanism designed for use in space was conducted by Tokyo Metropolitan University, Tokyo, Japan, and RMIT University, Melbourne, Australia. The project proposed a tether-net release mechanism with unique design aspects. Similar to the design of the Remove Debris project, this project's design featured a circular net compartment with four attached masses arranged around the perimeter. When launched, the masses were to be ejected forward and outward, expanding the net while the net moved toward the targeted space debris [13]. An innovation of this design was combining the net lid and masses. This was accomplished by cutting the net storage compartment lid into 4 parts and attaching each part to a designated mass. A diagram showing the lids, mass tubes, and central net compartment is shown in Figure 4 below. The result was a reduction in the size of the net expansion masses as each of the 4 had a portion of the lid that was used as part of each mass.

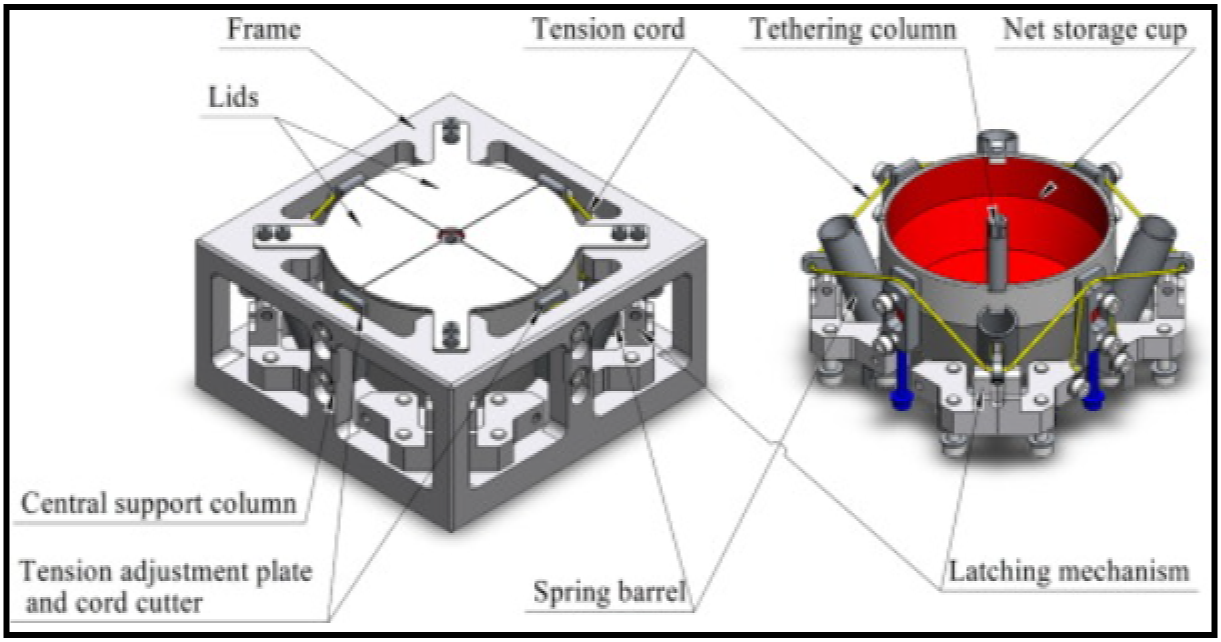


Figure 4: *Tethered-Net deployment mechanism design with 4 lids over the central net storage compartment*

Our proposed net launcher design combines features of the previous projects described and also adds further innovations. One innovation is the use of a net capsule, allowing a more compact net enclosure design shaped similar to that of a firearm bullet or rocket-propelled missile. A second innovation is having a reloadable launching mechanism to launch multiple net capsules. Together, the compact net capsules and reloadable launcher allow an increased impact by removing more than one targeted dead CubeSat (ratio of one net capsule per CubeSat to be removed). A third innovation for our design is the expansion method of the net capsule. Once a net capsule is launched, it will use cold gas thrusters to initiate a rotational spin along the axis of travel. This will generate an outward centrifugal force, pushing the walls of the net capsule apart to expand the net that is enclosed inside. A smaller launching force is needed to get the capsule from the launcher to free space by having the thrusters on the net capsule. This is beneficial since there will be a reduced resultant launch force on the host satellite so smaller positioning corrections would be needed after a launch. The disadvantage of this design is the increased complexity of using cold gas thrusters and the increased cost of having thrusters on each net capsule.

4.1.3 TECHNICAL COMPLEXITY

The physical design from a high-level perspective consists of a net launcher designed to automatically reload net capsules that are launched into space to capture dead/no longer operational CubeSats. There are three subsystems of the net launcher which are the net capsules' enclosure, the net capsule launcher, and the net capsules. Each of these subsystems' design details are discussed later in the final prototype section.

Another complexity is the launcher's operating environment will be in space or more specifically, Low Earth Orbit (LEO). Being in space poses new challenges, such as increased levels of solar radiation, extreme temperatures, and lack of gravity. Each of these environmental factors will add complexities to the project and will influence design decisions. Additional complexities of the design include aiming systems toward the target CubeSat before a net capsule is launched, net capsule navigation systems toward the target after launch, net capsule fuel management, and ensuring consistent and full net expansion. Each of these systems, the physical design, and the operating environment require the utilization of astrophysics, mathematics, and engineering principles, providing this project with adequate technical complexity.

4.2 DESIGN EXPLORATION

4.2.1 DESIGN DECISIONS

1. Net Materials
    a. Net materials are an important design decision we will face because this will impact our project's ISAM capabilities, weight, and size. The material of our net must be durable enough to capture and hold debris without tearing. Our net must also be light and flexible enough to comply with our weight and size requirements.
2. Propulsion System
    a. We must consider primarily how our net propulsion will function. Our propulsion system will directly influence the overall weight of our final design. If we choose to utilize gas propulsion for our device, we can utilize a single large propulsion canister to launch our nets. Alternatively, we can use smaller, individual gas canisters each capable of launching a net.
3. Communication
    a. Ensuring consistent and reliable communication between ground assets and our satellite will allow for safe in-orbit operations. Proper communication technology built into our net launcher will enable our design to receive relevant information about the location of potential pieces of debris.

4.2.2 IDEATION

In regards to Ideation, in the brainstorming phase, we considered 6 potential ISAM problems to pursue: Refueling, Repairing, Upgrading, Space 3d-printing, Removing Space Debris, Communication Constellations

- Refueling: The idea here was to design a module that would allow for the refueling of satellites, however our biggest problem with this was we were unsure of how we would refuel existing satellites. As we were unsure of the feasibility of such a process on older satellites, we abandoned this idea as we were looking for more of a catch-all at the time.
- Repairing: This would be the replacement of a given part
- Upgrading: Very similar to repairing, however, our ideas were in the field of making additions to existing satellites, and the challenge of not impacting existing functionality was too great for us to pursue the idea.
- Space 3D-Printing: After doing some research, we found that there is an existing grad team working on this, and felt that as a result the problem's scale was outside the feasible range for our team.
- Removing Space Debris: We were enamored by the idea of reducing the debris field, especially with some of us growing up hearing about it being a potential problem. Of our 2 ideas between robot arm and net, we were advised to stray away from an explicit robot arm in regards to the competition. Leading us to settle on a capture net idea.
- Secure Communication Constellations: The idea was to have a mesh network of satellites that used shorter range communications and the developing laser communication technology to drastically limit potential message interception in space. However as a concept built for a singular satellite it was impossible to rationalize within the projects scope.

4.2.3 DECISION-MAKING AND TRADEOFF

The process used for determining pros and cons of each design came down to what had been tested previously and how successful they were from our research. Each method of capturing space debris had pros and cons, such as design complexity, cost, reusability, and size constraints. Nets and a net launcher were selected by directly comparing these design parameters. The first reason for selection was the reduced cost and complexity of nets. Next, nets are foldable, making them ideal for our limited volume for the Venus class bus host satellite payload. Finally, nets could be reusable or retracted upon a misfire, making them reusable.

4.3 PROPOSED DESIGN

4.3.1 OVERVIEW

The current net launcher design has a net stored in a compartment with a lid, which is used as inspiration for our conceptual design. The lid is held down by a rope that is cut to release the net. Four spring-loaded masses in cylinders oriented in a circular pattern around the net's compartment give the net its momentum The mass cylinders and net compartments are all housed in a rectangular frame to make placement in the host satellite easier.

Our prototyped design utilizes a piston-compressed spring and cold gas thrusters to propel a net projectile at a target. The net will be housed in rounded cylinders that will experience rotation from cold gas thrusters to generate a centrifugal force. This force will cause the projectile 6-piece casing to be pulled outward and deploy the net from within the container.

4.3.2 DETAILED DESIGN AND VISUALS

4.3.2.1 CONCEPTUAL DESIGNS

The first design is shown in Figure 5, where the housing is shaped like a rectangular box. Inside that shape is a round bowl for the net and in a circular pattern around that are four cylinders for housing weighted masses. The masses are spring-loaded and attached to the net, so when released, the masses are launched outward at an angle to continue the forward momentum while simultaneously expanding the net, as shown in Figure 5. On top of each mass is a lid that covers the mass top and a portion of the net's bowl shaped housing to hold the net in place until launched. A rope is used to tie the masses down to secure the masses before launch. When ready to launch, the ropes are cut, releasing the spring-loaded masses and launching the net.

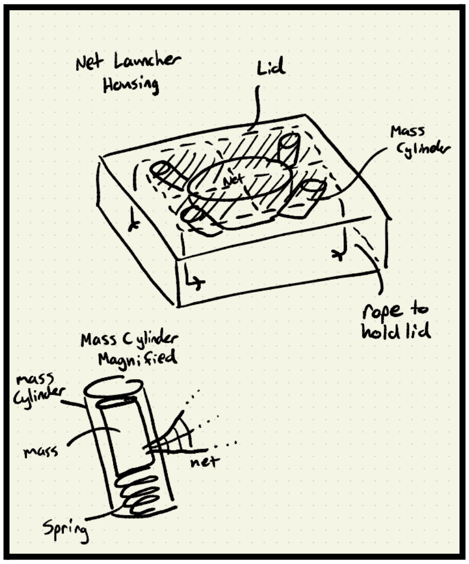


Figure 5: Net launcher housing and mass in the cylinder

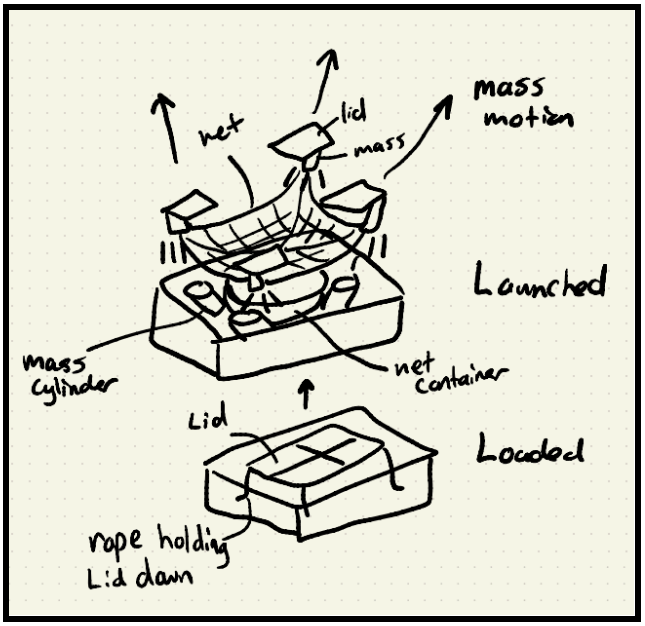


Figure 6: Net launching processes

Figure 6 shows a deployment mechanism that can be packed into a small area and uses force to expand and shoot the object and, in our case, a net toward the target. Another deployment mechanism is shown below in Figure 7 which utilizes the extension of collapsable linkages to push an object placed on top of the top plate.

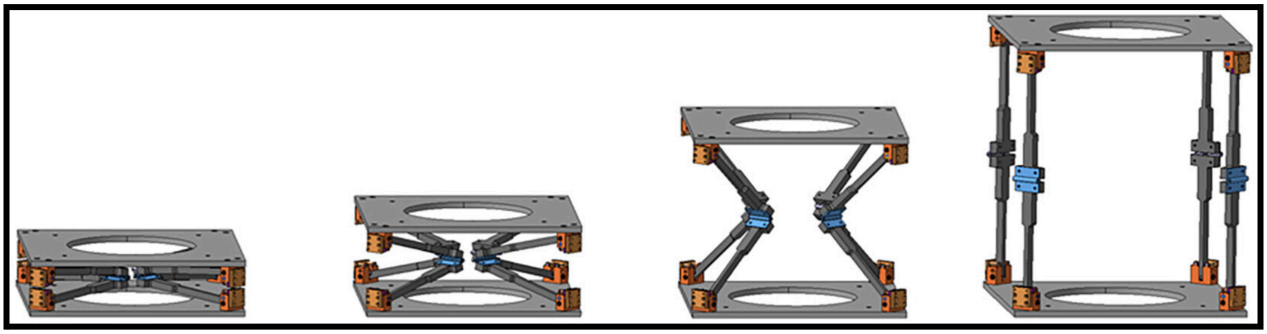


Figure 7: Possible deployment mechanism for the net

4.3.2.2 FIRST PROTOTYPE

We have not yet physically constructed or tested our net system. We have created and been revising designs in Solidworks (a computer-aided design or CAD software) to serve as the foundation for our prototype build and subsequent testing. The first design of the net capsule implementation is shown in Figure 8 below.

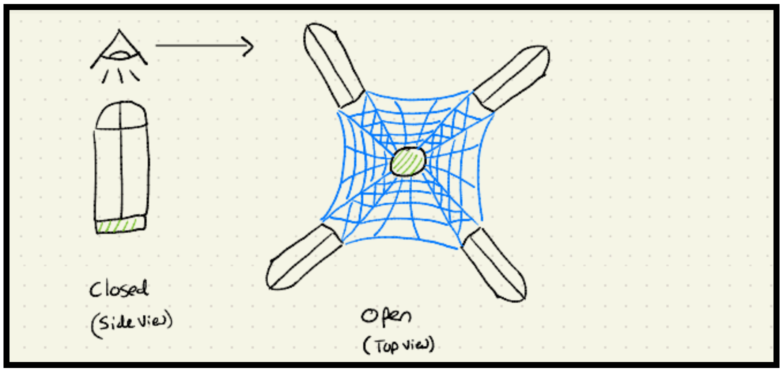


Figure 8: Net deployment container

Figure 8 above shows the net capsule which is the net housing unit. Each net capsule would be deployed from a rifled tube. For the first design implementation, we intended to use a gas propellent to launch the net capsule. Once fired, the net capsule was designed to spin through the tube, generating the centrifugal force that would be used to open the capsule and expand the net after leaving the tube. Figure 9 below shows the overall design of our model represented in CAD.

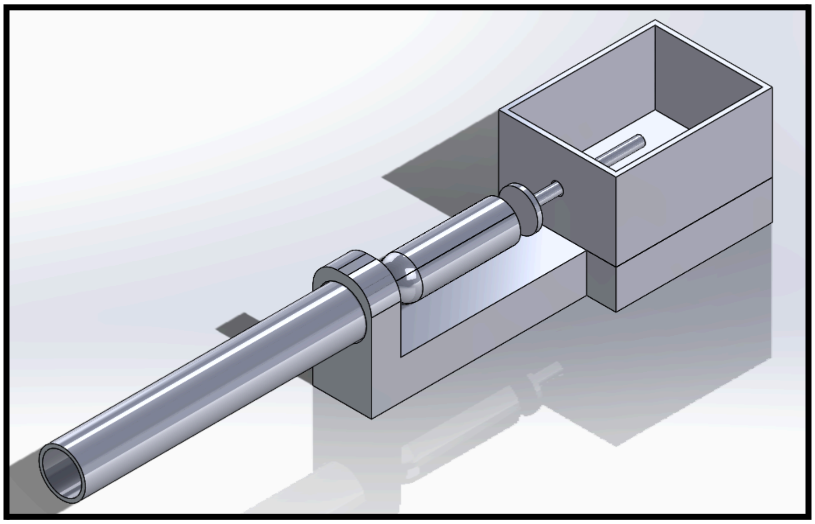


Figure 9: Net launching unit

Elaborating further, Figure 9 includes the net launching piston and enclosure (lid not shown) to house a piston pressurizing system. The launch projectile enclosesing the net is shown in the center in front of the piston (projectile holder not shown). Our implementation was to be propelled using a gas-operated pump to pressurize the piston. Then, the piston would be used to push the projectile through the barrel.

4.3.2.3 FINAL PROTOTYPE

After completing design reviews, the final net launcher high-level system is shown in Figure 10. It consists of multiple net capsules enclosed in a rectangular housing attached to a launching mechanism. There are three subsystems which are the net capsule enclosure, the net capsule launcher, and the net capsules.

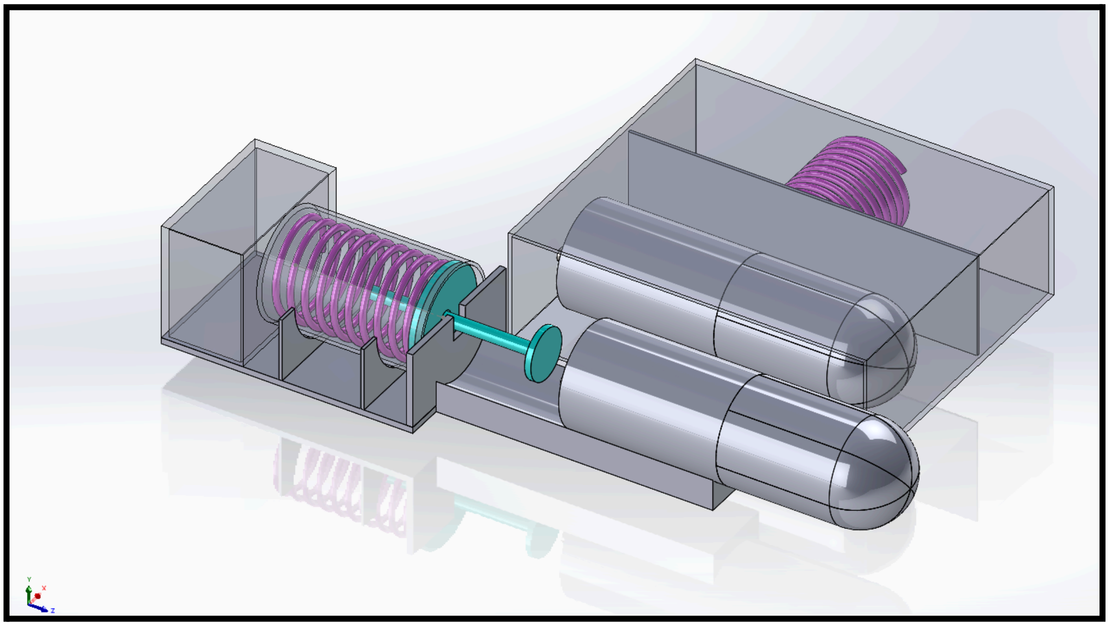


Figure 10: Spring Net Capsule Launch

Starting with the net capsule enclosure subsystem, its made of a rectangular enclosure that houses net capsules to be launched. One end of the enclosure is open for net capsules to be pushed in front of the blue launch piston shown in Figure 10 above. Then, on the other end, on the inside of the enclosure, is a spring-loaded plate that can move linearly to feed net capsules from the enclosure to the curved slot in front of the blue launching piston.

The second subsystem is the net capsule launcher. It utilizes a spring-loaded piston, shown in blue in Figure 10 above, to push loaded capsules into free space. The launcher only provides enough force to push the net capsule along and off the slot in front of the blue piston. This is by design as a “soft launch”, to reduce the resultant forces of a net launch felt by the satellite from which the net launcher is mounted. After a net capsule is launched, the piston is retracted to compress the piston spring shown in pink on the left of Figure 10 above and allow a new net capsule to be placed on the slot in front of the piston. This will be done by a winch and cable (not shown) attached to the piston’s rod in the center of the spring. The winch and a launcher control board will be housed in the enclosed area on the left side of Figure 10 above, behind the piston and piston spring.

Finally, a third subsystem are the net capsules. The net capsule design has two compartments. At the rounded tip is the net compartment. It's made of 6 pieces magnetically held together, which are each used as masses to expand the net. In Figure 11 below is a cutaway showing two of these masses removed, revealing the net compartment. In the rear portion are cold gas thrusters, shown in Figure 12 below, and a cold gas pressure vessel (not shown). These are used to propel the net capsule to the target CubeSat after the net capsule is launched into free space by the piston on the net launcher. The thrusters will also be used to induce a rotational spinning motion along the axis of travel of the net capsule. The centrifugal force of the spinning motion will force the 6 masses enclosing the net to expand outward, opening the net to capture the targeted CubeSat.

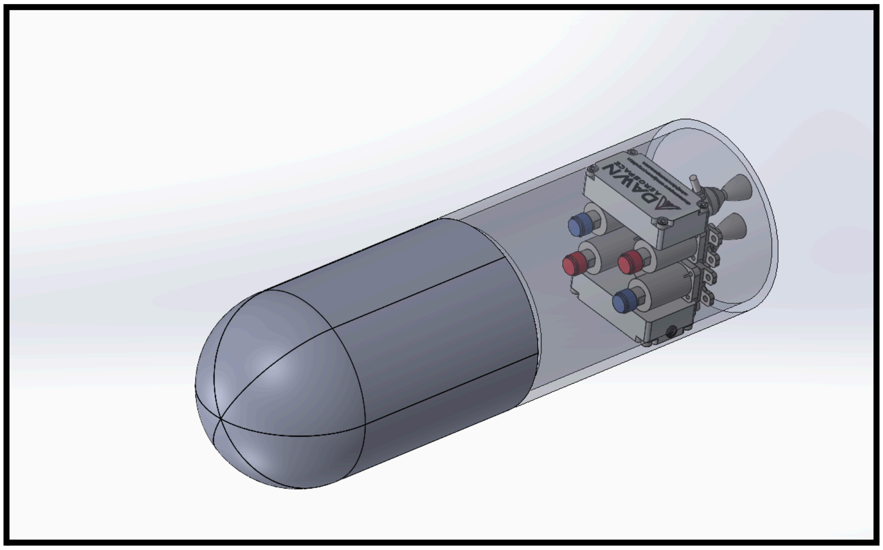


Figure 11: Net Capsule Boosters

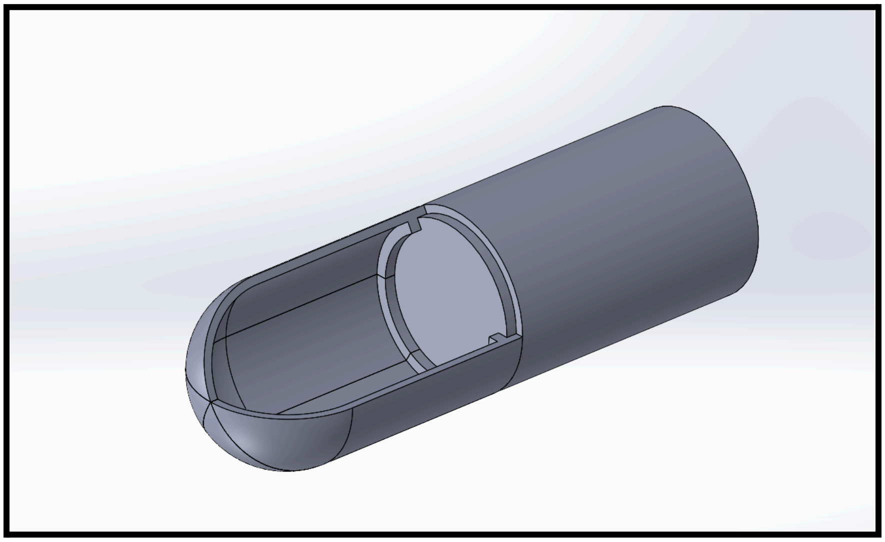


Figure 12: Net Capsule Payload Housing

4.3.3 FUNCTIONALITY

The net capture system uses target data to intercept, catch, and deorbit specific space debris automatically. The whole procedure, from targeting to system reloading, is broken down in detail below:

- Target Alignment and System Initialization:
    - After obtaining information on the target's position, orbit, and predicted intercept point, the system determines the best intercept trajectory based on its own orbital route.
    - After that, the soft launch from the spring-loaded piston occurs and the capsule uses cold gas thrusters to ensure proper alignment for net deployment.
- Target capture and net deployment:
    - With the cold gas thrusters active, they propel the capsule forward and generate rotation along the axis of travel.
    - The experienced centrifugal force generated by the cold gas thrusters causes the capsule to expand outward, expanding the enclosed net for catching that target upon impact.
    - To prevent escape during capture, the net securely entangles the target, even with little tumbling or rotating motion.
- The captured target's deorbiting:
    - Once the target is safely contained, the cold gas thrusters move the trapped item to a lower atmospheric reentry orbit through a controlled deorbit procedure. Upon reentry, the target will burn up.
    - This deorbiting procedure keeps orbital paths safer and reduces the possibility of more space junk.
- Reloading and Resetting the System:
    - The system autonomously repositions and resets itself when the capture and deorbit stages are finished, readying it for the subsequent target assignment.
    - The launch mechanism is reset to allow for a new deployment process for the subsequent mission, and a new net capsule is brought into the launcher via a reloading mechanism.

4.3.4 AREAS OF CONCERN AND DEVELOPMENT

The current design meets the basic requirements of launching a net at the target CubSat for capture and deorbiting. One concern for development is ensuring once a target CubeSat is entangled in the net it remains entangled. Often old CubeSats can be tumbling while in orbit as they have no fuel to stabilize themselves. This means when a net is wrapped around it, the CubeSat could spin out of the net, so a winching mechanism to ensure the net remains closed is essential. A potential solution is to have winches in the weighted masses to real the excess slack of the net to keep the net closed around the target CubeSat. Another concern is implementing a multiple/reloadable net feature to the design. This can make the design more complex as there are more moving components. One solution would be a revolving mechanism or spring loaded enclosure to guide the next net capsules into position for launch.

4.4 TECHNOLOGY CONSIDERATIONS

Our distinct technologies include

- The net
    - Materials: Lightweight, durable, flexible that can be compactly packed in a space
    - Packing Form: A hexagonal net shape that will be folded into a cylindrical capsule
- The launching mechanism
    - Pushing Force (Compressed Gas / Spring)
    - Destructive Tension Release (cut rope / cable-winch)
- The reloading mechanism
    - Net Capsule Enclosure: Loads the next net into the launcher
    - Primer: Preps the piston for the following launch

4.5 DESIGN ANALYSIS

There are three categories of the design that need to be tested to ensure desired operation. The first is component testing. The most important component of the design is the net. It will be what wraps around a CubeSat which will likely be rotating arbitrarily in space. To ensure secure capture of the target CubeSat, the net material will need to be temperature tested, tensile tested, and abrasion tested.

The second category is testing the three subsystems of the proposed design to ensure proper physical operation. First, the net launcher subsystem will need to test the physical operations of priming the launch piston, launching a net capsule, and reloading another net capsule. For the net capsule reloading system, the movement of reloading net capsules will need to be tested. Then for the net capsule subsystem, it will need to complete propulsion tests and net expansion testing.

Finally, the third category is the design as a whole and its ability to survive being launched into space, operating in space, and surviving re-entry. For this, several simulations and physical tests such as vibration testing, temperature testing, and finite element analysis will need to be conducted. From the results, it can be determined if the proposed design can successfully survive the extremes of space launch and operation.

5. TESTING

The testing of our design can be classified under the following categories:

1. Survivability during launch
2. Maintenance during orbit
3. Survivability during re-entry

Our testing will mainly be in computer simulated environments.Our main platform will be MATLAB and NASA based open softwares. The testing shall happen simultaneously as the design progresses. We do not foresee dealing with cost related requirements since as part of a design competition we have not been given restrictions on expenses for the purposes of the design competition. Therefore we are interpreting this as an unrestrictive budget for a final design, with the understanding that we have to work with a highly restricted budget for prototyping, hence our reliance on simulations and existing data.

5.1. PRELIMINARY TESTING

5.1.1 MATERIALS AND COMPONENTS

Due to a lack of testing apparatus for us to use, our components and materials are chosen from those that have already undergone tests that ensure that they are suitable to perform in an orbital environment. Specifically, we are looking for materials and components that have testing results indicating that they can survive the harsh environment of space; which includes thermal cycling, vacuum atmosphere, and solar radiation.

Once selected, components chosen will undergo fatigue testing to understand expected failure modes. Which will then be used to create more focused testing measures for autonomous identification and handling of potential performance changes or failures. Testing involving performance degradation will be done utilizing simulated data sourced from simulations using NASA’s Trick Simulation Environment.

5.1.2 SOFTWARE TESTING

Software tests will be designed prior to the actual writing of the software where applicable. This will ensure the software performs as expected. Testing for individual functions will exhaust all potential input parameter ranges where applicable. Functions will be designed as simple and modular to simplify this testing process.

For software testing involving interaction with the world, a prototype will be required, and as such will be handed as part of our functional integration testing once software testing indicates the functions given to the hardware should perform as expected.

5.2. FUNCTIONAL TESTING

Functional Testing will be primarily performed to ensure interactions between components, and that the performance of designs adhere to the requirements of the project. Functional testing should be done at the earliest stage possible to minimize potential technical debt. Additionally, as our design involves outgassing all components related to outgassing, sustained testing will be done in a vacuum chamber to ensure that the module does not unintentionally outgas either through leakage or component deterioration.

5.2.1 INTEGRATION TESTING

This testing will occur whenever components are combined together. To ensure that the software and hardware components successfully work together. This also includes testing to ensure that in the event of a failure, the system does not create additional orbital debris. To ensure compliance with NASA's debris mitigation requirements, we will use NASA's Debris Assessment Software to verify our designs.

5.2.2 SURVIVAL TESTING

Once we have a prototype designed, the next step is to ensure it can handle the additional stresses of being put in orbit. The testing required can be classified into the following:

a. Structural testing:
   Structural testing is done in order to understand how the payload is displaced during launch and reentry. For launch, MATLAB shall be used as the simulation environment. For re-entry, AutoORSAT shall be used.

b. Thermal testing:
   Thermal testing is done to analyze the impacts of heat throughout the payload. It helps us understand how heat affects the functionality of the capsule. This test will be conducted through MATLAB.

c. Modal Analysis:
   Modal analysis is a more in depth study of vibration and shock waves and its impact on the payload. This test will be conducted through MATLAB.

d. Drag:
   Ascension drag testing ensures the payload fairing remains intact. This test will be performed through OpenFOAM

e. Aerodynamic testing:
   Aerodynamic testing evaluates how a payload interacts with forces in the atmosphere throughout its ascent. This will be done through MATLAB and EMTAT

5.2.3. MICROGRAVITY TESTING

The final step of testing with an end stage prototype is to experiment in as close to a live environment as possible, this would be a parabolic flight, which would allow for testing for around 30 seconds of testing in a simulated zero gravity environment. However, due to the limited testing time, and limited availability of parabolic flights, this testing method should only be done when nearing the final product, as it is prohibitively expensive to utilize.

6. IMPLEMENTATION

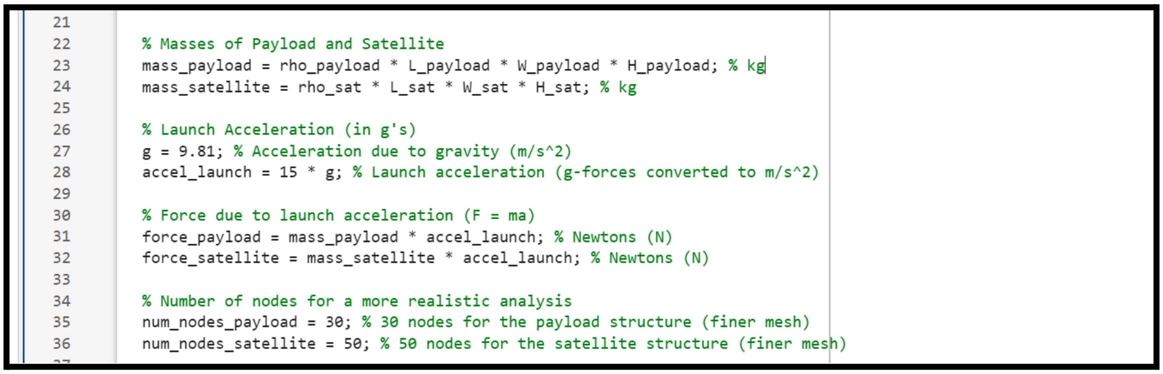
In order to implement our design, we conducted the following test that gave us more insight into what our payload can expect during the launch phase:

1. Structural Analysis:

Structural analysis tests the displacement of the payload during launch conditions. The goal is to understand how the payload performs under different forces such as gravitational, vibrational etc. This is done in order to test the integrity of the payload.

Considerations for the structural analysis:

- a. Since limited information is presented about the Blue canyon X-Sat Venus Bus carrier, it was assumed to be mostly made of aluminium due to its lightweight.
- b. Other assumptions made regarding the Venus Bus:
    - i. Payload Mass: 60 kg
    - ii. Overall Satellite Volume: 28 inches (710 mm) × 28 inches (710 mm) × 38 inches (970 mm)
    - iii. The solar panel is considered to be the length of the spacecraft's longest dimension, which is 28.0 inches (approximately 71.0 cm). The width of each panel would be proportional to the other dimensions of the spacecraft.
- c. For our payload, analysis was done for two different types of metal: Steel and Aluminium Alloy 2024. While steel is durable and resistant to wear and tear, aluminium 2024 is very lightweight.



```

% Masses of Payload and Satellite
mass_payload = rho_payload * L_payload * W_payload * H_payload; % kg
mass_satellite = rho_sat * L_sat * W_sat * H_sat; % kg

% Launch Acceleration (in g's)
g = 9.81; % Acceleration due to gravity (m/s^2)
accel_launch = 15 * g; % Launch acceleration (g-forces converted to m/s^2)

% Force due to launch acceleration (F = ma)
force_payload = mass_payload * accel_launch; % Newtons (N)
force_satellite = mass_satellite * accel_launch; % Newtons (N)

% Number of nodes for a more realistic analysis
num_nodes_payload = 30; % 30 nodes for the payload structure (finer mesh)
num_nodes_satellite = 50; % 50 nodes for the satellite structure (finer mesh)
```

Figure 13: Snippet of Code

Explanation:

The mass and payload of the satellite was calculated through Young’s modulus, Poisson’s ratio and density of the material. The gravitational force during launch was taken to be the average of 15g and the force on the loads were thus calculated. The number of nodes were taken into consideration. This represents the number of “critical” points that the payload is split into such as joints and edges.

Results for Steel:

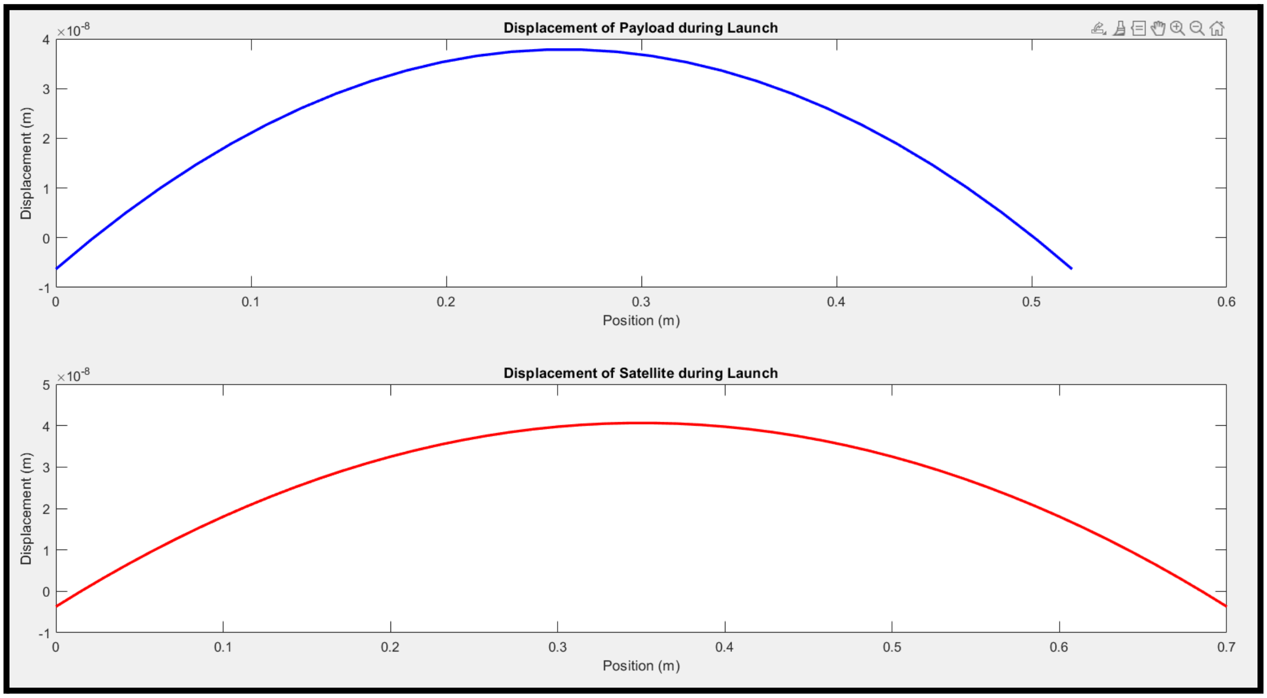


Figure 14: Displacement vs Position graph for Steel Payload

Results for Aluminium:

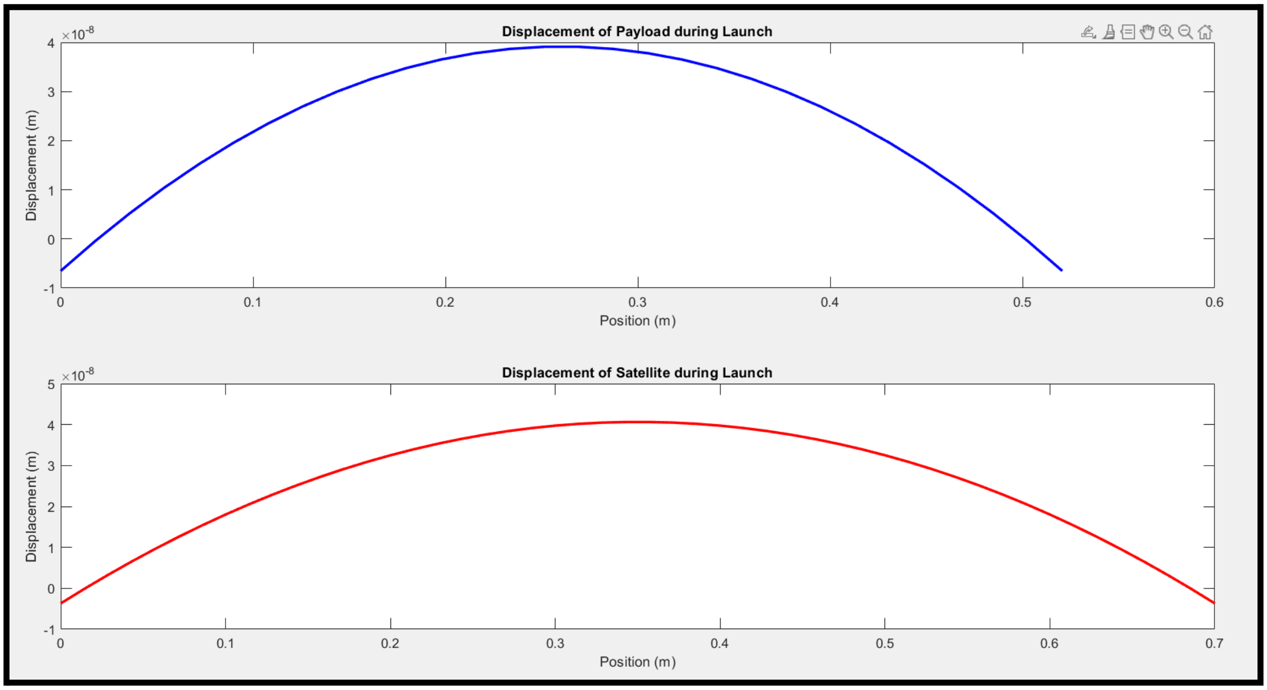


Figure 15: Displacement vs Position graph for Aluminium Payload

The above plots generate the displacement of the payload and satellite by considering the position from one end of the structure. This implies that at position 0m and 0.7m (for satellites), we would be at the edge of the structure and 0.35m would indicate the center of the structure.

As can be seen by the above plots, the maximum displacement occurs at the center of the structure for both payload and satellite during launch. The difference between the aluminium and steel plots can be most observable in the peaks of the charts. As expected, the steel payload has slightly less displacement than the aluminium one. To fully understand the vibrational impacts of this as well, modal analysis must be performed.

2. Thermal Analysis:

Thermal Analysis considers understanding temperature fluctuations experienced due to the following factors:

I. Thermal load
II. Internal heat generation
III. Thermal stress
IV. Conduction

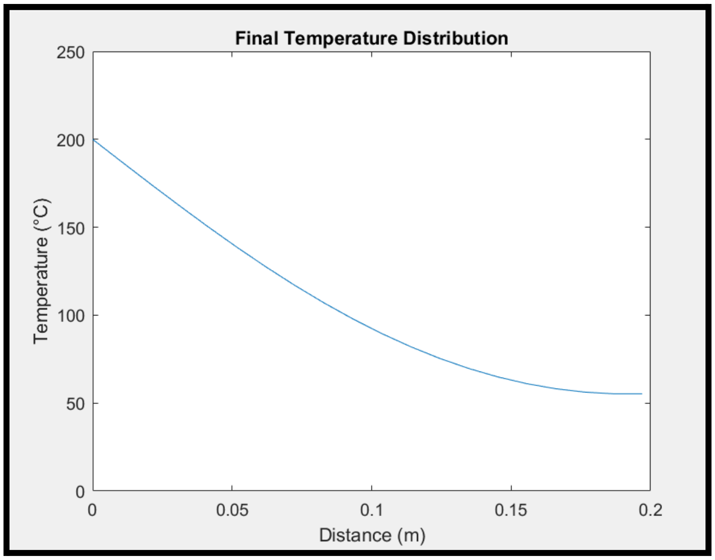


Figure 16: Distance vs Temperature graph for Steel Payload

It is assumed that the surface of the load experiences 200 celsius during launch. The above temperature vs distance graph measures the temperatures that the payload experiences as we go further into the payload from the surface.

In order to better understand the effects of thermal stress on the payload, time is also an essential factor to consider. Thus a 3d graph of time vs distance from the surface of the payload vs temperature was considered.

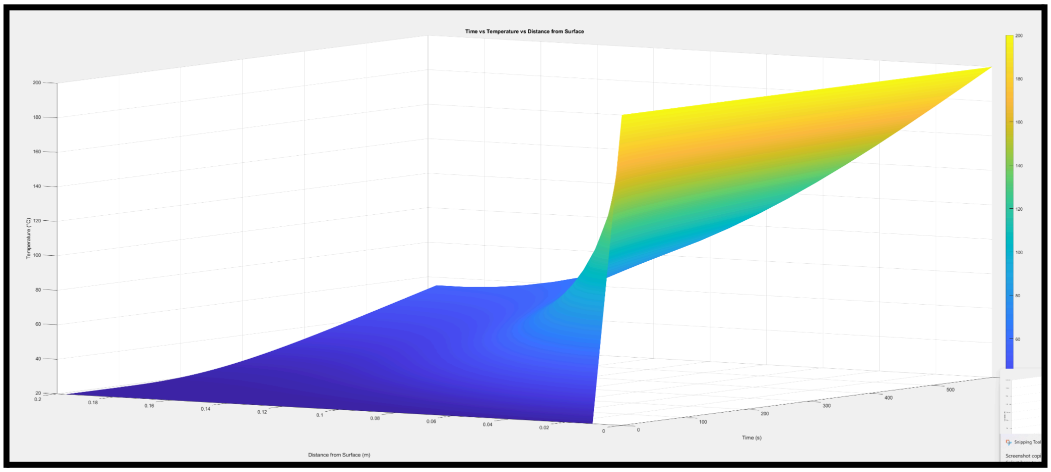


Figure 17: Distance vs Temperature vs Time graph for Steel Payload

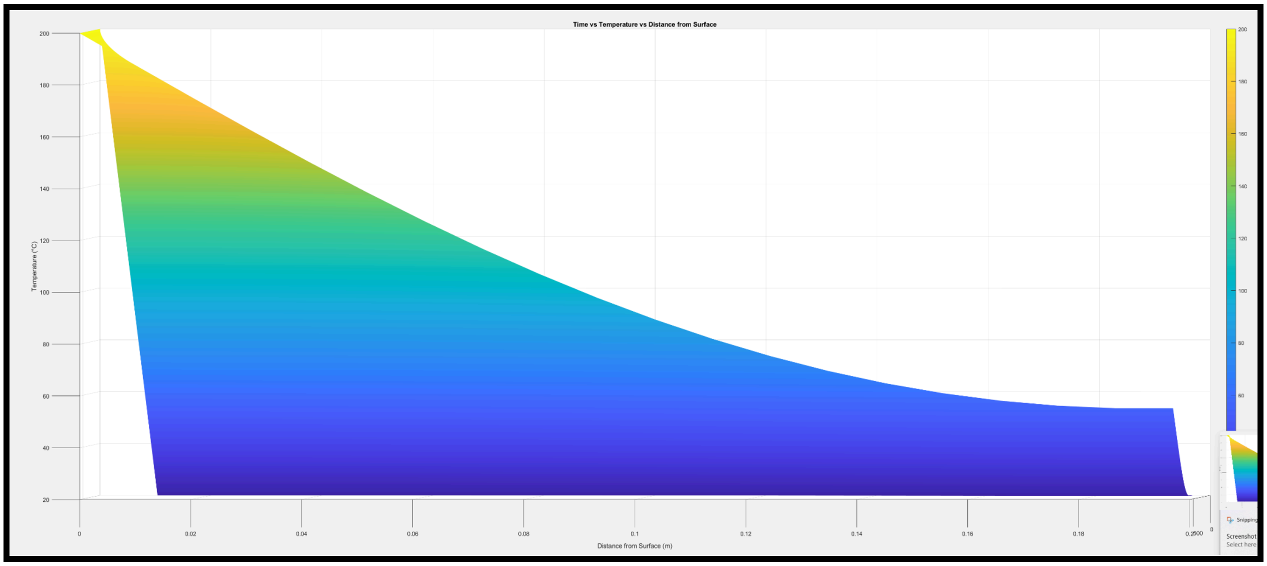


Figure 18: Distance vs Temperature graph for Steel Payload

From the above graph we can see that there is a gradual decrease in temperature as we go further into the center payload due to conduction. The temperature range is from 55 celsius to 200 celsius.

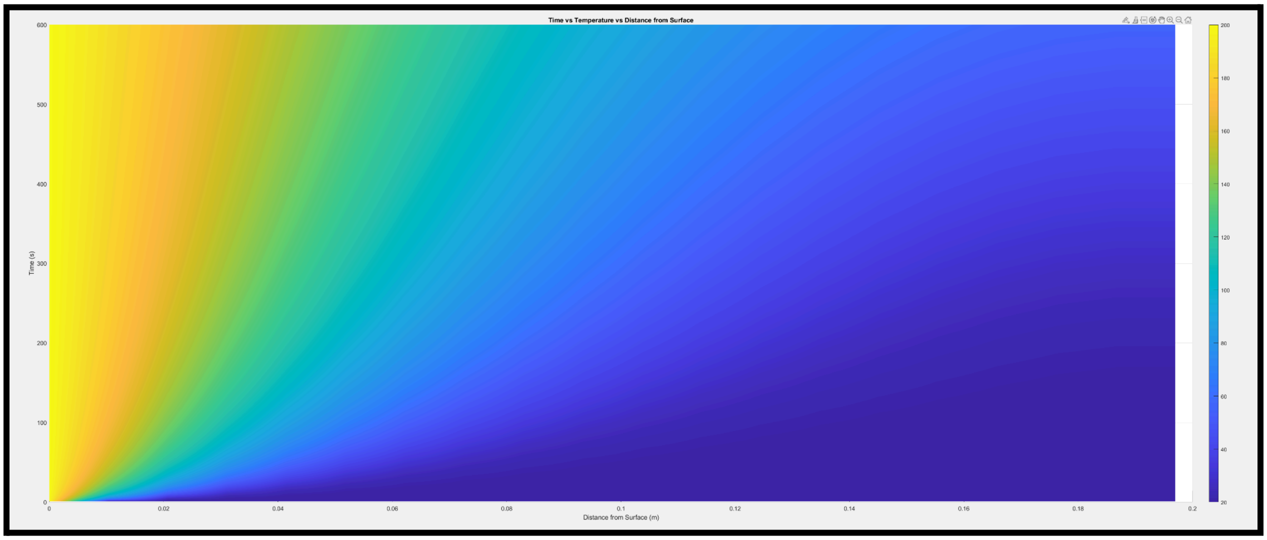


Figure 19: Distance vs Time graph for Steel Payload

The time vs distance graph shows the temperature gradient of the payload with time. The time is marked up until 600s and thus accounts for the first 10 min of launch time. It can be concluded that during this time the surface temperature of the payload doesn't experience much fluctuation. Based on this information we can choose to strategically place our net capsules away from the corners of the payload container.

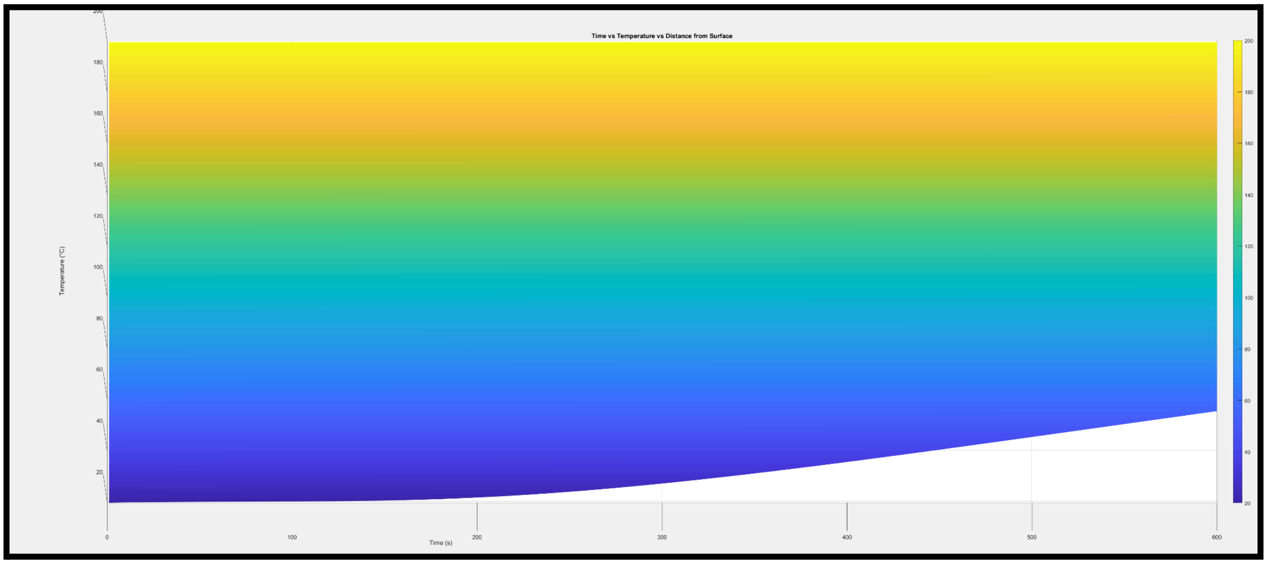


Figure 20: Temperature vs Time graph for Steel Payload

The time vs temperature graph describes the change in temperature range over time. It is observed that the range decreases gradually and more heat enters the payload.

Results for Aluminum:

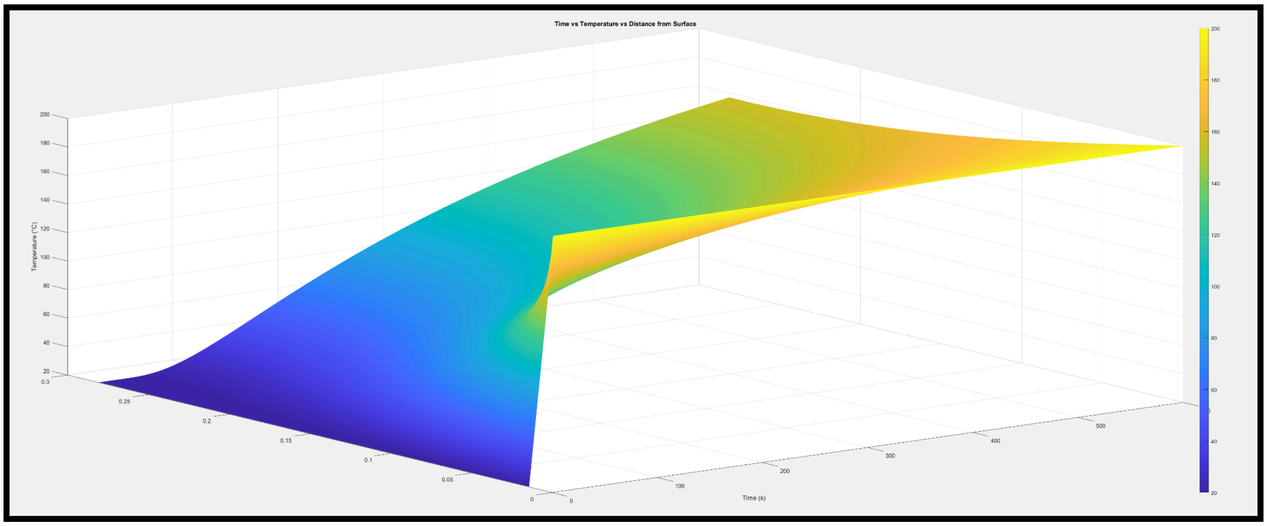


Figure 21: Distance vs Temperature vs Time graph for Aluminium Payload

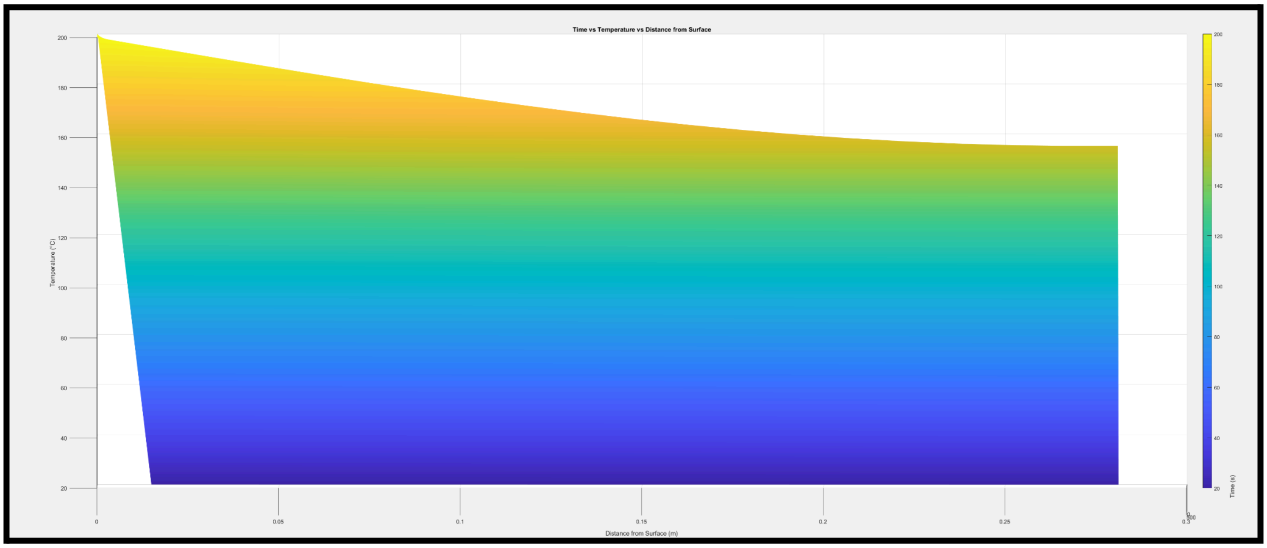


Figure 22: Distance vs Temperature graph for Aluminium Payload

Figure 23: Distance vs Time graph for Aluminium Payload

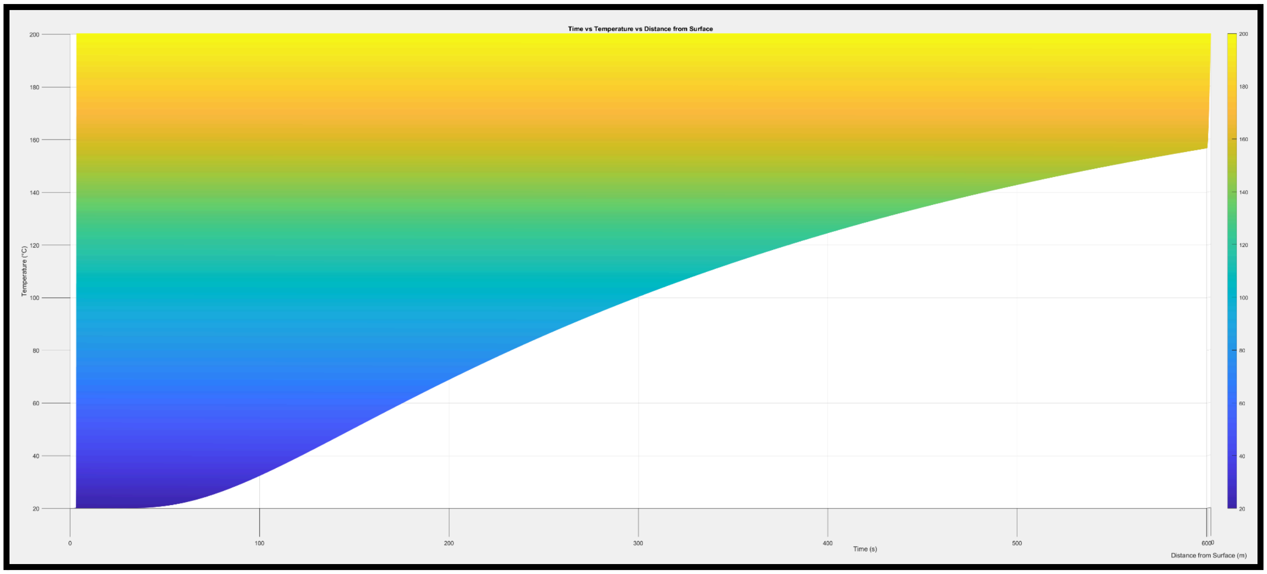


Figure 24: Temperature vs Time graph for Aluminium Payload

Aluminium is much less resistant to heat. As can be seen by the time vs temperature graph, aluminium rapidly loses the varied range in temperature which causes it to heat up very quickly. Heat spreads much faster toward the center of the payload as we advance. In conclusion, steel is much better for handling thermal stress than aluminium.

7. ETHICS AND PROFESSIONAL RESPONSIBILITY

7.1 AREAS OF PROFESSIONAL RESPONSIBILITY AND CODE OF ETHICS

Table 3: Areas of Professional Responsibility

Area of Responsibility	Definition	Relevant Item from ACM Code of Ethics	How Our Team Has Interacted/Adhered
Work competence	Completing tasks in which one is competent and informed while avoiding deception.	2.2 Maintain high standards of professional competence, conduct, and ethical practice.	Team members have actively researched various ISAM technologies and improved their skills.
Financial Responsibility	Managing resources and ensuring transparency in financial matters.	1.3 Be honest and trustworthy.	The team has had discussions but not too much in detail regarding finances to be applied to the solution.
Communication Honesty	Sharing accurate, clear and truthful information between the team and the stakeholders.	1.2 Avoid Harm 1.3 Be honest and trustworthy	Team members discuss progress and provide inputs weekly to be up-to-date.
Health, safety and well-being	Putting the security and well-being of everyone involved first in all choices and activities.	1.1 Contribute to society and to human well-being, acknowledging that all people are stakeholders in computing.	The ISAM payload design minimizes risks during on-orbit deployment and operational phases.
Property Ownership	Respecting others' intellectual property, ideas, and information.	1.5 Respect the work required to produce new ideas, inventions, creative works, and computing artifacts.	The team makes sure that all creative work is properly credited and that shared resources are properly attributed.
Sustainability	Ensuring environmental and societal sustainability in designs and implementations.	1.1 Contribute to society and to human well-being, acknowledging that all people are stakeholders in computing. 2.3 Know and respect existing rules pertaining to professional work.	The design considers environmental impacts and prioritizes to minimize harm.

Social Responsibility	To act ethically and responsibly to benefit society and uphold professional integrity.	3.1 Ensure that the public good is the central concern during all professional computing work.	Team has followed ethical practices and has worked on a solution designed to serve societal needs.

Performance Analysis:
Strengths:
Communication Honesty

The team has demonstrated exceptional communication skills throughout the semester. The team ensures to convey any and all progress towards the solution weekly during the team meetings. We assign tasks and make sure the team is aware of them and is working towards the same shared goal for the week. Any disagreements or concerns are addressed in a professional manner where the team discusses it collectively.

Weakness:
Financial Responsibility

The area that the team needs to put more emphasis on would be financial responsibility. Although the technical and operational components of the project are given a lot of attention, cost analysis and budget planning have received little attention. For example, the team has not thoroughly discussed the financial aspects of the project and estimated the project and prototype testing costs. In the future, the team will consider finances as an important factor while discussing testing and overall project. A thorough budget plan, an evaluation of the financial trade-offs of various design choices, and consultation with mentors or cost optimization specialists will be implemented.

The team can guarantee that the project is both technically sound and commercially sustainable, in accordance with professional ethical standards, by enhancing financial responsibility and preserving communication and competency strengths.

7.2 FOUR PRINCIPLES

Table 4: Four principles

	Beneficence	Nonmaleficence	Respect for Autonomy	Justice
Economic	Our designs allow for economic growth in space	Our design does not negatively impact economic growth and development	No economic hindrance is caused by our design, and it enables all groups to benefit	Our solution would provide equal economic benefits to all
Environmental	The design promotes clean-up and improvement of lower earth orbit	Our design does not actively contribute additional waste to the environment	We do not hinder any company or organization from being able to operate in the environment of space successfully	Our design would provide all of mankind with a debris-free space
Societal	The design will help society continue space exploration	Our design does not negatively impact society's functions	Our designs do not prevent any barriers to societal autonomy	Implementation would equally benefit all of society

Important Pair:
Environmental - Beneficence
Our project seeks to enhance the orbital environment by promoting debris removal and control of possibly harmful objects in the Low Earth Orbit(LEO). Since our team is encouraging environmental well-being and guarantees sustainable use of space for future satellites and space stations, which aligns with beneficence. To ensure this we are incorporating debris removal through net deployment, minimizing risks associated with it and prioritizing long-term environmental preservation.

Lacking Pair:
Economic - Justice
Equal financial gains for all stakeholders involved may be difficult to be guaranteed in regards to our project, particularly for smaller aerospace companies or nations with limited access to space technologies. This disparity may result in uneven access to the financial benefits of our project. In order to make progress in regards to the project our team will concentrate on getting the best outcome while keeping track of the cost. We will look for more affordable solutions while keeping the quality intact so that our project can benefit the entire world all together.

7.3 VIRTUES

Compassion: Treating everyone with the respect and kindness they deserve and need. Our team has demonstrated this virtue through open and respectful communication during the team meeting. Feedback is provided constructively and a safe environment is created so that everyone feels included, values and supported.

Competence: To be knowledgeable and understanding of technical aspects of our design to ensure smooth development of the project. Weekly meetings ensure that our team is progressing at a steady pace and every team member is aware of the technical aspects of the design. Tasks are assigned based on each member's strengths and peer reviews help maintain a high quality standard.

Commitment: Willingness to see the job through, ensuring the tasks are completed with diligence and integrity. All tasks are completed within the deadlines and team members take accountability for the tasks. We ensure that all the members' hard work is appreciated and motivation is consistent.

John:

One virtue that I have demonstrated throughout senior design has been competence. Competence is essential because it allows me to contribute effectively to the team's work and ensure we progress towards our goals. Technically and situationally competent will enable me to contribute to our designs while ensuring we address all project requirements.

A virtue that I am looking to improve upon going forward is patience. Practicing patience allows me to effectively collaborate with industry mentors and peers without getting frustrated by long design cycles and numerous rounds of feedback. Demonstrating patience looks like listening to my peers fully before attempting to contribute.

Maheeka:

A virtue that I believe I have demonstrated is curiosity. I believe that by being curious to learn new information and develop new skills it can not only help me improve myself but also help the team progress. By being eager to challenge myself, I am able to contribute more effectively to the team. Whether it be learning how to operate CAD for the first time or jumping at the opportunity to think outside the box, I feel that I have demonstrated this virtue throughout the project.

One virtue that I need to work on in the future is persistence. This semester, I haven’t been able to prioritize my senior design project and, thus haven’t been allocating the right amount of time for it. During exam and project weeks for other courses, I let the capstone challenge take the back seat. Despite rough weeks, I must persist if I want to give it my all.

Tanvi:

One virtue that I feel I have demonstrated during this semester of senior design would be perseverance. I believe that being persistent, staying dedicated is the key to being successful with a project. Despite challenges like limited access to documents with descriptive information about mechanisms and multiple ideas, I remained dedicated to researching new ways to proceed with the project. This helped me to keep moving forward and contribute to the progress of the team.

One virtue that I think I need to improve is time management. Dedicating ample amount of time for this project is really important and I noticed that I have not always been able to dedicate that amount. There were few instances where I could not get a lot of progress done due to multiple reasons, but I will work more on this aspect and make sure that I spent enough time dedicating myself to this project.

Daniel:

One virtue I feel I have demonstrated in this semester of senior design is creativity. With the core of the project being a design competition, I felt inclined to think of novel solutions to different types of problems, such as potential designs for a reusable launching mechanism which became a core feature of our resulting design.

One virtue I think I have poorly represented is communication, as I feel that I have done a poor job of documenting my work in a way that makes it both presentable to the group and easy to understand. This resulted in discrepancies between my thoughts and the teams, resulting in later than ideal clarification of intentions and concerns within the team. This is important to me because I prefer being presented with information in a clear and understandable way, and that I should be capable of delivering information in a way I would like to receive it in. Additionally I think it’s integral that we as a team are able to be on the same page as much as possible to minimize redundant work.

Ben:

A virtue I have demonstrated in senior design this semester is accountability. Two ways I've been accountable are by giving credit to team member's work and by completing portions of the project I set to complete. Giving credit to team members' work creates an open, collaborative environment, enabling better design sessions where everyone's ideas are heard. By completing the portions of the project I set to complete, I've helped move the team closer to our project goals.

One virtue I'm working to improve upon is thoroughness. Specifically in the design area, increased thoroughness can be shown by making more detailed drawings and CAD models. These will allow better visualization for all team members to have an increased depth of understanding of the design. All team members can make more informed decisions regarding design aspects to progress toward our project goals.

Riley:

A virtue I have demonstrated in senior design this semester is patients. When working in groups and on group projects it can be easy to get short with people and push your own ideas on people. I have tried very hard to hear out everybodies ideas and work with group members to figure out which ideas benefit our team even if that means my ideas have to be abandoned.

One virtue I'd like to improve is commitment. Through this semester there would be times that my school work would become difficult and my schedule would be packed. My responsibilities to my senior design team would be the first things that I would ignore. This isn't fair to my team and I would like to be better about my commitment to the team and project moving forward.

8. CLOSING MATERIAL

8.1 CONCLUSIONS

In our design, we have created a mock-up for a net launcher that will deploy a net capsule to capture and de-orbit defunct cube satellites.

Our goals laid out in the design competition are specified as follows:

- Analysis is required to sufficiently determine if a design is feasible, can survive launch, can operate successfully in a lower Earth orbit (LEO) environment, and can meet the BCT X-Sat Venus Class bus specifications
- The design needs to demonstrate three or more operations to demonstrate an orbital ISAM capable
- The payload should be designed to function autonomously with limited remote commands

The primary goal of our team during this semester was to develop a CAD model of our design. For our project we implemented a waterfall workflow design to prioritize research and development of a net launching prototype. Our first objective was to develop an idea for our ISAM payload. Over the first half of the semester, our team used online resources and the help of our industry advisors to learn more about the current state of ISAM. Once we completed our research phase we utilized our knowledge of ISAM to develop prototypes. With our design phase we prioritized rapid prototyping and redesigning based on feedback from our industry advisors. Following this development structure we were able to accomplish our goal of developing a CAD model.

Our group was hindered at times by the broad scope of our project. ISAM has multiple facets and working in space is an incredibly difficult task especially for novices in aerospace engineering. During our project, we would create prototype mock ups and designs only to receive feedback from our industry advisors that our design would not function properly in space. Beyond the difficulty of the operation environment, our group had to act on limited information pertaining to the platform we would be designing a payload for. Without full modeling of the satellite, it was difficult for our team to make accurate assessments about the capabilities of the satellite bus.

Going forward, if future teams were composed of more engineers with mechanical or aerospace engineering backgrounds, it would be very beneficial to accelerate development of prototypes. Our group experienced delays related to developing ideas and conducting research that would be previous academic knowledge for mechanical and aerospace engineers.

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9. TEAM

9.1 TEAM MEMBERS

John Beuter - Cyber Security Engineer
Tanvi Mehetre - Computer Engineer
Daniel Sprout - Software Engineer
Maheeka Devarakonda - Electrical Engineer
Ben Swegle - Mechanical and Electrical Engineer
Riley Heeren - Electrical Engineer

9.2 REQUIRED SKILL SETS FOR YOUR PROJECT

Technical Skills

- Engineering problem solving
- Circuit design and analysis
- Power system design and analysis
- Mechanical system design and analysis
- CAD modeling
- Cybersecurity systems design and analysis
- Proficiency in one or more coding languages

Intrapersonal

- Communication
- Idea presentation
- Conflict resolution
- Resource management

9.3 SKILL SETS COVERED BY THE TEAM

John Beuter
- Cybersecurity systems design and analysis
- All intrapersonal skills listed

Tanvi Mehetre
- Circuit design and analysis
- Proficiency in one or more coding language
- All intrapersonal skills listed

Daniel Sprout
- Proficiency in one or more coding languages
- All intrapersonal skills listed

Maheeka Devarakonda
- Circuit design and analysis
- Power systems design and analysis
- Proficiency in one or more coding languages
- All intrapersonal skills listed

Ben Swegle
- CAD modeling
- Circuit design and analysis
- Power systems design and analysis
- Proficiency in one or more coding languages
- Mechanical systems design and analysis
- All intrapersonal skills listed

Riley Heeren - Electrical Engineer
- Circuit design and analysis
- Power systems design and analysis
- Proficiency in one or more coding languages
- All intrapersonal skills listed

9.4 PROJECT MANAGEMENT STYLE ADOPTED BY THE TEAM

Our team opted for a hybrid management style that incorporated elements of an agile system and a waterfall system. Due to the nature of our project we were able tackle some tasks using an agile management style while other tasks that were linearly constrained required a waterfall approach.

9.5 INITIAL PROJECT MANAGEMENT ROLES

Team Lead/Advisor Contact: John
Materials Researcher: Riley
Security Director: Tanvi
Event Manager/Schedule Planner: Daniel
Lead CAD Design Manager: Ben
Systems Engineer: Maheeka

9.6 TEAM CONTRACT

https://drive.google.com/file/d/1jpA_ii_m0QT4qt7RIo6P0cOGYYHd-nsV/view?usp=drive_link